EFTA

Proceedings of a Workshop on

INDOOR AIR QUALITY MANAGEMENT

Lausanne, 27-28 May 1991

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DIRECTORATE GENERAL XII FOR SCIENCE, RESEARCH AND DEVELOPMENT

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Proceedings of a Workshop on Indoor Air Quality Management
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Participants in front of the port of Ouchy.

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Preface

One can observe a growing awareness, also outside the circle of experts, of the overriding importance of comfort in buildings; be it visual, thermal or acoustic comfort or comfort related to indoor air quality (IAQ). This awareness has been intensified by the diagnosis of the sick building syndrome in some buildings, resulting sometimes in abandoning and even destructing the building. A recent salient example is the Berlaymont building in Brussels, headquarters of the Commission of the European Communities, which will be demolished partly because it does not meet the comfort (IAQ) and safety standards (asbestos) for a modern office building.

The application of technological systems and materials in buildings should never come into conflict with the basic requirement of a building i.e. to provide shelter and comfort. On the other hand it is necessary to understand the comfort requirements as well as the causes of discomfort before even starting to design a building. There is, however, a general lack of information available to design professionals in particular regarding indoor air quality.*)

Comfort and energy in buildings are subjects closely related in more than one way: -thermal comfort is determined by heating and cooling of the building,
-visual comfort is strongly related to daylighting; a technology which importance for energy conservation is more and more recognised,
-IAQ is closely linked to ventilation (and infiltration), which is perhaps the single biggest energy consumer in buildings in general.
It seems, therefore, logical to address R&D on comfort, and in particular comfort related to IAQ, in an energy conservation R&D-programme for buildings. The Commission has proposed to do so in her forthcoming Non-nuclear Energy R&D-programme.

Past experience has shown that the state of the art and the areas for future research in a certain field can very cost-effectively be explored in a workshop with experts in that field. This book presents the proceedings of such a workshop on Indoor Air Quality Management held at Lausanne on 27 and 28 May 1991. The workshop was hosted by the Swiss Federal Office of Energy, whose support is gratefully acknowledged.

Theo C. Steemers

Commission of the European
Communities

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*) Levin, H (1991) "Critical Building Design Factors for Indoor Air Quality and Climate: Current Status and Predicted Trends" Indoor Air,1,79-92.

THE CONCERTED ACTION
"INDOOR AIR QUALITY AND ITS IMPACT ON MAN"
(COST PROJECT 613)

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INTRODUCTION

Indoor air quality (IAQ) in the residential and non-industrial working environment has received during the past 20 years growing attention from the scientific community and the public and is increasingly addressed also at political level. In Europe, the indoor air quality issue has emerged first, already in the late sixties, in the northern countries, in particular in Denmark and Sweden, whereas in most mediterranean countries it has been percieved only rather recently. The Commission of the European Communities has started at the beginning of the eighties to take interest in indoor air quality, when a small research activity was included in the Environmental Protection Programme of the Communities' Joint Research Centre in Ispra, Italy. This activity has from its beginning been accompanied by an effort to organize a collaboration of European workers in this new field. Such a collaboration appeared important in particular for two reasons:

- There are no scientific structures dedicated to indoor air quality research as they exist for research in the field of outdoor air or water quality. Therefore research is fairly scattered and often performed by small groups in a wide range of different institutions.
- Indoor air quality is an environmental issue which more than any other requires interdisciplinary collaboration. In fact representatives from a wide range of scientific/technical disciplines are involved in indoor air quality research: heating ventilation engineers, architects, psychologists, chemists, hygienists, biologists, toxicologists, medical doctors, epidemiologists - in order to name only the most frequently involved ones.

At the end of 1986 the Community Concerted Action "Indoor Air Qualtiy and Its Impact on Man" (IAQ&IIM) was decided.

I would like to report here on the scope, implementation, activities and results of this Concerted Action and outline in particular those activities which have some relation to the topic of this workshop.

But before doing so it may be useful to give a short overview on all activities of Commission Services related to IAQ.

BRIEF SURVEY ON COMMISSION ACTIVITIES RELATED TO INDOOR AIR QUALITY.

Commission activities related to IAQ are somewhat scattered and as far as I can see no common policy and view on the issue of IAQ has yet been developed by the Commission Services. Commission Services are organized in Directorates General and some Special Services or Agencies which are in charge of specific sectors of the Community policy and legislation. Table 1 gives an overview on Commission Services with an interest in some aspect(s) of IAQ.

DG III "***Internal Market and Industrial Affairs***" is in charge of the building products directive 89/106/CEE on the "approximation of laws, regulations and administrative provisions of the Member States relating to construction products", approved by the Council of Ministers in December 1988. This directive - issued in order to guarantee the free movement of goods - sets out a framework for regulations concerning construction products. It requires that such products "must be suitable for construction works which (as a whole and in their separate parts)......satisfy the...essential requirements" defined in the directive.

One of these requirements regards "hygiene, health and environment" and specifies: "The construction work must be designed and built in such a way that it will not be a threat to the hygiene or health of the occupants or neighbours, in particular as a result of any of the following:

- the giving off of toxic gas;
- the presence of dangerous particles or gases in the air;
- the emission of dangerous radiation..".

Setting this basic rule, the directive committs to "interpretative documents (ID) the creation of the necessary links between the essential requirements" and standards, guidelines or other technical specifications. An ID "hygiene, health and environment" has been drafted and asks for "harmonized standards" for calculation and measurement methods of a wide range of indoor air quality and climate parameters and for technical specifications of some others.

Limiting the emission of formaldehyde from wood based materials is presently under consideration as a first case to safegard the above mentioned essential requirement. For this scope CEN (Comité Européen de Normalisation), the organism recognized by the directive for the certification of technical specifications, has been charged to validate a method for the determination of formaldehyde emissions from wood based panels which previously had been specified by Working Group 3 of the Concerted Action IAQ&IIM (see below) in view of the preparation of a harmonized standard method.

Since March 1987 directive 87/217/CEE regarding asbestos is in force. Although it makes no explicit reference to indoor air pollution, it introduces measures to prevent and reduce air and other environmental pollution by asbestos. It also specifies rules to be observed during removal of asbestos containing materials from buildings.

DG V "***Employment, Industrial Relations and Social Affairs***" is in charge of the programme "Europe against Cancer". In the framework of this programme the Council of Health Ministers adopted in May 1989 a resolution to ban smoking in public places, except in clearly defined areas reserved for smokers. Such resolutions are not binding but are a commitment in principle to achieve a desirable goal.

The traditional interest of DG V in industrial medicine and hygiene issues rescently has been opened to non-industrial workplaces like offices. An expertize has been commissioned on potential future needs of regulation in this field focusing on IAQ. Also, the international conference "Clean air at work - new trends in assessment and measurement for the 1990s" organized by DG V in collaboration with the BCR has included a session on indoor air which is organized in collaboration with the Concerted Action IAQ&IIM.

DG XI "***Environment, Nuclear Safety and Civil Protection***" has prepared the 4th "Policy and Action Programme on the Environment (1987-1992)", approved by the Council of Ministers on 19 October 1987. It includes as one of the major objectives the development of "an overal longer-term strategy to reduce air pollution" and as part of this strategy "to define and implement preventive measures against indoor pollution from a growing number of substances". For the time being only a "Recommendation of the Commission on the protection of the public against indoor exposure to radon"

(90/143/Euratom) has been issued. It introduces "a reference level for consideration of remedial action" for existing housing (not intended for legal enforcement) and a "design level" for future housing. The two levels, in terms of effective dose equivalent, are respectively 20 and 10 mSv/year and, in terms of radon gas concentration, 400 and 200 Bq/m3. For the time being no further activity is under way.

At the ***Consumer Policy Service*** presently the impact of consumer products on indoor air quality is under consideration as a subject to be included in a new action program in the field of consumer protection.

DG XII "***Science Research and Development***" and the "***Joint Research Centre***" are both involved in the promotion of research at Community level. An important part of this are environmental and energy related research including some research into indoor air quality. The Concerted Action IAQ&IIM is for the time being the most important effort of the Commission to promote research in the field of IAQ, undertaken jointly by DG XII and the JRC.

Before explaining in more detail the Concerted Action it may be useful to briefly explain the interest and means of the Commission to promote research in general and indoor air quality research in particular.

INTEREST AND MEANS OF THE COMMISSION TO PROMOTE RESEARCH

As explicitely stated in the 4th "Policy and Action Programme on the Environment (1987-1992)" of the European Community, scientific research is an essential preparatory activity for almost any political action in the field of environmental protection. This statement explains already the particular interest of the Commission in prenormative research. Moreover, the Commission has to provide for the elimination of trade barriers, a task which may also need prenormative research. In this framework the Commission has e.g. issued the construction product directive (see above). Common rules on energy conservation must be based on research as well.

The Commission can promote research supporting environmental, trade, energy or other policies of the Community in three different ways:

- in-house or "direct" research performed at the Joint Research Centre either within the frame of its specific multiannual research programmes or, as contract research, on request of other Commission Services;
- contract or shared cost research performed in the Member Countries and co-financed by the Commission within the frame of specific Community research programmes. The research proposals to be prepared at this workshop are intended for this type of research promotion.
- Concerted Actions, which implement a co-operation at Community level among national research projects in specific research areas which are also defined in the specific Community research programmes. The financial contribution of the Commission to Concerted Actions covers only expenses for a secretariat and for the organization of meetings.

European Non-member countries may participate in Community Concerted Actions in the COST frame. COST ("CO-opération européenne dans le domaine de la recherche Scientifique et Technique") is the name of a co-operation agreement between all European OECD Countries and the European Community (EC). Community

Concerted Actions are becoming category A COST projects as soon as a COST country which is not EC member state is participating in it. (Category B COST projects are those developed and decided in the COST frame and which may or may not be included in the Commission's research programmes.).

For the time being IAQ research has been implemented at Community level as in-house research and as a Concerted Action.

THE CONCERTED ACTION "INDOOR AIR QUALITY AND ITS IMPACT ON MAN"
(former COST project 613)

GOALS AND IMPLEMENTATION. The most important activity in the field of IAQ at Community level is the Concerted Action "Indoor Air Quality and Its Impact on Man" which is part of the Community multiannual research programmes for the protection of the environment 1986-1990 and 1989-1992 and has been initially approved in June 1986. Work started in March 1987. Ten Community Countries (Belgium, Denmark, France, Germany, Greese, Ireland, Italy, The Netherlands, Portugal and the United Kingdom) and the Commission are actively participating. Through the association of Sweden and Switzerland the Concerted Action has become COST project 613/1 in 1988. Norway and Finland are on the way to join the Concerted Action and are already actively participating. The Environment Institute of the Joint Research Centre participates on behalf of the Commission in the Concerted Action and provides the scientific secretariat and organizational support.

From its beginning the ultimate goal of this Concerted Action has been to help answer the question of which consequences for human health and comfort derive from air pollution respectively inadequate air quality in non industrial indoor environments (homes, schools, offices, etc.). Therefore it has as main objective to promote

- identification and characterization of pollutants and sources
- assessment of population exposure
- assessment of health effects
- investigations into complaints about indoor air quality in office buildings.

The Concerted Action IAQ&IIM is implemented through a ***Concertation Committee*** composed of members of all participating countries, the Commission and a representative of the World Health Organization (WHO), the ***Secretariat*** and through ***working groups*** (WGs).

The Concertation Committee is responsible of the work performed by the Concerted Action. In view of the fact that the Concerted Action has no proper research funds available, the Concertation Committee has essentially three means to achieve the above objectives:

- development and validation of guidelines and reference methods for investigations or measurements
- collation, synthesis and dissemination of knowledge and data.
- organization of workshops, symposia, seminars and similar venues.

In particular the Concertation Committee

- decides on the working programme,
- discusses and evaluates the results of the work performed

- prepares reports summarizing available knowledge of important issues of indoor air quality
- identifies ongoing research in the participating countries and major research needs
- establishes working groups for well defined tasks and
- provides for exchange of information and collaboration with other international and national organizations active in the field of indoor air quality (e.g. WHO, NATO/CCMS, U.S. EPA)

Typical tasks for Working Groups are to

- develop working instruments like guidelines for measurements and investigations in order to promote the efficiency of research and the comparability of results
- organize intercomparison exercises for the validation of measurement guidelines
- assess the status of knowledge in specific areas and make proposals for solutions of indoor air quality problems.

In view of its ultimate goal (see above) work has been focused on providing and developing information and tools useful for a better understanding in how far and why indoor air quality may be inadequate and cause health and comfort problems to man. For the time being the question of how to improve indoor air quality or how to manage it in order to avoid unwanted effects has been addressed only marginally. However, indirectly much of the work performed so far or under way is linked to this question.as will result from the following presentation of the work of the Concerted Action.

WORK PERFORMED SO FAR. In the attempt to overcome the increasing difficulty of having at hand essential information in a concise form, the Concertation Committee, assisted by the Secretariat and by Working Groups, issues summary reports on single pollutants of high priority. Three such reports have been published: "Radon in Indoor Air" (4), "Indoor Pollution by NO_2 in European Countries" (5) and "Indoor Air Pollution by Formaldehyde in European Countries"(7). In all these reports the question of the prevention or reduction of unwanted exposures are briefly addressed.

Until now ten working groups have been established. Three of them have already achieved their tasks and summarized their results in a report:

WG 1: preparation of a practical guide to "Sick building syndrome" investigations (1); O. Valbjørn will report more detail on this work.

WG 2: preparation of a strategy for sampling chemical substances in indoor air (2); after an introduction the report issued by this WG presents general considerations regarding (i) the dynamics of the indoor environment, (ii) the sampling objectives among which to check the compliance with reference or guide values, (iii) time of sampling (iv) duration and frequency of sampling, (v) the sampling location and (vi) the question of quality assurance. In addition some special cases are addressed regarding sampling of formaldehyde, nitrogen dioxide, suspended particulate matter, asbestos, radon, and volatile organic compounds. Information of the report may be useful for the location of sensors for IAQ control.

WG 3: preparation of a guideline for the determination of steady state concentrations of formaldehyde in large test chambers due to emissions from wood based materials (3). This guideline is presently being validated by an interlaboratory comparison exercise of CEN aimed at establishing a harmonized standard for formaldehyde emission measurements. Eventually this work will be useful to avoid IAQ problems with formaldehyde in buildings.

Seven Working Groups are presently preparing status of art reports or guidelines for various indoor investigations:

WG 4: preparation of a discussion document on health effects of indoor air pollution;
WG 5: preparation of a guideline or standard procedure for the determination of microbiological pollutants; a draft document is scheduled to be ready in autumn 1991;
WG 6: preparation of a guideline on ventilation requirements based on percieved air quality; O. Fanger, the leader of this WG, will probably give some more detail on this work;
WG 7: Sick Building Syndrome research; this group is preparing a report with the tentative title "Sick Building Syndrome: The Design of Intervention Studies" which may become of particular value for some of the research proposed in the IAQM field.
WG 8: preparation and validation of a method for the characterization of VOC emitted from indoor materials and products using small environmental test chambers. This guideline is ready for printing and will be published within the next two months. An interlaboratory comparison involving European and North American laboratories for the validation of this guideline has been launched by the JRC in the framework of the Concerted Action;
WG 9: strategy/guideline for VOC measurements in indoor air (follow-up of WG2). Similar to the work of WG 2 the result of this WG will be pertinent to the control of IAQ;
WG10: review the state of knowledge of sensory stimulation by indoor air pollution and resulting sensory, neurological and psychological effects.

Of particular importance is an inventory of investigations and research projects in the field of indoor air quality going on in the countries participating in COST project 613/1 (6). This inventory is being updated at present and the updated version will be ready for printing within the next few weeks. Table 2 gives the number of projects in each of the participating countries notified for the first and the second edition. Although about 100 projects of the first edition are not contained in the second edition because finished within 1988, the number of projects increased from 239 in the first edition to 342 in the new edition, mostly due to the addition of projects from Finland, Norway and Sweden. Although it was not possible for this report to make a more detailed comparison of the content of the research projects in the two editions it can be anticipated that the number of project dealing with the investigation of effects of indoor air pollution on man is increasing.

The inventory will be of particular use for the identification of research gaps and for planning new research projects.

REFERENCES

(1) "Sick building syndrome - a practical guide". COST project 613 - Report No. 4. Prepared by Working Group 1 on behalf of the Community-COST Concertation Committee. Commission of the European Communities, Directorate-General for Science, Research and Development, Joint Research Centre - Ispra Establishment. EUR 12294 EN, 1989

(2) "Strategy for sampling chemical substances in indoor air". COST project 613 - Report No. 6. Prepared by Working Group 2 on behalf of the Community-COST Concertation Committee. Commission of the European Communities, Directorate-General for Science, Research and Development, Joint Research Centre - Ispra Establishment. EUR 12617 EN, 1989

(3) "Formaldehyde emissions from wood based materials: guideline for the establishment of steady state concentrations in test chambers". COST project 613 - Report No. 2. Prepared by Working Group 3 on behalf of the Community-COST Concertation Committee. Commission of the European Communities, Directorate-General for Science, Research and Development, Joint Research Centre - Ispra Establishment. EUR 12196 EN, 1989

(4) "Radon in indoor air". COST project 613 - Report No. 1. Prepared by James P. McLaughlin on behalf of the Community-COST Concertation Committee. Commission of the European Communities, Directorate-General for Science, Research and Development, Joint Research Centre - Ispra Establishment. EUR 11917 EN, 1988

(5) "Indoor Pollution by NO_2 in European countries". COST project 613 - Report No. 3. Prepared by the Community-COST Concertation Committee. Commission of the European Communities, Directorate-General for Science, Research and Development, Joint Research Centre - Ispra Establishment. EUR 12219 EN, 1989

(6) "Project inventory". COST project 613 - Report No. 4. Prepared on behalf of the Community-COST Concertation Committee. Commission of the European Communities, Directorate-General for Science, Research and Development, Joint Research Centre - Ispra Establishment. S.P./1.89.33, 1989

(7) "Indoor Air Pollution by Formaldehyde in European Countries". COST project 613 - Report No. 7. Prepared by the Community-COST Concertation Committee. Commission of the European Communities, Directorate-General for Science, Research and Development, Joint Research Centre - Environment Insitute. EUR 12219 EN, 1990

Table 1. Commission Services with interest in IAQ related issues: ongoing or planned activities

SERVICE	COMPETENCE	IAQ RELATED ACTIVITIES	STATUS
DG III	*Internal Market and Industrial Affairs*	• Directive 89/106/CEE on construction products defines "essential requirements" among which one regarding "hygiene, health and environment". Offers framework for issuing standards, guidelines or other technical specifications regarding for example • the giving off of toxic gas • the presence of dangerous particals or gases in the air • the emisssion of dangerous radiation	• Draft Interpretative Document "Hygiene, Health and Environment" asks for *HARMONIZED STANDARDS* for calculation and measurem. methods for a wide range of IAQ related parameters (HS for measurement of HCHO emission from wood materials being prepared)
		• Directive 87/217/CEE introduces measures to prevent and reduce air pollution by asbestos in air	• In force
DG V	*Employment, Industrial Relations and Social Affairs*	• In charge of actions against smoking. Directly related to IAQ is a Council Resolution to ban smoking in public places (1989).	• In force (does not oblige Member States to take action)
		• Recent interest in air pollution at non-industrial workplaces (offices)	• Session on indoor air at "Clean air at work" conference (in collaboration with CA IAQ&IIM)
DG XI	*Environment, Nuclear Safety and Civil Protection*	• 4th Policy and Action Programme on the Environment (1987-1992) requires a.o. "to define and implement preventive measures against indoor pollution by a growing number of substances"	• Commission Recommendation 90/143/Euratom for indoor radon concentrations: Intervention and design levels (400 and 200 Bq/m^3) - no further activity at present
	Consumer Policy Service	• Interest in emissions from consumer products	• planning phase
DG XII	*Science, Research and Development*	• Concerted Action IAQ&IIM (in collaboration with JRC)	• only until end 1991 (?)
		• Cost-shared research programme on IAQM	• under preparation
JRC	*Joint Research Centre*	• Research on organic indoor pollution and its sources	• ongoing
		• Management of the Concerted Action IAQ&IIM	• ongoing beyond 1991 (?)

Table 2. Number of notified research projects ongoing or concluded within the last two years in the countries participating in the concerted action "Indoor Air Quality and Its Impact on Man"

PARTICIPATING COUNTRY	NUMBER OF PROJECTS	
	1st EDITION	2nd EDITION
BELGIUM	-	3
COMMISSION OF THE EC	4	7
DENMARK	44	34
FINLAND	-	26
FRANCE	32	45
GERMANY	32	47
GREAT BRITAIN	41	33
GREECE	7	8
IRELAND	2	1
ITALY	12	20
THE NETHERLANDS	36	30
NORWAY	-	18
PORTUGAL	3	3
SWEDEN	-	51
SWIZZERLAND	26	16
TOTAL	239	342

INDOOR AIR QUALITY MANAGEMENT AND THE SICK BUILDING SYNDROME

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ABSTRACT. The paper is based on report no.4, "Sick Building Syndrome. A Practical Guide" from CEC Cost Project 613, and from the SBI report 212, "Indoor Climate and Air Quality Problems. Investigation and Remedy" from the Danish Building Research institute. Important factors associated with SBS and BRI for establishing healthy and comfortable indoor climate conditions are discussed. A stepwise method is recommended. From this background proposals for studies of several not well described cause-relationships are listed.

SICK BUILDING SYNDROME OR BUILDING RELATED ILLNESS

The symptoms

In every large group of people somebody is likely to be suffering from one of the following symptoms:
- eye, nose and throat irritation
- dry mucous membranes
- rash on the face and dry skin
- abnormal fatigue, feeling heavy-headed, headache or general malaise.

The following more unusual symptoms also occur inside buildings:
- throat infections, coughs, hoarseness, difficulty in respiration, itching, hypersensitivity, nausea and dizziness.

When more people than expected suffer from these symptoms and if it appears that they are related to staying in the building the building is often called "sick".

For example it is typical for symptoms to appear after a short stay in the building and then gradually to increase during the day. In general the symptoms quickly disappear after people leave the building, e.g. during the night or over the week-end. In many cases an increase of the symptoms has been recorded due to moving into new buildings or recently renovated buildings. However, cases in old buildings are also known.

As a basis for the solution of indoor climate problems the occupants should be questioned about their problems and statistics of the frequency should be established. This can in part lead to what are the main factors affecting the occupants (heat, cold etc.), but can also prove if these exposures may be associated with sickness symptoms. For this purpose the questionnaire (Annex 1) can be used.

Expected frequency of complaints

Regarding the specific physical exposures mentioned in the questionnaire, Annex 1, (for example draught and high temperature) in practice it cannot be expected that less than 10-15 p.c. will complain of being bothered often (more than once a week).

Expected Frequency of Symptoms

It might be appropriate to estimate the frequency of the symptoms within groups of symptoms in order to compare with reference data which are available for the danish population. (In other countries the individual number of symptoms are used). The following groups can be used,

- Mucous membrane symptoms involving dryness or irritation in eyes, nose or throat
- General symptoms involving headaches, feeling heavy-headed, abnormal fatigue, malaise and dizziness.
- Skin problem

A person is classified in one of the three groups having mentioned just one of the symptoms specified. Each person can only be counted once in each of the two symptom groups. Often only the work-related symptoms are counted e.g. symptoms which disappear when the people are not in the building investigated. This classification leads however to very low frequency of workrelated skin problems (app. 5 pct). In office work one can expect 60-70 p.c. of the total number of registered mucous membrane symptoms and also "headache" or "feeling heavy-headed" to be work-related, while "tiredness" naturally disappears when away from work and therefore normally all registered cases of general symptoms will be classified as work-related.

Table 1 gives the averages of the symptoms based on investigations (3) and (4), but it is to be expected that even in office buildings with the lowest incidences still 15-20 p.c. are affected with work-related mucous membrane symptoms more than once a week, and 20-25 p.c. with general symptoms more than once a week.

Investigations (3) and (4) have shown that besides the differences between the frequency of symptoms of men and women, working conditions can also have an influence. For instance people in leading positions in general complain three times less than people in other groups. In a specific building the complaints could very well be limited to individual rooms. It should therefore be investigated whether the symptoms are concentrated in particular sections of the building.

Table 1. Average prevalence of symptoms for men (m) and women (w) at home, at work, and especially office work. The numbers are based on investigations (1) and (2).

Symtoms once or more times weekly	At home		At work		In Office Work			
			all branches		all people		people recovering outside the working area	
	m p.c.	w	m p.c.	w	m p.c.	w	m p.c.	w
Dryness or irritation in eyes, nose or throat	6	8	12	21	35	49	20 (10)	32 (19)*
Headache, feeling heavy headed, fatigue, dizziness, malaise	-	-	-	-	28	45	26 (17)	41 (30)*

* Numbers in ( ) are the lowest frequences discovered in investigation (1) in buildings with more than 80 people employed.

EXPOSURE AND EFFECT

Physical Exposure

It is rarely possible to explain the symptoms occurring through the influence of a single factor like formaldehyde or dust.

The factors are normally far below the threshold limit values or within "acceptable" ranges. It is also possible that more than one factor results in the same symptom, for example heat radiation and formaldehyde can cause dryness of the eyes. Objective signs of exposure have seldom been proved besides of eye irritation.

From the investigation view point we can use the fairly reasonable hypothesis that several factors, each with a value not likely to cause any symptoms, cause the symptoms when they occur together. The most important influence is supposed to be via the skin and mucous membrane. Besides this influence especially caused by pollution and thermal climate there is exposure from other factors, e.g. static electricity, noise and lighting.

Odour

A common observation in buildings where high prevalence of symptoms occur, is a faint but unpleasant odour. The direct source of the odour can be difficult to detect, but mould growth, new building materials, new furniture, intensive use of copying machines and accumulated dust are often mentioned as sources. Apart from being an indicator of contamination the odour in itself forms a stress factor, which may contribute to the symptoms. This seems valid if the source of the odour cannot be discovered. The odour seems often to occur where materials with a large specific surface, e.g. fleecy material like floor carpets and hessian wall covering, but also where hygroscopic materials such as paper are present. In these materials the odourous components can be absorbed instead of being ventilated away and then later be given off when the climate conditions change, e.g. an increase of temperature.

Psychosocial Conditions

Stress and psychosocial conditions are also important factors as they are associated with the named symptoms either directly (tiredness) or by increasing the sensitivity towards physical and chemical exposure. A clear relationship between the physical exposure and the symptoms appearing will therefore be difficult to discover.

Examples of exposures

Table 2 states the most important of specific physical and the chemical factors and their proved or presumed effects on people. Tobacco smoke and odour are not mentioned here as they are indicators of pollutants. The table is worked out considering the effects of symptoms related to the indoor climate. The exposures can be found to a great extent in all types of buildings.

Table 2. Chemical and physical factors in non-industrial buildings and their effect or presumed effect on people. Only exposures and effects relevant to mucosal or general symptoms are dealt with. The expression "mucous membrane irritation" also covers the expression "dry mucous membrane".

Factor	**Area for possible effects**	**Proved effect**	**Presumed effect**	**Source among others**
Organic gases and vapours	5-20 mg/m^3	Dryness mucous membrane	Mucous membrane irritation	Paint Glue Plastic
Formaldehyd (and other aldehydes)	0.1-0.4 ppm 0.12-0.5 mg/m^3	Mucous membrane irritation Dry skin Eczema		Paint, acid hardening lacquer Glue (in chipboards) Tobacco smoke
Amines	Unknown		Mucous membrane irritation	Paint
Phthalates	c. 0.5 mg/m^3		Mucous membrane irritation	Plasticizer
Fluorides	Unknown		Mucous membrane irritation Headache	Wood impregnated
Nitrogen dioxide	0.1-0.3 ppm 0.2-0.5 mg/m^3	Reduced lung function	Mucous membrane irritation	Gas Cooker Unvented gas or petroleum oven
Hydrogen chloride	1.3 ppm 1.4-4 mg/m^3		Mucous membrane irritation	Acid washed brick walls
Carbon-dioxide	1500-5000 ppm 2.7-9 g/m^3 (0.15-0.5 %)	Indicator of human bio-effluents	Fatigue Headache	People Unvented combustion
Carbon-monoxide	c. 10 ppm c. 12 mg/m^3		Fatigue Headache	Tobacco smoke Unvented combustion Exhaust gas from automobiles

Ozone	0.05-0.1 ppm 0.1-0.2 mg/m^3	Mucous membrane irritation		Copying machines Electrofilters
Inorganic dust	c. 1 mg/m^3 (in the air)		Mucous membrane irritation	Dirt from outside and from building materials
Man made mineral fibres	1.000-20.000 fibres/m^3		Mucous membrane irritation Eczema	Acoustic ceilings (Insulating materials)
Organic dust	c. 1 mg/m^3 (in the air) 3-6 mg/g *) (in floordust)		Mucous membrane irritation Fatigue	Paper Textiles
Organic biological dust **)	Micro fungi c. 100-1.000 colony forming units/ m^3 air	Asthma Allergy	Fatigue Eczema Reduced lung function	House dust mites (residence) Animal dander Mould
Metabolic products of micro-organisms	Unknown		Fatigue Headache Mucous membrane irritation	Mould
High temperature	24-30 °C	Lack of concentration	Fatigue Headache Sensation of dryness	Sun radiation Lighting Heat-emitting apparatus
Low frequency sound	70-120 dB in frequency area 20-100 Hz		Fatigue Heavy in the head	Ventilators Machines Compressors
Noise	60-80 dB (L_{Aeq}) equivalent noise level		Fatigue Headache	Machines Ventilation system Traffic
Lighting: Glare Reflection Contrast low			Eye-irritation Headache	Daylight Artificial lighting Visual display

*) Macromolecular organic dust

**) Specific conditions for development of allergies and release of symptoms in people suffering from allergies.

Table 3. Indirectly acting factors, their process of influence and their possible effects.

Factor	Process of influence	Possible effects
High temperature and/or high humidity	Increases the rate of off-gassing from building materials and furniture	Mucous membrane irritation
	Increases microbial growth	Mucous membrane irritation and fatigue
Fleecy and hygroscopic materials (carpets, textiles, paper)	Changes the off-gassing conditions in a room by adsorption and desorption of pollutants	Mucous membrane irritation and fatigue
	Increases the risk of accumulating sources of biological activity released by high humidity	Increases the risk of mucous membrane irritation and fatigue
Dust and gases	Gases are absorbed in dust which is transmitted to skin and mucous membranes	Rash and mucous membrane irritation
High temperature and noise	The ability to concentrate is reduced by high temperature but increased by simultaneous noises (stresses the organism)	Increases the risk of headache and fatigue (stresses the organism)
High temperature and low level of lighting	The ability to concentrate is reduced	Where the ability of high concentration is needed the risk of headache and fatigue is increased (stress)
Static electrical charge and dust	Dust is transmitted to the skin	Flush and facial skin and rash
Inadequate lighting conditions	Distorted working postures result in muscular tensions	Headache
Draughts and low temperature	Increases muscular tensions locally	Headache

CAUSES OF INDOOR CLIMATE AND AIR QUALITY PROBLEMS

The symptoms related to buildings are supposed primarily to depend on the quality of the air and the thermal climate and to a lesser degree on sound and lighting conditions. Examples of factors regarding indoor climate symptoms can be seen in (2).

Thermal Climate

Regarding thermal climate it is in general easy to identity problems. The complaints are often directed towards a particular cause e.g. draught, high and low temperature, and frequently they appear in connection with unspecified complaints (symptoms). The estimation can be carried out according to NKB-report No. 41 (5) or DS/ISO-standard 7730.

The essential and important thermal conditions causing symptoms are: too high a temperature level and heat radiation to the head. Ceiling heating and strong lighting from incandescent lamps may therefore be a cause of symptoms. The operative temperature should not to be above 24 °C and experience seems to show that 23 °C should be an indicative upper operative temperature limit for the most part of the year. It is anticipated that the effect is caused by higher offgassing rates perhaps also dependent of the relative humidity. The microbial activity is normally also higher at high temperatur levels. Therefore a low temperature level reduces the fequency of symptoms. When the temperature decreases the sensation of draught will increase and for sedentary work (wearing normal indoor clothing) the temperature should not be below 21 °C even at air velocities about 0.15 m/s, which must be considered as an upper acceptable value for sedentary work.

Air Quality

Questions of air quality are more difficult to deal with. One of the first things to do would be to identify and remove the sources of the pollutants. In general this is only possible if the source is visible or has a characteristic odour. A simple method to test if a material is the source of the odour is to put some of it into a closed jar for a couple of days after which the odour will appear. The material must be aired some days before it is placed in the glass to remove the odour adsorbed from other sources.

This method is further developed by Ole Fanger, who has introduced the OLF and the DECIPOL units to quantify air pollution sources and levels of pollution as perceived by human beeings. However it is difficult to specify the true source from the perceived decipol level in field studies. This is due to the dynamic processes like adsorption and desorption. In most cases it is therefore not possible to identify and remove a particular source. The sources can also be so widespread and slowly offgassing that it is not economically reasonable to remove them. Instead the next step would be to increase the ventilation.

Ventilation

It is important to make sure that the ventilation related to air quality supplies at least 4 litres per second per person with outdoor air. It should be noticed that such a suggested minimum air supply is established taking into account only human bioeffluents and app. no off-gassing from building materials, furniture etc. There are no values which consider other or intensified pollutants. Recent research seems to show that the valid guidance of ventilation is not sufficient. The OLF and DECIPOL concept shows it, and the dynamic conditions where ad-and desorption takes place confuses many researchers. However with a ventilation about 3 air changes per hour (ach) in kindergartens and above 8 litres per second per person (app. 1,2 ach) in offices problems however seem to be rare. Only when such a level of ventilation is obtained does it in general become reasonable with more thorough and expensive remedies to remove possible pollutants. Water damage, mould attack, and dirty carpets always have to be taken care of first.

In many buildings with problems unsatisfactory ventilation is a common denominator. The ventilation system often works poorly, has a low efficiency (short circuit) or much too low outdoor air supply. Energy savings have resulted in a common reduction of air changes in buildings because of extensive sealing precautions, reduced operating hours, direct reduction of outdoor air supply or increased recirculation. Furthermore, the systems are often poorly adjusted which results in proper ventilation in some rooms while other identical nearby rooms are hardly ventilated. A dirty ventilating system can contribute to increasing pollution and odour perhaps by dust adsorbing the odourous components by recirculation at night, and these smelling substances are then released to the supply air during the day.

Microbial Pollution

Microbial growth, e.g. in connection with water damage, humidity absorbed by dirty carpets from water used during cleaning processes or growth in humidifiers, probably are an essential cause of the increase in symptom occurrence. The Danish Town Hall Investigation (4) showed that a relatively high organic part of the floor dust was also associated with a high prevalence of symptoms. It is probably the airborne organic dust which is important, but except for bacteria and mould spores this was not measured because of lack of analysing methods for small amounts of dust. It is then essential to remove the risk of the accumulation and spread of microbial pollutions by removing the cause of water damage or high humidity (leaking roof, wet footwear) and ensure that it does not accumulate by using floor coverings and furniture which can be cleaned effectively.

Expected Types of Problems

The causes of the problems mentioned do not in general occur simultaneously. Off-gassing from building materials is highest immediately after they are produced and built in (about 6 months) and it is seldom a problem in buildings that are more than one year old. A decomposition of the materials can start the off-gassing, however. This is, for example, known from chipboard containing ureaformaldehyde glue. The glue is decomposed by water or high humidity and releases formaldehyde. On the other hand, in old buildings microbial pollution is more likely to occur and it is most probable that heating and ventilating systems do not function as designed as a result of poor maintenance e.g. because of blocked filters and heating coils. Regarding office buildings, new office technology in general results in smaller free area per person, higher air temperature and sometimes not adequate lighting and more annoying noise, and therefore poorer physical working conditions.

Psychosocial factors

Psychosocial factors may play a role by increasing the stress in people and thus making them more susceptible to environmental factors. In multifactorial analyses of data from (4) factors like sex, jobtype,and psychological factors were associated with SBS to the same degree as the building related factors. In some cases it is still a question which of the two group of factors, psychosocial or physical, are the modifiing element or if they at all interfere.

STEPWISE PROCEDURE

To avoid using resources for measurements or remedies which have no connection with the real problems or for measurements which are difficult to interpret, a stepwise procedure is recommended and outlined in table 4. The principle of this procedure is that obvious indoor climate problems or problems found by using a questionnaire investigation should be solved first. Thereafter, more complicated investigations or investigations and remedies resting on a slender foundation are made.

The questionnaire for the occupants ought at least to include questions about annoyances and symptoms (hygiene investigation) and be supplemented with information about the actual building conditions obtained from a questionnaire to the person responsible for the building maintenance (technical investigation). Already important knowledge of the problems is available. This investigation forms the basis of estimating whether the problems should be considered only from a technical point of view or if hygiene or psychosocial experts should be consulted.

Action Programme

An important element in the solution to indoor climate problems is the preparation of an action programme. An action programme has great pedagogical value because it can inform the employees of the background and aim of the stepwise procedure in order to obtain a proper result. It can also be used to give proof and to predict future expenses in connection with carrying out the solutions. It is natural to work out this plan after receiving the results of the questionnaire investigations concerning building conditions, complaints and symptoms because the questionnaire investigations show the kind and extent of problems and describe building conditions and then form the basis of the decision as to how the improvement should be made. The action programme can also form the basis of negotiation with the Labour Inspection. The action programme should be revised after each step.

Table . Summary of stepwise investigation of buildings with indoor climate problems.

Step	Investigation	Performed by	Examples of actions
1	Control of operation	Safety Organization Maintenance engineer	Introduce normal control and maintenance conditions Instruct the users
2	Technical and hygiene (employee) questionnaire investigation	Safety Organization Maintenance engineer Industrial Health Service or consulting engineer	Prepare action programme on the basis of what kind of problems and extent, if necessary contact the Labour Inspection
3	Inspection Measurement of climate indicators	Safety Organization Maintenance engineer Industrial Health Service	Adjust operation conditions for ventilation and heating systems Improve cleaning Remove sources of pollutants Revise action programme
4	Measurement of ventilation and justified measurements	Ventilation engineers Industrial Health Service	Increase the ventilation Mount sunscreening Renew or remove carpets
5	Clinical test and connected specific measurements	Medical doctor Clinic of Occupatinal Medicine Industrial Health Service	Renew furniture and building material Change production process Relocate people

RECOMMENDATIONS FOR EUROPEAN ACTIONS

It is accepted that we are dealing with a multifactorial cause-effect problem and research has shown many of the single factors which are associated with the symptoms related to occupancy in buildings.A more profound knowledge of the mechanisms behind and the strength of the effects is still a key issue. Many of the socalled causes may only be indicators of others.

I can therefore propose the following to be studied:

Human exposure studies i climate chambers

- The effect of free organic components (VVOC;VOC;SVOC)
- The effect of organic components adsorbed on particles and of particles of biological origin
- The effect of various elements of noise (low frequency noise, pure tones)
- The effect of fluctuations due to the AC in artificial lighting

Other studies

- Studies of adsorption and desorption of pollutants on materials as a function of temperature, humidity and air velocity
- Influence of air velocity on evaporation rate and composition of pollution from materials in use
- The importance of indoor fungi, bacteria and other microorganisms (odor,mycotoxins,endotoxins, etc.)
- The importance of individually controlled ventilation for the total required outdoor air supply and for the general satisfaction(low symptom frequency) among the occupants for physical or psychological reasons
- The interference between psychological stress and physical exposures i.e. the modifiing function of stress
- Intervention studies with both psychological and physical environments as target for intervention

LITERATURE

1.Molina C. et.al. Sick building syndrome. A practical guide. Report no.4, Commision of European Communities 1989.
2.Valbjørn O. et.al. Indoor climate and air quality problems. Investigation and remedy. SBI report 212. Danish Building
3.Valbjørn O. Kousgaard N. SBI report 175. Danish Building Research Institute 1986.
4.Skov P. et.al. Influence if indoor climate on the sick building syndrome in an office environment. scan J Work Enviro Health 1990
5.Indoor climate. The Nordic Committee for Building Regulations. National Building Agency, DK, 1981.(revised partly 1991 concerning air quality and ventilation requirements.)

ANNEX 1

INDOOR CLIMATE **Work environment** **ENGLISH VERSION**	**MM 040 EA** Date year month day	Name Company/institution
Number ☐☐☐☐☐ User ☐☐☐☐ Filled in by investigator	Occupation ☐☐☐☐ Group ☐☐☐☐	Department

This questionnaire concerns your indoor climate and possible symptoms you may be experiencing.

BACKGROUND FACTORS

Year of birth 19 ☐☐

Sex male ☐ female ☐

Do you smoke? Yes ☐ No ☐

Occupation ....

How long have you been at your present place of work? ☐☐ years

WORK ENVIRONMENT

Have you been **bothered** during **the last three months** by any of the following factors at **your work place**?	Yes, often (every week)	Yes, sometimes	No, never
Draught	☐	☐	☐
Room temperature too high	☐	☐	☐
Varying room temperature	☐	☐	☐
Room temperature too low	☐	☐	☐
Stuffy "bad" air	☐	☐	☐
Dry air	☐	☐	☐
Unpleasant odour	☐	☐	☐
Static electricity, often causing shocks	☐	☐	☐
Passive smoking	☐	☐	☐
Noise	☐	☐	☐
Light that is dim or causes glare and/or reflections	☐	☐	☐
Dust and dirt	☐	☐	☐

WORK CONDITIONS

	Yes, often	Yes, sometimes	No, seldom	No, never
Do you regard your work as interesting and stimulating?	☐	☐	☐	☐
Do you have too much work to do?	☐	☐	☐	☐
Do you have any opportunaty to influence your working conditions?	☐	☐	☐	☐
Do your fellow-workers help you with problems you may have in your work?	☐	☐	☐	☐

Environment med, Dept. Occ. Med,
Örebro, test version 8910/KA/BY ©

PAST/PRESENT DISEASES/SYMPTOMS

	Yes	No
Have you ever had asthmatic problems?	☐	☐
Have you ever suffered from hayfever?	☐	☐
Have you ever suffered from eczema?	☐	☐
Does anybody else in your family suffer from allergies (e.g. asthma, hayfever, eczema?)	☐	☐

PRESENT SYMPTOMS

During **the last 3 months** have you had any of the following symptoms?

	Yes, often (every week)	Yes, sometimes	No, never	**If YES: Do you believe that it is due to your *work environment*?** Yes	No
Fatigue	☐	☐	☐	☐	☐
Feeling heavy-headed	☐	☐	☐	☐	☐
Headache	☐	☐	☐	☐	☐
Nausea/dizziness	☐	☐	☐	☐	☐
Difficulties concentrating	☐	☐	☐	☐	☐
Itching, burning or irritation of the eyes	☐	☐	☐	☐	☐
Irritated, stuffy or runny nose	☐	☐	☐	☐	☐
Hoarse, dry throat	☐	☐	☐	☐	☐
Cough	☐	☐	☐	☐	☐
Dry or flushed facial skin	☐	☐	☐	☐	☐
Scaling/itching scalp or ears	☐	☐	☐	☐	☐
Hands dry, itching, red skin	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

FURTHER COMMENTS

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Sick Building Syndrome, epidemiological studies and medical aspects

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Abstract

The sick building syndrome comprises a group of symptoms that are common in the general population, but which are more prevalent in some buildings than others. The principal symptoms are lethargy, headache, blocked nose, runny nose, dry eyes, sore eyes, dry throat and sometimes dry skin and asthma. These problems have usually been studied in office workers, where there are less confounding factors, but similar symptoms occur in other indoor environments such as schools and hospitals. All studies so far have shown that naturally ventilated buildings have less symptomatic workers than air conditioned buildings, despite conditions which conform less to indoor environmental standards, which have been developed for comfort rather than health. Women are more susceptible than men, and public sector workforces have more problems than those in the private sector. The mechanisms for the symptoms are not yet defined, their elucidation will provided clues to the causes.

EPIDEMIOLOGICAL STUDIES IN EUROPEAN OFFICE WORKER POPULATIONS

The first study of a number of buildings unrelated to known building sickness was by Finnegan et al in 1984 The study looked predominantly at the role of humidifiers but included the first systematic sick building enquiry of nine buildings. Doctor administered questionnaires were used. Five of the buildings had air conditioning with humidifiers, three were naturally ventilated and one had mechanical ventilation without humidification. Work-related symptoms of sick building syndrome were substantially more common in the air conditioned buildings than in the naturally ventilated buildings. The prevalence of nasal symptoms, headache and lethargy were two to three times higher once the buildings were sealed (compared with naturally ventilated buildings). The addition of humidification would further increase the eye irritation, nasal symptoms, asthma, humidifier fever and dry skin. This study suggested that not all the symptoms of building sickness had the same cause and that sealing the building and the introduction of humidification and chilling were associated with symptoms.

A similar questionnaire, this time self administered, was used in the study of 4,373 office workers in 47 different working groups in the UK with different ventilating conditions (Burge et al 1987). This study confirmed that in general, naturally and mechanically ventilated buildings without humidification or chilling had fewer symptomatic workers than buildings with any kind of full air conditioning. They also investigated the individual factors which contributed to symptoms, in particular females had more symptoms than males and workers lower down the office hierarchy had more symptoms than those higher up, irrespective of sex. These factors need to be taken into account when comparing different workforces. An adjusted figure for the average number of work-related symptoms for occupants of the building (the building symptoms index) was developed to make each worker equivalent to a male manager (the class of workers with the least symptoms). The results for the 47 buildings are shown in Fig 1. This shows that the best buildings are naturally ventilated but that some of the naturally ventilated buildings have more symptomatic workers and some of the air conditioned buildings have less. However, there is a great variation within each ventilation class. The study also showed that in general workers in public sector buildings had more symptoms than workers in private sector buildings. One building was studied with both a public sector and a private sector workforce, each had similar building symptom indices, suggesting that the reason for the difference between the two sectors was in the buildings and their maintenance rather than the management structure. This needs to be confirmed in larger studies.

A study of public sector work is in and around Copenhagen (Skov and Valbjorn 1987) removed the confounding factor of type of employer. Fourteen town halls were studied, six were naturally ventilated, only two had re-circulated air and two humidification. Most of them had predominant natural ventilation. Their study confirmed findings of the previous two studies, again there were substantial differences between different buildings. They grouped their symptoms into lethargy and headache on one hand, and eye, nose and throat symptoms on the other. In most buildings the prevalences of the two groups of symptoms correlated reasonably well. However, there were a group of buildings where eye, nose and throat symptoms predominated over lethargy and headache, suggesting that the causes were different, at least in these buildings. Their study contacted 3,507 out of a possible 4,369 employees. Their work suggested that the amount of dust and absorbent material in the environment contributed to building sickness. They introduced the term 'fleece' factor (the area of fabric such as carpets, curtains, soft furnishings. divided by the volume of the room) and 'shelf factor' (the length of open shelves and cupboards divided by the room volume). Both of these correlated with symptoms. Symptoms are also related to the concentration of dust that could be extracted from the carpets but not related to personal factors such as drinking coffee (which actually reduced symptoms).

The largest study to date has taken place in Holland in 61 buildings largely contacted through their Occupational Health Service (Preller et al 1990). Nineteen of the buildings were naturally ventilated, 42 had some sort of air conditioning, 13 had steam-humidification and 12 water spray humidifiers. Completed questionnaires were returned from 7,030 out of 10,500 workers (74% response rate). The study confirmed the increased number of symptoms in females compared with men and the increased number of symptoms in air conditioned versus naturally ventilated buildings. They were unable to demonstrate any effect of humidification or any difference between steam or water spray humidifiers and were unable to confirm the shelf and fleece factor hypothesis from the Copenhagen study. They showed that subjects reporting allergy had increased risk of symptoms. As many of the symptoms could be regarded as allergic (such as runny noses and sore eyes) it is difficult to know whether the allergy reported was preceding the sick building syndrome symptoms or was reported because the symptoms of sick building syndrome were thought to be allergic. The study also showed an increased number of symptoms in those dissatisfied with the procedure for handling complaints within the building (this was in fact the strongest risk factor) increased symptoms with those who were unable to adjust temperature locally and a small increase in those using VDU's. The study was unable to find any effect of active smoking (present in 35% of the workforce), opening windows, age, education, the number of people in the room or the presence of carpet, shelves or curtains (i.e., the 'fleece' factor and 'shelf' factor of the Copenhagen study could not be reproduced).

A preliminary report has appeared of a large study from Northern Sweden (Stenberg et al 1990) which studied 6,000 office workers in buildings with at least 10 workers per building (the other studies have usually had a minimum of 50 per building). The study involved a screening questionnaire and case control studies nested within the responders, 4,943 questionnaires were processed. Again females have more work-related symptoms than males. The study showed that atopy (defined as a history of asthma or hay fever) doubled the risk of being a sick building syndrome case (not defined). Symptoms were also about 20% more common in VDU users but these were more often female and this was not adjusted for. A nested study investigated 584 rooms in 192 buildings, the rooms selected either for cases of sick building syndrome or controls (Sundell et al 1990). The rooms containing those with building sickness had the same fresh air supply rate, the same relative humidity, temperature, shelf factor and fleece factor as the buildings from these who were asymptomatic. However, the variation of these factors between the buildings studied was not very large (for instance mean temperature varying from 22.4 to 23.2°C and mean relative humidity from 22.1 to 28.8%). We also have been unable to demonstrate that "sick" buildings have poorer standard indoor air quality measures than healthier buildings, but did show that plant maintenance was worse in the sicker buildings (Burge et al 1990).

None of the above studies have used a random selection of buildings and some would argue that they have picked out buildings where symptoms were known to occur (although this wasn't stated at the time). It is attractive to designate buildings as either sick or healthy, in fact the evidence suggests there is a continuous gradation. An interesting study has taken place in Germany using a market research company to contact adults away from the workplace (Kroeling 1987). Those who worked in offices and schools were asked whether they worked in an air conditioned or naturally ventilated building. The symptoms of building sickness were all significantly more common in those working in air conditioned buildings (420 workers) compared with those working in naturally ventilated buildings (699 workers). Workers from air conditioned buildings also rated their environment as less satisfactory than those working in naturally ventilated buildings.

Several of the above studies have used different interview techniques and different definitions of work-related symptoms. Some reported symptoms which had to have a frequency of at least once a week whereas others only required the symptoms to be present at least twice a year. The interviewer administered questionnaires have generally produced lower prevalences of symptoms than self-administered questionnaires. This is the general finding related to inhibitory effects of an interviewer that is not confined to the sick building syndrome. The number of workers who have severe building related disease (in medical terms) is likely to be small. The severity of disease required to count as a case of sick building syndrome during epidemiological surveys is likely to affect the comparisons between buildings. The more severe the requirement the more unusual occurrences, such as mould growth following flooding and water leaks, will feature as a cause. The less stringent the requirements the more relatively trivial features, such as general dustiness, may feature. If weekly symptoms throughout the year are required it is unlikely that disease due to humidification and chilling will be prominent, as humidification and chilling may only be required for part of the year. Despite this some consistent factors emerge.

1. Females have more symptoms than males.

2. Workers in naturally ventilated buildings are in general less symptomatic than those in air conditioned buildings.

3. Buildings that are hotter have more symptomatic workers than those that are cooler.

4. Some humidification and chilling systems are associated with disease

5. There is an association between the perception of the environment that has been poor and unsatisfactory in symptoms.

6. Poor job satisfaction is associated with more symptoms.

Other factors which are found in some but not all studies are an association particularly in naturally ventilated buildings, between symptoms and extractable floor dust and perhaps the shelf factor and fleece factor. Some studies show more symptoms in VDU workers also the risk factor is not strong. The Dutch workers using a linear aggression were able to 'account' for only 5-20% of a variation in complaints using the factors that they studied. They wondered whether this was the way to proceed.

THE SYMPTOMS OF SICK BUILDING SYNDROME

Building sickness comprises a group of symptoms which are common in the general population, but which are more common in workers in some buildings than in others, and are temporarily related to work within these buildings. Most of the studies have identified similar symptoms, the most common are usually lethargy and tiredness and headache followed by a blocked nose, runny nose, sore eyes, difficulty with wearing contact lenses, dry eyes, dry throat, dry skin and sometimes symptoms suggestive of asthma. A much wider range of symptoms was investigated in the German market research study, the ones that were different between workers in air conditioned and naturally ventilated buildings were similar to the ones just described.

Lethargy has two different time patterns. In some workers the lethargy comes on during the day at work and improves within a few minutes of walking outside the building or going out at lunch-time. In others the symptoms are more profound, the worker needing to sleep for 1-2 hours after work as well as having a normal night's sleep. The headache is usually described in medical terms as a 'tension' headache, it occurs across both sides of the forehead and sometimes at the back of the neck. Migraine is not in general a feature of building sickness.

Many have wondered whether the symptoms are 'real'. Several different attempts have been made to validate the symptoms but as there received, in random order, a self-administered questionnaire similar to the usual sick building questionnaire, and a medical opinion based on questionnaire at the time. The average number of work-related symptoms for workers (building symptom index) which is used to compare one building with another, showed a good agreement between the two methods. There were, however, consistent differences between their two assessments and individual symptoms. The self-administered questionnaire produced a higher prevalence of work-related runny nose and flu-like symptoms, hich were often regarded as being due to infections from the medical opinion. Work-related symptoms on the self-administered questionnaire were validated by the medical opinion in over

75% of cases with eye and throat symptoms, lethargy and headache, but only 31% of those with a runny nose and 21% with flu-like symptoms were regarded as work related in the medical interview. The medical opinion identified an extra 5% of work-related symptoms that were missed by the self administered questionnaire. The self-administered questionnaire therefore, produced a satisfactory estimate of work-related symptoms, removing the potential bias from an interviewer. The questions on runny nose and flu-like symptoms would be improved by including only those that occurred at least weekly.

There are no absolute tests for lethargy, headache and dry throat. Objective measurements have, however, been used to validate dry eyes, blocked nose and asthma symptoms. Dry eyes can be investigated by putting fluoricine into the eye and measuring the time taken between putting the drops in and the breakup of the fluoricine film. Those reporting dry eyes more frequently were shown to have a greater proportion in which the tear film broke up in under five seconds (Franc, 1986).

An attempt has been made to measure nasal inspiratory flows serially using an inverted peak flow meter with a nasal mask. This technique has is in general, been found to be too complicated for workers to master as the nostrils need to be flared when making the measurements, otherwise the major source of resistance is in the alae nasae. Measurements of nasal resistance have been made at a single point in time and correlated with a self assessment of nasal patency at the same time in office workers, who have subsequently kept serial diary cards of symptoms (Robertson, personal communication). Work-related patterns in these diary cards can often be seen (Fig.2). It is unlikely that further physiological measurements will prove rewarding in symptom validation.

RESEARCH NEEDED RELATING TO THE MEDICAL PROBLEMS OF SICK BUILDING SYNDROME.

Mechanism of Symptom Production

It is unclear whether sick building syndrome relates to an agent or agents in the environment, and if so whether these are specific chemicals. There is some suggestion that allergic individuals are more likely to be more symptomatic than non-allergic individuals (for instance from the Dutch and Swedish studies). The mechanism of action at least of the nasal symptoms should be definable by studying individuals with symptoms, for instance by looking for eosinophils in nasal smears which would favour an allergic cause. If the cause is thought to be allergic then a detailed search for allergens in the environment would be the next stage (for instance house dust, mites, biocides, de-scalers etc.). If the nasal changes do not look allergic then both physical factors (such as temperature in the humidity) and irritant factors (such as fibres and general environmental dirt) would be more likely.

Some studies have identified passive cigarette smoking as a risk factor. Passive cigarette smoking may occur both at work and away from work and is amenable to study in the workplace, particularly looking at buildings where smoking policies are being introduced and smoking prohibited in the workplace. Passive cigarette smoking exposure can be determined in individuals by several means (for instance urinary or salivary cotinine measurements, or measuring nicotine in hair samples, Nilsen and Zahlsen 1990)

There are suggestions that fungi (and perhaps bacteria) are associated with sick building syndrome, particularly in air conditioned buildings (Austwick et al 1989). There are a number of well documented cases where major fungal colonisation has occurred and where symptoms have increased. The mechanism may be via allergy or by mycotoxins. The fungal levels in naturally ventilated buildings in total are usually higher than in air conditioned buildings, so it is likely to be specific fungi rather than fungi in general that are related to symptoms. Further characterisation of the fungi present in the indoor environment and the search for specific IgE antibodies in affected individuals, would be worthwhile. Very similar symptoms occur in humidifier fever (although these are more severe) where an IgG mechanism is likely.

It is likely that the most useful studies will be interventional where individual factors are changed, particularly important factors to look at would be :

1. General cleaning.

2. Improving the maintenance of the plant, particularly making it clean.

3. Improving the quality of filter maintenance.

4. Removing biocides and de-scaling agents from contact with the circulating air.

5. Removing humidifiers.

6. Providing local individual control of temperature, airflow and lighting.

7. Improving the communication between plant managers and workers and setting up a confidential system for dealing with complaints and getting action taken.

Other questions which have a medical input would include looking at sickness absence related to symptoms (there is some early work on this). Investigating productivity and symptoms, looking at the effects of menstrual cycle on symptoms in females, looking at the effects of season on symptoms.

It is quite likely that the causes of sick building syndrome will be different in different environments. Most of the studies described have taken place in the more temperate areas of Europe where air conditioning is often unnecessary. Those in sub-arctic regions (for instance the Swedish study) take place in environments where humidity levels are extremely low in the winter. In some tropical regions the humidity is exceedingly high. The role of humidity may be different in these two extreme circumstances.

References

1) Austwick, P.K.C., Little, S.A., Lawton, L., Pickering, C.A.C. & Harrison, J., Microbiology of sick buildings. Airborne deteriogens and pathogens, 1989, pub Bioteterioration Society, occasional publication 6, 122-128.

2) Burge, P.S., Hedge, A., Wilson, S., Harris Bass, J. & Robertson, A.S., Sick building syndrome; a study of 4373 office workers. Ann Occup Hyg, 1987, 31, 493-504.

3) Burge, P.S., Jones, P. & Robertson, A.S., Sick Building Syndrome; environmental comparisons of sick and healthy buildings. Indoor air 90, 1990, 1, 479-483.

4) Burge, P.S., Robertson, A.S. & Hedge, A., Validation of self-administered questionnaire in the diagnosis of sick building syndrome. Indoor air 90, 1990, 1, 575-580.

5) Finnegan, M.J., Pickering, C.A.C. & Burge, P.S., Sick building syndrome; prevalence studies. Brit Med J, 1984, 289,1573-1575.

6) Franc, C., Eye symptoms and signs in buildings with indoor climate problems. Acta Opthalmologica, 1986, 64, 306-311.

7) Kroling, P., Gesunderheits Haustechnik Bauphysik Umwelttechnik, 1987, 108, 121-131.

8) Nilsen, O.G. & Zahlsen, K., Hair nicotine as a marker for ETS exposure. Indoor air quality and ventilation, 1990, ed Lunau, F and Reynolds, G.L. pub Selper, London., 437-446.

9) Preller, L., Zweers, T., Boleij, J.S.M. & Brunekreef, B., Gezondheidsklachten en klachten over het binnenklimaat in kantoorgebouwen. Directoraat-Generaal van de Arbeid, 1990, S 83.

10) Skov, P. & Valbjorn, O., The sick building syndrome in the office environment; the Danish town hall study. Environ Int, 1987, 13, 339-349.

11) Stenberg, B., Mild, K.H., Sandstrom, M., Lonnberg, G., Wall, S., Sundell, J. & Zingmark, P.A., The office illness project in northern Sweden. Part 1: a prevalence study of sick building syndrome related to demographic data, work characteristics and building factors. Indoor Air 90, 1990, 4, 627-632.

12) Sundell, J., Lonnberg, G., Wall, S., Stenberg, B. & Zingmank, P.-A., The office illness project in Northern Sweden part 3: a case-referent study of SBS in relation to building characteristics and ventilation. Indoor Air 90, 1990, 4, 633-638.

Figure 1
The average number of work related symptoms (the building symptom index) in 47 different workgroups divided into office ventilation category. The rates have been adjusted for sex and job. The naturally ventilated buildings had opening windows and radiator heating, the mechanically ventilated buildings had some ducted air supply, which was usually warmed, but never chilled or humidified, some of these buildings were sealed. Air conditioned buildings either used induction systems, where room air was passed over heated or chilled induction units, or used an all air system with supply of heated or chilled air to the office space from a central plant room.

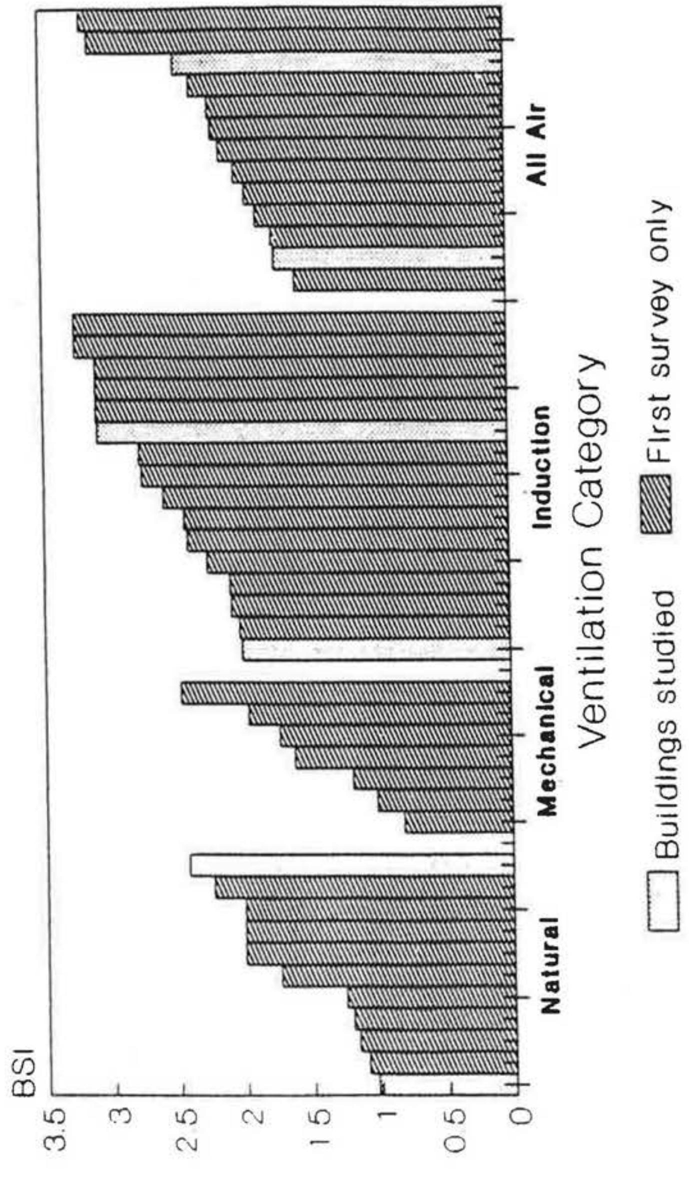
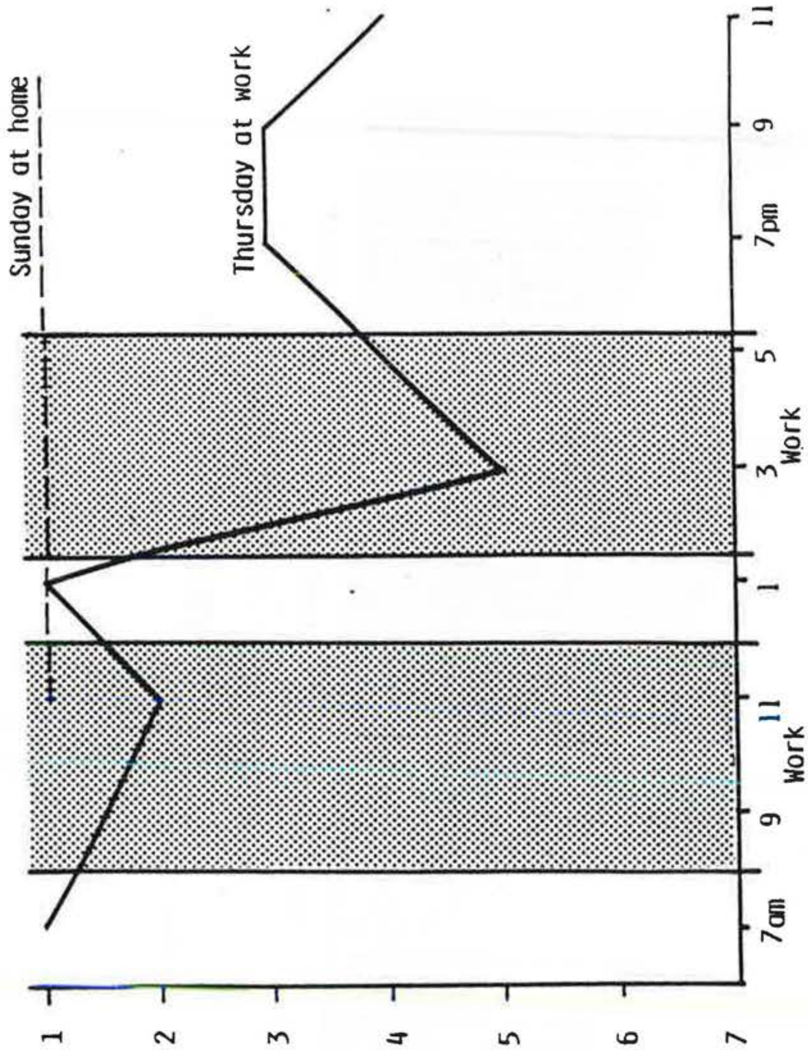


Figure 2
Diary card showing two hourly assessments of nasal symptoms on a day at work and a day off work in a worker with work related rhinitis. The nose is patent throughout the Sunday at home, on the Thursday at work there is a little nasal stuffiness during the morning at work (shaded background), some improvement at lunchtime away from the building, and more severe nasal blockage in the afternoon at work which continues into the evening at home.



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Requirements of Comfort, Health and Hygiene for Indoor Air Quality Management

- What we know and what we should know

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ABSTRACT

A good indoor air quality management pays off in monetary terms as well as in terms of public health and comfort. The main purpose of almost all buildings is to meet human functional requirements. Those set by demands for health, comfort and hygiene are the most important. There are less building regulations, recommendations and guidelines on the indoor climate than in any other sector in the Nordic countries. The authorities involved have been uncertain to what extent the requirements should be set and in which form the regulations should be presented. Joint Nordic R&D enterprises are focussing on the development of new Nordic IAQ guidelines and a medical basis for the evaluation/ classification of building materials. It is time for the European countries to join in a common R&D identification program on the essential human biological pieces of knowledge still lacking for making the IAQM successful: criteria for source control, outdoor air rates, and air treatment; characterization of building related allergy and other hypersensitivity reactions, sensory effects of indoor air pollution, occupant complaints and symtom reports, and interaction effects of low concentration air pollutants; and finally formulation of limits and prospects for energy efficient yet healthy buildings.

THE PURPOSE OF BUILDINGS

Buildings are erected for mainly three reasons. They are:
- to provide protection of people and their belongings against outdoor climate, illegal entry and destruction,
- to ensure that adequate functional requirements are met for indoor activities, as a home or as a work, public or leisure space, and
- to constitute a value in economical, social as well as psychological terms.

It is imperative that healthy buildings used for habitation are buildings in which no occupant catches a disease due to the building. However, health is more than absence of disease. To construct a healthy building means more than simply avoiding indoor climate problems. We need positive criteria that surpass the mere avoidance of negative effects on occupants and buildings (Berglund and Lindvall 1990). Thus the definition of health made by the World Health Organization is still valid: a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity.

The first priority in health promotion is to protect the sensitive individuals and the groups at high risk. The second is to protect the general population. Thus it is essential to identify and characterize the sensitive groups or the groups at high risk, and to specify their specific needs. Methods for measuring health effects should reflect this demand. Measures in the built environment to promote health should involve both general measures directed to the whole population as well as individual measures to support the very sensitive persons.

Besides the prevention of risks and realities of adverse health effects the "healthy building" must meet a large number of environmental, social and psychological requirements. These include environmental perceptions as well as various induced aspects such as environmental promotion of mood, orientation and communication. The latter involves, for example, the physical or social warning signals for avoiding accidents or misunderstandings. The efficient use of a building from a social point of view is influenced by how supportive the environment is, for example, in terms of sensory signals for social interaction.

EXPOSURE AND DOSE

Human exposure to environmental factors (chemical, physical or biological) can be through inhalation, ingestion and skin contacts, and may vary much between homes, workplaces, public spaces, vehicles and outdoors. The links beteween air, food and water pollution are getting increasing interest. For example, in terms of total body exposure a toxic compound may reach the body by several routes, not just by air. For many hazardous compounds all routes of exposure have to be taken into account jointly.

There has also been a shift from the one-substance one-effect view to the acknowledgement of interactions that may lead to amplified or attenuated effects. Interactions may occur between compounds in complex, real-life mixtures of air pollution as well as between various body responses to pollution exposure.

Not surprisingly, we still have large difficulties in predicting health effects from chemicals as they appear naturally, especially the early, subtle and reversible effects. We need biological indicators for environmental health monitoring that will identify
- adverse health effects at realistic exposure levels (low dose effects),
- the vulnerable portions of the general population, and
- the interaction effects of pollutants and other environmental factors, and of physiological and toxicological reactions in the human body.

Traditional methods of pollution measurements often lack sufficient environmental health relevance. Althogh they express concentrations of substances in air, water and food, they provide little or no indication of how much ends up in the human body, or of which, after conversion in cells or organs, give rise to health effects. The effect is further complicated by the complex patterns of human behavior, which must be taken into account when assessing total exposure.

Concentration in
air, water, food

Biological dose in
organs and tissues

Biological dose
in cells

Interaction with
DNA in cell nucleus

Concentrations of pollutants in air, water and food have the least biological relevance. The biological dose in organs and tissues may be more relevant since it includes the impact of a number of background factors like lifestyle and exposure pattern. Still more relevant is the biological dose in cells which is influenced by additional background factors like biodistribution, metabolism and excretion. The most relevant dose measure may be of the biological dose to the cell components, e.g. as reflected by interaction with DNA in the cell nucleus, including the impact of immune defence and repair mechanisms.

Thus, in addition to measure pollutants in the air combined with forecasting individual exposures from activity patterns we often gain more from measurements, when possible, of concentrations in biological tissues and fluids (blood, hair, urine, milk). Biotests may be used, such as tests of chromosome aberrations as a measure of mutagenicity, and sensory measurements with panels of human observers to assess pollution concentration in terms of odor or mucosal irritation potency.

ADVERSE EFFECTS ON HEALTH AND WELLBEING

Of the health effects caused by air pollution cancer is of major concern. However, equally important from a health point of view are long term effects on the respiratory system and the nervous system (especially in children), interactions with infectious agents, allergies and other hyperreactivities, and sensory reactions, the latter since they, among other things, are widespread in the population. In the following some of the more recently acknowledged effects will be discussed.

Allergies and hyperreactivities

"Hypersensitivity" is an umbrella term used to describe conditions in which the sensitivity of organs in the body to different substances is pathologically increased. This increased sensitivity is due to either immunological (allergy) or non-immunological (non-allergic hypersensitivity) mechanisms.

The number of hypersensitive or allergic individuals appears to have increased substantially in recent years. One of the causes is believed to be shortcomings in the environments within and around buildings (Swedish Allergy Committee 1989). The relationship between hypersensitivity and air quality is thus one of the major contemporary problems encountered in buildings.

Allergy means that the hypersensitivity is of an immunological nature, in other words that the reaction is caused by special antibodies or by blood cells after contact with a foreign substance (antigen).

The substances (allergens) which are the prime causers of allergies are pollen and animal hair or dender. Consequently, the allergies are often conditional on seasonal and environmental factors. Dust mites are also increasingly common causes of allergy, highly suscpected to be building related. The common hypersensitivity to "dust" is usually caused by mites and animal epithelia. A large number of species of airborne mould spores have also proved to be capable of causing allergic reactions. However, the latter are not frequent.

The ability to produce antibodies after exposure to natural concentrations of certain substances (atopy) is highly hereditary.

Pollen allergies are seasonally bound. Tree pollen is present in the air during the spring, grass pollen during the early summer and herbaceous pollen until the late summer. There are also differences in dispersion. Tree pollen travels a long way, whereas the spread of grass pollen is limited.

The proportion of the population suffering from allergies of the type mentioned here is estimated at about 15 per cent. However, almost 50 per cent of the population react to one allergen or another when tested.

Non-allergic hypersensitivity reactions include, among other things, hyperreactivity, defined as an increased tissue sensitivity to such things as smoke, dust, chemicals, odours, cold and moisture. Hyperreactivity usually occurs in the respiratory passages but can also appear in the gastrointestinal tract. The biological mechanisms are largely unknown. As a rough estimate, at least half of the hypersensitivity reactions are unrelated to allergies. The symptoms and their gravity may be the same as in cases of allergically induced hypersensitivity.

Even normally healthy individuals can display increased sensitivity of the bronchi in conjunction with diseases of the respiratory passages or upon exposure to high contents of air pollutants such as ozone. The protective barrier afforded by the mucous membranes in the respiratory passages can be weakened in different ways by exposure to tobacco smoke or large amounts of air pollutants.

Asthma is a temporary condition of breathing difficulty caused by contraction of the bronchi. Among children, asthma is commonly induced by allergic factors, whereas two-thirds of asthma cases among adults have other causes such as infections, irritating substances, side effects of pharmaceutical drugs, physical exertion and psychological stresses. Although the asthmatic reaction is temporary the triggering causes are often so frequently occurring in and around buildings that the disease becomes virtually chronic. Most asthma sufferers notice a direct deterioration in their bronchi when they come into contact with substances that bring on the disease. Acute attacks can be fatal.

The incidence of asthma is 3-4 percent among children below school age and about 2-3 percent among adults. Among 18-year-old conscripts (upon signing on) the incidence of asthma has been shown to increase from 1.9 percent in 1971 to 2.8 percent in 1981 (Åberg 1988). The corresponding figures for hay fever were 4.4 percent in 1981 and 8.4 percent in 1981. The increasing incidence of asthma and hay fever was more striking in northern Sweden than in other parts of the country. This may possibly be due to differences in the built environment.

Increased mortality due to asthma has been suspected in recent years in reports from New Zealand, Britain and the U.S. Despite the substantial variations in asthma mortality with time there is a strong suspicion that the long-term trend is an increase. The cause of this is unclear but environment pollution is a suspect.

Adverse sensory effects

As pointed out in the WHO Air Guality Guidelines for Europe (1987) many substances in the outdooor and indoor environments may cause sensory effects at concentrations far below those at which toxic effects occur. As an example, odor annoyance may not by all be regarded as an adverse health effect but it is commonly viewed as adversely affecting the quality of life. As criteria for acceptability and annoyance the WHO Guidelines use the nuisance threshold level, being defined as the concentration at which not more than a small proportion of the population (less than 5%) experiences annoyance for a small part of the time (less than 2%). Since annoyance will be influenced by a number of psychological and socioeconomic factors, a nuisance threshold level, the WHO Guidelines say, cannot be defined on the basis of concentration alone.

Outspoken criteria for adverse sensory effects are given in a WHO document on indoor air quality (WHO 1989). It is recommended for non-industrial indoor environments that unwanted odorous compounds should not be detectable by more than half of the occupants and then just barely (ED_{50} detection threshold), and similarly that sensory irritants should not be detectable by more than one tenth of the occupants (ED_{10} detection threshold).

In the WHO document on environmental health criteria for formaldehyde (WHO 1989), the evaluation of human health risks is partly based on sensory criteria. The argument applied is that human exposure to formaldehyde should be minimized, not only for its probable carcinogenic effect, but also for its potential for irritant effect. Recommendations are given to avoid strong sensory reactions in the workplace environment (peak max 1.0 and mean max 0.3 mg/m^3) as well as a much lower value to avoid odor and sensory irritation for the general population in the outdoor and the non-industrial indoor environments (max 0.1 mg/m^3). Even a very low guideline value is given intended to support the specially sensitive groups that show hypersensitivity reactions without immunological signs (max 0.01 mg/m^3).

The established practice in ventilation engineering in the US (ASHRAE 1989) is that the air of a space can be considered acceptably free of annoying contaminants if 80% of a panel of at least 20 untrained observers immediately after entering deems the air to be not objectionable under representative conditions of use and occupance. Users of the method are cautioned that the metod is only a test for odors. Many harmful contaminants will not be detected by this test (e.g. carbon monoxide and radon).

Neurotoxic effects

It is well known that environmental pollution can influence the nervous system. Although inhalation is not the major route of exposure in comparison with ingestion of food, for example, neurological effects of exposure to air pollution are not to be neglected; the effects of occupational exposure to organic solvents is one example, that of residential exposure to carbon monoxide is another. Foetuses and children are particularly at risk for neurotoxic effects as a result of the higher lifetime exposure and of the sensitivity of the brain during its growth stages. A wide spectrum of effects might be of importance, from those at molecular level to behavioral abnormalities.

Nervous system disorders are one of the leading causes of work-related diseases. In the United States (U.S. Congress 1990) a significant number of workers have potential for exposure to neurotoxic substances, neurotoxic substances are prominent among the top 25 chemicals emitted into the air. Neurotoxic substances may play a role in the occurrence of some neurological and psychiatric disorders such as Parkinson's disease and Alzheimer's disease. It is deemed that neurotoxicity may be a neglected non-cancer risk since few chemicals have been evaluated adequately for neurotoxicity.

Chemically induced neurotoxicity and carcinogenesis have some similarities but also major differences (Bonnefoi et al. 1990). Carcinogens will often lead to malignant cancer and death while the neurotoxins will lead to a large variety of effects from the very subtle (e.g., abberant social behavior) to the severe (e.g., paralysis). It is often very difficult to demonstrate evidence of neurotoxicity and scientists disagree on the definition of what is an adverse effect on the nervous system. Considerable research will be required in order to develop methods of measurement, and to clarify the size of the problem in different populations and the reponsible mechanisms in the nervous system.

OUTDOOR AIR POLLUTION

It has been demonstrated that outdoor air pollutants can have an acute effect on the respiratory system of sensitive individuals, including asthmatics. The effects of prolonged exposure are, however, not fully known. Examples of air pollutants that can irritate or damage the mucous membranes include nitrogen dioxide, sulfur dioxide and photochemical oxidants (substances such as ozone and aldehydes formed in photochemical smog; aldehydes are also present in vehicle exhaust). It is also suspected that other hydrocarbons irritate the mucous membranes. Particles, particularly acid ones, are formed on combustion and in the atmosphere and are major sources of irritation. Particles also carry various chemical substances which in themselves may be irritants.

In the densely populated areas several diseases deemed to be related to prolonged exposure to air pollution are over-represented. Chronic bronchitis is one. Even if the over-representation is largely attributable to other causes such as tobacco smoking, there are nevertheless indices that air pollution may be a contributory factor. It has also been established that the air in densely populated areas contains several mutagenic or carcinogenic substances. This affords at least part of the explanation why cancer of the lungs is more common in urban than in rural areas.

It is evident from epidemiological studies of annoyance reactions to motor vehicle exhausts (Ewets and Camner 1983) that a large proportion of the urban population report annoyance. Considerable groups of sensitive persons are particularly inclined to experience annoyance, and air pollution seemingly can aggravate some respiratory tract symtoms, although clinical tests are negative.

The air pollution in population centres comes mostly from traffic and, in cold regions, also from heating of houses. The pollution normally comprises a mixture of different substances. Some of these are gaseous, such as sulfur dioxide, nitrogen oxides and carbon monoxide. Other pollutants consist of particles (particulate matter) of varying origin and composition. Sulfur dioxide comes mostly from heating plants, whereas cars and other motor vehicles are largely responsible for particulate matter, carbon monoxide, nitrogen oxides, hydrocarbons and lead.

The pollution pattern in Sweden, as in many other countries, has been tangibly improved in recent decades insofar as sulfur dioxide is concerned. The contents of nitrogen dioxide, in contrast, are just as high today as they were ten years ago and no reduction can be discerned.

The guideline values for outdoor air are based on "minimum effect" levels which are frequently uncertain and have small margins of safety. With but few exceptions, it has not been possible to make allowance for the interactive effects of, for instance, different chemical substances. Recommendations are lacking of the requirements in quantative terms of the quality of the outdoor air when it is used as intake air to a ventilation system.

INDOOR AIR POLLUTANTS

Radon

In some countries radon in dwellings has become not only the the single most important contributor to human radiation dose burden, but, in Sweden for example, is twice as important as the sum of all other sources, including nuclear energy and medical diagnostics. In many countries radiation doses from radon have increased considerably during the last decades. Measurements in Sweden 30 years ago indicated an average concentration of radon daughters of 12 Bq/m^3. Measurements in randomly sampled dwellings have shown the average concentration to be 53 Bq/m^3 - a fourfold increase in Sweden in 30 years. The most important source is radon entering the building from soil (sometimes with no unusual activity of radium), filling, or the capillary breaking layer beneath the building. In flats with no contact with the ground, exhalation of radon from building materials is the major source.

Exposure to radon is generally assumed to result in a linear increase in the probability of developing fatal cancer. Results of epidemiological studies have shown a significant association between bronchial cancer and estimated exposure to radon in dwellings. It is estimated that around 400 out of the present almost 3 000 cases of lung cancer in Sweden may be related to inhalation of radon daughters in the indoor air. In Sweden about 10 % of the population is exposed indoors at home to more than 400 Bq/m^3, which may mean a lifetime risk of 3.4 % or more to develop lung cancer, roughly 10 times the risk of the average citizen.

Environmental tobacco smoke (passive smoking)

One of the most important sources of air pollution indoors is tobacco smoking. The smell of tobacco smoke is far stronger than that from other common sources indoors. It also persists for a longer time. This means that the amount of smoking is directly decisive for the ventilation need insofar as odor is concerned. Discomfort caused by tobacco smoke is also indicative of generally poor ventilation and consequently, that other, unnoticed substances may be present.

The adverse effects on health of exposure to tobacco smoke in the environment (passive smoking) have been increasingly observed in recent years (U.S.National Research Council 1986). The health effects that are the most common and which make their presence felt most quickly are sensory reactions: irritation in the mucous membranes of the eyes, nose and throat, and an annoying smell.

Users spending any length of time in premises in which people are permitted to smoke or where the ventilation has return air containing tobacco smoke from other parts of the building do not perceive odors as strongly because their sense of smell becomes dulled (olfactory fatigue). Instead, the dominating trouble is irritation of the mucous membranes and particularly of the eyes. These symptoms are aggravated by both increasing concentration and longer exposure time.

Precisely which substances in tobacco smoke cause the sensory reactions has not been determined. Almost 4000 substances - in both gaseous and particulate form - have been identified. The composition of the smoke gases varies with the manner of smoking, chemical reactions in the smoke, separation of particles upon inhalation (tiny particles reeach deep respiratory passages more easily) etc.

Environmental tobacco smoke contains substances that can cause cancer. Although the findings of investigations differ to some extent, overall experience nevertheless indicates that cases of lung cancer increase among non-smokers exposed to environmental tobacco smoke.

The findings of some studies indicate that environmental tobacco smoke might also affect the cardiovascular system of adults and children, the birth weight of newborn infants and the rate at which children grow taller, etc. However, it is not necessary for these findings to be confirmed by other similar studies before the relations can be considered confirmed.

Both laboratory studies and field trials indicate that tobacco smoke resulting in CO contents in excess of 1-2 ppm lead to eye irritations or other discomfort among about 20 per cent of those exposed.

Certain individuals are particularly sensitive. Children of smokers suffer more often than others from diseases of the lower respiratory passages, bronchitis and asthma. Further research is needed in order to describe in more exact terms the relations between exposure to tobacco smoke and different states of hypersensitivity. The current level of knowledge nevertheless justifies vigorous measures against smoking - particularly in environments occupied by children and other sensitive persons.

The total consumption of tobacco in Sweden has remained relatively unchanged since the beginning of the 1950s. Cigarette consumption, in contrast, has declined since the middle of the 1970s. The compensating increase can be attributed in its entirety to the use of snuff, so that smoking in total actually follows cigarette consumption.

For some years now the proportion of habitual smokers has been larger among women than among men. The youngest groups of women top the statistics. A forward look at the youngest group indicates a cautious total reduction in the entire population. During a foreseeable future, however, there is unlikely to be any major change.

The Swedish Building Codes prescribe that the flow of outdoor air in offices in which smoking is permitted must be at least 10 l/s and person. The corresponding value for premises in which smoking is not permitted is minimum 5-7 l/s and person. The Nordic Committee for Building Regulations recommends 20 l/s and person when smoking is allowed.

In buildings which use return air, tobacco smoke is returned to all spaces embraced by the ventilation system. Properly functioning filters are capable of removing solid particles but not gaseous substances. Whether or not return air should be permitted is a matter that has been under discussion in recent years. The Swedish Building Codes do not contain any prohibition of the use of return air in offices and similar premises. The Swedish Allergy Committee has proposed that the use of return air ventilationg systems be prohibited in new buildings and that smoking be prohibited in all old buildings with return air systems.

"Sick buildings"

"Sick buildings" are modern buildings in which occupants show symptoms similar to those caused by formaldehyde exposure although the concentrations of formaldehyde many times are far below the reaction thresholds. Occupants complain of deteriorated air quality and of subtle medical symptoms ("sick building syndrome")that may be related to the indoor air.

The extensity of mucosal irritation symptoms among occupants of large buildings is never at zero level. The sick building is commonly characterized by the higher prevalence of just the same symptoms as are reported in the non-sick building but at a lower frequency.

Sensory reactions are typical for the "sick building" syndrome but usually no single irritant can be held responsible. More complex causal mechanisms are probably at work. From the literature on sensory research it is evident, that a number of interactions are taking place in the senses. The sick building symptoms may involve not only the specialized chemical senses but also the cutaneous senses. Many skin receptors respond to at least two classes of environmental stimuli. Warming and cooling the skin can affect the sensitivity to touch and vibrotactile stimulation. This does not mean that every receptor respond to the full range of all environmental stimuli.

The sensory thresholds also depend on the stimulus duration and the total stimulus amount. A series of subthreshold stimuli directed to the same skin spot may result in the sensation threshold being passed. The threshold is influenced by general factors like age, anxiety, attention, and other sensitivity variations.

The symptoms appearing in sick buildings are at present best characterized as multisensory perceptions. For example, dryness sensation of the mucosa and feeling of thirst may becaused by low humidity, by thermal stimulation of exposed parts of the body and by chemical pollution, e.g., formaldehyde. Perceived eye irritation may be caused by chemicals, draft, dust, dry and warm air, thermal radiation, as well as by adverse lighting conditions that strain the eye muscles.

Another important factor may be the interaction between volatile chemicals and particulate matters. Adsorption to particles may concentrate gaseous irritants so that locally at the mucosa, the sensation threshold is passed. It is not known whether the electrical charges of the airborne particles indoors affect their deposition on the body surfaces.

Thermal factors

There is no doubt that improved insulation and tightness in the last decade have made the indoor climate more comfortable from a thermal point of view, at least in cold climate areas. This is mirrored by trends in the instrumentation aspects of thermal comfort over the years: from methods for the prediction of the optimum comfort conditions for a group, to the keen exploration of comfort limits originating from energy saving demands , to the present search for means for individual control of thermal comfort indoors.

The diminished economic margins in heating and cooling have caused an increased interest in research on the combined effects of environmental factors, including cultural determinants. The emphasis in today's thermal climate research seemingly is on the impact of air velocity, humidity, asymmetric heat radiation and cold floors in the build-up of the thermal discomfort sensation. However, the present standards do not meet contemporary requirements.

Heating and cooling systems must be planned and installed so that they can be adjusted and checked regularly to ensure that the required performance in the occupant zone is maintained. There is a need to develop instruments and methods that will permit the end user to check the climatic conditions, and climate control systems and instructions that will allow the end user to control her own local climate conditions.

Humidity

Indoor mould growth is a recurrent problem in dwelling hygiene. The indoor air is never free from mould spores. There is a large variety of species which requires expert knowledge in measuring and interpretation of results. In "clean" rooms up to 25 mould spores/m^3 have been found, and in dwellings with mould problems up to 12 000 spores/m^3 of potentially pathogenic mould organisms. Common causes of mould problems are capillary water transport to a concrete slab from the ground, use of contaminated construction material, water vapour producing household activities, use of unflued combustion appliances, and insufficient ventilation and heating. In most cases there is a combination of several factors.

There is little field study evidence of casual relationships between moulds in dwellings and allergy. But, for sensitive persons a number of irritating symtoms are associated with exposure to indoor moulds, their spores or metabolites. The salient effect on the occupants of many "mould buildings" is the persistent and annoying odor which frequently causes psychosocial problems.

A common indoor allergen is protein from dust mites which is associated with asthma. The most important indoor factor leading to the growth of house-dust mites in dwellings is a high indoor humidity. The problems of mite allergy and indoor climate was reviewed recently in a WHO-meeting (1988).

Low indoor humidity in centrally heated buildings during the winter time is often said to cause dry nasal symptoms and respiratory illnesses. Controlled observations in climate chamber have not been able to demonstrate that ambient air humidity is significant for nasal symptoms in healthy persons. The complaints by healthy persons of dry air during winter periods may be caused by one or several other factors occuring simultaneously with low air humidity, e.g., higher levels of dust and irritating pollutants. For hyperreactive patients (perennial allergic rhinitis) clinical observations indicate that artificial humidification may be beneficial during the winter time.

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

Ventilation

A basic requirement for a healthy building is that the room air must not cause illness or discomfort during normal use. The building must also be able to withstand a fair amount of misuse by its occupants without giving rise to health hazards. Ventilation, for example, must have some surplus capacity, and be "forgiving" in its operation. Basically indoor air quality can be controlled by

- controlling emissions from various sources,
- guidelines or standards for air pollutant concentrations,
- prescribed outdoor air flow requirements, and
- specific design requirements which research or practical experience have shown to be essential for a good indoor climate.

A combination of these requirements is always needed. Maximum permissible values should be specified for commonly encountered and well-researched pollutants such as humidity, formaldehyde, man-made mineral fibres, radon, asbestos, nitrogen oxides, sulphur oxides, carbon monoxide and total volatile organic substances. Maximum values should also be given for indicators such as carbon dioxide (presence of occupants and their emissions) and carbon monoxide (presence of tobacco smoke or traffic exhausts). In a recent publication on Air Quality Guidelines for Europe WHO (1987) has proposed a guide for 28 major chemical compunds in the outdoor and indoor general environments. However, we lack adequate toxicological knowledge of all the other several hundred low-level pollutants and their possible interactions.

Requirements for maximum, permissible emission levels of selected types of pollutants must be specified. Standard test methods should be developed.

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

Building materials

For healthy buildings it is essential to choose building materials with a minimum pollutants emission to the indoor air. Materials to be recommended are ones that are
- proven and found to be low-emittant,
- accompanied by a statement of contents in respect of pollutant emissions,
- stable, lasting and durable under the conditions likely to be encountered, and
- free from heavy metals, asbestos, biocides, radioactivity, etc.

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

RISK MANAGEMENT

In view of the complexity of pollutant sources and exposures indoors as well as in composition of the exposed population there is a need for an overall view of action for source control. This should include a screening of chemicals, a specific control of selected compounds, an evaluation of design and system solutions, an evaluation of occupant/environment interactions and the establishment of guidelines incorporating adequate safety margins.

Screening of chemicals

The ever increasing number of new chemicals and materials in building construction, installations, furnishings, maintenance and home activities indoors require some sort of a screening system to avoid the potentially harmful or otherwize adverse compounds. Andersen et al. (1982) suggested a strategy to reduce the exposure to the major groups of toxic indoor pollutants in non-industrial spaces. By a notification system products are to be selected with the least impact on human health and comfort, focusing on the reduction of three groups of substances:
- genotoxic substances,
- eye-airway irritants, and
- odorous chemicals.

The first are few in numbers and cause severe diseases, the second are numerous and have great prospects for substitution, and the third should in general be avoided because they are annoying.

There are at present a number of screening methods developed for the testing of genotoxicity of chemicals. Many of these tests are in use already for product control in some countries.

More than 2/3 of all threshold limit values for occupational health purposes are based on the irritant properties of the chemicals. The occupational limit values are set high since they are aiming only to protect most workers but not all. However, the approach shows that screening for sensory irritation effects among building products would be an acceptable method consistent with other areas of health control.

Since 50 years ventilation requirements have been set from the odor criterion, first to compensate for occupancy emissions only but later to indicate ventilation performance and to be used as an early warning of indoor non-human pollutants. The odor criterion is not only a sensitive and relevant basis for decision by its own value but is also consistent with decades of practical experience as reflected in most building codes in the world.

Since most indoor air pollutants in office spaces and dwellings are odorous, odor control would result also in a reduction of air pollutants in general. Provided no non-ethical manipulation of the sensory capabilities of the occupants is introduced (like odor masking), the efficiency of the odor control measures are easily checked. Furthermore, sensations are the integrated net response of the body to a large number of interacting components, and the effects appear at an early stage. A few pollutants lack sensory warnings and behave differently from the odorants, precluding the use of odor as an indicator effect. These substances must be controlled by other means.

Specific control of selected compounds

For some chemicals and environment factors society knows the need for specific control actions. Major urban air pollutants such as sulfur oxides, nitrogen oxides, carbon monoxide and ozone are controlled for by air quality guidelines and surveillance programs, nowadays also directed to the indoor environment. Pollutants originating mostly indoors such as radon, formaldehyde, certain pesticides and some heavy metals are controlled for in specific ways. The resources in society and research, however, will remain too limited to manage to identify and specifically control for the majority of compounds. For these more general solutions must be searched.

Evaluation of systems

Buildings and ventilation installations are complex systems whose performance not always can be predicted however close they are to the building codes and practice handbooks. Especially in times which favour innovations in energy saving the designer/constructor may abandon the old rules and the long experience. Scientific evaluations of the new systems are badly needed - from technical, economical, and human points of view. The health implications of new system solutions, positive and negative, deserve special attention in such evaluations: air quality characterization, toxicity evaluations of exposures from the knowledge of dose-effect relationships, sensory evaluations of indoor air quality and climate by human observers, and biotests using biological indicators.

Evaluation of occupant/environment interactions

A building in use by occupants is something quite different from the same building when it is brand new. The building "gases off" over time but also "smells up" when being used due to pollutant adsorbtions and condensations. The performance of a building may well change over time as a consequence of the maintenance standard, structures drying up, cracks appearing in the building envelope etc. Occupants affect the building and the building affects them. Ventilation performance is largely dependent on the performance of the occupants, i.e., if they are working with or against the technical systems. Up to now very little efforts have been directed to the scientific evaluation of such interactions.

Establishment of safety margins in guidelines and codes

Guidelines for indoor air quality, thermal climate and system performance always have and always will incorporate safety margins. The choice of the magnitude in safety margins should not only be made on mathematical calculations or derivations from the known facts, but also include a common sense judgement. It is mandatory that the risk manager in setting his guideline or code takes into consideration not only what we know but also what we know that we do not know. The setting of safety factors thus is a demanding task which takes place on the very borderline between the scientific risk analysis and the policy dependent risk management.

CONCLUSIONS AND RECOMMENDATIONS

1. The hygienic and climatic requirements have been disregarded far too often in designing and managing the built environment. "Healthy buildings" require a combination of proven experience and scientifically founded knowledge.

2. In the assessment of risks and realities of adverse health effects priority should be given to effects of major concern, such as building related cancer and allergy and other hypersensitivity reactions. However, since sensory reactions, climate discomfort reports and annoyance reactions are frequent, widespread and early signs of technical systems malfunction and of human strain, they are important parts of the health assessment.

3. The target is to control human exposure and should be reached primarily by source control. Dilution is not the main solution to pollution.

4. A ranking system is needed for building and consumer products based on harmonized test procedures. Fast screening procedures should be developed for appropriate endpoints of health and comfort. Test facilities will be needed to assist governments, manufacturers, builders and consumers.

5. The physical planning is critical. If buildings are erected on poor ground or close to sources of hazardous or annoying emissions, greater care and special solutions will be needed. This should be reflected in the building documents.

6. Feedback of experience must not be neglected. Warning signals of poor designs and materials, and working environment problems at the construction place, indicating later problems for the users, must be fed back to avoid further mistakes.

7. Technical systems in the built environment should either be very simple and self-explaining or be so automated that the need of maintenance and control is virtually eliminated. The rule of thumb is: Keep it simple!

Bibliography

Åberg N. Allergic diseases in childhood and adolescence in relation to background factors. Doctoral thesis. University of Gothenburg, 1988.

Akimenko V, Andersen I, Lebowitz M and Lindvall T. Report of a WHO subgroup on the "sick building" syndrome. In B. Berglund, U. Berglund, T. Lindvall & J.Sundell (Eds.) INDOOR AIR, Volume 6. Stockholm: Swedish Council for Building Research D13:1986, 87-97.

Andersen I, Lundquist G R and Molhave L. Indoor air pollution due to chipboard used as a construction material. Atmospheric Environment 9:1121-1127, 1975.

Andersen, I., Lundqvist, G.R., and Proctor, D.F. Human perception of humidity under four controlled conditions. Archives of Environmental Health, 1973, 26, 22-27.

Andersson K. and Lindvall T. (Eds). Health effects of community noise. Nordic Council of Ministers, Copenhagen, 1988.

ASHRAE. ASHRAE Standard 62-1989: Ventilation for Acceptable Indoor Air Quality. 1989.

Berglund B, Berglund U, Johansson I. and Lindvall T. Formaldehyde - absolute odor threshold and perceived odor intensity. In B. Berglund, T. Lindvall & J. Sundell (Eds.) INDOOR AIR, Volume 3: Sensory and hyperreactivity reactions to sick buildings. Stockholm: Swedish Council for Building Research D18:1984, p. 89-96.

Berglund, B., Berglund, U., and Lindvall, T. Psychological processing of odor mixtures. Psychological Review, 1976, 83, 432-441.

Berglund B and Lindvall T. Sensory reactions to sick buildings. Environment International, 12, 147-159, 1986.

Berglund B. and Lindvall T. (Eds). Healthy Buildings: State of the art reviews. Swedish Council for Building Research, Stockholm, D:19, 1988.

Bonnefoi M, Bolon B, Davenport C J and Morgan K T. Neurotoxicology at CIIT. CIIT Activities 10(6):1-7, 1990.

Cain, W.S. Olfaction and the common chemical sense: some psychological contrasts. Sensory Processes, 1976, 1, 57-67.

Colligan, M.J. The psychological effects of indoor air pollution. Bulletin of the New York Academy of Medicine, 1981, 57, 1014-1026.

Dawidowicz N., Lindvall T. and Sundell J. The healthy building. Swedish Council for Building Research, Stockholm, G:14, 1988.

Green, G.H. The health implications of the level of indoor air humidity. In (B. Berglund, T. Lindvall & J. Sundell, eds.) Indoor Air, volume 1: Recent advances in the health sciences and technology. Stockholm: Swedish Council for Building Research, 1984, p. 71-78.

Hensel, H., and Zotterman, Y. The response of mechanoreceptors to thermal stimulation. Journal of Physiology, 1951, 115, 16-34.

Holmberg K. Mould growth inside buildings. In B. Berglund, T. Lindvall & J. Sundell (Eds.) INDOOR AIR, Volume 3: Sensory and hyperreactivity reactions to sick buildings. Stockholm: Swedish Council for Building Research D18:1984, p. 253-256.

Johnson B G, Kronvall J, Lindvall T, Wallin A, Weiss-Lindencrona H. Buildings and health (Hus och hälsa). Stockholm: Swedish Council for Building Research T4:1990. (In Swedish).

Korsgaard J. Demands of the allergic and hypersensitive populations. In (Berglund B. and Lindvall T., Eds) Healthy Buildings: State of the art reviews. Swedish Council for Building Research, Stockholm, D:19, 1988.

Lindvall T et al. An environmental health monitoring system based on biological indicators. Stockholm: National Environmental Protection Board Informs, 1989.

Melzack, R., and Wall, P.D. On the nature of cutaneous sensory mechanisms. Brain, 1962, 85, 331-356.

Melzack, R. and Wall, P.D. Pain mechanisms: A new theory. Science, 1965, 150, 971-979.

Niemela, R. and Vainio, H. Formaldehyde exposure in work and the general environment. Scand. J. Work Environ. Health, 1981, 7, 95-100.

Olsen J H and Dossing M. Formaldehyde induced symptoms in day care centers. J Am Ind Hyg Assoc 43:366-370, 1983.

Pershagen G, Damber L and Falk R. Exposure to radon in dwellings and lung cancer - a pilot study. In B. Berglund, T. Lindvall & J. Sundell (Eds.) INDOOR AIR, Volume 2. Radon, passive smoking, particulates and housing epidemiology. Stockholm: Swedish Council for Building Research D17:1984, p. 73-78.

Platts-Mills T.A.E. and de Weck A. Mite allergy - a world-wide problem. In de Weck A. and Todt A. (Eds): Mite Allergy. The UCB Institute of Allergy, Brussels, 1988.

Sale, C.E. Humidification during the cold weather to assist perennial allergic rhinitis patients. Annals of Allergy, 1971, 29, 256-357.

Stevens, J.C. Thermo-tactile interactions: Some influences of temperature on touch. In D. Kenshalo (Ed.), Sensory Functions of the Skin of Humans. New York: Plenum, 1979, pp. 207-222.

Stolwijk, J.A.J. The "sick building" syndrome. In (B. Berglund, T. Lindvall & J. Sundell, eds.) Indoor Air, volume 1: Recent advances in the health sciences and technology. Stockholm: Swedish Council for Building Research, 1984, p.23-29.

Swedish Allergy Committee. To prevent allergy and hypersensitivity. Stockholm: Allmänna Förlaget. In Swedish only. 1989.

Svedjemark G-A and Mjönes L. Exposure of the Swedish population to radon daughters. In B. Berglund, T. Lindvall & J. Sundell (Eds.) INDOOR AIR, Volume 2. Radon, passive smoking, particulates and housing epidemiology. Stockholm: Swedish Council for Building Research D17:1984, p. 37-43.

U.S. Congress, Office of Technology Assessment. Neurotoxicity: Identifying and controlling poisons of the nervous system. Washington, D.C.:U.S. Government Printing Office, 1990.

U.S. National Research Council. Environmental tobacco smoke. Washington, D.C. National Academy Press, 1986.

World Health Organization. Noise. WHO Environmental Health Criteria Document No. 12, 1980.

World Health Organization. Recommended health-based occupational exposure limits for respiratory irritants. WHO Technical Report Series No. 707, 1984 b.

World Health Organization. Air Quality Guidelines for Europe. WHO Regional Publications, European Series No. 23, 1987.

World Health Organization. Guidelines for Healthy Housing. Environmental Health Series, Regional Office for Europe, No. 31, 1988.

World Health Organization. Indoor Air Quality: organic pollutants. EURO Reports and Studies No. 111, 1989.

World Health Organization. Formaldehyde. Enviromental Health Criteria 89, 1989.

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"INDOOR AIR QUALITY INSIDE PREMISES WHERE NATURAL GAS APPLIANCES ARE OPERATING"

ABSTRACT. This paper deals with the correlation existing between the combustion of natural gas by appliances operating in the domestic environment, and indoor air quality found in these same environments, to the following effect.
Certain considerations are developed relating to the most widespread appliances, particulary to new types of burners able to reduce the amount of pollution produced by combustion.
The process of natural gas combustion is analysed, under conditions of both regular and anomalous operation of the burners.
In conclusion, research initiatives are examined for the development of devices to reduce NO_x, and for the prevention of the reflux of products created by combustion into the environment.

1. INTRODUCTION

In the past three decades, a significant effort has been placed by the research and professional community in developing technologies and regulations aimed at protecting the quality of outdoor air.

In recent years only, it has been argued that even higher risks for human health may derive from the exposure to indoor air pollution, for two basic reasons: firstly because in developed countries most people spend the greater part of their lives in confined spaces, secondly because pollutants may be present in indoor air at levels which are higher than outdoors and hazardous to humans.

The gas industry - which has played an important role in the fight against atmospheric pollution, by promoting the diffusion of a "cleaner" energy source - is deeply concerned about the Indoor Air Quality (IAQ) issue.

There are several reasons which justify an active involvement of the gas industry in research on IAQ. One reason is the fact that combustion equipments (no matter what fuel they use) are a potential source of indoor pollution. Compared to other sources of indoor pollution, which are virtually impossible to eliminate and often even to reduce, the impact of gas appliances on indoor air can be controlled by proper design, installation and maintenance.

A second important aspect is the interplay between IAQ, safety and energy efficiency. It is well known that one of the causes of poor indoor air quality is insufficient ventilation, a consequence of "unwise" energy saving policies; but poorly ventilated spaces, in turns, can also be unsafe, if they host combustion equipment; safety and higher IAQ are therefore linked goals, which must be pursed by technological innovation, better design and more detailed regulations.

Finally, there are interesting opportunities for development in gas combustion technology, leading to higher energy efficiency and lower pollutants emission, applicable not only to large industrial plants, but also to small-scale residential installations.

2. THE COMBUSTION OF GAS AND IAQ

Combustion appliances for cooking, service hot water production, or space heating are normally present in Italian dwellings. Such appliances, which are mostly fired with natural gas or LPG, have an impact on IAQ whenever flue gases are released indoors.

Combustion of natural gas originates, under stoichiometric condition, carbon dioxide and water vapour.

In addition to such components, other substances are generated in real combustion processes which need consideration: Carbon Monoxide (CO) and Nitrogen Oxides (NO_x) are the most significant indoor pollutants which may form in the combustion of natural gas.

The risks that may be attributed to exposure, even for limited times, to CO concentrations in indoor air exceeding a few hundreds ppm are well known. NO itself has a negligible sanitary impact, but constitutes the first step in the formation of photochemical smog, a complex mixture of substances, including ozone and nitrogen dioxide, which are hazardous to human health.

The formation of both CO and NO are closely linked to the combustion conditions. A high concentration of CO in flue gases is due to incomplete combustion, which takes place if the supply of oxygen to the flame region is low campared to the mass of gas to be burned. In domestic gas appliances, such phenomenon may be due to incorrect gas supply or, more frequently, to anomalies in the supply of combustion air. The link between CO formation and O_2 concentration in air is clear: if the latter drops to about 19%, the rate of formation of CO raises dramatically.

The most usual causes of air supply anomalies are the following: a poorly designed gas exhaust system or an insufficient supply of combustion air, due either to the underdesize or even to the absence of purpose-provided openings.

The installation of gas appliances in living spaces and the combustion air supply characteristics are specified in Italy by law, as discussed in section 3.

The formation of NO is mostly influenced by the combustion temperature, the excess of air, and the residence time of flue gases in the high-temperature flame region. All such parameters may be controlled, at least in theory, by proper design and management of the combustion process.

As it will be discussed in section 4, Italgas has been involved in recent years in several research program related to IAQ. The main line of research is concerned with innovative combustion technologies, aimed at NO_x reduction in gas flames (see section 4.1). Such technologies have a significant impact, both in reducing atmospheric pollution and improving IAQ. In addition to this research area - which is carried out in Italgas's laboratories - a new program on IAQ has been recently started (see section 4.2.).

3. ITALIAN STANDARDS ON THE VENTILATION OF ROOMS WHERE GAS EQUIPMENTS ARE OPERATING

There is, at present, no specific set of regulations in Italy regarding the quality of air in domestic environments. Nevertheless, the UNI-CIG regulations, enacted at the beginning of the seventies, though indirectly are the first set of regulations regarding the quality of air in domestic environments where gas equipment is operating.

These regulations concern problems regarding the safety of gas equipment and, in particular, the discharge of combustion products and the replacement of combustion air in premises in which gas equipment is installed.

The following are the main points of these regulations:

a) gas equipment for the heating of premises and the production of domestic hot water (with the exception of small instant water heaters) must by law be connected to a flue with outlet into the open air;

b) cooking equipment (rings, cookers) must discharge combustion products into special hoods connected to flues or leading directly outside. It has been demonstrated experimentally, though, that even where this regulation is ignored, as long as the regulations regarding ventilation of premises are respected, exposure to nitrogen oxides is negligeable, and in any case below the levels indicated by literature as the threshold of risk. This is due to the modest output of the equipment installed (in the order of 10 - 12 kW), the short time for which it is employed and its occasional use (at most 1-2 hours twice a day);

c) the regulations, for the ventilation of premises in which gas equipment is operating, require permanent ventilation openings of at least 6 cm^2 for every 1.16 kW installed capacity, with minimum free ventilation area of 100 cm^2. These openings ensure that the equipment operates regularly and correctly, combustion being optimal (with negligeable production of carbon monoxide), and at the same time they facilitate the ventilation of the premises with the consequent dilution and elimination of other pollutants, such as water vapour and carbon dioxide, deriving from domestic activities.

In conclusion, the utilization of gaseous fuels, in accordance with the regulations cited above, does not compromise the quality of the indoor air in closed premises.

4. THE ROLE OF THE GAS INDUSTRY IN IAQ RESEARCH: ITALGAS'S EXPERIENCE

Gas companies have always paid attention to the problem of environmental pollution, and in particular to that of the indoor environment. Italgas, for example, has been involved for a considerable time in sectors of particular interest:

- in supporting research and technological development of low environmental impact burners;
- in supporting the introduction of regulations concerning gas equipment and clean combustion;
- carrying out studies on the quality of air.

4.1. Research into new conception burners and development of relevant technology

Italgas's activity in this sector is aimed in particular at verifying the environmental performance, as well as the energy performance of burners which limit the production of nitrogen oxides (NO_x).

This greater interest for NO_x than for other pollutants is a consequence of the physical and chemical characteristics of natural gas;

- physical, because with natural gas it is possible to create homogeneous fuel-air mixtures, thus reducing the quantity of unburnt products;
- chemical, because in the composition of natural gas, certain pollutants are absent (sulphur compounds) and thus the combustion products are particularly clean. Furthermore, although the stoichiometric combustion process produces water and carbon dioxide, the need to operate in an excess of air in order to complete and speed up the combustion reaction causes nitrogen oxides to be produced.

4.1.1. The formation of the nitrogen oxides and some measures to reduce their emission. Various factors influence the formation of nitrogen oxides during the combustion process: flame temperature, excess of air, reaction times, as well as the type of reaction adopted.

The scientific literature and tests carried out show that, because of its physical and chemical characteristics, gas is the fuel which, conditions being equal, produces the smallest quantity of nitrogen oxides.

TABLE 1 - Estimate of the emission, in tons, of the main atmospheric pollutants in Italy in 1984.

	Coal	Natural gas	Petrol	Diesel oil	Fuel oil	Tot.
Sulphur oxides	179,000	292	6,400	240,000	1,740,000	2,165
Nitrogen oxides	109,000	107,000	498,000	497,000	220,000	1,431
Suspended particles	9,050	1,440	21,300	214,000	118,000	3,637
Carbon oxides	10,000	19,200	4470,000	578,000	17,900	5,095
Volatile Organic compounds	1,910	7,060	379,000	253,000	4,030	6,400

As can be seen from Table 1 (2), emissions of NO_x from the combustion of natural gas for domestic, manufacturing and commercial use in Italy are much less conspicuous than those derived from other fuels, in particular from solid and liquid fuels.

TABLE 2 - Division of the emission in tons of the main atmospheric pollutants in Italy in 1986, by type of utilization of the fuel.

	Agric. fish.	Transport	Ind.	Resid. comm.	Electr. produc.	Tot.
Sulphur oxides	22,000	84,000	616,000	153,000	1,199,000	20740
Nitrogen oxides	74,000	809,000	189,000	69,000	428,000	15690
Suspended particles	28,000	231,000	49,000	48,000	56,000	4120
Carbon oxides	148,000	5048,000	87,000	261,000	26,000	55700
Volatile organic compounds	41,000	668,000	8,000	44,000	7,000	76800

From Table 2 (3), which gives the emission from combustion processes of the major atmospheric pollutants in Italy in 1986, analysed by sector according to the use of the fuel, it emerges that the sector with the highest production of nitrogen oxides is transport by road, followed by the production of electricity.

With regard to CO, petrol and diesel (Table 1) and thus the transport sector (Table 2) are the fuel and sector of utilization, respectively, which are most polluting.

As already mentioned, the theory states that the formation of nitrogen oxides depends predominantly on the reaction temperature, and to a lesser extent on the partial pressure of the comburent oxygen.

Some measures make it possible to reduce the emission of NO, in particular:

- the effective combustion temperature should be kept as low as possible;
- the partial pressure of oxygen should be reduced;
- the air index should be kept as low as possible: Fig. 1 gives the emissions of nitrogen oxides and carbon monoxide as a function of the air index for a forced-air gas burner. The reduction of the excess of air is a delicate operation because, as can be seen from the diagram (Fig. 1), a reduction of the air index corresponds both to a reduction of nitrogen oxides, and at the same time to an increase in the production of carbon monoxide;
- the time which the gas remains in the zone above 1300°C should be reduced.

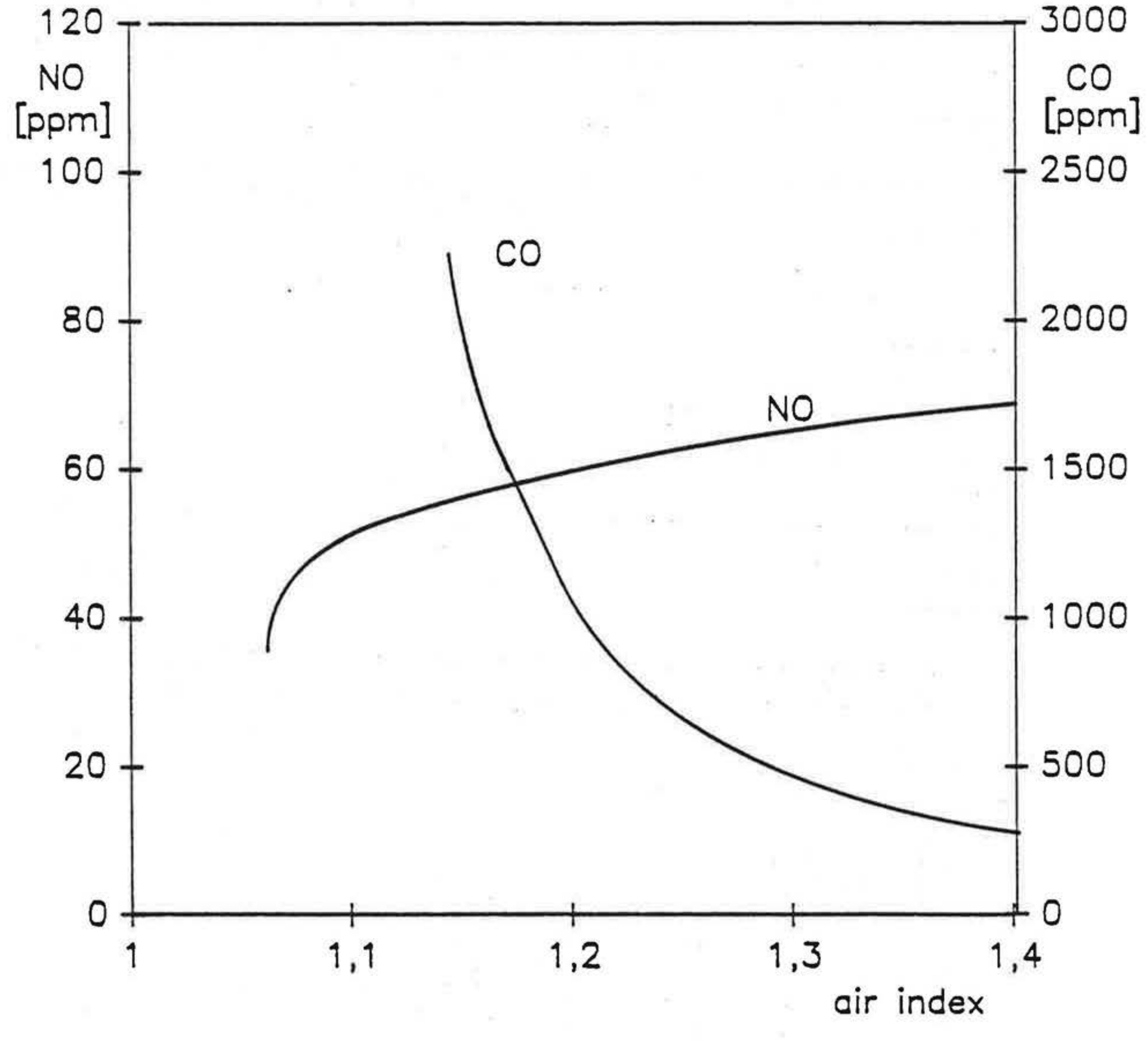

FIGURE 1 - NO and CO emission from a forced-air gas burner

4.1.2. Review of the types of burners. The following types of burners limit the production of nitrogen oxides.

a) Burners with complete pre-mixing of fuel.

Burners with complete pre-mixing of fuel and air are at present believed to be most effective in limiting the production of nitrogen oxides. With this type of burner, with increased mixing of fuel and air, it is possible to avoid or limit zones of high temperature. These burners also possess the positive characteristic of permitting combustion with smaller excesses of air, without excessive increase in the emission of carbon monoxide.

b) Catalytic burners.

The aim of these burners is to reduce the temperature of the flame by using suitable catalyzers to allow the combustion process to develop at lower temperatures.

c) Burners with insert (ceramic or metal).

In these burners, the temperature reduction in the combustion zone comes about through a suitably-placed insert which dissipates part of the heat of the flame into the combustion chamber. Materials are used which are resistant to high temperatures; these can be ceramic or metals.

d) Ceramic burners.

The operating principle, which is common to practically all models, can briefly be described as follows. Gas fuel and air, thoroughly pre-mixed, pass through a porous ceramic burner; a pilot light starts combustion on the surface of the burner; combustion then becomes selfsustaining, causing the outer surface of the ceramic support to become incandescent.

Another interesting characteristic is the size and shape of the flame, which remains small: just a few millimetres. The combustion temperature is also kept within limits (approximately 1000 °C).

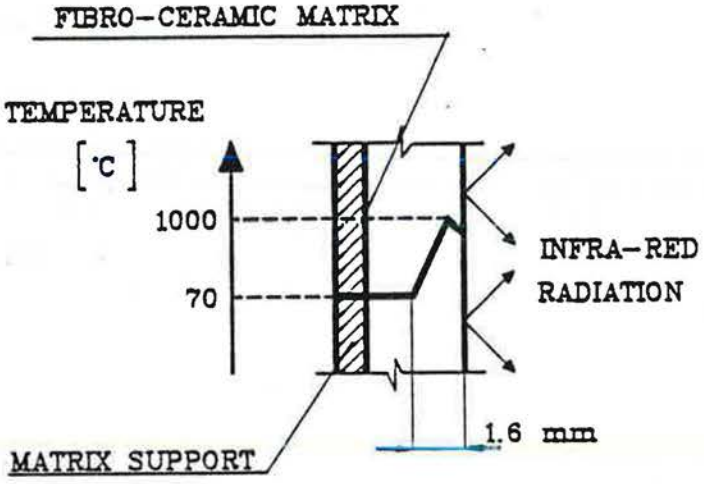

FIGURE 2 - Diagram of the temperature within the fibro-ceramic burner

Figure 2 is a diagram of the temperatures within the fibro-ceramic support. On the surface, temperatures of 850 to 1100 °C are reached; this low temperature keeps emissions of NO_x in the order of 10 - 20 ppm.

e) Perforated matrix burners.

This type of burner consists of a support for combustion made of a perforated ceramic material. In this case, the pre-mixed fuel and air pass through the perforations in the support and produce an external combustion with a free flame, which is very close to the support and exchanges radiant heat with this.

Operating temperatures are of the order of 900 °C, and emissions of nitrogen oxides are below 20 ppm.

Some problems with this type of burner are:

- possible flash-back during operation in the radiant field;
- difficulty of obtaining correct operation below 20% excess of air;
- vulnerability to thermal shock due to the considerable mass of ceramic support.

f) Burners with metallic mesh.

In these burners, a metallic mesh or a perforated steel sheet substitutes the ceramic matrix as a support for combustion. The mesh is manufactured from stainless steel or Inconel, which have similar performances to those of the ceramic support. In order to avoid overheating of the radiating screen, these burners must operate with an excess of air between 30 and 50%, but despite this the emission of nitrogen oxides remains below 20 ppm.

4.2. Experimental research program on IAQ

An experimental research program, jointly conducted by Italgas and Politecnico di Torino, is presently under way.

Two identical, instrumented single-family houses have been recently completed by Italgas. Such dwellings have been constructed according to a design and technology representing the current building practice, and complying with existing regulations on safety and energy conservation

During the first year of research (September 1990 - August 1991) a thorough analysis of the thermal and fluidynamic behaviour of the two buildings has been conducted. A computerized monitoring system was installed in order to collect data on the energy balance of the buildings (weather data, indoor temperatures, energy consumption). Infrared thermography was used to identify anomalies in the building envelope (thermal bridges). Pressurization tests were performed using calibrated blower doors, in order to evaluate the air thightness of the two dwellings. Tracer gas equipment was used to measure the actual air exchange rate under normal operating and weather conditions.

In parallel with the experimental work, computer models were developed, in order to simulate the thermal dynamics and the air flow patterns in the buildings, with particular attention to the interplay beetween air movement and combustion equipment operation.

REFERENCE

(1) A. Defedele, 'Bruciatori radianti a gas a basso impatto ambientale'. CH_4 Energia Metano, n° 2 - 1989.

(2) W. Boccola, M. Cirillo, 'Le emissioni di inquinanti dell'aria dai processi di combustione: un'analisi della situazione italiana'. Energia, 1986, n° 4.

(3) Autori vari, 'Schema di Piano Energetico Nazionale 1988'. Energia e Materie prime, luglio/agosto 1988, n° 62.

(4) H. Kremer, 'Principi sulla formazione degli NO_x e misure adottate per limitarne la produzione'. Gas Wärme International, maggio/giugno 1986, n° 4.

(5) M. Guiducci, 'Determinazione, in laboratorio, delle emissioni di ossidi di azoto da generatori di calore ad uso civile'.

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INDOOR AIR POLLUTANTS: SOURCES, CONCENTRATIONS AND CONTROL

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ABSTRACT

Besides man himself as a source of pollutant emissions (carbon dioxide, body odours, microorganisms), the major sources of indoor air pollutants can be divided into three categories: (a) outdoor air penetrating indoor spaces via infiltration or ventilation, (b) building products and other continuously emitting items, (c) intermittently operated sources.

Although the "classical" inorganic air pollutants well-known from outdoor air studies may also be found in indoor air at elevated concentrations if there are active sources, it is a special feature of indoor air that it generally contains a large variety of organic compounds at concentrations much higher than those found in outdoor air. In some cases the concentrations of some of these organics are high enough to affect human health and comfort. However, exposure rather than concentration needs to be considered to evaluate health effects.

Of the three remedial options, viz. dilution by ventilation, reduction by air cleaning, and prevention of emissions by product amelioration, the latter should always be given preference. Only in cases where already installed materials and products are responsible for elevated concentrations, may ventilation or air cleaning be appropriate tool.

The paper ends by identifying areas for future research.

1. INTRODUCTION

Like other compartments of the environment, indoor air is polluted by a large variety of sources. Depending on the quality of these sources and their strength, the air inside enclosed spaces contains mixtures of pollutants which vary in terms of both their composition and magnitude. According to the occurring concentrations and the resulting exposure, there may or may not be a need for controlling the sources.

In the following text the existing knowledge with regard to sources and concentrations of selected indoor air pollutants is compiled*). Such knowledge forms the background of a sound indoor air quality management. It also provides the basis for decisions on future research programmes.

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*) Throughout this article, no individual references are given. The reader is referred to general publications, e.g., to the respective parts of the proceedings of the international INDOOR AIR conferences: IA '84 in Stockholm, IA '87 in Berlin, IA '90 in Toronto.

2. SOURCES OF INDOOR AIR POLLUTANTS

To be able to properly characterize the indoor environment, it is important to understand the sources of indoor air pollutants. Table 1 gives an overview of the most important of these sources which can be divided into the following categories: outdoor air, man and his activities, materials.

Table 1: Important sources of indoor air pollutants and the major compounds emitted by them

Source	Emitted compounds or classes of compounds
Outdoor environment	
Air	Common outdoor air pollutants,
Soil	Radon, Volatile organic compounds
Water	Volatile organic compounds
Man and his activities	
Man himself	Carbon dioxide, Water vapour, Body odours
Energy production	Nitrogen oxides, Carbon monoxide, Carbon dioxide, Water vapour, Volatile organic compounds, Suspended particles and Semi-volatile organic compounds
Smoking	same as for Energy production, in addition: Nicotine, Nitrosamines
Household and hobby products	Volatile organic compounds, Semi-volatile organic compounds
Materials	
Building and renovation materials	Volatile organic compounds, Fungicides, Asbestos and other fibres
Furnishings	Volatile organic compounds

2.1. Outdoor environment

All buildings exhibit a more or less pronounced exchange between outdoor air and indoor air. In buildings with natural ventilation this exchange is highest if windows are opened, but takes also place - although at a reduced level - if they are closed (infiltration through cracks and interstices). In the case of mechanically ventilated buildings the ventilation system forces outdoor air (unless indoor air is recirculated) into the building shell to guarantee the air exchange.

Outdoor air cannot be neglected as a source of contaminants in indoor air if it has an elevated level of pollution. For mechanically ventilated buildings provisions should be taken to clean the incoming air as much as possible. However, experience shows that this is not always done to the extent needed. Due to malfunctioning of the ventilation system or an unfavourable location of the air inlet (e.g., close to parking garages or loading docks) polluted outdoor air may become an important source of indoor air pollution. In addition, outdoor air may also contribute to indoor air pollution under special meteorological conditions (air pollution episodes). Whereas in naturally ventilated buildings the decay of pollutants on walls, material surfaces, etc. generally provides a protection under these circumstances, mechanically ventilated buildings (unless the ventilation system is equipped with effective filters) normally do not have this protective function.

A special case of contamination from outdoors is the migration of gaseous substances into the building from the soil surrounding it. The most prominent example is radon, although a number of organic compounds may also play a role in houses built on waste sites.

Finally, the outdoor environment may contribute to indoor air pollution through a number of substances resulting from the use of drinking water. In fact, chloroform and other volatile halogenated hydrocarbons have been found to reach non-neglectable concentration levels during showering.

2.2. Man and his activities

Man himself emits carbon dioxide and water vapour into indoor air. In addition, the human metabolism sets free a large number of compounds, many of which contribute to the body odour.

Energy production, e.g. by using gas appliances for cooking and heating, causes the presence of many indoor air pollutants among which the oxides of nitrogen and carbon have been widely studied. The combustion processes also generate suspended particulate matter, volatile organic compounds (VOC) and semi-volatile organic compounds (SVOC). In recent times, the formation of acid aerosols containing nitrite and nitrate as well as nitrous and nitric acids has been studied. The use of unvented kerosene heaters which leads to high concentrations of sulphur dioxide is much less widespread than in the United States. Open fireplaces should not substantially contribute to indoor air pollution if properly installed and maintained. However, elevated concentrations of polycyclic aromatic hydrocarbons (PAH) may occur.

Smoking is one of the most important sources of indoor air pollutants. Interestingly enough, side stream smoke contains more pollutants and at a higher level than main stream smoke. In addition to the compounds generally formed in combustion processes, nicotine is emitted which can be considered as an indicator substance for tobacco smoke.

The large variety of existing household and hobby products makes it impossible to list all possible components. Among the most important VOC are those belonging to the classes of normal and halogenated hydrocarbons (solvents), aldehydes and esters. The use of special products, such as those for pest control, causes the lasting presence of certain SVOC in indoor air.

2.3. Materials

While generally human activities lead to short-term intermittent emissions, the presence of building and renovation materials in a room mostly causes chemicals to be emitted into indoor air on a long-term, more or less continuous basis.

In the past, formaldehyde has been the most important compound emitted from materials such as wood products, carpets, textiles, but also from glues and sealants. Besides formaldehyde, a large number of VOC are emitted from such materials, especially shortly after their installation.

As many paints and lacquers today are produced using water as the basic solvent, they do no more emit important amounts of organic solvents. However, higher boiling compounds now added to the product may significantly contribute to the occurrence of SVOC. These will often be bound to dust particles.

Most of the emissions from new furnishings belong to the class of VOC.

3. CONCENTRATIONS OF INDOOR AIR POLLUTANTS

In indoor spaces - especially in private rooms - there is a large variety of different situations with regard to the ventilation status, the presence or absence of sources and the source strength. Thus, the concentration of indoor air pollutants may vary widely as a function of both time and space. In addition, the sampling strategy used to determine the concentration level together with the boundary conditions encountered or set on purpose before and after the measurement will have a marked influence on the final result.

Table 2: Ranges of NO_2 concentrations in the air of 12 Dutch homes averaged over different periods of time

Location of sampler	Maximum concentration ($\mu g/m^3$) over		
	1 min	1 h	24 h
Kitchen	400 - 3800	230 - 2050	53 - 480
Living room	195 - 1000	100 - 880	49 - 260
Bedroom	57 - 800	48 - 720	22 - 100

From Lebret et al.: INDOOR AIR '87, Vol. 1, 435-440 (1987)

As an example of how much the duration of sampling and the location of the sampling equipment may affect the result, Table 2 gives the concentration intervals obtained for nitrogen dioxide in 12 Dutch homes The figures were obtained from real-time monitoring data. As can be seen, there is a clear gradient from the upper left to the lower right of the table, namely from very short-term measurements close to the source (gas appliance) to long-term measurements away from it. As real-time monitoring usually is not the rule in studies dealing with indoor air pollution, very few such experimental data exist so that the magnitude of the effect is difficult to be estimated for other compounds.

3.1. Concentrations of inorganic compounds and suspended particulate matter

Despite the difficulties in predicting the concentrations of indoor air pollutants, there is enough information in the scientific literature to attempt giving the order of magnitude of these concentrations. The figures given in Table 3 represent the author's best estimate and it is almost certain that there may be circumstances under which they will not apply. In particular, the peak concentrations given in the table do not necessarily represent the upper-bound limit of what can be found in practice. However, Table 2 clearly indicates that short-term peak concentrations may exceed average concentrations by factors between about 5 and 10 or even more. This is of particular importance in cases where a potential health effect is associated with a short-term exposure at elevated concentrations rather than with a long-term exposure at average concentrations.

Table 3: Estimate of concentrations of selected inorganic indoor air pollutants

Pollutant	Concentration *) Average	 High
Carbon dioxide (ppm)		
Occupied room	500 - 1000	3000 - 5000
No occupancy	300 - 400	300 - 400
Carbon monoxide (ppm)	2 - 5	10 - 20
Nitrogen dioxide ($\mu g/m^3$)		
Kitchen with gas	40 - 80	300 - 3000
Other room with gas	20 - 60	100 - 1000
Rooms without gas	10 - 40	50 - 100
Sulphur dioxide ($\mu g/m^3$)		
Without indoor source	10 - 20	50 - 100
With source	50 - 200	500 - 1000
Suspended particulate matter ($\mu g/m^3$)		
Without tobacco smoke	20 - 50	100 - 200
With tobacco smoke	40 - 80	500 - 1000
Radon (Bq/m^3)	20 - 60	5000 - 10000

*) "Average" is the value for long-term periods (24 h or more), whereas "High" represents values for short-term periods (1 to 2 h or less). For radon, both values given cover long-term periods, "Average" and "High" referring to the source strength (see text for details).

The case of radon needs separate discussion. In fact, differences between average and peak concentrations as large as those given in Table 3 will never be observed in one and the same building, but - as a consequence of varying geological conditions - only between buildings from different geographical areas. Therefore, for radon the "Average" column reflects the situation in houses built on "normal" ground, whereas the "High" column refers to levels encountered in houses in "hot spot" areas.

3.2. Concentrations of organic compounds

For organic compounds there is a much larger number of species and not all of those potentially involved in the generation of indoor air problems can even be measured. For methodological reasons, most research work in the past has been focussed on non-polar volatile organic compounds (VOC). Hence, Table 4 which is limited to VOC represents only a small portion of the "true" burden of indoor air in terms of organics. Most organics with higher boiling points, e.g. SVOC which are generally bound to dust particles, have until now not been sufficiently studied.

Table 4: Estimate of concentrations of selected volatile organic compounds in indoor air

Pollutant	Concentration (μg/m^3) *)	
	Average	High
Formaldehyde	30 - 60	200 - 500
Decane	10 - 20	50 - 100
Undecane	5 - 10	20 - 50
Benzene	5 - 10	20 - 50
Toluene	50 - 100	200 - 500
Naphthalene	1 - 3	5 - 10
1,1,1-Trichloroethane	5 - 10	50 - 100
Trichloroethene	5 - 10	50 - 200
Tetrachloroethene	5 - 10	50 - 100
p-Dichlorobenzene	5 - 10	50 - 500
a-Pinene	5 - 10	20 - 50
Limonene	20 - 30	100 - 200
Ethylacetate	5 - 10	20 - 100
Butylacetate	2 - 5	10 - 50

*) "Average" is the long-term concentration observed in most homes under normal living conditions. "High" represents values found regularly in a small percentage of buildings for various reasons. In periods of high source strength, e.g., during and after renovation works or the introduction of special sources, concentrations may be much higher also in average buildings.

The large variety of VOC makes it difficult to deal with each of them individually. Thus, the concept of total VOC (TVOC) has been developed.

Although this is an ill-defined term since the TVOC concentration depends on the analytical method used (without there being a standardised method) it merits further consideration. In fact, limiting the TVOC concentration, which may reach dozens of mg/m^3, especially in new or newly renovated buildings, may reduce the number of complaints from the occupants.

4. EXPOSURE TO INDOOR AIR POLLUTANTS

The mere knowledge of the concentration levels of pollutants in indoor air may give a wrong picture of where priorities have to be set in terms of reduction strategies. Rather, the concentration levels have to be combined with the time spent at these levels to obtain an information about exposure which is the parameter of importance for health effect considerations.

Although it is recognized that measuring personal exposure is the best way of getting such information, it is also known that personal exposure measurements are more difficult to be carried out than measurements at a fixed location. Hence, the latter - in combination with human activity patterns - are used to generate exposure data. Although progress has been made in the USA to get a better knowledge of people's time budget, such information is still scarce for the European situation.

The use of biomarkers to characterize exposure (e.g., cotinine in urine as a marker for environmental tobacco smoke) cannot be elaborated on in this paper. Similarly, the need for evaluating what part of total exposure is made up by exposure to indoor air pollutants can only be mentioned.

5. REMEDIAL ACTIONS

In the management of indoor air quality, there are three important options to reduce the concentration level of pollutants in indoor air:

(a) decrease the source strength by choosing more appropriate products and materials or removing already installed materials;
(b) reduce the level of contaminants using air with air cleaning devices;
(c) dilute the polluted air by ventilation.

Among these options, source control is certainly the most obvious because it reflects the general philosophy of environmental protection: preventing rather than curing. Only in cases where already installed materials and products are responsible for elevated concentrations, may ventilation or air cleaning be an appropriate tool. In some cases the only possibility to achieve acceptable indoor air quality may even be to completely remove the source.

Selecting a "safe" product or material is not an easy task. First of all, today there is only very limited information on product composition since manufacturers are generally not obliged to provide such information. Second, even if the full body of information on a product's composition were available, a rule would still have to be developed to evaluate this information. Such rule could have the form of an index. The index should be derived from both the toxicological and comfort-related properties of the product/material. The index would permit the ranking of products/materials to ease the selection of a product.

6. AREAS FOR FUTURE RESEARCH

Although much progress has been made in the past in the collection of information about sources and concentrations of indoor air pollutants, many questions are still without answer. The following list contains recommendations for research activities. All of these activities merit common European efforts, some in view of the Single European Market, others to save resources.

Table 5: Proposals for research activities

Sources and Source Control

Develop schemes for ranking of products/materials according to their potential effects on health and comfort.

Study the routine applicability of protocols to determine emission factors for solid and liquid products/materials.

Develop receptor models for source apportionment.

Study the usefulness of pre-conditioning procedures to obtain low-emitting products.

Study the effectiveness of coating procedures to prevent emissions from already built-in materials.

Develop satisfactory air cleaning devices.

Concentrations

Enlarge the data base of concentrations of polar and semivolatile organic compounds.

Establish frequency distribution for concentrations of suspended particulate matter.

Study the decay behaviour of pollutants indoors to permit a more correct application of models to calculate concentrations from emissions.

Exposure

Study the links between concentrations at fixed indoor sites and personal exposure.

Establish activity patterns for the European population.

Validate models to predict exposure.

VENTILATION NEEDS VARY WITH MARKET TYPE

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ABSTRACT

Domestic ventilation energy is a significant but neglected and rarely measured loss. In most houses the occupants' behaviour with window opening determines the magnitude of the loss. Comfort criteria are closely linked with internal moisture levels and satisfactory conditions are best provided by planned ventilation with heat recovery.

Commercial buildings have paternal control. The economic criteria are those of accountancy and are quite different from those in housing. The comfort interaction between air movement and temperature means that energy cost is strongly influenced by the quality and type of air distribution.

Industrial buildings often have high ventilation losses due to the constant flow of material. In such cases comfort conditions can be best provided by radiant heating.

Non domestic buildings, without people, should be treated differently. In many cases the buildings are heated simply to maintain dry conditions. Dehumidification offers a low energy solution.

1. INTRODUCTION

The energy implications of ventilation are different for the three classes of customer, housing, commercial and industrial. The personal volume varies from $10m^3/p$ in homes and offices to over $10,000m^3/p$ in warehouse (Figure 1). The motivation for change is also different in each category. In homes the individual decides on the strategy for cost, in the office the manager chooses conditions for productivity while in industry the concentration is on the produce being manufactured.

Let us examine the general comfort criteria and then explore the three markets.

2. COMFORT CRITERIA

There are four major physical characteristics of the air around us:

2.1. Temperature

The contribution of temperature to thermal comfort has been well documented in recent years (Fanger 1972, McIntyre 1980). It has a clear physiological basis in controlling a comfortable heat loss from a person.

2.2. Moisture

The subtle ways in which moisture can influence us have been much less well studied. Factors such as the risk of electrostatic shock from carpets or the perception of damp clothing are identified with ambient relative humidity. Other factors such as sultriness, dry throats and in extreme dryness chapped skin, are much more clearly linked to ambient water vapour pressure. An outline of these parameters and their relationship with temperature is summarised in Figure 2 (Brundrett 1990). In practice the comfort envelope for each country is influenced by local clothing styles, activity and to some extent ambient outdoor temperature. An illustration of the recommended comfort zones for four countries, USA, Germany, France and Britain is given in Figure 3.

2.3. Odour

The three main sources of odour are people, organic matter and chemical compounds. The human odour strength is closely linked with time elapsed since the last wash. Improved facilities for hot water and showers are reducing the general body odour strength because people now bathe much more frequently. Organic odours have traditionally been from the musty smell of mould spores. Such symptoms reflect an unsatisfactory damp indoor climate in which moulds can propagate. Chemical smells are of more recent origin as solvents are added to plasticize plastics and to bond materials together. These are increasing with the growing use of synthetic materials and modern methods of adhesion. The best chemical analysis is much less sensitive than the nose but the new approach of 'olf' values now permits a more satisfactory scientific basis for analysis (Fanger 1988).

2.4. Air movement

Air movement creates personal cooling and if excessive is termed an unpleasant draught. The basic principles have been well defined (Fanger 1972), although recent work on a heated manikin has revealed an interesting importance of turbulence (Mayer 1985).

People are interactive with this environment and will endeavour to optimise their own conditions. They can perceive temperature and odour clearly and can identify the cooling which air movement supplies. They find perceptions of moisture difficult unless the humidity is very high and oppressive.

More research is recommended on the interactions between the different physical conditions, e.g. influence of moisture and temperature on odour.

3. HOUSING

The householder controls his energy expenditure to a level he finds acceptable. This money is surprisingly insensitive to income and on average is 5% of the household budget. His preferred comfort temperature is 3°C cooler than he requires from his employer. The energy at home is regulated through zone control and temperature. Ventilation plays little part except in the recognition of draughts and therefore in tight weatherstripping of the fabric. This in time can then lead to high indoor relative humidities, mould growth and high dust mite populations. The mites can introduce asthma problems.

The information gap between architect and householder is the predictable behaviour pattern of the households in opening windows figure 4 (Brundrett 1977). This behaviour is not recognised by most householders as extravagant in energy. Estimated air changes for such behaviour are illustrated in Figure 5 (Brundrett 1975).

Pilot studies in the use of sealed houses with high quality, balanced mechanical ventilation systems showed that not only was the indoor climate highly acclaimed but that windows were not opened during the bulk of the heating season (Siviour 1991). The fresh air supply was around 0.7 a.c.h.

Choice of the correct amount of fresh air needed depends upon three factors. The first is the amount of ventilation needed for odour control. The second is the amount of moisture released within the house. This is typically 7kg/day for a normal family but can easily rise to 14kg when clothes are dried in the home. The third factor is the outdoor humidity. Britain has a mild damp climate which means that during winter the air is near saturation (Figure 6). The ventilation needs are summarised in Figure 7.

3.2. The five major areas for further research are:

3.2.1. Field studies to confirm the magnitude of the normal ventilation energy loss in conventional houses and in flats as a function of height.

3.2.2. Field confirmation of the benefits of planned mechanical ventilation in terms of satisfaction, elimination of mould, prevention of mite infestation and provision of an asthma free climate.

3.2.3. Appraisal of the conflict between better controls or better heat recovery technique. As heat recovery improves the need for controls reduces.

3.2.4. Assessments of the effectiveness of cooker hoods in preventing moisture and pollution from gas flames entering the living area.

3.2.5. Practical development of methods of fitting planned ventilation into existing homes.

3.2.6. Practical developments in pressure testing and sealing houses which are having planned ventilation.

3.2.7. Exploration of production engineering techniques which will reduce the capital cost of planned ventilation.

4. COMMERCIAL BUILDINGS

Commercial buildings are controlled paternally by the management to provide good working conditions for the staff. The two factors which determine ventilation needs are:

4.1.1. Pollution control

This has traditionally been assumed to be body odours and cigarette smoke. It is now recognised that many other building components are generating undesirable odours and the 'olf' concept has been devised to cater for these unmeasurable odours.

4.1.2 Building cooling

In air conditioned buildings the air is used to remove heat from the occupied zone. This air is usually recycled with a small but adequate fresh air component. Odours can be picked up during this recycling. Large quantities of fresh air can be used to provide 'free' cooling.

Outdoor city pollution and deeper plan buildings led to a rapid growth in air conditioning but this development has been countered by recent concern over the sick building syndrome, which is more closely linked to air conditioning than other types of ventilation. British surveys have found that the operation and maintenance of air conditioned buildings is not up to the expected standard. Temperature drift, relative humidity and odours picked up by the air can all contribute to dissatisfaction. One survey of an office built with care, commissioned with skill and maintained by a full time engineer proved to be an exception to the rule. This building had a sickness score comparable with the best of any office surveyed. The office had displacement type ventilation through a pressurised plenum under the floor. The results are illustrated in Figure 8 in comparison with the other surveys.

Field surveys around one office which was not air conditioned revealed the importance of close temperature control. The large glazed areas of many offices lend the building to the rapidly changing temperature savings caused by solar gains. In winter conditions sluggish temperature control on the wet radiator systems can easily lead to overheating. Window opening is then the technique to provide cooling.

The use of proportional control electric heaters offered very close control and surveys of the window opening behaviour showed that the windows then remained closed (John etc 1990).

4.2 Research areas include:

4.2.1. Further sick building studies, done when the building is properly functioning, would help to identify the importance of the maintenance factor.

4.2.2. Field studies to investigate the influence of the ventilation distribution effectiveness on sickness scores.

4.2.3. Economic appraisal of once through air conditioning where the economic penalty of high fresh air rates is combated by advanced heat recovery techniques.

4.2.4. Economic re-appraisal of radiant cooling in the ceiling of offices.

4.2.5. Field surveys on the early installations of personal ventilation and cooling modules in offices.

4.2.6. Improved controls for heat pump heat recovery.

4.2.7. Feasibility studies on cleaning and deodorising techniques for recirculating ventilation systems.

5. INDUSTRIAL BUILDINGS

In this sector the ventilation is designed for the plant or process. In many cases the ventilation rates are determined by the flow of goods through the doors.

Ventilation should be designed to contain all contaminants. Space heating is much more economically provided by radiant heating.

In special cases such as unoccupied storage warehouses, switchgear or substation designs the designer often applies the same rules as if the building was inhabited. This is unnecessarily wasteful on energy. Where corrosion resistance is required it is prudent to seal the unoccupied room as well as practicable and dehumidify inside the room. This provides a dry cool room and can save some 80% of energy (Brundrett 1988).

5.1. Research areas include

5.1.1. Field surveys to quantify the ventilation energy loss in factories.

5.1.2. Encouragement in the development of practical ventilation weatherstripping for factories.

5.1.3. Guidelines on the application of radiant heaters in large spaces.

5.1.4. Field appraisals on the effectiveness of air curtains.

6. CONCLUSION

Once the building fabric is well insulated then the bulk of the energy loss is through ventilation. At present this is an extravagant uncontrolled process with little understanding. Planned ventilation is essential and not only engineers the environment properly but lends itself to heat recovery and an even further reduction in energy.

Care is needed in more complex buildings such as air conditioned ones to ensure that the system is operating satisfactorily in every sense.

Ventilation studies are now needed to combine the good qualities of a pleasant environment with the lowest energy cost.

7. REFERENCES

Fanger P O, 1972. *Thermal comfort*, New York.

McIntyre D A, 1980. *Indoor climate*, Applied Science, London.

Brundrett G W, 1990. *Criteria for moisture control*, Butterworths, London.

Mayer C, 1985. Studies of draught phenomena with the aid of physical measuring methods. *Gesundheits Ingenieur*, 106 (2) 65-73. Electricity Council Overseas Activities Translation No 3303.

Fanger P O, 1988. A comfort equation for indoor air quality and ventilation. *Healthy Buildings* 1988, Sweden Vol 1, pages 39-51.

Brundrett G W, 1977. Ventilation: a behavioural approach. *Energy Research* 1 289-298.

Brundrett G W, 1975. Electricity and comfort in the home. *International Conference on Energy Use Management*, Arizona, October. Pages 385-391.

Siviour J B, 1991. Development of Medallion 2000 award advanced house specification. *Power Engineering Journal*, 41-47.

John R W, Willis S T P and Salvidge A C. Electric heating in highly insulated buildings - experiences from the Building Research Establishment Low Energy Office. *BRE Report BR 175*, 76pp 1990.

Brundrett G W. *Handbook of dehumidification*, Butterworths, London, 1988.

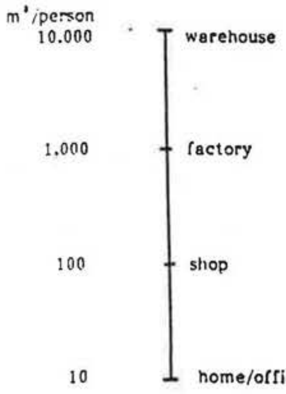

Figure 1. Typical personal volumetric space

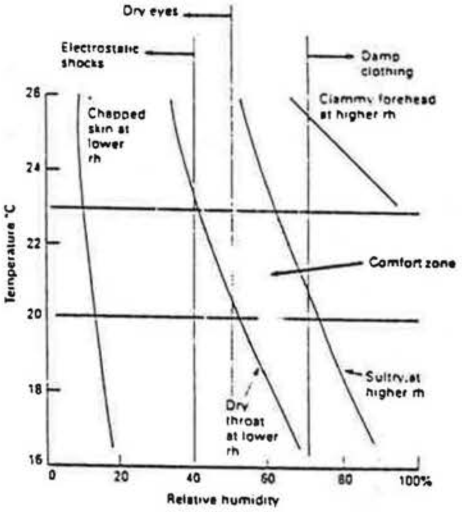

Figure 2 Moisture criteria for comfort

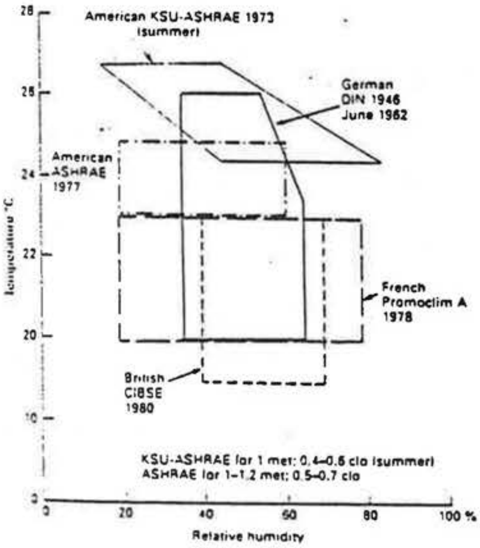

Figure 3. Illustrative comfort envelopes

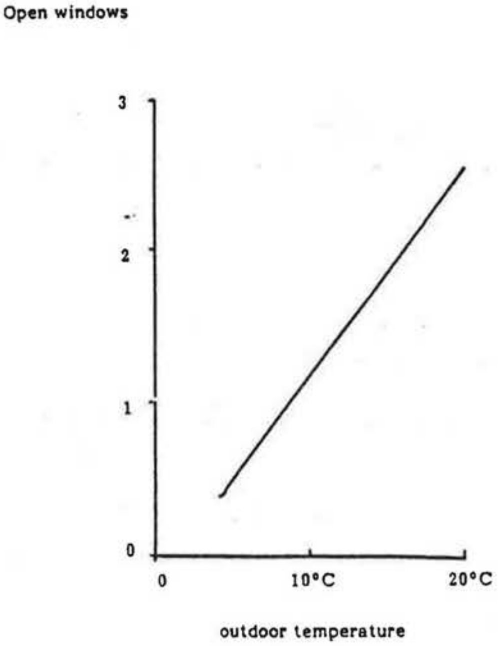

Figure 4. Window opening behaviour (N = 123)

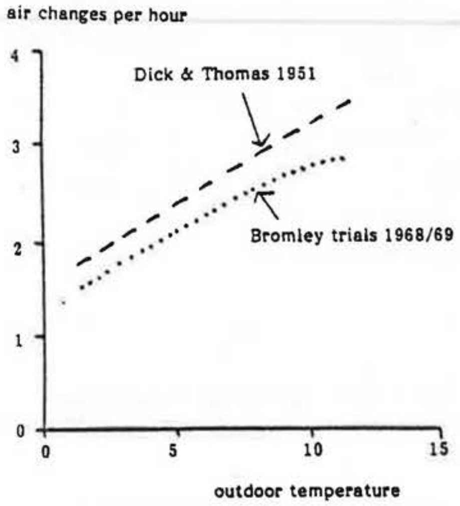

Figure 5. Estimated air changes in practice

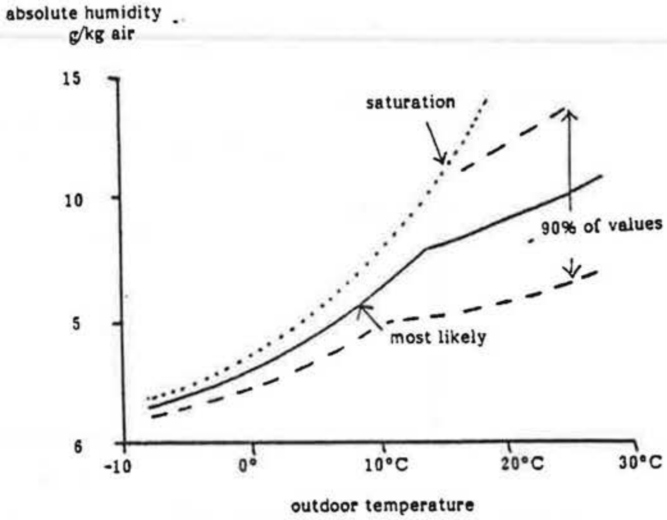

Figure 6. Britain's mild damp climate

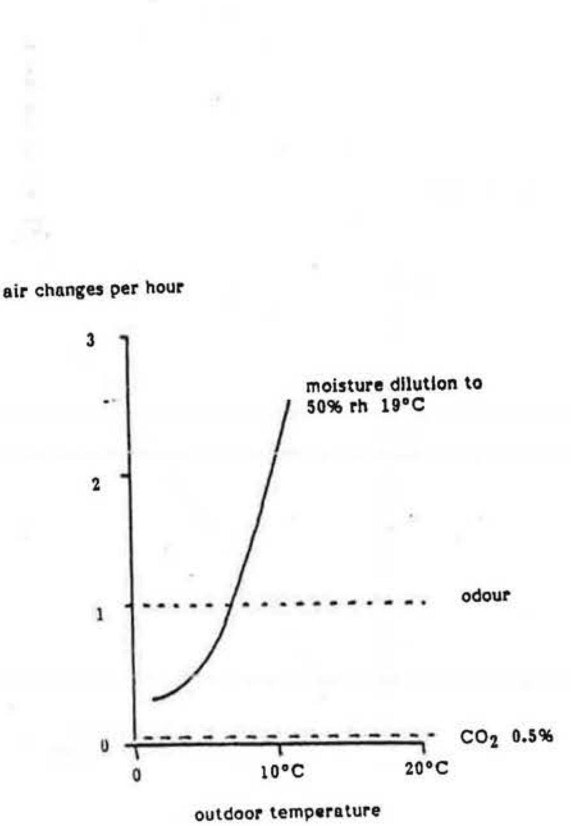

Figure 7. Theoretical ventilation requirements for a family home

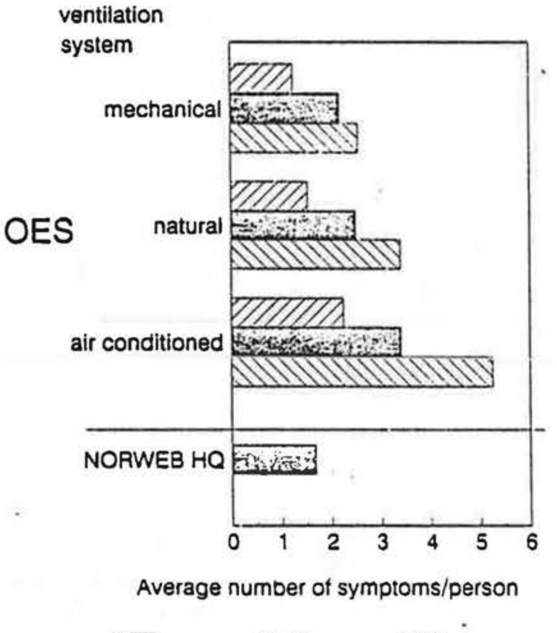

Figure 8. Comparison of Norweb HQ with the

Office Environment Survey (OES)

CEC WORKSHOP ON IAQ-MANAGEMENT
Lausanne, Switzerland, May 27 and 28, 1991

THE RELATIONSHIP COMFORT - IAQ - ENERGY; RECOMMENDED RESEARCH ON IAQ-MANAGEMENT IN BUILDINGS

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ABSTRACT

Energy conservation in buildings is often connected with reduced ventilation and draughtstripping. Therefore it is usually thought that comfort and health are negatively affected by demands for energy conservation. The achievement of health and comfort in the indoor environment combined with energy efficiency however requires both minimization of human exposure to indoor air pollution, i.e. source control, and a well-functioning and energy efficient heating, ventilating or airconditioning system. If these requirements are not met, the price will be more complaints and/or higher energy costs for ventilation.
A number of workshops and meetings on healthy and energy efficient building have already been held, among others in the USA, Canada and the Nordic countries. Of their findings we can take advantage. Research needs which were identified at those workshops and relevant to this CEC Workshop on IAQ-management, are presented in this paper.
Based on the results of those Workshops and author's experience and opinion two topics for common CEC research in the field of IAQ-management are recommended.

INTRODUCTION

The Commission of the European Communities is planning to extend its R&D Programme on Energy Conservation in Buildings with research projects in the field of Indoor Air Quality (IAQ-)Management.
There are still missing links in the field of IAQ-management and further research is needed. A number of workshops and meetings, e.g. US DOE and EPRI (1), US EPA (3), IEA (2), (5), NATO/CCMS (4), ENBRI/CEC (6), CEC Cost 613 (7) on healthy and energy efficient building have already been held. Of their findings we can take advantage. Therefore research needs arrived in those workshops, and relevant to our Workshop on IAQ-management, will be presented in this paper.

The available funds for IAQ research are limited. Therefore the choice of topics within the field of IAQ, which are suitable for common European research, has to be made carefully. So it is necessary although not easy to select research topics that:
a. have a more general nature (not too much country- nor building-dependent);
b. clearly take benefit from international cooperation.

THE RELATIONSHIP COMFORT - IAQ - ENERGY; STATE - OF - THE - ART

In the paper prepared for the preparatory meeting for this workshop on the 11th February 1991 P. Wouters of the Belgian Building Research Institute gave an overview on the aspects comfort (in the sixties), energy (in the seventies) and IAQ (in the eighties). This approach is summarized and extended hereafter.

Comfort - The sixties

The technology available in the sixties, the economic expansion and the increase in income have stimulated the development of new construction types, new heating systems and also new ventilation systems. The main aim of these changes was to increase human comfort. The application of mechanical ventilation systems, especially in office and apartment buildings, increased significantly. Due to the low energy prices, high ventilation rates per person were no real problem. An energy conscious design was in these circumstances less crucial.

Energy - The seventies

The strong increase in energy prices due to the energy crises in the seventies significantly changed this situation. This resulted in:

- increased thermal insulation of the building envelope to reduce heat losses;
- efforts to reduce ventilation losses, e.g. by draught-stripping, low standard values for ventilation and higher percentages of recirculated air;
- lower indoor temperatures (in winter);
- use of appliances with a higher efficiency.

Research activities in the second half of the seventies and the beginning of the eighties were primarily focussed on strategies to reduce the energy consumption. In most countries the concern for a good indoor air quality was a marginal part in the research activities. It is important to realise that arbitrary reductions in ventilation rates solely for reasons of energy economy can result in health complaints.

Energy - End of the eighties

Environmental issues have become more and more important towards the end of the eighties. The problems of acid rain, deterioration of the ozone layer and warming up of the atmosphere due to CO_2-increase are seriously threatening our future. Therefore energy conservation and energy efficiency are important issues, not only for budgetary reasons and greater energy independency but also for environmental reasons.

IAQ - The eighties

In the eighties health issues and increased concern related to the quality of the indoor environment have received large interest by the public and the media. Topics of concern are:

- environmental tobacco smoke (ETS);
- radon;

- asbestos and other fibres;
- air quality related allergic reactions;
- sick buildings;
- moisture and mould growth.

While we have expended much effort over the past 20 years to assess and manage outdoor pollutants, the identification and assessment of hazardous indoor air pollutants (in the non-industrial environment) have only recently begun.

In presenting conference 'highlights' at the Healthy Buildings '88 Conference in Stockholm Rolloos stated: "Indoor Air Quality (IAQ) is a holistic phenomenon and should therefore be viewed holistically".

All the aspects presented in figure 1 result in an indoor environment (physical, chemical, biological, psycho-social), the quality of which is of utmost importance for our health and well-being.

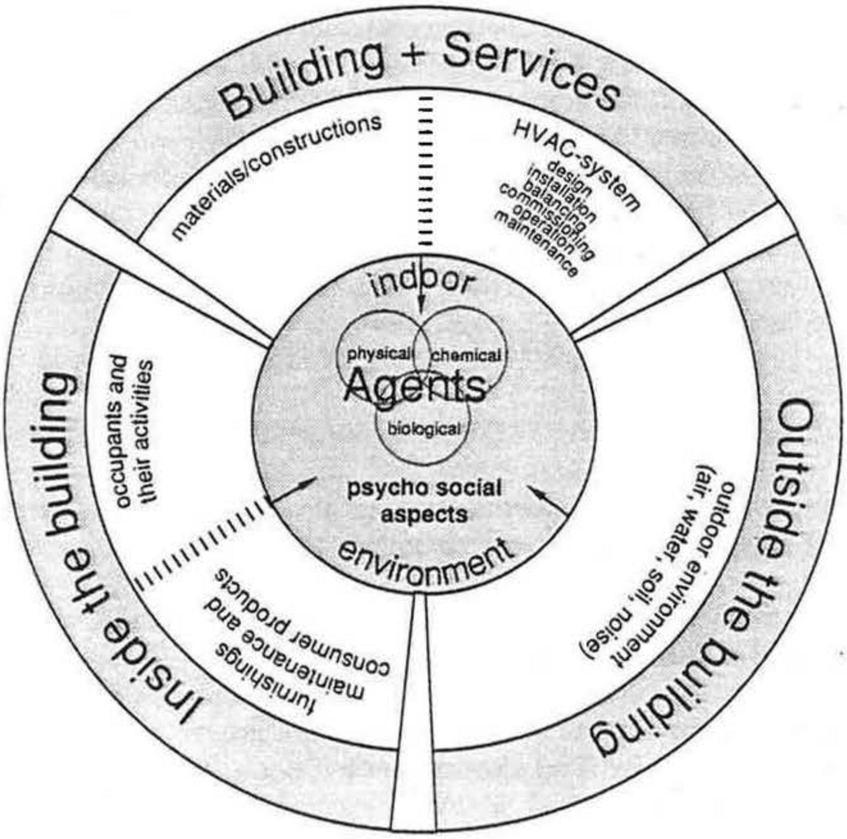

*Figure 1. Holistic view on indoor environment (in commercial and domestic buildings)
Healthy Buildings '88, Stockholm.
M. Rolloos, TNO*

Comfort - IAQ - Energy; The nineties

The relationship comfort - IAQ - energy will be considered in the form of the following statements:

1. The challenge for the near future is to aim at a low energy consumption on the one hand and a comfortable and healthy indoor environment on the other hand.
2. Energy conservation and energy efficiency are important issues, not only for budgetary reasons and greater energy independency but also for environmental reasons.
3. With respect to comfort there is the tendency to classify the indoor climate into quality levels: high, fair, moderate (9); the highest comfort level being coupled to a higher energy consumption for heating and cooling.
4. So far there is little evidence for the statement that sick buildings are often airtight and poorly ventilated buildings (Liddament in (8).
5. Less ventilation is not the only possible cause for IAQ problems, neither is dilution the only solution for pollution.
6. Ventilation is directly coupled with energy consumption, therefore ventilation is not a cost effective method for reducing pollution levels.
7. To achieve the goals of health, comfort and energy conservation control of pollution has to take place at the source of emission.
8. Source control can be achieved by selecting "low emitting" materials, by designing and operating low-olf buildings and installations and by proper selection and use of cleaning and other maintenance supplies.
   The award is a decreased ventilation requirement, a smaller ventilation system and a lower energy consumption (7).

IDENTIFICATION OF NEEDS AND PROBLEMS IN IAQ-MANAGEMENT

Because of the holistic character of IAQ the summing up of needs and problems in IAQ-management is not restricted to the relationship comfort-IAQ-energy.

From reference (1), US DOE and EPRI Workshop on Opportunities to Improve Indoor Environments of Commercial Buildings:

Participants of the Workshop divided into two working groups to develop specific research recommendations for: Commercial Building Programming, Design, and Construction; and Commercial Building Life-Cycle Operations, Maintenance, and Rehabilitation, respectively.

Each working group developed a lengthy list of specific research projects which they then prioritized and presented to the group at large for general discussion and comment. The six highest priority activities recommended by each group are listed below:

- Commercial Building Programming, Design and Construction
  - Evaluate air cleaner equipment effectiveness
  - Study air quality vs. productivity (including absenteeism and health costs)
  - Develop field measurement data base of pollutant concentration levels and air flow rates in "sick" and "healthy" buildings

  - Assess cost-effectiveness of "local" environmental control strategies for commercial buildings (individual control of environmental conditions)
  - Review ASHRAE/BOMA/other standards and recommend simplifications
  - Identify minimum outside and total air circulation requirements by building type and function

- Commercial Building Life-Cycle Operations, Maintenance and Rehabilitation
  - Improve monitoring equipment and protocols for data collection. Build a data base of results
  - Better define pollutant sources, concentrations and effects
  - Better define "habitability" and the architectural and engineering variables affecting it
  - Simplify building systems to make them more reliable, maintainable and foolproof
  - Better define optimal levels of occupant environmental control and information transfer between management and occupants
  - Better define the building commissioning process including pollutants of concern, concentrations of concern, indicators of concentrations and possible mitigation strategies.

From reference (2), IEA Workshop on Air Quality, Heating and Cooling of Buildings:

The Workshop identified an increasing lack of acceptable indoor air quality and thermal comfort in buildings. The systems used for heating and cooling of buildings sometimes lead to inferior air quality and unnecessary high energy consumption due to a lack of overall view of the problems. Research, Development and Demonstration projects for better heating and cooling installations in buildings must therefore have energy efficiency and good indoor air quality as prime goals.
Most problems identified, and lacking proper solutions, are common to many IEA countries, even if some of the problems are restricted to those countries having similar climatic conditions.
The energy saving potential could be jeopardized by the increased outside air flows required to increase the quality of the indoor air.

Recommendations

The following R&D-Projects were recommended for international collaboration within IEA/CRD/EUWP:

- CFC-free cooling installations for buildings
  - Develop and assess system alternatives not using refrigerants dangerous for the ozone layer.

- Combined heat/cool seasonal storage systems
  - Most promising way to use renewables in cost-effective way (the project should be operated in collaboration with I.A. on Energy Storage).

- Assessment of cooling and building integration
  - Architectural concepts that favour passive cooling through integration of cooling effects of the building envelope.

- Develop practical guidelines to avoid health hazards form inferior building installations
  - Designed performance is often not achieved due to defective building commissioning and/or operation and maintenance.

- Assess impact of "fast-track" schedules on construction quality
  - Time, money and quality are often related to each other. Lack of time for proper control and commissioning of the building installations may be detrimental to the future operation of the building and may cause unnecessary energy consumption.

- Recommendations and rules for designing, installation, operation and maintaining of new products, systems and components
  - New products, systems and components are often used without proper knowledge of how to design, install, operate and maintain them. This is critical for the success of low energy buildings. It is not possible for a single country to produce necessary recommendations and rules but is suitable for international collaboration.

- Investigation of methods of humidification which minimize exposure to microbials and chemicals (e.g. biocides, corrosion inhibitors)
  - As a result of energy conservation strategies humidifiers are seldom used today. This had lead to very low indoor relative humidities in cold climate. At R.H. below 30% many suffer from eye irritation (David Wyon). All used methods for humidification cause problems.

- Investigation of the impact of energy storage systems (heating/cooling) on microbial growth and on emissions of biological and chemical contaminants into occupied space.

- Demonstrate energy management strategies which improve environmental quality while reducing energy waste (e.g. ventilation efficiency).

- Develop control strategies, including parameter for sensing, that utilize concepts such as demand ventilation to optimize system performance for minimal life-cycle costs (L.C.C.) and maximal productivity.

- Develop control strategies that utilize recirculation, dilution and air cleaning procedures to optimize system performance for minimal life-cycle costs (L.C.C.) and maximal productivity.

- Investigate the application of "sub-normal" supply air temperature systems to improve environmental quality while minimizing energy waste and L.C.C.

- Investigate the influence of window design and management strategies on air quality and thermal comfort, energy efficiency, L.C.C. and productivity.

- Good housekeeping and sanitation rather than the use of biocides are appropriate control measures also for mites.

Volatile organic compounds (VOCs)

- Overall exposure to VOCs should be kept at the lowest possible level primarily by proper control of the emission sources.

- Pending improved methods, the TVOC concept is a useful tool for a practical assessment of the overall quality of materials and of indoor air.

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

Guidelines and standards

- The ideal solution for IAQ is to combine health and comfort with energy efficiency. Efficient control of emission sources of indoor pollutants is critical to this target. Should a conflict arise between health and energy conservation, the health target has to prevail.

- The relative importance of the different indoor pollutants as well as of their adverse effects on the population should be assessed in each community in order to identify those conditions that deserve priority, either for the severity of the effects or the extent of the affected population. Within the population, the first priority in health promotion should be to protect the most sensitive individuals.

- The development of guidelines and/or standards is an essential tool to promote the achievement of high IAQ and should be encouraged whenever it is possible and appropriate. In particular, development of guidelines is recommended for pollutant concentration in indoor air, ventilation, emission from materials and methods for IAQ assessment and control.

- Ventilation standards should take into consideration the total pollutant load present in a building as the result of building constituents, occupants and their activities. The ultimate goal of ventilation should be to provide good IAQ and satisfaction for the large majority of occupants.

- Pro-active interventions at economical level as well as information and education of the community should be regarded as very effective tools to achieve advanced objectives in IAQ. These actions should accompany and complement any regulatory policy on indoor air.

From reference (5), IEA B&C:s Workshop ECO & IAQ:

Indoor climate and energy conservation (1st Draft)

Objective

The objective of the annex is to evaluate the links between energy conservation and indoor climate giving guidelines and strategies for different measures in different building types.

Topics

- State of the art review on the relationships between energy conservation measures and indoor climate in different building types of various age.
- Matrix for presenting possible relations between energy conservation measures and indoor climate including acceptable deviations from optimum conditions.
- Guidelines on strategies to achieve energy efficient energy conservation measures and an acceptable indoor climate. The guideline is a source book for practitioners in the building operation and maintenance process and also a guide for standardization.

Quality assurance (1st Draft)

Objective

The objective of this proposed Annex is to give guidelines on quality assurance and product responsibility for buildings and installations in order to ensure that the energy consumption, the indoor climate and the life-cycle cost for the building to be kept within set values during the set time of usage.

Topics

- State of the art review of existing guidelines, regulations and standards.
- Evaluation of methods for testing and rating installations in situ with respect to energy efficiency and indoor climate.
- Implementation methods for organizing the procedure of QA and risk analysis.
- Benefits of QA giving cost calculation with and without QA with respect to possibilities of saving energy and keeping a good indoor climate.
- Guidelines for QA giving the benefits for proper organization to implement QA from design stage to operation and maintenance of the building including staff training.

Central air handling system (1st Draft)

Objective

The objective of the annex is to develop guidelines for the choice of central air handling systems to achieve good indoor climate with reduced energy consumption in commercial and official buildings. The guidelines are based on state of the art review, calculation and case studies.

- Good housekeeping and sanitation rather than the use of biocides are appropriate control measures also for mites.

Volatile organic compounds (VOCs)

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- Pending improved methods, the TVOC concept is a useful tool for a practical assessment of the overall quality of materials and of indoor air.
- More research is recommended for the health and sensory effects of VOC's mixtures as well as for some individual compounds typically present in indoor air mixtures for which little toxicological knowledge is available.

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- The development of guidelines and/or standards is an essential tool to promote the achievement of high IAQ and should be encouraged whenever it is possible and appropriate. In particular, development of guidelines is recommended for pollutant concentration in indoor air, ventilation, emission from materials and methods for IAQ assessment and control.
- Ventilation standards should take into consideration the total pollutant load present in a building as the result of building constituents, occupants and their activities. The ultimate goal of ventilation should be to provide good IAQ and satisfaction for the large majority of occupants.
- Pro-active interventions at economical level as well as information and education of the community should be regarded as very effective tools to achieve advanced objectives in IAQ. These actions should accompany and complement any regulatory policy on indoor air.

From reference (5), IEA B&C:s Workshop ECO & IAQ:

Indoor climate and energy conservation (1st Draft)

Objective

The objective of the annex is to evaluate the links between energy conservation and indoor climate giving guidelines and strategies for different measures in different building types.

Topics

- State of the art review on the relationships between energy conservation measures and indoor climate in different building types of various age.
- Matrix for presenting possible relations between energy conservation measures and indoor climate including acceptable deviations from optimum conditions.
- Guidelines on strategies to achieve energy efficient energy conservation measures and an acceptable indoor climate. The guideline is a source book for practitioners in the building operation and maintenance process and also a guide for standardization.

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Objective

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- Evaluation of methods for testing and rating installations in situ with respect to energy efficiency and indoor climate.
- Implementation methods for organizing the procedure of QA and risk analysis.
- Benefits of QA giving cost calculation with and without QA with respect to possibilities of saving energy and keeping a good indoor climate.
- Guidelines for QA giving the benefits for proper organization to implement QA from design stage to operation and maintenance of the building including staff training.

Central air handling system (1st Draft)

Objective

The objective of the annex is to develop guidelines for the choice of central air handling systems to achieve good indoor climate with reduced energy consumption in commercial and official buildings. The guidelines are based on state of the art review, calculation and case studies.

Topics

- State of the art review:
  The review will deal with the relevant technology for central air handling systems with respect to
  - Case studies
  - Air cleaning
  - Duct work including silencers
  - Air handling units
  - Heat recovery units
  - Air terminal devices
  - Control systems
- Test of systems in existing buildings before and after modification.
- Energy savings potential calculation in different central air handling systems giving comparable and acceptable indoor air climate and quality taking into account leakage in the envelope and the stack effect.
- Tests of proposed systems.
- Design, construction, operation and maintenance.
  - The design and construction of central air handling systems based on state of the art review and case studies.
  - Commissioning procedure included recommendation of test procedures.
  - Operation and maintenance including recommendation of regular inspection and staff training.
- Guidelines to energy efficient central air handling systems giving an acceptable indoor climate.

From reference (6), ENBRI/CEC Symposium on Construction Research Needs in Europe:

Low energy, high comfort buildings

The aim of this project would be to demonstrate the feasibility of reducing the energy consumption of buildings by a factor of two or more, for an over-cost of less than 10% on current costs. The project would benefit from the active participation of designers, materials and components suppliers, and building contractors, and would benefit from the immense amount of knowledge accumulated within Europe in the last 15 years. Much of this information has been obtained from CEC-sponsored research, and so the further demonstration of benefits and savings will add to the value of the original studies.

Such a project would provide considerable benefits for the European economy, because the building industry is one of the few industries which can provide dramatic reductions in the specific energy consumption of its products without needing a major revolution in its basic production technologies. It would, though, have a great impact on the practices of various members of the building industry, and so it would be essential to adopt an integrated approach so that all participants can make a full contribution to the work from the outset.

(7) European Concerted Action. Indoor Air Quality & Its Impact On Man, Cost Project 613. Environment and Quality of Life. Guidelines for Ventilation Requirements in Buildings. Draft Report, CEC, November 1990.

(8) Wouters, P. Proposal for a CEC DG XII programme on indoor air quality management. First draft December 1990.

(9) Scanvac - Classified indoor climate systems. Guidelines and specifications. Swedish Indoor Climate Institute, Stockholm 1991.

(10) Woods, J.E. Continuous accountability: a means to assure acceptable indoor environmental quality. Preceedings Indoor Air '90, Toronto, Volume 5, pp. 85/94.

(11) Mill, P., Hartkopf, V. and Loftness, V. Transdisciplinary Building Diagnostics and The Concept of Total Building Performance. Joint U.S.-Romanian Seminar on Earthquakes and Energy, Bucharest, 2-9 September 1985, Volume 3: Energy pp. 3/27.

When developed and included in a manual than this guideline is a source book for practitioners or those involved in the phases of the building process mentioned before and also a base for future standardization.
The availability of such guidelines for classified indoor environments and energy conscious options opens up new opportunities for producing purpose-designed buildings with good indoor environments adapted to individual technical and economic requirements. See lit. (9) as a first step.

The development of procedures for 'continuous accountability' or quality assurance as a means to assure acceptable indoor environmental quality.

To increase assurance that occupants of non-industrial buildings are not exposed to environmental stressors at levels that cause discomfort, illness, and lost productivity, efforts must be focused on improving environmental control throughout the phases of planning, design, construction and use of commercial and residential buildings. These efforts will require increased commitments from those who occupy the facilities, as well as from those who plan, design, build and operate them.
Today's responsibility system is unclear and needs to be improved. Quality assurance during the phases of planning, design, construction, running in, handing over and operation and maintenance is inadequate.
Policies and procedures for establishing continuous accountability of building performance should be instituted.
The criteria or guidelines derived from the first research proposal can be used as bases for it. See lit. (10) and (11) as a first start.

REFERENCES

(1) US DOE and EPRI Workshop: Opportunities to Improve Indoor Environments of Commercial Buildings, March 24-25, 1987, Palo Alto, California.
EM-5530, Research Project 2034-21, Proceedings December 1987.

(2) Final Report on IEA Workshop on Air Quality, Heating and Cooling of Buildings, Gothenburg, September 12-14, 1988, BFR DNo. 221/88/29.03.89.

(3) Report to Congress on Indoor Air Quality. Volume III: Indoor Air Pollution Research Needs Statement US EPA, Office of Research and Development, Washington, DC 20460, August 1989.

(4) NATO/CCMS Pilot Study on Indoor Air Quality 3rd Plenary Meeting, Saint-Adèle, Québec, August 6-8, 1990. Executive summary and provisional recommendations, First Version, October 16, 1990.

(5) IEA B&C:s Workshop ECO & IAQ.
Stockholm 10-11 October 1990.

(6) ENBRI/CEC Symposium on Construction Research Needs in Europe, Luxemburg, 31 October 1990.

(7) European Concerted Action. Indoor Air Quality & Its Impact On Man, Cost Project 613. Environment and Quality of Life. Guidelines for Ventilation Requirements in Buildings. Draft Report, CEC, November 1990.

(8) Wouters, P. Proposal for a CEC DG XII programme on indoor air quality management. First draft December 1990.

(9) Scanvac - Classified indoor climate systems. Guidelines and specifications. Swedish Indoor Climate Institute, Stockholm 1991.

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THE RELATIONSHIP COMFORT - ENERGY - IAQ

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ABSTRACT. This paper starts from the point that indoor air quality problems are not a fatality. Much can be done in order to prevent IAQ problems starting from the very brief for the building design. The balance between energy use in buildings and IAQ and comfort must be, before all, a compromise between building physics and energy. There may be a need for systems with growing level of sophistication, but it is up to the designer to select the most appropriate means for the required objectives.

Comfort is considered under a broader perspective than just thermal comfort. The case of the free-running buildings, as it is common in many regions, is taken as an example of the need for a better understanding of the comfort issue under transient conditions. The energy use in those buildings calls for a larger participation of the environmental energy in the building design, including the use of natural ventilation. Then, the IAQ issue, when addressed, tends to have smaller relevance and, in any case, a larger dependence on outdoor air quality than in the conventional air condicioned buildings.

New comfort information must be given to the designers, in particular for the case of free-running buildings, both in cold climates, for the summer period, and in warm climates, for all seasons.

1. INTRODUCTION

The problem of the quality of the indoor environment has been addressed through several different perspectives. The threshold limite values used for the industrial environments are orders of magnitude higher than the concentration values issued as air quality guidelines by WHO (1). This seems to suggest a clear separation among the situations where the indoor environment represents an occupational or an hygiene and health problem from those where one is concerned with a problem of comfort.

However, some standards, like ASHRAE ST-62 1981(2), bring together objective and subjective criteria to define indoor air quality stating that acceptable indoor air quality is "air in which there are no known contaminants at harmful concentrations and with which a substancial majority (usually 80%) of the people do not express dissatisfaction". It implies that a lower level of concentrations of contaminants, not necessarily harmful for the health, may have some consequences upon comfort.

The contamination of indoor air is due to a large variety of sources such as the occupants, fabrics and other building materials, the outdoor air and even the HVAC systems themselves. The tightness of the

Comfort, particularly in the 60s and in the 70s,was mainly a thermal issue (air temperature, radiant temperature, humidity and air velocity) but air quality, lighting and background ambient noise also gradually became important issues.

Comfort has been largely studied, particularly during the past thirty years. However one must say that this does not mean that comfort is a well known parameter and that what is known on comfort hardly covers all environmental conditions and responds to all personnal or behavioural situations.

One could say that comfort has been mostly seen so far as a quasi-steady state issue, starting from the experience of colder regions where spaces tended to be well insulated and sealed and where people were subjected to steady environments, either under heating or cooling processes, for a relatively long period. But it was reported that the owners of passive solar buildings in the USA, in the late 70s and early 80s, accepted the considerable temperature swings of the indoor air temperature quite well. That raised the question of how comfort is much more than just a thermophysiologic process and how comfort can be characterized under transient heating or cooling conditions. The case of the free-running buildings is a common example where there is a lack of information concerning comfort under transient conditions and consequently on how to deal with the comfort issue in order to be able to convey the appropriate information on comfort for designers of such buildings.

2. ENERGY IN BUILDINGS

Energy is needed as a decisive contribution to fulfill some requirements for comfort, namely thermal (heating and cooling) and lighting comfort. For some time, a great emphasis was placed on thermal comfort. Daylighting only recently regained importance as a peculiar aspect of lighting comfort. This does not mean any refusal of the benefits and potentialities of artifitial lighting. On the contrary, it simply puts the accent on the specific benefits that daylighting can provide whenever applicable, bringing together both natural energy and visual comfort advantages.

But the experience of energy as a scarce resource in the World only seems to have been understood since the early 70s, when some political crises and cartel "games" called for more rational attitudes towards energy use.

The use of energy in buildings became a problem of energy conservation under two main perspectives: attenuation of energy consumption and diversification of the primary forms of energy. In the beginning, economics, under both macro- and micro- perspectives, supported the rationale for energy options such as heat pumps in France, an electricity paradise, and increasing levels of cost-effective insulation in the colder regions. Nowadays, when the energy situation became somewhat more relaxed, another crucial issue was raised: the environment. The use of fossil fuels is being blamed for problems relating to global warming and some fluorcarbons used in refrigerating equipment have been identified as harmful for the ozone layer.

The attenuation of the energy consumption has asked for the reduction of energy needs for heating and for cooling, rendering envelopes better insulated and better sealed for reducing the ventilation rates. The variation of recommended ventilation rates has pointedly changed in close response to changes in energy prices. IAQ has been seen mainly as a consequence of energy use. In fact, IAQ has to do with building envelopes, as a way of promoting energy economy, the use of some building materials and the lack of appropriate maintenance of the HVAC systems have given a particular dimension to the IAQ problem. The recommended solutions are source control, avoiding or attenuating the emission of contaminants,air cleaning, and, the most common, the use of ventilation. While some sources of contaminants, such as the occupants, cannot be avoided, others can be eliminated or reduced, through appropriate choice of materials, and, in particular,the case of the systems themselves, through an adequate maintenance.

What seems to be somehow forgotten is that IAQ is not a fatality for neither the northern nor the southern latitudes, whichever differences in climatic conditions and energy strategies between those regions. The IAQ issue must be addressed at the design stage.The point to make is that the IAQ problem must not be approached under the some perspective as, e.g., the stability problem in earthquake-prone areas. In the latter case, nothing can help but to be prepared for the fatality to happen.For the IAQ problem, the same happens with the cases of contaminants that cannot be avoided, such as the contaminants derived from occupancy or particular necessary industrial processes. But in all the other cases, there are many options to prevent the contaminants. An essencial role of the design process is to create the conditions to prevent the contaminant sources before addressing the cleaning strategy (filtering) and the dilution strategy (ventilation).

That is why the current knowledge about IAQ should be brought as an essencial feedback for the design process from the very brief for the building design. The objectives of every building should be analysed and the strategies for comfort and for the use of HVAC systems must be discussed from the earliest stage of the design process taking into account the different climatological caracteristics and the different energy options, namely those related with the climate. As stated in (1), "Several sources of air pollutants have unique national components that are best subject to national control procedures. For example, indoor ventilation and heating systems, major determinants of indoor air pollution levels, are heavily influenced by the geographical location of the building".

It is out of question that the more demanding the indoor environmental conditions are, the more sophisticated the system must be and, moreover, the more accurate the controls and the maintenance routines ought to be. However, technological advances do not necessarily mean that they shall be used everywhere: it simply means that the designers have a larger spectrum of design options to consider. Let us consider as an example the case of an air conditioning system in a building in a region with a mild climate. As there are potentially longer periods of intermittent functionning, it is more likely to require stricter maintenance of the HVAC system for obvious reasons, because, if not in use, it may be a source of contaminants that would not appear in the building if that particular type of system was not the one to be installed.Therefore there a reason to weight the pros and the cons of installing some sort of HVAC system is in this case .

The climatic conditions may allow for naturally obtained comfortable indoor environments, in many cases without any auxilliary systems.Therefore, understanding comfort is necessary for a good or at least, an adequate choice of a system for a given building. That is why one could say that the balance between energy use in buildings, IAQ and comfort is, in first place, a compromise between building physics and energy for a particular climate.

the quality of the outside air, but it is mostly related with the presence of internal sources of contaminants in a rather closed space. That is why energy conservation measures such as reduced heating/cooling loads, low ventilations rates and minimal outside air ventilation have contributed to increased IAQ problems. Other contributions to IAQ problems are consequences of other inovations in building fabrics and building materials such as the large diffusion of synthetic materials.

While aiming to reduce energy needs to minimum acceptable levels an other way of conserving energy is trying to diversy the energy sources, looking at more efficient energy systems and energy forms that may be more friendlier to the environment, paying more attention to the climatic conditions, e.g., through the use of solar energy.

The actual situation in most of the southern european countries is characterized by a dramatic growing rate on the use of air conditioning systems in response to better commercial and living conditions. Knowing that air conditioning systems are among the least efficient energetic systems and particularly dependant on electricity, the consideration of the general problem of energy requires the creation of conditions for a more rational use of the cooling systems. That is why passive cooling must become a strategic issue and that IAQ in the warm season should warrant a carefull treatment together with consideration of comfort under transient conditions (for both the heating and the cooling modes).

3. BUILDING PHYSICS AND ENERGY

In general terms, comfort in buildings is mainly related with many environmental parameters such as:

- type of the building and its psycological relevance for the occupants;
- quality of inside spaces: form, dimensions, openings, colours, etc.;
- relation with the outside environment: visual, thermal diode effect, ambient noise, infiltration or ventilation level;
- behaviour of the occupant, including levels of activity and clothing and other behavioural aspects;
- hygiene and health aspects.

So, the comfort issue has very much to do with the building physics, particularly with the building envelope that bounds the indoor and outdoor spaces.

Taking the envelope as a boundary through which heat losses, heat gains and air circulation may take place, the envelope can play one of two main roles: either a) a "definite" barrier between the indoor and the outdoor environments, avoiding losses but also favouring the eventual solar gains; or b) an element that is an integral part of the dialogue of the interior space with the climate, as it is the case of passive solar buildings.

The first type of buildings, is dominated by the internal loads caused by lighting, equipment and occupants. Being well insulated and well sealed, the influence of the outside climate parameters is less important than the internal loads. In this case, energy conservation strategies favour better insulation and reduced levels of ventilation. Consequently, there are greater risks of high levels of concentration of unpleasant contaminants, both gases and particles.

But the second type of buildings is, instead, the so called "envelope-dominated" buildings. In this case, the envelope must allow to play with the geometry of the sun and the solar radiation in order to reduce the needs for conventional forms of energy, using solar radiation for heating and keeping the radiation away to reduce the cooling load. In this case, energy conservation also means insulation but, above all, it means the adoption of the building as a truly "sun trap", collecting and managing the solar energy in winter and rejecting it in summer.

Buildings dominated by internal loads represent the right application for most of what is known and is documented concerning comfort, i.e., steady-state comfort, and what one will call, for the sake of some clarification, the "technological" type of comfort.

A famous architect, Victor Olgyay, all the way back in the 50's, wrote, a book called "Designing with the Climate"(3), where he proposed some sort of low energy architecture that was supported by theorectical evidence. Olgyay, and his brother as well, while being Hungarians, were living in the USA and were doing quite well. Their perception and concept of what should be done concerning building design was something much more fundamental than just conserving energy. Being attentive to the trends in the building industry, Olgyay claimed that a great deal regarding comfort and energy conservation could be done working out better urban planning and architectural solutions. That is why he proposed the bioclimatic chart as a tool to express the climatic conditions of a given place and to evaluate the potentialities of the building design for reaching a certain level of comfort.

Definitely, to assume that the optimum thermal comfort (technological comfort) is not always required or necessary is not a question of descrimination or a minimalist approach. There are many more "nuances" in comfort which will allow for other design options. It appears clear to some authors that what one could call the "technological comfort" may be avoided in some cases and, on the contrary, it seems that there is no reason to recommend as a must, the generalised use of auxilliary equipment for heating and, particularly, for cooling. It appears to be desirable the establishment of a hierarchy of comfort conditions and the definition of the environmental control options accordingly. As an illustration, it is interesting to mention the conclusions of "nordika"(4) concerning the advantages of the decentralization of the systems and, in particular, the need for the systems to allow for the windows to be openable. If the option of the scientific and professional people familiar with buildings dominated by the internal loads is such, how much further can the designers of envelope-oriented buildings go in regions such as those of the southern european belt, avoiding or reducing the use of air conditionning through the "inteligent" use of the envelope? The complexity of the problem in this particular case is evident: not only is it important to avoid heat gains in summer, where the sun is usually abundant, but it is also necessary to enhance heat gains in winter to reduce the needs for auxiliary energy. Moreover, the midseason period is very much adverse to the HVAC designers because while the outdoor temperature is around comfort levels, the solar gains lead quite easily to situations of overheating due to the geometry of the sun rays.

The consideration of the building physics as a pre-condition for smaller energy consumption and, also, a less important IAQ problem has a strong scientific and realistic bacground. Making a plea for a more critical use of the HVAC systems does not mean any type of refusal of the technological development but, well on the contrary, it suggests the need for a wiser use of the available technologies.

Assuming the very first priority for building physics, e.g., urban planing, architecture and construction technologies, the systems are not necessarily to be eliminated. In any case, they shall be more adequate to the real needs, certainly smaller and, hopefully, simpler.

It is offen considerer that natural ventilation should be avoided of the energy consumption associated with it. Everything that has been said suggests that energy consumption with natural ventilation cannot be the unique criteria to decide about the convenience of its use. It must be balanced with other "costs" such as those related with the IAQ.

An unsolved question remains however: how to pass on the information needed by the professionals? Is it available? Or the only solution is to copy what was studied and compiled for other types of climates, needs and cultures? Without forgetting that, even in the latter cases, there have been several changes in the building design strategies, in the last two decades, it seems clear there is a need for a comprehensive study of this issue.

4. COMFORT AS A PREREQUISIT FOR DESIGN

The nature of thermal comfort as a statistical parameter is such that, for all pratical purposes, it is only adequate in nonresidential buildings where conditions must be near the optimum at all times so as to garantee that the largest percentage of occupants may feel comfortable: a minimum of 80% according to ASHRAE (2) and ISO Standards.

Two facts must be taken for granted: the whole framework regarding comfort established by the above mentionned standards; and the progress that has been reached on the assessment and the understanding of IAQ and comfort conditions under such a framework. Nevertheless, this did not avoid the phenomena of the sick building syndrome which seems to lead the treatment of IAQ as an unavoidable problem.

There are, however, many cases of buildings in different regions that may allow for comfortable or almost comfortable conditions by natural means most of the time. What seems to be regrettable is to let the market, every day more globalized, "impose" equipments and systems that are absolutelly necessary in some regions - those where they have been conceived and produced - to other regions where they can be avoided or used in a quite diferent way. The fact that comfort has been better understood and characterized in the more developped regions has to do with the fact that those regions are both the coldest and the richest. There, heating was a necessary condition for survival while cooling resulted mainly from the high level of insulation and sealing of the envelope and of important heat sources inside - cases of hot and humid climate are typical for the use of cooling. The needs for the definition of standards were the natural consequence of a balance between the objectives regarding the indoor environment and economics.

The point to be made here is that, rather than socio-economical reasons, there are comfort and IAQ reasons for differentiating the buildings of different regions as well as there are reasons to differenciate the environmental treatment according to the type of buildings. In residential buildings, the indoor environmental conditions can be allowed to fluctuate. Then, the technological comfort conditions are no longer fully applicable. The same may occur in the case of the envelope-dominated buildings, i.e., buildings where the envelope plays a decisive role in the heating/cooling loads. In this case, as it happens with residential buildings, a large part of the environmental control may be reached by some operating attitudes, either of the users or of some "inteligent systems" on the envelope: shading devices; nocturnal insulation, etc.

An even more complicated situation occurs when those spaces have some probability of being in open contact with outside. In this case, some actions can be taken at the level of the urban planning itself and landscaping as a microclimate control. There appears to be some room for other comfort approaches than the technological one. Authors as N.Baker (5) and X.Berger (6) make a more individual comfort approach, talking of "personnal heating" or "personal cooling" instead of space heating or space cooling. This approach does not respond to the situations where the technological comfort applies, but it will cover a large number of situations such as those of the free-running buildings or those with passive heating and cooling systems. The experiences conducted at the EXPO 92 site in Seville are very good examples of outdoor climatic control approached under this perspective. Many experiences of passive buildings relying on natural ventilation, thermal inertia and free cooling are examples of the same type. Of course, something to be aware of is that, in such cases, IAQ is particularly dependent upon outside air quality since there will be no means, such as filters, to remove the contaminants.

Today, one could dare to try to find a new definition for comfort in parallel with the WHO definition for health: comfort is a state of complete physiological and psycological well-being and not merely the effect of some parameters related with thermodynamics, fluid mechanics and heat and mass transfer, or with the presence or absence of some contaminants. If one could agree on such a definition, comfort would become, as it happens for health, even more of an individual affair. So, it becomes almost impossible to generalize comfort. Therefore, at first, buildings should be designed offering forms of natural control that the ocupant can adjust to obtain the indoor air of his preference.

But one cannot, of course, take into account the temperature, air velocity, moisture levels and chemical and particle effects without ignoring the effects of the behavioural aspects, cultural and personnal habits and activity.

5. CONCLUSIONS

The objectives to be satisfied in buildings have been defined within the framework of the Directive 89/106 (7) and its six essencial requirements. Two of those deal with, respectively, "hygiene, health and environment" and with "energy economy and heat retention". Overcoming the expression "heat retention", which appears in the english version, and clearly demonstrates a bias established by the traditional practice in northern climates, it is clear that the single market of construction materials will impose a broader perspective of energy use in buildings through standards and regulations based on a framework of much more openess to different situations of climate, of culture, of building technologies, etc.

From the discussion, above the following conclusions can be proposed :

- Energy strategies in buildings are influencing the actual IAQ and the comfort situations.
- A large share of buildings could avoid at all or at least have much smaller heating or cooling systems if they were better designed according to climate condition.
- IAQ conditions can be controled by several different ways other than just ventilation rates. Design according to the type of utilization has much to do with it: architectural form, selection of materials, systems option.
- In some buildings there is room to establish a hierarchy of comfort conditions and assure a diversification and a descentralization of energy sources and comfort systems.
- In a free running building, the current concept of thermal comfort may need some adjustments. Comfort, which depends on IAQ and energy parameters, may require much more study and research to deal with less objective conditions and non-steady environmental situations (e.g. person heating or person cooling rather than space heating or space cooling).
- Energy strategies in buildings may reinforce the need for a specific energy conservation strategy that stresses the advantages of designing with the climate. In this case the information on comfort to be passed on to designers must be much better studied and elaborated.

REFERENCES

(1) WHO. Air Quality Guidelines for Europe. European Series n.23,1987

(2) ANSI/ASHRAE ST-62 1981. Ventilation for Acceptable Indoor Air Quality.

(3)Olgyay,V. Design with the Climate. Princeton University Press, 1963.

(4)Seppanen, O. Ventilation of Better Indoor Air Quality. ICBEM, pp.32, Presses Romandes, Lausanne, 1987.

(5)Baker, N. Comfort and Passive Cooling, Workshop on Passive Cooling, pp.15, Ispra, 1990.

(6)Berger, X. Thermal Comfort. Workshop on Passive Cooling, pp.35, Ispra, 1990.

(7)Directive 89/106/EEC. On the Approximation of Laws, Regulations and Administrative Provisions of the Member States relating to Construction Products.

AN OVERVIEW OF VENTILATION FOR THE CONTROL OF AIR QUALITY IN BUILDINGS

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ABSTRACT

Ventilation is needed to satisfy the metabolic needs of occupants and to dilute and disperse pollutants generated within an occupied zone. The purpose of this paper is to provide an overview of the role of ventilation in providing for a good indoor climate. Particular emphasis is devoted to what ventilation can and cannot be expected to achieve. A review is also made of the generic approaches to ventilation and consequent design needs. Discussion is focused on ventilation needs in relation to occupants, occupant activities and pollutant emissions from internal sources. The energy implication of each of these needs is also discussed. Finally, proposals for future research activities in relation to ventilation are outlined. These include identifying the current position with regard to the magnitude and range of ventilation rates within the existing building stock, evaluating ventilation needs according to occupant requirements and pollution emissions, and formulating both energy and cost effective ventilation strategies for meeting ventilation needs.

INTRODUCTION

As the thermal performance of buildings continue to improve, air exchange will eventually become the dominant mechanism for building heating or cooling loss. Although, therefore, an essential parameter of the energy equation, ventilation is nevertheless vital for the dilution and removal of pollution generated within buildings. An inadequate supply of fresh air or poor air distribution may result in high levels of indoor contaminants, discomfort and a poor living environment, it could also result in more serious health related problems. As a consequence, reduced air change as a means to minimise energy demand has become inextricably linked to the problems associated with unhealthy buildings. Despite this apparent connection between indoor air quality and air change rate, it is, nevertheless important that the role that ventilation plays in controlling indoor air quality is fully understood. In many instances, ventilation may not be the most appropriate control mechanism. Furthermore, the need to increase the rate of ventilation, in order to control the concentration of pollutants introduced into occupied spaces, can be equated with an energy penalty. Often too there is a misconception about the role of ventilation and the role of building airtightness. Building 'tightness' especially is sometimes used to describe many problems including the re-entry of exhaust air, poor ventilation, bad maintenance and the incorrect operation of ventilation systems. Equally the term 'inadequate ventilation' may be used to express conditions of discomfort and poor temperature control. It is important, therefore, that a clear distinction is made between ventilation problems and other building health issues.

The purpose of this paper is to review ventilation as an air quality control mechanism and to attempt to explain what ventilation can be expected and not expected to achieve. Some of the future research proposals of the Air Infiltration and Ventilation Centre are also outlined.

BACKGROUND

Minimum ventilation rates needed to secure adequate indoor air quality have been the subject of intensive investigation. In many instances, the control of pollution should arguably involve the restriction or elimination of the polluting source but often it falls upon ventilation to provide an answer. This can result in increased energy demand and in the need to provide extra ventilation capacity. The derivation of minimum ventilation rate is dependent on identifying the dominant pollutant, its source strength and its maximum acceptable indoor concentration. This approach is well documented as illustrated, for example, in British Standard BS5925:1990. Other recent assessments of needs include ASHRAE Standard 62-1989 on Ventilation for Acceptable Indoor Air Quality (ASHRAE 1989) and the results of IEA Annex 9 on measures to control indoor air quality (Trepte 1989). This latter report summarises the efforts of experts in 11 countries and at the EC ISPRA Research Establishment to focus on the sources and characteristics of common indoor pollutants and to evaluate the effects of such pollutants in relation to risk, annoyance and damage to building fabric. Control measures such as source control and ventilation needs are assessed for each pollutant.

In a review of indoor air quality problems (Liddament 1990), a brief analysis of in excess of 90 technical papers revealed many suggestions as to the causes of such problems. These can essentially be categorised into the following three broad themes:

- ventilation system performance

- contaminants

- other parameters

A summary of the first theme is presented in Table (i).
While insufficient or inadequate ventilation was widely cited as a cause, the measurement of air change is, as yet, not a common feature of air quality investigations. Unfortunately, without having routine knowledge of air change rates in buildings, it is to recommend any changes to ventilation rates in order to improve building air quality. A conclusion, therefore, would be that if ventilation is thought to be a problem, then indoor air quality investigations should include air change rate measurements. At the very least efforts should be made to ensure that fresh air requirements as specified, for example, by ASHRAE 62:1989 are being satisfied.

Table (i) Reasons for Sick Buildings
- Ventilation Systems

Ventilation too low
Ventilation too high
Inoperative ventilation system
Air conditioning problems
Poor filtration
Poor Maintenance

Some of the indoor contaminants investigated as part of indoor air quality studies are listed in Table (ii). Those such as asbestos and formaldehyde,are specific to building components or choice of thermal insulation, others, such as outdoor pollution and radon are more dependent on building location. The remainder tend to be contaminants which depend on building use and occupancy patterns. Since, over time, the pattern of building use can vary, the relative concentrations of occupant generated pollutants and hence ventilation needs may also be expected to vary.

Table (ii) Reasons for Sick Buildings
- Building Contaminants

Asbestos
Carbon Dioxide
Carbon Monoxide
Dust
Formaldehyde
Fungal Spores
Humidity (too high, too low)
Ions
Odour
Outdoor Pollution
Ozone
Radon
Smoke
Volatile Organic Compounds

Other reasons cited in the literature as causes of "sick" buildings are indicated in Table (iii). These tend to be linked to psychological or work related problems, the absence of user controls (eg openable windows), excessive noise and inadequate or inappropriate lighting.

Table (iii) Reasons for Sick Buildings
- Other Parameters

Lighting
No User Control
Noise
Psychological Factors
Stress

Since such a wide range of problems are associated with unhealthy buildings it is unlikely that a single common cause exists. However it is clear that ventilation is perceived to have an important role to play in the avoidance of such problems.

DEFINING OPTIMUM VENTILATION NEED

From the preceding discussion, it is possible to consider the following contributions to indoor pollution, each of which have an important bearing on ventilation needs and resultant energy impact:

(a) Metabolic Pollution (CO2 and Odour)

The need to ventilate to maintain metabolically produced carbon dioxide and odour to acceptable levels represents a minimum ventilation requirement and hence the minimum ventilation energy condition. A building or a zone within a building in which high concentrations of metabolically produced pollutants are measured clearly indicates insufficient ventilation. Furthermore, for a given occupancy pattern, the problem can only be solved by increasing the rate of ventilation.

(b) Pollutants Produced by the Activities of Occupants

Occupants produce pollution as a consequence of normal day to day activities. This could be tobacco smoke, moisture generation through cooking and washing, and contaminants generated by the use of unvented combustion appliances. Whether or at what level such pollutants are acceptable is largely a medical judgment but, if any of these contaminants or other occupant generated contaminants are found in a building in which the previous criteria set by (a) above is satisfied, then either these activities must be reduced or further ventilation is needed. Any such additional ventilation represents an easily definable energy penalty. Thus the energy consequence of such activity may be costed. Furthermore, increased ventilation requirements may also result in additional costs for installing and operating extra ventilation capacity.

(c) Pollutants Produced by Building Fixtures and Furnishings

These pollutants include volatile organic compounds, ozone and formaldehyde emissions. As with (b) above acceptable concentrations must be based on medical judgment and the control strategy is either removal or increased ventilation. If the solution is increased ventilation, then the energy consequence is, again, clearly definable.

(d) Pollution Generated by the Ventilation System or through Poor Design

Some problems may be associated with poor ventilation design. These include air intakes being located too close to ventilation exhaust vents or too close to flues. In these examples, the rate of ventilation will not solve such problems and therefore increasing the rate of ventilation is not a viable control strategy.

(e) External Pollution

External pollution could include soil gasses, dust, industrial pollutants or traffic fumes. Again, ventilation of the internal space will not necessarily solve these problems. Strict airtightness controls and, in the case of external airborne pollutants, filtration systems are needed.

(f) "Unidentifiable" Air Quality Problems

Once identifiable sources of pollution have been eliminated, further indoor air quality problems may be apparent. This seems to be especially a problem with air conditioned spaces. Some evidence points to toxic microbiological or fungal infection of the duct work. Again, it must be regarded as unlikely that the ventilation rate itself is too low and a different control measure (eg disinfection of the ductwork) is needed.

By undertaking an analysis in such a structured way, the significance and implications of ventilation can begin to be identified and the consequent energy impact of ventilation can be evaluated. It is proposed, therefore, that such a study should take place.

SYSTEMS AND STRATEGIES

Once a ventilation need has been identified, then a system to achieve this must be designed. Overestimation of ventilation will influence heating or cooling losses as well as the energy needed to operate the system. Essentially, systems can be divided into two generic forms, these being 'dilution' systems and 'displacement' systems. In a dilution system, incoming air is uniformly mixed with the interior air mass whereas in a displacement system the interior air is displaced by incoming air with mixing kept to a minimum. In practice some combination of the two approaches is common. While, from an air quality aspect, displacement approaches are generally preferred, very precise operating conditions are normally needed and their operation can be impaired by occupant activities, temperature fluctuations and door opening etc. Where air is conditioned, or warm air heating is used, high recirculation rates and resultant mixing ventilation may be necessary.

The motivating force for ventilation may be either natural or mechanical. This choice will influence the generic form of approach. Natural driving forces, for example, tend to be very variable and therefore cannot normally be used to control a displacement ventilation system, although the use of passive ventilation stacks can provide some measure of flow control between zones in a building. A full account of developments in ventilation strategies is presented by Knoll (1991).

Integral to the selection of a ventilation strategy must be consideration of the building itself. In other words the building must be constructed to suit the ventilation system. Mechanically balanced supply/extract systems demand very airtight building shells for correct operation. Extract or supply only systems demand sufficient perimeter or envelope openings to avoid build up of excessive pressure differences across the building envelope. Such pressures can cause air quality or comfort problems, incorrect operation of the ventilation system and/or excessive operating energy demand. Natural ventilation systems cannot be expected to supply a constant flow rate and therefore user controllable perimeter openings are needed to ensure provision for adequate air flow under all operating conditions. Ideally, these should be openable windows for Summer cooling purposes and air vents for Winter air supply. Building airtightness is therefore inevitably a vital part of the design strategy. It is only when a building is tightened without regard for ventilation that 'tight building' problems will arise. The Swedish approach has been "build tight - ventilate right" (Elmroth 1980). Stringent airtightness with combined ventilation requirements are successfully enshrined in the Swedish Building Code (1989).

Since buildings are frequently transiently occupied, ventilation needs may also be variable. Demand controlled systems are therefore becoming popular. At its most basic level odour is widely used as an indicator of air quality and ventilation may be controlled to minimise the intrusion of odour. However, the quantitative measurement of odour using instruments is not possible and therefore other indicators are needed for the automatic control of ventilation. One such indicator is carbon dioxide which is often used as a measure of occupancy and occupancy generated pollution. ASHRAE Standard 62-1989 sets an upper concentration limit of 1000ppm for comfort (odour) although British Standard 5925:1990 still uses 5000ppm. CO2 systems are used in commercial buildings, schools , shops and theatres. In the home, humidity controlled sensors may be found for the control of extract fans or systems in bathrooms and kitchens. Demand control is being investigated in detail by IEA Annex 18 (Raatschen and Mansson 1990). The principal objective of this task is to develop guidelines for demand controlled ventilation systems based on the varying needs of domestic, office and other environments. While essentially focusing on carbon dioxide and humidity sensors for ventilation control, mixed gas, tobacco smoke and carbon monoxide sensors are also being considered. Additional work, within Annex 18, includes the development of guidelines for the implementation of demand controlled ventilation systems. A number of case studies have also been reviewed by this Annex.

The choice of ventilation system is therefore extremely wide and no single approach to ventilation can be expected to meet the requirements of all applications. Inevitably cost effectiveness as well as energy efficiency will be an important consideration in most instances. Ultimately the choice will be motivated by such considerations as capital costs, running costs, maintenance needs, reliability, heat loads and gains, building size and location, building purpose, climate, energy effectiveness and occupant needs. Whichever choice is made, however, it is thought that much more can be achieved in the design of efficient ventilation than is accomplished at present. Hence a proposal of the AIVC is to produce a Guide to Ventilation which would be aimed at policy makers, designers and other groups interested in promoting and developing energy efficient ventilation.

ENERGY IMPACT OF VENTILATION

In a global sense, the energy impact of ventilation is considerable and, in the future, may be expected to exceed that of building transmission heat or cooling loss. To offset this loss, there is, of course, considerable, opportunity for ventilation heat recovery using air to air heat recovery systems and/or heat pumps. In capturing this return, however, consideration needs to be given to cost effectiveness, long term reliability and quality of building construction.

If it is assumed that air enters the building at the external air temperature and leaves the building at the internal air temperature, then the energy of ventilation is given by:

$$H = Q\rho c_p(T_{int} - T_{ext}) \qquad (W)$$

where Q = air flow rate (m^3/s)

ρ = air density (kg/m^3)

c_p = specific heat of air (J/kg/K)

T_{int} = internal temperature (K)

T_{ext} = external temperature (K)

Heat loss may conveniently be expressed in terms of Watts/m3 of enclosed space/deg C temperature difference. Alternatively it may be expressed as a "ventilation heat loss coefficient" analogous to U-value, ie Watts/m2 of envelope surface/deg C. Both of these measures provide a simple way of comparing the magnitude of ventilation heat loss with conduction losses from buildings.

Because the measurement of air change in buildings has, until recently, been both difficult and time consuming, there is little perception of actual ventilation rates and resultant heat loss in the overall building stock of Europe. A first step in any comprehensive ventilation analysis would therefore be to undertake a comprehensive evaluation of the existing building stock as outlined in the following section.

FUTURE RESEARCH

The Air Infiltration and Ventilation Centre has recently prepared a strategy document identifying research needs for future ventilation and related energy research. The fundamental intention has been to identify the prime objectives and tasks needed to secure energy efficient ventilation. A strategy to determine the current energy consumed in buildings through ventilation is also proposed.

The principal objective of the future work programme is to understand, develop and promote the role of ventilation in indoor air quality and energy control (Figure 1). In order to achieve this the following tasks are proposed:

(i) Establish Indoor Air Quality Needs

Before ventilation requirements can be quantitatively identified, it is essential that indoor pollutants are understood. The purpose of this task, therefore, is to address this problem. Proposals include:

- reviewing existing IAQ codes, standards, requirements and knowledge.
- classifying indoor pollutants, sources and sinks.
- assessing the interaction of pollutants.
- establishing acceptable pollutant concentrations.

Many of these tasks are seen as falling within the domain of IAQ specialists.

(ii) To Identify the Role of Ventilation

The role of ventilation as an IAQ control mechanism must be clearly identified. In some instances, for example, ventilation may be essential while in others, ventilation control may be totally inappropriate. The suggested tasks include:

- a review of existing knowledge and evidence.
- an analysis of the influence of flow rates, flow patterns and ventilation efficiency on the control of pollutants.
- field measurements to assess the role of ventilation.
- the specification of minimum ventilation rates and/or alternative control mechanisms.

These tasks are principally seen as ventilation specialist activities.

(iii) To Evaluate Optimum Ventilation Needs and to Identify the Associated Energy Impact

The purpose of this exercise is to assess ventilation needs for both occupant and IAQ requirements in order to derive optimum air change rates.

Starting with the basic need for metabolic ventilation, the extra ventilation needed to cope with occupant activities and pollutant sources is identified. In each case, the resultant energy consequences need to be assessed. The tasks proposed include:

- compiling requirements on metabolic needs.
- compiling requirements for occupant activities.
- determining requirements to cope with pollution sources within buildings.
- evaluating associated energy impact.

(iv) Assessing the (Global) Energy Impact of Ventilation

This task is seen as a major activity. The intention is first to assess the air change rates and resultant energy demand in the existing building stock (commercial buildings and dwellings), the second task is to evaluate the potential reduction in energy achievable by meeting basic ventilation needs. Both aspects of this study will help to provide information on the energy demand of building ventilation and to provide information on the potential for energy reductions. The tasks include:

- Evaluate the ventilation heat loss in the existing (occupied) building stock:
  - (a) by analysis of building energy use statistics.
  - (b) by sample simplified measurements in a statistically significant number of occupied buildings combined with supporting detailed measurements in selected buildings.
- Evaluate theoretical minimum ventilation heat loss.
- Evaluate potential for energy reduction.

(v) Achieve Energy and Cost Effective Ventilation

Once the target for energy reduction has been determined, the final objective is to establish the strategy needed to achieve this goal. The necessary parameters are illustrated in Figure 2. The results of the preceding studies are combined with other factors such as climate, cost considerations, building integrity and occupant requirements in order to optimise system design and achieve reduced energy demand. From this analysis a realistic aim for optimum air change combined with energy efficiency may be set. In undertaking this analysis, input from other international activities covering air flow and multizone modelling techniques, database information and control systems will be essential.

CONCLUSIONS

(1) Ventilation is inextricably linked to the indoor air quality needs of buildings, however, the role of ventilation needs to be clearly defined. Problems for which ventilation is not appropriate should be identified.

(2) Ventilation requirements should be quantified in relation to occupant needs, occupant activities (eg smoking, use of office equipment etc), and

emissions from building materials and furnishings.

(3) The energy consequences of each category of ventilation requirement should be individually assessed, since this will identify the energy and cost consequences of ventilation for pollution control.

(4) In order to evaluate the future benefits of modifying current ventilation approaches, the magnitude and range of ventilation rates in the existing building stock should be evaluated and the consequent energy impact determined.

(5) Based on the identification of ventilation needs, appropriate energy and cost effective ventilation strategies should be formulated and implemented.

REFERENCES

ASHRAE Standard 62-1989 "Ventilation for acceptable indoor air quality" American Society for Heating, Ventilation and Air_Conditioning Engineers 1989 ISSN 1041-2336

BS5925:1990 "Code of practice for the design of buildings: ventilation principles and designing for natural ventilation" British Standards Institute 1990 (in draft)

Elmroth A "Build tight - ventilate right" Air Infiltration Review, August 1980

Fanger P.O "Introduction of the olf and decipol units to quantify air pollution perceived by humans indoors and outdoors" Energy and Buildings, Vol 12 1988

Knoll B "Advanced ventilation systems - state of the art and trends" AIVC Technical Note 33 (Air Infiltration and Ventilation Centre) July 1991

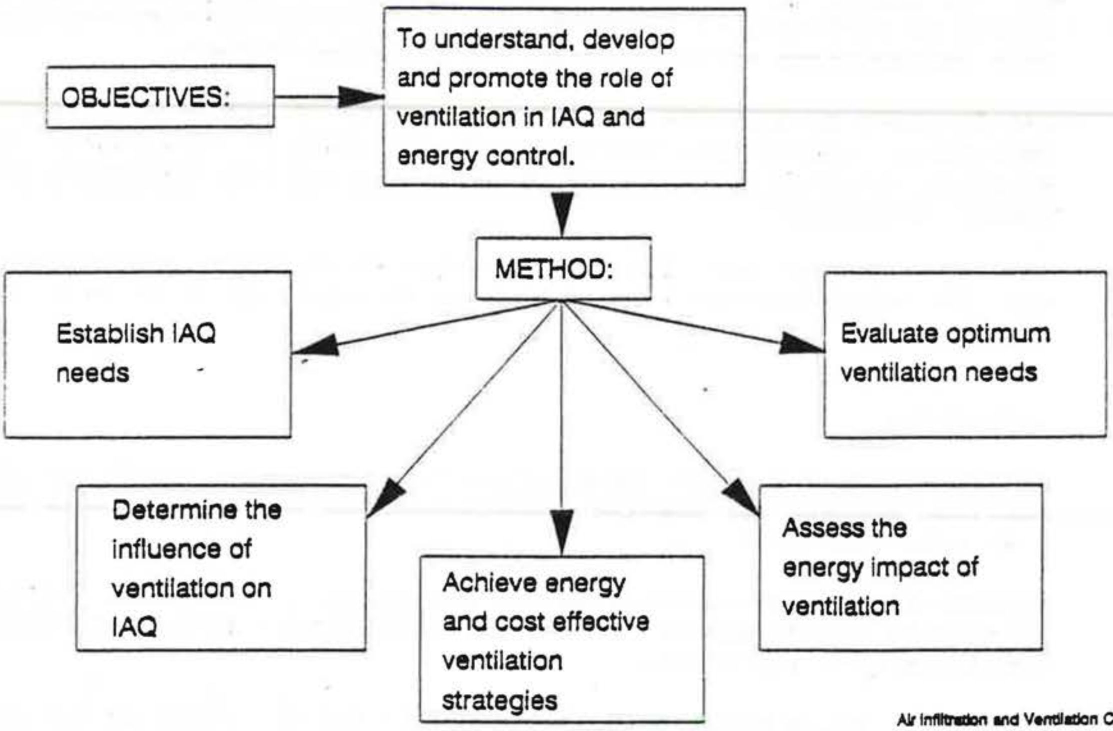
Liddament M.W "Ventilation and 'building sickness' - a brief review" Air Infiltration Review, September 1990

Raatschen W "Demand controlled ventilating systems - state of the art review" Swedish Council for Building Research, ISBN 91-540-5169-X, D9:1990

Swedish Building Code BFS 1988:18 Chapters 3:13 airtightness, 3:14 heat recovery, 4:1 air exchange National Swedish Board of Physical Planning & Building 1989

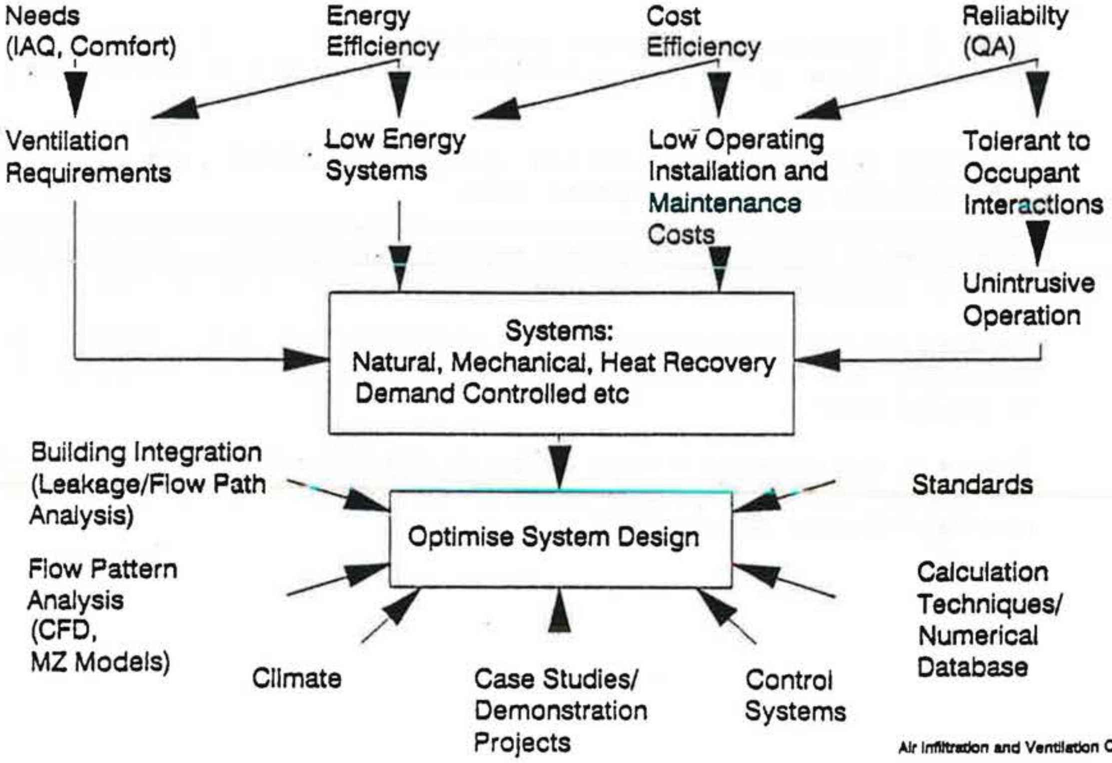
Trepte L and Haberda F "IEA annex IX minimum ventilation rates and measures for controlling indoor air quality" Technical Note AIVC 26 Air Infiltration and Ventilation Centre 1989

Figure 1 A Strategy for IEA Ventilation Analysis



Air Infiltration and Ventilation Centre

Figure 2 Achieve Energy and Cost Effective Ventilation



Air Infiltration and Ventilation Centre

CEC WORKSHOP ON IAQ-MANAGEMENT
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VENTILATION ASPECTS OF AIRBORNE POLLUTANT TRANSPORT IN BUILDINGS

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ABSTRACT

The concentration level of a contaminant in a room is not only dependent on the source strength in the room itself and the ventilation of that room, but due to transport of air from outside to inside or from another inside room, contaminants can be brought into a room and hence influence the concentration level in that room. Ventilation will mix and dilute this contaminants, while on the other hand the transport of air through system and building fabric also causes a decrease in concentration due to filtration, adsorption or any other form of deposition.
The performance of a ventilation system can be determined as the optimum of fresh air distribution at minimum pollutant levels and minimum energy use.
The distribution of air, as well as the distribution of a contaminant in a single room or through a building can be seen as a result of the effectiveness of a ventilation system.
An overview of existing knowledge will be presented, together with research areas to be exploit.

INTRODUCTION

In the frame work of the European Communities Research Program Indoor Air Quality is an item which has not be taken into account very thoroughly in the past. Looking to air management in the building-environment a lack of knowledge exist.
Improving the understanding of the complex air infiltration and ventilation processes and at the same time reducing the energy consumption due to air transport through buildings is a challenge for everyone.
One has to realize that there is more than infiltration and ventilation. The enormous environmental problems in the world put also a pressure on us. We have to consider our contribution on solutions. Taking that as a starting point for our the problem of airborne pollutant transport, it looks that a variety of new items comes to us.
The importance of infiltration and ventilation as a key

parameter for indoor air quality and comfort must be our motivation to undertake new projects. Specially where the interaction between other specialists play an important role. Interdisciplinary work has to be undertaken. Hygienists, medical doctors, designers of new buildings and installations need our special attention.
We still have a lot of existing knowledge which did not really found their way to practice.
On the other hand new research has to be started. There are still questions which cannot be answered with the existing knowledge.
For instance the questions :

- What is the overall exposure of a housewife, a young child, an elderly due to typical indoor air pollutants during their stay in our existing housing stock.
- What effect can infiltration and ventilation have on that exposure.
- Can we improve our ventilation systems in that way that a positive effect of it can be reached.

The questions given, have to do with indoor air quality. But at the same time, it is unacceptable that we waste energy and moreover are misusing energy and put an extra burden on the quality of our outdoor environment.
From that standpoint one can easily see new investigations for our future.
This paper describes the role of air transport in relation to pollutant levels taking into account the energy use of that air transport. Although it is mainly focused on dwellings, most phenomena are also valid for other buildings such as offices for instance.

PROBLEM DESCRIPTION

A person in a building is exposed to pollutants. There can be a variety of pollutants. There are pollutants which only cause nuisance. Others can give serious health problems. Some have short term effect others long term. A pollutant source will emit to the air and mix with the surrounding air, depending on the air flow pattern in the room and the momentum of the emitting source. In most cases the pollutants release at very low velocities. The air flow pattern in the room is therefore very important for the mixing process.
Ventilation will dilute pollutant emissions to a certain concentration. But on the other hand ventilation can also cause transport of air from one room to another and hence influence the pollutant concentration level in other rooms.
During mixing and air transport deposition of a pollutant will take place. Different kind of deposition mechanism play a role.
People are not always on the same place in the same room. This means that the doses of a pollutant they are exposed to is the integral of the concentration over time and place.

EXISTING KNOWLEDGE

This paper will not describe sources and contaminants. This topic will be covered in session 3 of this workshop.

Ventilation

Although there are lots of measurements carried out in buildings, the bulk of the information is gathered in dwellings. In most cases it concerns overall air change rates over a relative short term.
But an overall air change rate is not a good quantity to evaluate pollutant levels. This can easily be explained with the figure 1. This is a result of an EC project on ventilation in low cost housing.[1][2]

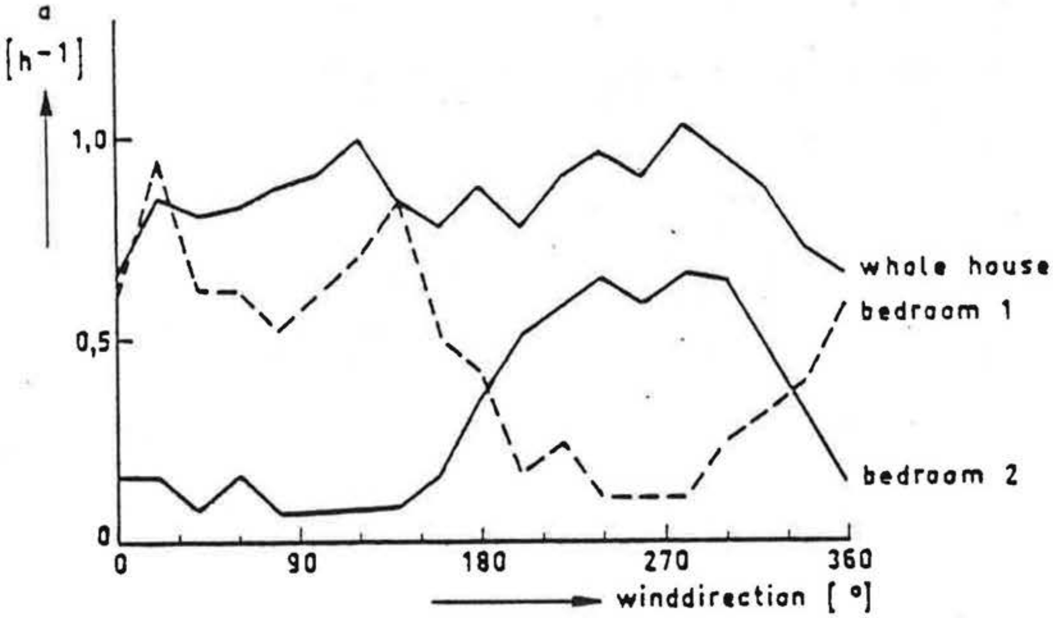

Figure 1 Infiltration rates versus winddirection for the whole house and two opposite bedrooms. Windspeed 5 m/s

Although the air change rate of the whole house is, as given in figure 1, in this case almost independent of winddirection about 0.8 h^{-1} , the different air change rate for the bedrooms vary with winddirection. The air change rate for the bedrooms is high when there are exposed to wind(windward side) and very low even almost zero when they are located on the leeward side of the building. This means a the same time transport of air from the windward side bedrooms to the leeward side. The same effects is also measured in a dwelling.[3] The results of about 1000 hours of ventilation rates for the whole house are given in figure 2. The house had a mechanical ventilation system. Some people believe that one cannot have indoor air quality problems in such houses. But be careful.

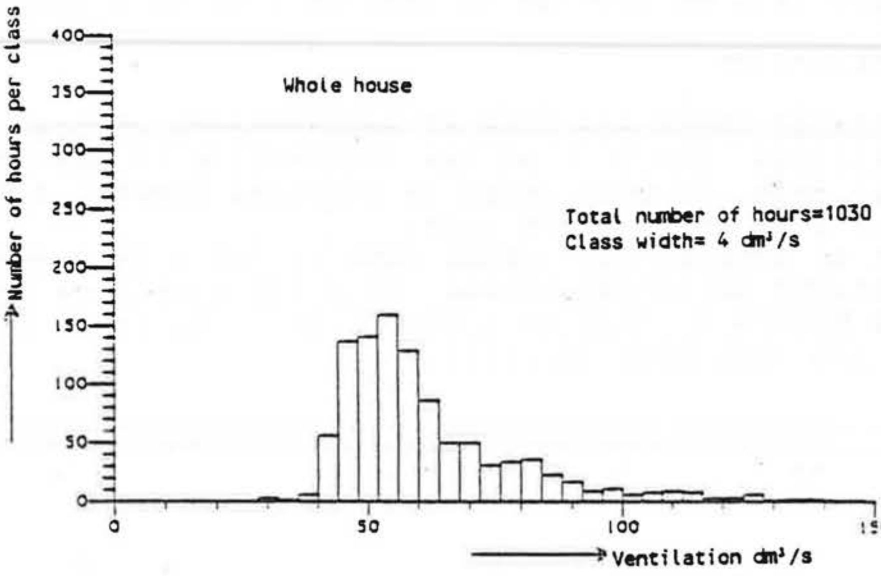

Figure 2 Histogram of whole house ventilation rates for 1030 hours of measurement.

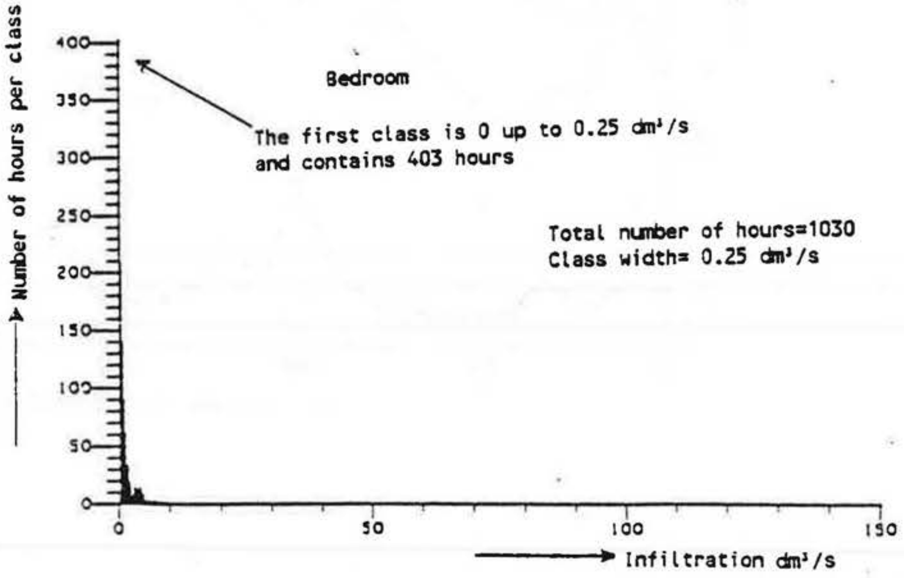

Figure 3 Histogram of the infiltration rate for an airtight bedroom in a dwelling located for most prevailing winddirection on the leeward side of the dwelling

As one can see the air flow rate is almost always above 40 dm^3/s. This is equal to an air change rate of about 0.5 h^{-1}. The results for a bedroom located on the leeward site with

respect to the most frequent winddirection are plotted in figure 3 on the same scale for the X axis. The air flow rate is always lower than 10 dm^3/s, and some 400 hours of the total 1000 hours lower than 0.25 dm^3/s. The guaranty of a high enough overall ventilation rate for the whole house does not necessarily mean a good indoor air quality for all the rooms. The inhabitant did not open a window or grid during this measurements.
In general it is not the ventilation rate which depends mainly the concentrations of pollutants, but the outside infiltration rate and the transport of pollutant from other rooms, together with the use of the ventilation provisions by the inhabitants. The importance of knowledge about how people use their ventilation provisions and also doors can be found as a result of IEA Annex 8 summary report[4].

Transport air from one room to another

The transport of air through a buildings is very complex. It will change in time readily. From the point of view of pollutants, in most cases we are only interested in mean values over a certain amount of time.
Measured air flow rates between rooms over longer periods are scarce. In some studies this phenomena is investigated. The position of internal doors play an important role. Even in the most extensive study on inhabitants behaviour with regard to ventilation [4] very less information can be found on the use of doors.
The concentrationlevel of a pollutant in a room is a function of the air flow pattern in the room. The transport of a contaminant through air transport depends also on the pressure differences and the size of the openings between rooms. When internal doors are kept closed, the air exchange over it is relatively small. A few Pascals pressure difference and over a normal internal door gives an air flow of about 10 dm^3/s. Flow over large openings like for instance doors and open windows is of course much larger. Nevertheless there is a lack of knowledge in the understanding of flow over large openings as can be seen from the results of IEA Annex 20. [5]

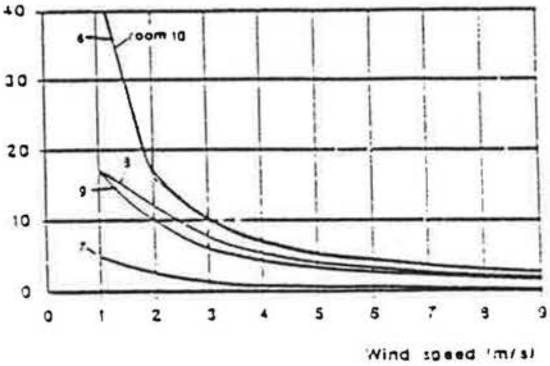

Figure 4 The smell level due to air flow from crawl space

An open door with a temperature difference over it of about 1 K causes an air flow over the door of about 100 dm^3/s.
There are two other paths which can be of importance for the transport of pollutants. Floors and leakage from crawlspaces to the cavity in walls. Information about airflow and contaminant transport along these paths is almost completely failing. In literature one can find explanation of for instance radon levels on higher floor due to air transport over floor and cavity leakages [6]. Measured quantitative values cannot be found. About indoor air flow and smell transfer some information from a model study can be found in [7]. Figure 4 gives a result of that study.

Air movement in stairwells

Because of relative high temperatures on the lower floor of a dwelling in most cases and due to lower outside- than inside temperatures. Air will flow from lower areas to higher floors. But cold infiltrated air in the roof and bedroom area will flow downstairs at the bottom of the stairwell. As one can understand the airflow pattern in this special shaped room in a building is very complicated.
An example is given in figure 5.
Up till now measurements as well as models cannot give adequate answers for this phenomena.[8]

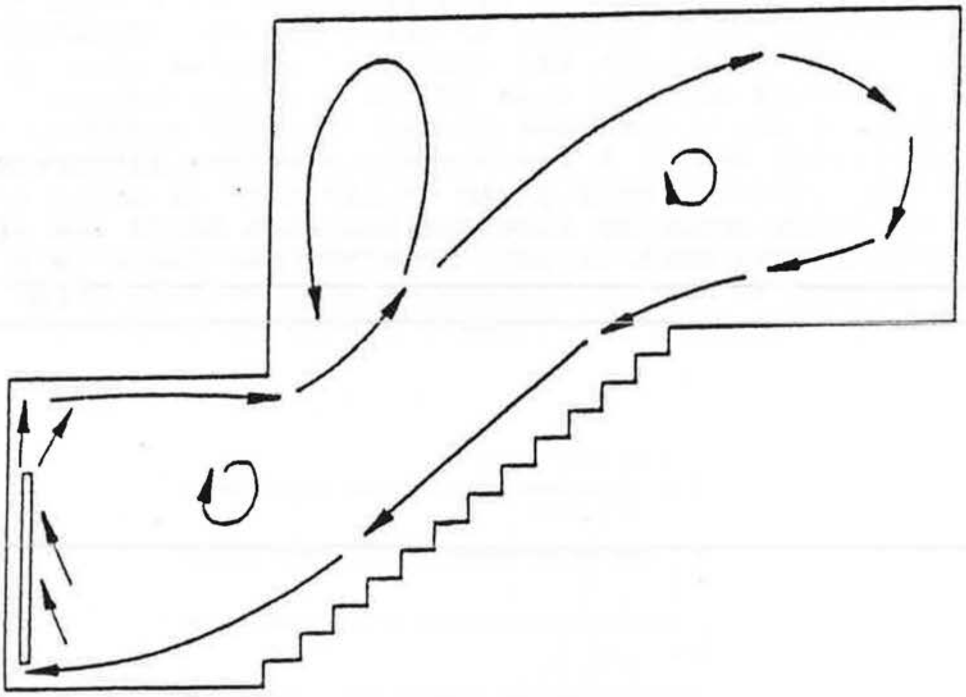

Figure 5 A two dimensional view of the flow pattern in the stairwell

Loss terms

Due to various mechanism pollutantlevels will decrease during the transport of air. Ad- and absorption, gravity forces but also filtering in cracks will cause a decrease in pollutant levels. An overview of existing literature can be found in [9]. All indoor air quality models have a gap in their knowledge for this item. One has to realize that not only loss terms but also the opposite likes desorption and evaporation plays a role in the prediction of contaminantlevels.

NEW RESEARCH

It is easy to produce a research program when all questions about the role of ventilation and infiltration on the pollutants in buildings must be answered. It is our challenge to put forward a well balanced program, which in the near future will lead to a lower exposure of pollutants for inhabitants of buildings. Priorities must be given, choices have to be made. In this paragraph my choices for this item are given.

Studies on the following items are advisable:

- The interaction between multizone flow and room air flow. Specially when the connection between the two is a large opening ore even large openings. The flow through large openings (for instance the turbulence effects) is not quit well known and play on the other hand an important role in the transport of pollutants through the building.

- The existing models must have the possibility to communicate with each other. Again the flow over large openings is highly dependent on the temperature difference. If this will be only estimated in the ventilation models, we might miss a good insight in this effect.

- Deposition of pollutants such as absorption, desorption, condensation etc. are factors who strongly influence the pollutant levels in the rooms. Data from experiments is lacking at this moment. Models has to be modified on this point.

- The behaviour of occupants need to be studied in more detail. Occupants spent their time in different rooms. They have an significant influence on the production of some pollutants and they are the predominant factor in the proper use of the ventilation systems.

- The development of ventilation strategies depending on building style, behaviour, local circumstances like weather and concentrations of pollutants outside the building is necessary.

-Measurements on the ventilationlevels during the heatingseason as well as exchange between different zones in a building. The PFT tracer method can be a good approach to gather rather simple a lot of information.

-The effect of flow over almost unknown airpaths such as leakages from crawlspace to inside and the role of leakages between different rooms and cavities in walls.

-The construction of a European test house in which an evaluation of the best systems can be carried out as a demonstration of the possibilities of systems to control the indoor environment at minimum energy use.

REFERENCES

[1] Gids, W.F. de
Natural ventilation and energy consumption of dwellings
IMG-TNO,report C 482
Delft, July 1981

[2] Gids, W.F. de
Influence of different parameters infiltration and infiltration heatloss
IMG-TNO,publ. 824
Delft, 1982

[3] Phaff,J.C.
Ventilation, inhabitantsbehaviour and moisture in dwellings (in Dutch)
IMG-TNO
Delft, 1986

[4] Dubrul, C.
Inhabitants Behaviour with respect to ventilation- A Summary Report of Annex VIII
AIVC,TN 23
Bracknell, March 1988

[5] Maas, J. van der,C.-A. Roulet and J.A. Hertig
Some aspects of gravity driven air flow through large apertures in buildings
ASHRAE Transactions 1989, Vol. 95, part 2.

[6] Coholis, P, P. Wouters and D. L'Heureux
Prediction of the performance of various strategies of subfloor ventilation as remedial action for radon problems.
WTCB
Limmelette, 1990

[7] Li, Y.
Indoor air flow and smell transfer in single family dwelling
Royal Institute of Technology
Stockholm, 1990

[8] Zohrabian, A.S. and others
Buoyancy driven air flows in a closed half scale stairwell model
AIVC 10 th Conference Proceedings, Vol. 2 , P12
Espoo,1989

[9] Lanting, R.W.
Deposition velocities of gasses and particles in the indoor environment (in Dutch)
TNO-Building and Construction Research, rep. BI 91-074
Rijswijk, May 1991

THE VENTILATION PROBLEM
TOWARDS MORE EFFICIENT VENTILATION SYSTEMS

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ABSTRACT

- In a first part, the different ventilation systems (existing or projects) are reviewed ;

- In a second part, some domains where international research collaboration is thought to be more effective are indicated :

. building retrofitting because, it accounts for about 50 % of construction activities and a lot of improvement in IAQ and energy conservation is possible, particularly when use of mecanical systems would be too expensive
. residential buildings because the relative homogeneity of buildings is likely to ease possibility of international research collaboration
. large volumes (atria, assembly halls, ...) which requires improvement of models, particularly with respect to temperature stratification
. etc...

- In the last part, research areas are proposed :

. passive stack ventilation and combined systems (with respect to retrofitting)
. models in order to predict IAQ level and energy efficiency (models should handle items such as pollutant stratification or absorption-desorption : reliable and validated models are likely to ease the assessment of systems with respect to the construction products directive.
. specific research on ventilation related pollutants (H_2O, radon, NOx, CO) : mould growth, combustion products emission as a function of ventilation rates, radon ingress as a function of pressure difference, ...
. pollutant recirculation around building
. comfort problems (draughts, ...)

A/ INTRODUCTION

Reduction in energy loss from the fabric has probably reached a point decreasing returns and further substantial reductions in energy use from th source are likely to be uneconomic. However there is substantial potential for energy saving in ventilation. Dwellings represent about 30% of EEC countries energy use, most of it in heating. Thus ventilation in dwellings could in futu represent up to 15% of energy use. Therefore even relatively small reductions overall ventilation levels could represent significant savings in total energy use.

B/ DIFFERENT SYSTEMS IN USE IN EEC

Today, depending on national practice, there is a vaste range of differe ventilation strategies in the different OECD countries. The final goal of this projec is to improve the performance of existing and new systems. Broadly domestic ventilation may be divided into:

1/ Adventitious ventilation,
2/ Natural/passive stack v2entilation,
3/ Mechanical extract ventilation,
4/ Combination of passive stack ventilation and extract ventilation, here after called hybrid system,
5/ Balanced supply and extract ventilation.

Of these, probably, the most interesting currently are natural/passive stack and mechanical extract. Adventitious ventilation is known to be unsatisfactory and balanced ventilation economic only in colder climate. Natural/passive stack ventilation are easy to maintai however there performance are likely to be uneconomic because of higher flow in winter, at a time when energy consumption per each m^3/h is higher. Hybrid systems which combin feature of both systems are likely, if property sized, to give appropriate results.

C/ POSSIBLE RESEARCH SUBJECTS

1 - RETROFITTING OF COLLECTIVE RESIDENTIAL BUILDINGS WITH PASSIVE STACK SYSTEMS

When existing buildings are retrofitted, the air leakage of the building enveloppe is often improved, which may cause condensations or IAQ problems, unless the ventilation proble is dealt with. Use of existing stack is often a convenient way, both in single family hous and collective buildings, to create a ventilation system.

Work programme :

- cowls characterization (wind tunnel tests and analysis, flowrate model, influence of obstacles)
- modelling work
- experimental validation in real buildings (les Ulis, Namur,...)
- drafting of European climatic Zones (wind and temperature) with respect to natural ventilation
- ...

2 - CALCULATION OF AIR CHANGE IN RESIDENTIAL BUILDINGS

Air change in residential buildings is depending on the following :

- building air leakage
- climatic conditions
- occupant behaviour
- thermal effect
- cross ventilation due to wind
- air change due to ventilation provisions
- ....

Different calculation methods (for instance CEN TC 89 WG 4) have been derived, but none of these methods takes completely into account all these parameters. Moreover, basic research is still needed in order to improve the understanding of basic phenomena, for instance the effect of wind on air passages in the facade accounting for the wind turbulence, the eddy flow and the air mass. On the other hand accurate methods are needed in order to have a better assesment of the performance of some new components, for instance : advanced air inlets.

3 - RADON MEASUREMENT AND MITIGATION TECHNIQUES

a/ Radon concentration in houses is very much dependent on ventilation conditions. Measurement for diagnosis purpose should therefore account for this source of uncertainty.

Combined expertise of radon measurement specialists and ventilation experts would allow to draft recommendations for cost efficient and reliable measurements :

Work programme :

- analysis of building ventilation systems and computation of radon concentration as a function of time
- drafting of a measurement methodology
- assessment of this methodology for houses in different countries comparing the results with long term radon monitoring.

b/ Radon mitigation techniques are dependent on the architectural and ventilation provisions and may differ according to the different countries.

Work programme :

- investigate, with respect to national habits, the interest of different solutions (cost, heat losses, efficiency,...), both for existing and new buildings
- field experimentations in order to assess their interest.

. Particular emphasis could be paid to the dependence of radon concentration on negative pressure inside the house, which is of great importance with regard to ventilation techniques.

4 - FLOW AROUND BUILDINGS

Two problems need scientific investigations :

1°) which is the distance (both vertical and horizontal) required between air exhaust terminals and air intake (both on the roof and on the facade) in order to prevent significant air recirculation ?

2°) location of passive stack cowls with respect to roof slope, roof ridge, obstacles,...

. Work programme :

- wind tunnel
- CFD analysis
- field experimentation

5 - EFFICIENCY OF VENTILATION SYSTEMS IN RESIDENTIAL BUILDINGS

It is recognized that most of the ventilation systems does not always provide time constant air flowrates. Accordingly, the development of energy efficient advanced ventilation systems would be considerably enhanced if recognized and validated methods enabling to predict the efficiency (i.e. indoor air quality level versus heat losses) of the ventilation systems could be drafted.

This would also concern existing ventilation techniques and allow performance comparison on rationnal basis.

A possible product could be a technical guide for the assessment of ventilation systems. This guide would specify and develop the requirements :

- air quality
- condensation
- comfort (draughts,...)
- safety
- acoustic
- ....

6 - COMBUSTION PRODUCTS

Carbon monoxyde poisoning (both acute and low level) is a major problem in many countries (hundreds of death each year in France for instance). Better design of ventilation systems (both in existing and new buildings) with respect to this problem is necessary.

Work programme :

- monitoring of CO and NO_2 in houses and analysis
- survey of houses where accidents occured in order to understand how it happened
- laboratory experimentation on vented gas and coal appliances
- modelling work on flue stacks

7 - DRAUGHT PROBLEMS

Cold draught prevention is a major requirement of air inlets. Climatic chamber tests and analyses would help to improve the design of air inlet and their location in the room. Research is needed for establishing correlation between jet characteristics and temperature/velocity profile in the room.

8 - MOISTURE

Humidity level of the indoor air is highly depending on moisture capacity. More experimental and theoretical work is required for improving models. Relation between RH level and mould growth is also required in order to yield a better knowledge of the requirements.

9 - POLLUTANT CONCENTRATION GRADIENT INSIDE ROOMS

methods : CFD, Zonal models, laboratory experiment
product : predictive calculation tool
goal : guidance for design and location of air terminal devices, particularity in the kitchen.

10 - AIR MOVEMENT IN LARGE ENCLOSURES AND ASSEMBLY HALLS

Models of air movement and temperature stratification accounting for wind and thermal effect would help to improve the design of heating devices, particularly with respect to temperature stratification.

11 - WIND TURBULENCE

This topic and its influence in multizone buildings or chimmeys flues needs further theoretical experimental study.

12 - AIR QUALITY IN VAV SYSTEMS

In variable air volume systems, the air change can be very different in the rooms of a building, depending or the heat imputs. A study of these systems would help to ensure that minimum hygienic air flow rate is always obtained.

13 - NEW DESIGN OF AIR CONDITIONNING AND CONTROL SYSTEMS IN NON RESIDENTIAL BUILDINGS IN ORDER TO COPE WITH THE FOLLOWINGS :

- human occupancy variation
- heating or cooling load spatial and temporal variation.

14 - AIR CLEANING DEVICES

Pollution of the make up air by aerosols or dust should be kepts as low as possible:

work programme

. new design of air ducts in order to limit fouling
. research and development of centralized air cleaning devices
. basic research on dust deposition as a function of air inlet flowrate as a function of time.

15 - DESIGN OF COST EFFICIENT VENTILATION SYSTEMS

The objectives would be to produce guidelines:

- for architects on the choice of ventilation systems for new and refurbished buildings,
- for engineers on an energy efficient design of ventilation systems for residential buildings, meeting the need for a healthy indoor climate,
- on maintenance of ventilation systems.

These guidelines should deal with the following:

- design criteria,
- economic criteria,
- installation recommendations,
- cooling requirements in summer,
- fire precautions,
- acoustic problems,
- maintenance and operation,
- climatological factors,
- radon protection,
- combustion products.

work programme

a/state of the art in different countries and basic requirements:

According to national practice, many different designs of natural, hybrid or mechanical systems do exist. A preliminary stage will therefore be to gather any relevant information (design tools, real performance ,....)on these systems.

A very important issue will be then to draft the basic requirements (g: acoustic requirements, condensation prevention, air flowrate constancy vs time,...) which will have to be met by each kind of system

b/Research topics:

- pressure drop in converging ducts,
- modelling of combustion appliances with respect to combustion product temperature and pollutant release.
- investigation of the failure modes (for instance failure of fan),

- actual performances of heat recovery units and modelling,

- fire problems, acoustic problems,

- flow bistability of venting systems.

- influence of heat losses and duct thermal inertia on exhaust flowrates,
- condensation hazards in ducts,
- analysis of air flow in ducts at low Reynolds numbers,
- analysis of climatological data.

c/laboratory and field work

will include:

- testing cowls in wind tunnel,
- testing vented combustion appliances,
- validation of models.

INDOOR AIR QUALITY MANAGEMENT
Workshop Lausanne, Switzerland
May 27-28, 1991

HEALTH, COMFORT AND AIR QUALITY EFFECTS OF MECHANICAL SYSTEMS AND COMPONENTS

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1. INTRODUCTION

The design and construction of healthy office buildings has become a major challenge for building designers and constructors due to increased number of symptoms and environmental complaints expressed by office workers. The problem of indoor air pollution in office buildings has increased in two ways: new sources of potentially hazardous indoor air pollutants, and the reduced ventilation rates after the energy crisis have increased the accumulation of pollutants in indoor air.

Often the cause of the symptoms and complaints has not been found in spite of thorough measurements of indoor air, although the occupants have often blamed the poor indoor air quality and the ventilation system for their problems. The phenomenon as well as the outcome has been called the sick building syndrome (SBS), tight building syndrome, building illness, building-related illness and stuffy offices.

The paper summarizes some of the research results of the multidiciplinary research group at Helsinki University of Technology on the performance of ventilating and air conditioning systems. The major goal for the research has been to find out how to construct ventilating and air conditioning systems so that they do not as such cause unhealthful conditions or discomfort. Because the laboratory conditions can never simulate the real working environment the research has mainly been conducted in the real buildings.

2. VENTILATION RATES AND TEMPERATURE

Experiment. The first experiment and epidimiologic study was performed in 1985 in the Pasila Office Center (Jaakkola et al 1991), a modern eight storey building with 2150 workers, located in the center of Helsinki.

The building is mechanically ventilated, mainly without recirculation and humidification. The windows are openable. The building is a concrete structure and has exterior walls of brick.

Study design. Baseline data of air handling and heating systems were collected and measurement of airflow, temperature and relative humidity in the office rooms were made in February 1985. After the baseline data collection the ventilation was shut off in one part of the building, reduced in two parts and one part was left unaltered as a reference. A self-administered questionnaire was sent to each worker in February and twice after the change in ventilation in March-April. These inquired symptoms, diseases, environmental complaints, attitudes toward working conditions and health behaviour.

The main outcome, a summation score (range 0-6) was calculated to describe the total amount of symptoms including the six components of SBS nasal, eye, and mucous membrane symptoms, lethargy, skin symptoms and headache. The occurrence of a symptom mostly at work or equally at home and work would add 1 point in the respective component of the summation score.

The relative humidity during the study, in February, was low (10-20%) which reflects the cold winter season. The ventilation rates were in the average large (mean 26 L/s*person) but varied considerably (SD 10 L/s*person, range 7-70 L/s*person). The concentrations of measured indoor air pollutants were far below the values known to cause adverse health effects. The mean carbon dioxide concentration was 420 cm^3/m^3 and did not exceed 950 cm^3/m^3. The concentration of formaldehyde was 47 ug/m^3 in a room with typical furniture, textiles and ventilation rate. The maximum concentrations of organic gases were: ethanole 98 ug/m^3 (mean 73 ug/m^3), hexane 10 ug/m^3 (9 ug/m^3), acetone 33 ug/m^3 (32 ug/m^3) and toluene 165 ug/m^3 (107 ug/m^3).

Temperature. Room temperature was found to be the most important indoor air determinant of the SBS symptoms. The room temperature varied in otherwise very similar rooms due to the lack of individual control of room temperature. This created an exceptional situation for the estimation of the effects of temperature. The variation of the room temperature (21-26°C) was large and the mean temperature was high (23.3°C). There was a linear correlation between increase in both the SBS symptoms and the sensation of dryness and temperature (Table 1). It was also shown that there was an excess of the SBS symptoms both when the temperature was considered too cold and too warm.

Table 1. The adjusted mean SBS-score in office workers in different categories of room temperature (°C) in nonhumidified rooms (February).

Room temperature (°C)	n	adjusted mean SBS-score
<22	30	2.1
22-<23	102	2.5
23-<24	135	2.8
>24	50	3.0

Linear trend by regression $p < 0.05$

Ventilation. During the baseline stage in February the ventilation rates were well above the minimum and no association between airflow rate and SBS symptoms could be seen. There was no association between the room temperature and the ventilation rate. According to our results ventilation rate above 10 L/s*person seems to be sufficient with respect to the SBS symptoms. The ventilation rates were reduced in part of the building, one part remaining as unchanged reference. Results after the change in ventilation show that decrease in ventilation rates increases SBS symptoms. There is an increase of symptoms already when the ventilation decreases below 15 L/s*person (Table 2).

Table 2. The mean SBS-score in office workers in different categories of ventilation rate (April).

Ventilation rate (L/s/person)	n	mean SBS-score
<5	28	2.8 *
5-<10	121	2.6
10-<15	52	2.5
15-	363	2.2

* analysis of variance: $p < 0.05$

Draught. Complaints of draught were also common (Palonen et al 1990). It appeared that sensation of draught cannot be explained only with the air velocity in the rooms. The mean velocities in small offices were only 0,05 m/s and there was no significant difference between rooms. Neither did the supply air flow (L/s per person) correlate with draught complaints. Instead significant factors were room air temperature, relative humidity, sex, and number of exterior surfaces. The results in Table 3 show that draught complaints depended mostly on sex and thermal sensation which of course depended on the air temperature and surface temperatures. The draught complaints were most common in the rooms where air temperature was below 21°C.

Table 3. Percentage of occupants complaining draught depending on their thermal sensation and sex. (n=1250)

Draught complaints	Thermal sensation Too cold	Satisfied	Too warm	Sex Male	Female
No	22	74	81	85	59
Yes	78	26	19	15	41

p=0.0000

Heat recovery. Both regenerative (heat wheel) and recuperative (plate heat exchanger) heat recovery systems are used commenly in Finland. Heat wheels may transfer pollutants to the supply air which may have an adverse effect on health or comfort. Both types of heat recovery systems were used in the Pasila Office Center. Perceived air quality and number of symptoms per occupant recorded in the parts of the building where different heat recovery systems were used showed no significant difference (Table 4).

Table 4. The adjusted SBS-score by heat recovery type.

Type of heat recovery	Symptoms per person	No of employees
Regenerative (heat wheel)	2.60	582
Recuperative (plate heat exchange)	2.67	385

p=0.55

3. HUMIDITY

A sensation of dry air is a common complaint among Finnish office workers. In the first stage of the study in the Pasila Office Center 78% of workers felt the air too dry during the heating period. In the Nordic countries relative humidity indoors usually decreases to 10-20% during the cold winter months. Air humidification is nowadays seldom used to increase the comfort of occupants, although sometimes the humidification is necessary because of the requirements of work processes.

We conducted a six period cross-over trial to evaluate the effect of air humidification on dryness of the skin and mucosa, allergic and asthmatic reactions and the perception of indoor air quality (Reinikainen et al 1991). Our purpose was to use a level of relative humidity which could be both economically and technically feasible in office buildings in Finland. The hypothesis was that proper humidification can alleviate dryness symptoms and a sensation of dryness during the cold winter period when relative indoor air humidity is otherwise low.

Pasila Office Center was chosen for our study, because we knew the building from the previous studies.

The effect of air humidification was studied in a six period cross-over trial. During the baseline period two similar wings were run without air humidification. During the first week, after random selection, one wing of the building (A) was operated with 30-40% air humidification while no air humidification was used in the other wing (B). After each period, during the week-end, the humidified wing was changed. The relative humidity in the nonhumidified wing was determined by natural conditions, mainly by the outdoor temperature and absolute humidity.

During the study period, from January 2 to February 17 1988, the weather in Helsinki was exceptionally warm. January 1988 was third warmest and February the warmest corresponding month of the century. The mean outdoor temperature was -0.3 °C in January and 0.0 °C in February. Due to the warm weather the relative humidity in the nonhumidified spaces was higher than expected, 21-31%. The relative humidity in the humidified spaces was constant at 30-35% during the first three weeks but during the fourth week the relative humidity in the two wings was nearly equal.

The mean of the primary outcome, the dryness symptom score was smaller during the humidified (1.49) than during the reference phase (1.60) and the intraindividual difference (d -0.112, SE(d) 0.049) was statistically significant (paired t-test: $p < 0.05$). All the single symptoms of the score, except nasal dryness, were less frequent during the humidified period, skin and eye symptoms reaching statistical significance ($p < 0.05$).

The mean of the allergic symptom score was also statistically significantly smaller during the humidified phase (1.04) than during the reference phase (1.12) ($p < 0.05$).

No significant difference was observed in the asthma symptom score, although all the symptoms, breathlessness, wheezing and cough were less common during the humidified phase. In all the symptoms breathlessness and wheezing were rare during the study period.

There was no considerable difference in the mean general symptom score including headache, lethargy, weakness and nausea between the two phases. The rare symptom weakness was significantly less frequent during the humidification than during the reference phase.

We found in our cross-over trial that office workers reported less symptoms of skin, and mucosa symptoms of allergic reactions and a sensation of dryness during 30-40% air humidification than during no humidification with a relative humidity of 20-30% defined by natural conditions.

4. AIR RECIRCULATION

Recirculation of air in mechanical ventilation systems is used to control the ventilation and to conserve energy. The magnitude of recirculated air is expressed as a proportion of the total supply air flow. Proportions of recirculated air as high as 80-90% are commonly used in North America. In Finland return air proportions are usually between 30 to 50%. The amount of fresh air intake is also another important parameter when estimating the effects of air recirculation. The Nordic research meeting considered, in 1987, the use of air recirculation as a "risk solution" not recommended for use in public buildings (Lindvall and Sundell 1987). The recommendation was justified by the risk of spreading indoor air pollutants and by experience with poor technology and maintanance of ventilation systems with air recirculation.

We carried out an experimental cross-over study to test the hypothesis that the use of air recirculation in mechanically ventilated office buildings with sufficient intake of fresh air (exceeding the regulatory recommendations) and without any unusual point sources of indoor air pollution causes mucosal irritation, skin and allergic reactions and general symptoms (commonly known as the sick building syndrome) as well as environmental complaints of unpleasant odor, stuffiness or dustiness (Jaakkola et al 1990).

Two identical office buildings in Kilo, 15 km from the center of Helsinki, were selected for the study. The buildings, constructed in 1974, are 8 stories high. The lengths are 72 m, width 18 m and inside volume 35

000 m^3 in each building. The structures are concrete and the windows can be opened. Mechanical ventilation with 30 to 40% of recirculated air during the heating season was normally in use during working hours.

The proportion of recirculated air was designed to be 70% during the experimental period and 0% during the reference period with a constant intake of outdoor air providing for a mean of 6 and 23 L/s/person. No air humidification was used in the buildings. There were 4 one week periods. After each period, during the week-end, the building exposed to recirculated air was changed ("cross-over").

Four outcomes based on the potential health effects were considered and reporting of corresponding symptoms were used in operationalizing the outcomes. 1. **Mucosal irritation score**: dryness, itching or irritation of eyes; nasal dryness; nasal congestion ("stuffy nose"); pharyngeal irritation. 2. **Skin reaction score**: dryness, itching or irritation of skin; rash. 3. **Allergic reaction score**: nasal congestion; nasal excretion ("runny nose"); sneezing; cough; 4. **General symptom score**: headache; lethargy.

The source population included about 470 workers. Workers meeting the following eligibility criteria were recruited for the study population:

1. experience of symptoms and/or environmental complaints, during past 12 months, which were attributed with the work environment or to indoor air quality.
2. working in the assigned room on the average at least 3 days per week.
3. no anticipated absence from work due to vacation, trips or other reasons, during the study period.

There were 78 subjects fulfilling the eligibility criteria and willing to participate in the study.

The use of air circulation did not increase significantly the occurrence of the four health outcomes or reported complaints of unpleasant odor, stuffyness and dustyness. No significant differences in smoking in the office nor opening of the windows were found during the two periods.

5. RESIDENTIAL VENTILATION

The office workers have complained of a similar set of sick building symptoms. There is not much information whether these symptoms are related to the home environment in the occupants of dwellings. Many physical, chemical and biological indoor air factors found in indoor air of dwellings can cause mucosal irritation, allergic and asthmatic reactions and nonspecific central nervous symptoms such as lethargy or headache. The sensation of poor indoor air quality is disturbing and can also indicate an unhealthful environment.

A study of ventilation and indoor climate combined with a questionnare of symptoms and complaints was made in 251 typical Finnish residences during the 1988-1989 heating season (Rönnberg et al 1990). The sample was selected randomly of the buildings in the metropolitan area of Helsinki, and it consisted of 162 residences in detached or semi-detached houses and 89 residences in blocks of flats. The ventilation systems in the sample included natural ventilation (78 recidences), mechanical exhaust (108) and balanced ventilation with mechanical supply and exhaust air (65).

The average air exchange rates were measured during a period of two weeks using an integrating constant tracer flow technique. Miniature permeation tubes are used to create the constant injection of up to three different perfluorocarbon tracer gases. An integrating adsorption sampler measures the average concentration of each tracer. The samplers are analysed in a laboratory using an ECD gaschromatograph.

The average air excange rates had a high variation. The mean value of all the residences was 0.52 1/h. In over half of the residences the value was under 0.5 1/h and in 73 % of the residences the air exchange rate was between 0.2 1/h and 0.7 1/h. The average air exchange rates in the flats was above recommended (building codes) value 0.5 1/h independent on the ventilation system where as in houses the air exchange rates were lower (Fig. 1). The building type with different stack heights may explain for natural ventilation systems the differences in the results. For mechanical systems the differences are partly due to irregular use (or misuse) of the ventilation system in houses. In 46% of the detailed houses which had mechanical ventilation the fans were operated only during cooking or not operated at all. For natural ventilation systems the air exchange rates were slightly lower than for mechanical systems. Allthough the lowest ventilation values appear in natural ventilation systems there were also some quite high air exchange rates among the natural ventilation systems.

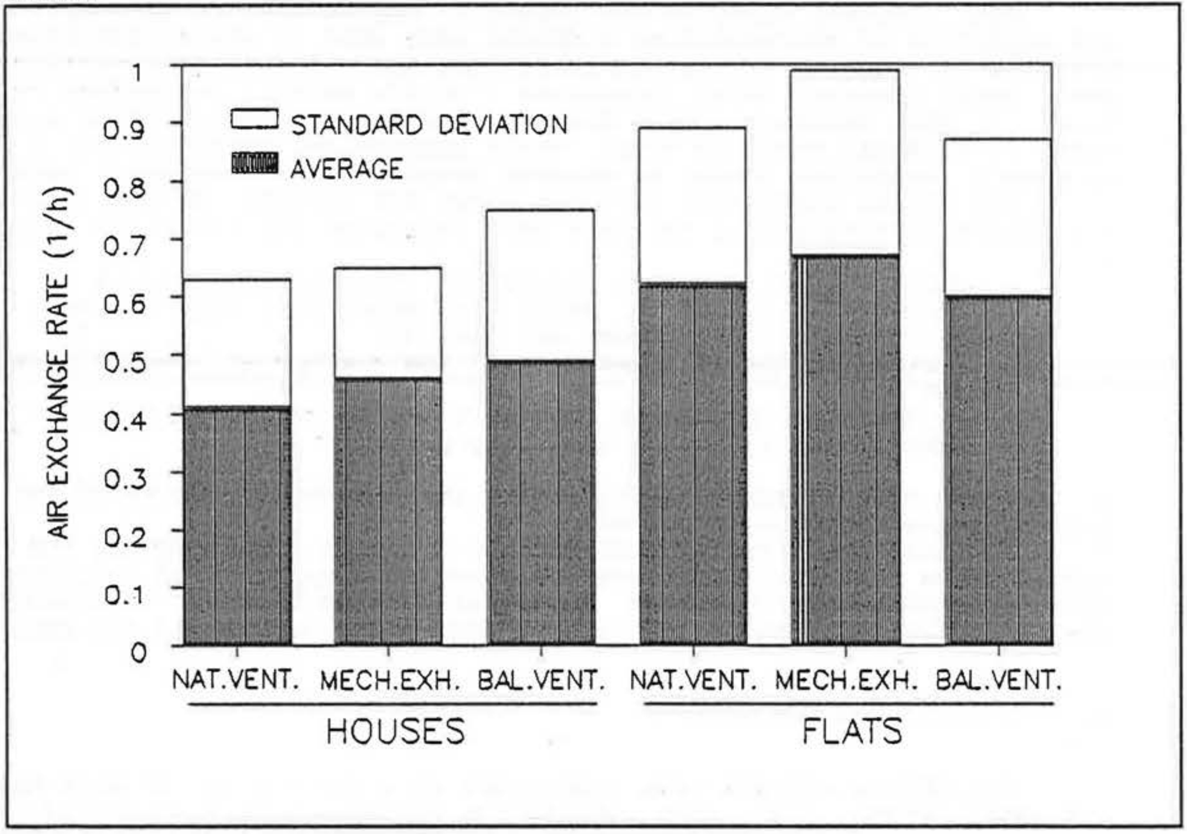

Fig. 1: The average air exchange rates and standard deviations by ventilation systems and building type.

Simultaneously with the measurements of the indoor climate a health survey with a questionnaire was made (Ruotsalainen et al 1990). The study population in the survey consisted of 473 adult occupants (> 15 years), 224 males (47.4 %) and 249 females (52.6 %); the response rate was 93.1 %. The dwellings were categorized into houses (detached and semi-detached) and apartments (in blocks of flats) and within each category according to the ventilation system into buildings with natural ventilation, mechanical exhaust and balanced ventilation.

The presence of the following symptoms during the past 14 days was asked: dryness or itching of skin; dryness, irritation or itching of eyes; nasal congestion ("blocked nose"); nasal dryness; nasal discharge ("runny nose"); sneezing; cough; breathlessness; headache or migraine; and lethargy, weakness or nausea. Another group of outcomes consisted of environmental complaints in the bedrooms including: coldness; warmness; draught; dryness; stuffyness; and sufficiency of air exchange. The period prevalences were defined according to the presence of the symptoms and the complaints.

The symptoms and environmental complaints were systematically more common among the occupants of the apartments than those of the houses. The occupants of the houses with natural ventilation seemed to have more symptoms and complaints than those with balanced ventilation. However, in the apartments with balanced ventilation the occupants reported, in general, more symptoms and complaints than those with natural ventilation. The measurements of indoor air quality in the different type of dwellings did not provide a clear answer for the differences in the occurrence of symptoms and complaints.

The preliminary analysis of the results have not showed any simple relation between measured ventilation rates, symptoms and complaints. This emphasises the complex nature of ventilation and indoor air quality. The association of the occurrence of symptoms and complaints with the type of ventilation system does not necessary indicate that certain type of ventilation system cause adverse effects, because the type of ventilation system is certainly associated with other potential environmental determinants at home. However, in studying the determinants of reactions causing symptoms, the most efficient approach is to concentrate in the environment where the occupants have most problems.

6. ODOR EMISSION OF FILTERS

Until recently the major sources of pollutants were thought to be the outdoor air, building materials, occupants and their activities. However, experiments in eight office buildings (Pejtersen et al. 1989) showed that the air handling system itself can also be a source of pollutants. In the air handling system the dirty filters are suspected of being one of the major sources.

The chief parameters effecting the odor generation of old used filters are not clear. Our hypothesis was that odor generation must depend on the accumulation and the quality of dust on the filter. The hypothesis was tested by measuring the odor generation from filters in buildings in different localities at different operation times.

Ten used filters from office buildings in three types of locations were taken to the laboratory, where their odor generation was measured in controlled conditions in an air handling unit. The filters were taken from buildings in three types of surroundings in respect of air quality: the center of the capital city, Helsinki, a Helsinki suburb and the city of Kuopio (70,000 inhabitants) 500 km north of Helsinki.

Air samples were taken before and after the filter. Outdoor air was used as a reference. The odor of the air samples was evaluated by a trained panel.

The perceived air quality of the outdoor air during all the tests was on average 0.15 decipols. The odor intensity before the filter varied from 0.2 to 1.5 and after the filter from 1.0 to 4.4 on the butanol scale of from one to ten. The average increase in perceived air quality was 2.3 and ranged from 0 to 6.2 decipols. The variation between the filters was high.

Three separate groups of data points can be seen when the perceived air quality is plotted against the total air volume through the filter Fig 2. The highest odor generation was from the filters taken from the buildings in the center of Helsinki. The filters from the Helsinki suburb generated substantially less odor. The filters from Kuopio generated least odor.

The results showed that not only the dust accumulation on the filters but also the location of the building must be considered when determining the replacement period of filters. The odor generation of the filters in the laboratory test was higher than may be expected from the odor of the supply air. This may be due to sorption effects in the air distribution system.

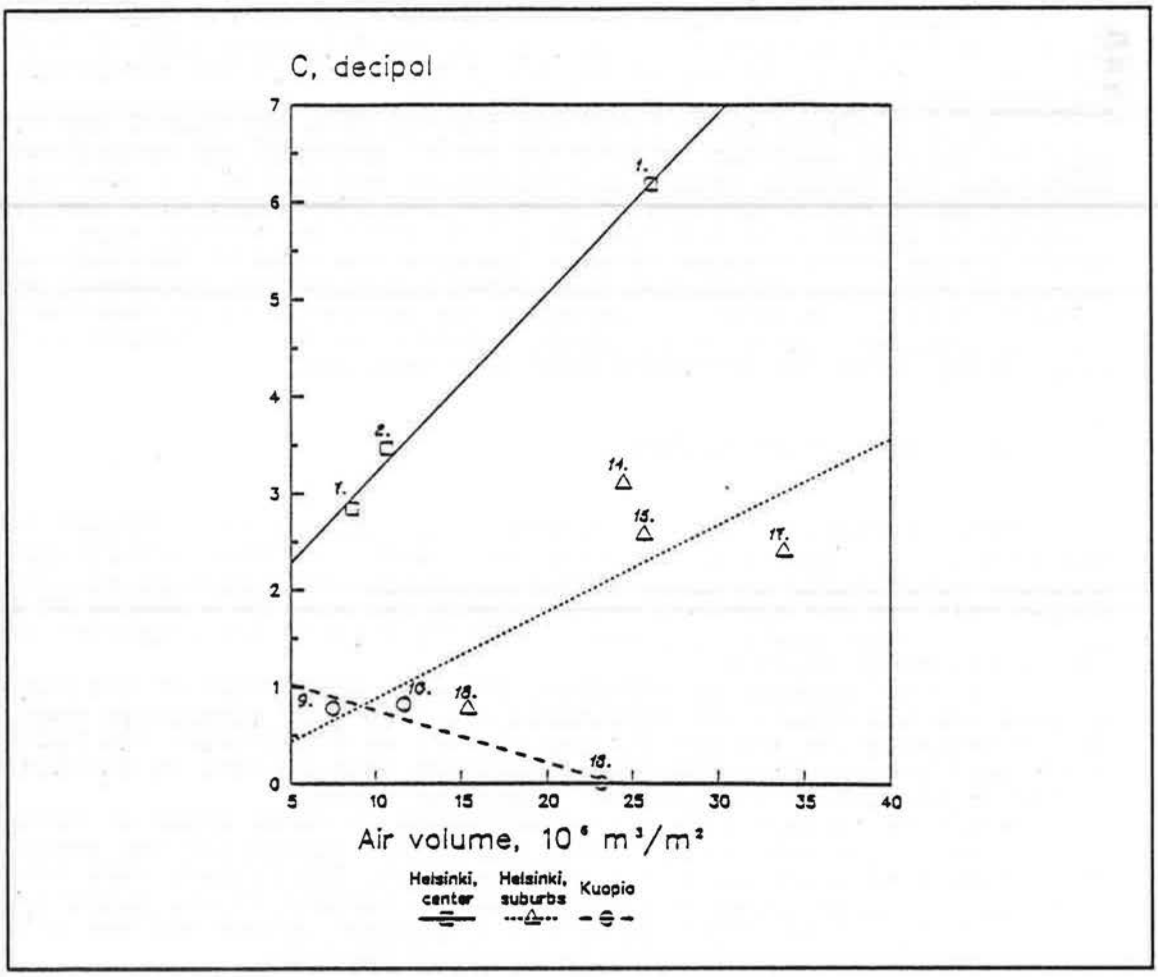

Fig. 2. The increase in perceived air quality caused by dirty filters taken from buildings in three surroundings.

7. FUTURE RESEARCH NEEDS

Based on the research described above and our experience it is known that the prequisite for good indoor air quality is:

- good temperature control of indoor climate
- adequate ventilation
- adequate but not too high relative humidity

It is also known that indoor air quality depends on building related factors not yet fully known. Adequate ventilation is required for good indoor air quality, however, the adequate ventilation rate seems to depend on the building. The reason for this must be caused by the variation of source strength of pollutants and actual performance of ventilation system. Building materials, furniture and interior decoration are obvious sources, but ventilating system itself seems also to be a source. Because of the sources and their behaviour are not known, the dimensioning of air flow rates is arbitrary, and the numeric values are usually based on the experience. On the other hand this leads in some cases to excess ventilation and waste of energy and in other cases to deteriorated air quality due to inadequate ventilation.

The minimum ventilation rates proposed some years ago by IEA (International Energy Agency 1987) were based mainly on the occupants and their activities in the building. The other pollutant sources were widely discussed but no recommendations for the design of ventilation based on these sources were made. A new attempt to rationalize the selection of air flow rates based on perceived air quality was done some years ago (Fanger 1988). The method, which is widely discussed owing to its simplicity, provides the first rationale approximation for the control of the total pollution load in a building in respect of perceived air quality. Research is needed to make the method more accurate and applicable to the various conditions. For this goal the following research program is proposed.

Proposed research program:

Objective criteria for ventilation rates

Objective

The goal of the program is to develop a procedure for selection of ventilation rates based on outdoor air quality and pollutant sources in buildings including ventilating systems, activities and materials in a building.

Sub-projects

1. Hygiene of HVAC-components

It has been shown that components in HVAC-systems can also be pollutant sources. These sources include filters, ductwork, interior lining of ducts (silences etc), fans and their drives and heat exchangers. Research is needed to characterize the sources, to develop test methods and, of course, to manufacture better components.

2. Air cleaning

Cleaning of air becomes more and more important because of exterior and interior pollution of air. It has been shown that traditional fiber filter can be also a source of pollution. New methods are needed not only for filtering of particulate matter but also to remove gaseous pollutants from the air.

3. Modelling of indoor air quality

The simple mass balance models of indoor air quality are not adequate for reliable results. The processes are much more complex. Models should include factors such as variation of source strengths and interaction of pollutants, materials and ventilation. Physical factors such as temperature, pressure and air humidity should be incorporated in the model.

4. The control of pollutant sources

The control of the source strength is important and a large task in itself. However, ventilation can be used to reduce the spread of pollutant from these sources. Research is needed in the areas such as air flows and pollutant transfer in a real building, efficiency of air distribution systems in respect of pollutant control, and local exhausts for the controlling of pollutant sources.

5. Quality assurance

Several studies have shown considerable variation in the performance of ventilation and air conditioning systems. Often they do not perform even in a new building as intended, not even mentioning the performance after years of operation. Quality assurance has to cover the entire building process from design to operation including the whole lifetime of a building. Common European effort is required to develop accepted methods.

REFERENCES

Fanger, P.O., 'The olf and decipol'. ASHRAE Journal, October 1988.

Hujanen, M., Seppänen, O., Pesanen, P., 'Odor emission from the used filters of air handling units'. Healthy Buildings IAQ-91 (submitted) September 1991.

Jaakkola, J.J.K., Reinikainen, L.M., Heinonen, O.P., Majanen, A. and Seppänen, O., 'Indoor air quality requirements for healthy office buildings: recommendations based on an epidemiologic study'. Environment International 1991 (in press)

Jaakkola, J.J.K., Miettinen, O.S., Komulainen, K., Tuomaala, P., Seppänen, O., 'The effect of air recirculation on symptoms and environmental complaints in office workers. A double-blind, four period cross-over study'. Indoor Air '90 Toronto Canada 29.7.-3.8.1990. **Vol 1** pp. 281-286.

International Energy Agency, Energy Conservation in Buildings and Community Systems Programme, 'Annex IX, Minimum ventilation rates, final report of working phases I and II' November 1987.

Lindvall, T., Sundell, J., (1987) 'Healthy building - conclusions and recommendations' (in Swedish). Det Sunda Huset (ed. Davidowicz, N. et al) Building Research Council, Stockholm.

Palonen, J., Seppänen, O., 'Design criteria for central ventilation and air-conditioning system of offices in cold climate'. Indoor Air '90, Toronto Canada 29.7.-3.8.1990. **Vol 4**, pp. 299-304

Pejtersen, J., Bluyssen, P.M., Kondo, H., Clausen, G. and Fanger, P.O., (1989) 'Air pollution sources in ventilation systems'. Proceedings of CLIMA 2000 conference, Sarajevo, **Vol 3**, pp. 139-144

Reinikainen, L.M., Jaakkola, J.J.K., Seppänen, O., 'The effect of air humidification on symptoms and perception of indoor air quality in office workers. A six period cross-over trial'. Indoor Air '90 Toronto Canada 29.7.-3.8.1990. **Vol 1** pp. 775-780.

Ruotsalainen, R., Rönnberg, R., Majanen, A., Seppänen, O., 'Symptoms and environmental complaints in occupants of houses and apartments with different ventilation systems'. Indoor Air '90 Toronto Canada 29.7.-3.8.1990. **Vol 1**, pp. 525-530.

Rönnberg r., Ruotsalainen, R., Säteri. J., Majanen, A., Seppänen, O., 'Indoor climate and the performance of ventilation in 251 residences'. Indoor Air '90 Toronto Canada 29.7.-3.8.1990. **Vol 4** pp. 269-274.

Session 6 : The Mechanical Systems and Components

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AIR CONDITIONERS AND FAN-COIL UNITS

ABSTRACT

Air conditioners provide comfort and clean air to the enclosed environment and are therefore the most important means to achieve the proper indoor air quality. Equipment must be correctly designed, properly sized, with properly matched components, properly applied, correctly installed and properly maintained. If some of these actions are not carried out in a satisfying way, the equipment itself can become the source of the indoor air quality problems. It is therefore necessary to undertake an investigation of various factors able to produce these problems; research topics cover design, materials, ageing and maintenance of air conditioners and fan coil units.

1. INTRODUCTION

Using a mechanical system for ventilation or air conditioning is an obvious way to control indoor air quality. Ventilation remove pollutants from the air by dilution or using filters or air washers and, when combined with source control, is considered as the best available technique.

However, ventilation can introduce new problems which would not exist without forced air movement. Pollutants may concentrate on some places, they may propagate or redistribute increasing health hasards or simply hygiene.

The equipment itself can become the source of the indoor air quality problems. It must be correctly designed, properly sized, with properly matched components, properly applied, correctly installed and properly maintained. This list of "correct" and "proper" actions is rather long and not at all obvious. Other parameters must be also included such as operating performance, sound generation and naturally the cost of the system.

Many potential problems can be avoided applying knowledge already existing but for some of them research must be carried out in order to find a reasonable solution.

In this paper, air conditioners and fan-coil units, equipment more and more used in Europe will be considered. Only problems arising directly from this equipment will be examined as the general problems related to air conditioning systems including ductwork, filtration, humidification or heat exchangers will be considered elsewhere.

2. AIR CONDITIONERS AND FAN-COIL UNITS

2.1. Air conditioning

Air conditioning is the general term used to designate the ventilation system built in order to satisfy the comfort requirements of the occupants of a given space. It includes heating, cooling, ventilation, humidification, dehumidification and filtration.

2.2. Air conditioners

An air conditioner is a factory made encased assembly or assemblies designed as a unit to provide conditioned air to an enclosed space. It includes an electrically operated refrigeration system for cooling and possible dehumidifying the air. It may have means for heating, circulating, cleaning and humidifying the air.

When such units are intended for use in relatively small places, they are often called room air conditioners. Their capacity is then generally under 10 kW and they deliver air freely without any ducting. Much larger units are used to supply the cold air to a number of rooms through a duct system: in this case the system is very similar to full air conditioning installation.

Air conditioners are more and more used in Europe for homes, small office buildings and retail stores. The European market has been estimated at more than 700,000 units and previsions for future are very optimistic.

In the United States, 4 million small room air conditioners and 4 million larger units are installed every year.

2.3. Fan-coil Units

Fan-coil units are used for cooling and heating air with an appropriate medium, most often water. They may be of the cabinet style within a room for free air delivery or concealed within the building structure with a short ducting connected to an outlet. The principal components are:

- one or more heat exchangers,
- one or more fans with electric motors,
- condensate collecting facilities,
- air filters,
- controls,
- an appropriate enclosure.

Fan-coil units are popular and relatively cheap systems very much used in Europe. The European market has been estimated at more than a half million units installed every year.

3. PRODUCT DEVELOPMENT

In Europe, air conditioning still has a relatively bad image as a consequence of some real or supposed problems produced by such systems. However, the market has been strongly increasing in the last several years caused by several factors:

a) better thermal comfort has been more and more required even if cooling is generally needed only during a few weeks in the summer,

b) employees' productivity is strongly increased if the environment is controlled and the cost of air conditioning becomes more acceptable for company's management,

c) marketing and promotion by electricity producers are pushed very much in some countries in order to increase electricity consumption in summer time,

d) In theory, indoor air quality problems may be solved by air conditioning as all parameters (flow-rate, temperature, humidity, cleanliness of air) are controlled.

In the more competitive market, the manufacturers are obliged to develop better equipment. Progress has been made with more or less success on different aspects. For air conditioners and fan-coil units, the principal development concerns: efficiency, sound control and indoor air quality and comfort aspects.

To increase the efficiency, better and more efficient heat exchangers have been developed. They have to be matched correctly with fans and the combination fan-exchanger has in turn a very strong effect on sound generation. The sound is a very important parameter in selection of equipment. For some applications, the sound power is even the principal parameter used for selection (if cost is naturally not considered). The problem for designers is not easy because there are different possibilities to build this rather compact equipment.

Fan system effect is still not very well known and the development must involve important experimental checkings and verification. There is still a large possibility to improve this equipment.

For instance, we recently tested ten fan-coils of comparable size produced by ten different manufacturers. For a given cooling capacity, the sound power generated by different units were very different - up to 10 dBA difference between the most noisy and the most silent unit.

Controls are one of the important aspects under development. The users must be allowed to select proper operation of the unit in accordance with their needs. Electronics is widely used but the design becomes complicated as the unit should operate correctly and efficiently under very different conditions.

Up to now, indoor air quality aspects concerned mostly thermal comfort. Cold air should be distributed throughout the room without draught; the problem is not simple as there is a very strong influence of the environment. Other problems as dirt or odour have not been usually taken into account - normal practice is to consider that there is no problems related to the equipment.

4. ELIMINATION OF INDOOR AIR QUALITY PROBLEMS

4.1. Problems

Air conditioning may generate a number of indoor air quality problems. They concern mostly general problems of recirculation, filtration, humidification, condensation and dirt accumulation in the systems. These general problems have been considered elsewhere during this workshop; here only terminal equipment such as room air conditioners and fan- coil units will be treated.

A room air conditioner or a fan-coil unit are installed directly in the room with human occupancy and are therefore highly visible. Following problems can be easily identified:

a) excessive noise and/or vibration,

b) excessive air velocity producing draught problems,

c) aerosol introduced in the respirable air often consisting of fibrous materials from carpets and curtains,

d) odours, generated by the dust fixed into the equipment and often connected to stagnant water, product of condensation.

The first two of these problems are not strictly speaking related to the indoor air quality; however, it must be pointed out that the equipment should be considered as a whole and when solving one problem, it is necessary not to generate another.

4.2. Solutions

Many problems related to equipment may be solved within the present state of art. Following procedure should be used:

a) Design. Elimination of product related indoor air quality problems should be included in the first stage of design together with considerations on efficiency, sound or control. Properly designed equipment will have little or not at all indoor air quality problems.

b) Sizing. By correct selection of the equipment , a number of problems can be avoided. Unfortunately, the correct information is often missing. It is now generally agreed that the majority of catalogues present deformed characteristics of equipment. Claimed capacity is easily 30% higher than in reality and sound data are not at all reliable. These uncertainties are more or less taken into account by consultant engineers and system designers and selected units are therefore, often rather badly sized for given application.

European manufacturers through EUROVENT organisations are presently trying to set-up a Certification Programme for air conditioners and fan-coil units. The essential feature of this programme will be third party checking of values given in catalogues. Very active promotion of the system is in preparation and strong penalties for dishonest claims will be applied.

c) Component matching. Correct selection of components include their mutual interaction which in general is not very well known. As already indicated, fan system effect may be very important and more fundamental information is needed in this field.

d) Application. Design may be correct but if not applied correctly, the equipment can have a number of problems. Quality assurance system is an important tool used in order to avoid these problems. There is a general trend in the world and particularly in Europe to introduce and generalize the use of the quality assurance schemes, essentially based on the international standard ISO 9000.

e) Installation. The equipment may be installed in different manners and there is often a possibility to avoid problems using a correct installation. For instance, current indoor air quality problems is generated if return air opening of fan-coil unit is placed too close to the floor: dust and fibres from carpets are easily introduced in the unit.

f) Maintenance. Accessibility for inspection and maintenance should be part of design criteria. Regular changing of filters and cleaning of heat exchangers and condensate collecting tray may avoid most of the problems. However, only in relatively large organisations the maintenance will be organised. It is therefore important to try to avoid problems without requiring a regular maintenance.

5. NEED FOR RESEARCH

Air conditioners and fan-coil units must be:

- correctly designed,
- properly sized,
- with properly matched components,
- properly applied,
- correctly installed,
- properly maintained.

If some of these actions are not carried out in a satisfactory way, the equipment itself can become the source of the indoor air quality problems.

At the present state of art, it is generally possible to satisfy a majority of above requirements However, more fundamental research is needed in order to supply more information concerning behaviour of some important components. Following topics of research would be interesting:

Filter performance characteristics must be better defined. This include fractional efficiency (a test method should be able to determine the efficiency for each particle size), the filter performance at variable air volume conditions, influence of air leakage on filter frames, dust holding capacity and so on. Air filters are an essential component of air conditioning systems and their behaviour must be perfectly understood and known.

Adherence of dust on surfaces should be better understood in order to avoid or at least delay the accumulation of dirt in some places. A practical guideline for component design should be a final goal of such research work.

Air diffusion in a single room together with pollutant distribution including problems of stratification is still one of the essential topics where more knowledge is needed. Supply grills of air conditioners and fan-coil units should be designed in a way to insure proper air diffusion in the whole occupied zone. Unfortunately, this is done entirely in an empirical manner, clear design guidelines are still missing.

Mixing sections in some units allow supply of fresh air and in theory, insure the proper indoor air quality. Unfortunately, various dampers used for this control do not operate correctly and real conditions may be far from design values. Systematic study of dampers and air velocity distribution in mixing section would be highly appreciated; a practical guideline is needed.

ELIMINATION OF PRODUCT RELATED INDOOR AIR QUALITY PROBLEMS

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1. ABSTRACT: ELIMINATION OF PRODUCT RELATED INDOOR AIR QUALITY PROBLEMS

Indoor air has recently been a favourite among scientists. The research has even been succesful: our knowledge of the problems has increased remarkably.

Less attention has been payed on solving the problems. The progress in the knowledge has generated less progress in technology.

It has been claimed - and some evidence has been presented - that a ventilation system itself may be a source of IAQ-problems. Little has been done to analyze the problems, to indentify potential sources, and to eliminate them. E.g. guidelines of hygienic requirements are almost totally lacking.

In this paper are presented the first attempts to solve the problem. A Finnish project aiming to produce hygienic guidelines for ductwork is described. Also the first draft of a state of art report of product related IAQ-problems produced by Eurovent WG 12 is presented. The latter considers all components of ventilation system.

The European industry has recognized a gap between science and practice. The successful research has lead to few improvments in components and systems. It is suggested that an European project participated both by the industry and the scientists aiming to eliminate the product related IAQ-problems is started.

2. REGULATIONS AND STANDARDS

We have very strict and detailed regulations and standards considering what we eat or drink. The hygienic requirements for manufacturing, transport, stocking and sales of food and beverages are numerous, detailed and strict.

Very little care is taken of what we breath. Except rules for eliminations of legionella bacteria there are not standards or regulations for general hygiene and cleanliness of ventilation systems. My question is: is elmination of legionellas enough to quarantee the proper hygienic level of ventilation systems?

In the final (?) draft of the interpretative document "Hygiene health and the environment" of council directive for construction products (3) is said:

"I. GENERAL HYGIENE AND CLEANLINESS

1.2. Control of general hygiene and cleanliness

Unfavourable conditions may arise from:
- conditions that impair the normal cleaning and maintenance
- accumalation of dirt on surfaces
- inadequate measures for the disposal of waste or refuse.

Hygienic conditions may be controlled through:
- appropriate cleaning and maintenance programmes
- appropriate design of works and construction products, by providing easy access and operational conditions for cleaning activities and maintenance.

1.3. Technical specifications for construction products (cat B)

Harmonized tehcnical specifactions are required to cover the ability of construction products to provide easy access and operational conditions for cleaning activities and maintenance. Products for the lining of pavemtns, the construction of floors, and the inner surface of kitchens and toilets are concerned. Also building services such as ventilation systems where access for cleaning and maintenance is important.

Product characteristics are:

- chemical and mechanical resistance to normal cleaning
- resistance to climatic conditions (temperature, humidity)
- resistance to abrasion
- resistance to shock
- shape
- evenness
- dust adsorption, taking also account of static electricity if necessary
- moisture absorption.

Specifications are also required for products which must be kept clean at all times, such as those for food storage, preparation and cooking, products for toilets activities, excreta disposal and refuse disposal.

Product characteristics are:

- shape and size to facilitate cleaning
- hydraulic behaviour
- porosity. "

The listed standards might give a good base for remarkarble improvements in the hygienic level of ventilation systems. Unfortunately such standards cannot be prepared because the whole scientific base is lacking. Resistance to cleaning, climatic conditions, abrasion and shock may be specified in form of exact figures, but influences of shape and evennes as well as tendency to dust adsorption and moisture absorption are very poorly known.

3. PROJECT "HYGIENIC REQUIREMENTS FOR DUCTWORK"

A research project in order to develop design and installation guidelines and rules to cover the ability of ventilation system to provide easy access and satisfactory condition for cleaning and service was started year 1989 in Finland by Association of Manufacturers and Association of Cleaning and Service Companies.

Guidelines for the design of systems and components in order to decrease risk of dust accumulation, condensation, leakages etc. were decided to include in the project.

Relevant literature was studied and all available practical experience was obtained from cleaning companies. A draft standard to be circulated for comments was produced. The contents of the standard is enclosed.

At a very early stage of the work was observed that only rough qualitative recommendations may be considered. Any method e.g. to specify the quality level of and individual construction or compare two alternative constructions does not exist.

In figure 1 are presented alternative constructions of a 90° bend. Quite obviously number 1 is best because of its circular form and smooth surfaces. Cleaning the corners and guide vanes of number 4 is difficult and the risk of depostis is obviously much greater in alternative 4 than in alternative 1.

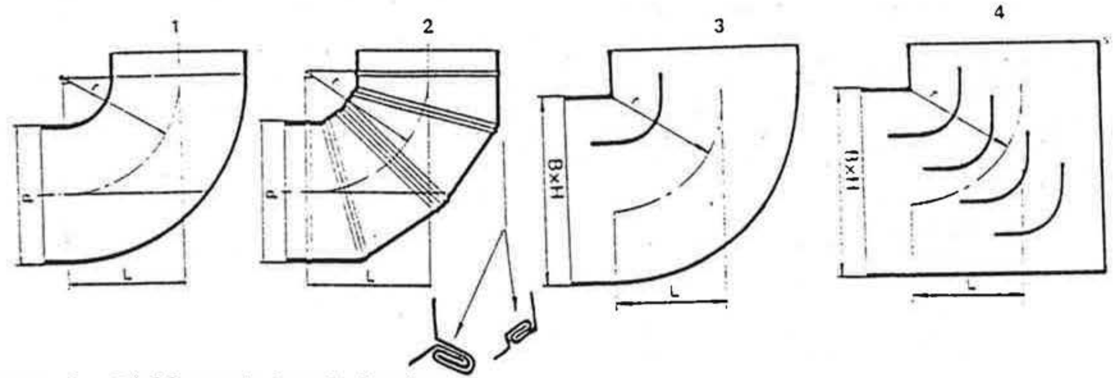

Figure 1. Different bend designs

Even in the most simple case of figure 1 we have no method to evaluate these alternative construciotns. We cannot even say, if alternative 4 is acceptable or not. Its recommended in many handbooks on base of low pressure loss. The cleaning presonnel has found that in practice they are often totally clogged, and they recommend prohibition of this alternative. It is, in addition, very difficult to clean.

The evaluation in this project was based on practical experience and common sense. The guidelines of good and not acceptabe practice (4) are given quite indefinitely and for quite evident cases only. The most important conclusion is that we need better methods to evaluate and test the risk of deposites in different components, constructions and practices.

4. EUROVENT-PROJECT "ELIMINATION OF PRODUCT RELATED INDOOR AIR QUALITY PROBLEMS"

Eurovent WG12, Indoor Air Quality, started the project in the beginning of the year 1990. Studies of relevant literature gave very little result. Problems are discussed and identified to some extent. The real origine of the problems is very poorly known and almost nothing is said of elimination of the identified problems.

However, it was decided to produce a state-of-art report of all Eurovent-products covering more than 90 % of components used in general ventilation. The work was devided among 7 authors, everyone specialized in a certain group of prodcuts.

The general feeling of the authors was again that very little exact scientific knowledge of the elimination of the potential problems is available. Rough guidelines are given for different products, but instead of research and tests, they are based on practical experience and common sense. Exact design methods, methods of evaluating and comparing constructions and - perhaps the most important one - methods of testing, are totally lacking.

Draft reports of components or groups of components were produced by nominated experts as follows:

Air handling units	Mr. Rodrigue
Air distribution	Mr. Railio
Filters	Mr. Macdonald
Humidifiers	Mr. Norell
Room and unitary air conditioners, fan coils	Mr. Roth
Cooling towers	Mr. Mager
Summary	Mr Becirspahic.

The draft reports we studied and critizized by the whole Eurovent working group 12, Indoor Air Quality. It was decided that Eurovent Technical Secretariat will prepare as an extract of the draft reports a state-of-art report "Elimination of product related indoor air quality probelms" (5), which has recently been circulated among group members for critics and proposals for revisions.

In addition, it was decided that for every product group will be developed a more detailed report in co-operation with relevant Eurovent working groups. This work has not started for the present.

The summary report gives, to some extent, even guidelines for practical design. In addition to what is listed in item 2 of this report, following common methods for control of hygiene and cleanliness are reported:

- improvment of filter efficiency
- elimination of filter by pass leakage
- avoiding condensation in cooling coils, especially in fan coil units
- protection of equipment during installation
- avoiding certain constructions, e.g. concrete and masonry ducts because of rough surfaces
- location of air intakes
- pressure relations in heat recovery units
- strategy of running a system, e.g. avoiding to close the system for nights and weekends

etc.

However, the general opinion in the group was that we have no methods to estimate the risks of component or system designs, or to compare two alternative designs. We have no test methods and no theoretical base to relate results of existing tests to this problem. E.g. pressure losses of alternative designs quite obviously indicate also tendency to dust deposits, but we do not know the relations. We have no grounds to evaluate on which stage of pollution a ventilation system should be cleaned and no grounds to rate the result of cleaning either. The influence of surface roughness on dust adsorption, cleaning job and result of cleaning is not very well known.

In addition to technical points of view, even economical grounds are quite poorly known. E.g. costs of increased filter efficiency and, on the other hand, cost reductions due to decreased cleaning costs of ventilation system and the rooms it serves, has not been studied. A Swedish research (6) gives good reasons to believe that the rise and reductions of costs are, at least, in balance.

5. PROPOSALS FOR RESEARCH PROJECTS

It is quite obvious that our knowledge of the sanitation of ventilation systems is very limited. Merely the realization of the essential requirements of construction products directive is not possible without research work.

Many of the gaps in our knowledge is mentioned before. I have priorized the numerous potential subjects from the point of view of the industry as follows:

A. Development of a test method for the tendency of components to accumulate dirt on surfaces in order to cmpare different products and constructions. Reasonable costs and testing period are presupposed. The method should be verified with field studies in systems polluted in "natural" way.
Exact scientific truth may probably not be achieved. The degree of accuracy is not very relevant. Maybe +/- 50 % might be enough for practical purposes. Even this level of accurace might help the industry to improve its products remarkably.

B. A research of the correlation of other product characteristics to the tendency of dirt accumulation. Potential indicators:
   - pressure loss
   - friction factor
   - surface roughness.

C. A research of the indicators to determine intervals for cleaning a ventilation system. E.g.
   - reduction of volume flow
   - increase of pressure loss of critical components.

REFERENCES:

1. *P.O. Fanger, J. Lauridsen, P. Bluyssen and C. Clausen: Air pollution sources in offices and assembly halls, quantified by the olf unit. Energey and Buildings, 12 (1988), 7-19*
2. *P.O. Fanger: Introduction of the olf and the decipol units to quantify air pollution perceived by humans indoors and outdoors. Energy and Buildings, 12 (1988), 1-6*
3. *Commission of the European Communites, technical committee essential requirements: Document TC3/018, Hygiene, Health and Environment, Brussels, 6 March 1991*
4. *Association of Finnish Air Handling Equipment Manufacturers: Ductwork, qualification for cleaning and fire safety. Draft report, Helsinki 1991*
5. *Eurovent WG12: Elimination of product related indoor air quality problems. Draft B, Paris 1991.*

APPENDIX

QUALIFICATION FOR CLEANING ADN FIRE SAFETY
SUMMARY

1. FIELD OF APPLICATION

2. QUANTITIES AND SYMBOLS

3. CONSTRUCTION AND DESIGN
  - *Construction methods to prevent the accumulation of dirt*
  - *Recommended, acceptabe and rejectable construction details*
  - *Consideration of cleaning in design and constructions*

4. QUALIFICATION OF DUCTS AND FITTINGS
  - *Standard sizes*
  - *Sheet thicknesses*
  - *Fire, sound and heat insulation. Protection of insulated surfaces*
  - *Consideration of cleaning*

5. SPECIAL MATERIALS AND STRUCTURES
  - *Flexible ducts*
  - *Plastics and other non-metallic materials*

6. HANGERS AND SUPPORTS
  - *Strength*
  - *Maximum spacing*
  - *Fire protection*

7. ACCESS OPENINGS AND REMOVABLE FITTINGS
  - *Minimum sizes for different duct dimensions*
  - *Location in ductwork*
  - *Construction, fire protection, removing and refixing*
  - *Space reservations for cleaning*
  - *Safety at work*
  - *Access openings for special equipment (e.g. fire dampers)*
  - *Removable fittings*

8. TERMINAL DEVICES AND OTHER ADDITIONAL EQUIPMENT
  - *Consideration of cleaning*
  - *Service, space reservations*
  - *Removing and refixing*
  - *Electric installation*
  - *Terminal boxes (convectors etc)*
  - *Silencers, heating and cooling coils, filters etc.*

9. DUCTWORK FOR SPECIAL SPACES
  - *Professional kitchens and grilles*
  - *Paintshops*
  - *Industrial and process-like spaces*

10. DUCTWORK COMBINED WITH BUILDING CONSTRUCTION
  - *Hollow slabs*
  - *Counter ceilings and floors*

IMPACT OF AIR FILTERS, HEAT EXCHANGERS, HUMIDIFIERS AND MIXING SECTIONS ON INDOOR AIR QUALITY

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ABSTRACT

Air filters, by controlling the level of particulate contamination, can improve indoor air quality (IAQ), yet the benefits of high efficiency filtration are not fully understood. Research studies are needed to quantify the benefits. Heat exchangers and humidifiers on the other hand are more normally associated with problems for IAQ, so work is required to establish how these problems can be overcome. Much research is currently being focussed on minimum outdoor air ventilation rates, yet no attention is being paid to the device that directly regulates this - the mixing section. The author doubts the effectiveness of mixing sections and feels that there is a very real need to research their performance so that guidelines can be produced and standards drawn up.

INTRODUCTION

This paper concerns itself with the effect on indoor air quality (IAQ) of some of the components within heating or airconditioning units, specifically filters, heat exchangers, humidifiers and that relatively neglected item - the mixing section. All these, to a greater or lesser extent, have the potential for affecting IAQ in both positive and negative ways.

Heat exchangers and humidifers provide the means by which comfort conditions can be maintained through heating, cooling, humidifying or dehumidifying the air. However, they do also have the potential for introducing infection and odours. The positive effects - the influence of temperature and humidity - are well researched, and the negative side too has seen much research attention. But the impact of air filtration on IAQ, the positive impact in particular, has been little considered, so therefore air filters will be dealt with first.

AIR FILTERS

Air filters typically are specified and selected not from any considerations for IAQ, but to protect the heat exchangers and fans of the heating or air conditioning units. The filters are only expected to remove from the incoming air the fibres and large dirt particles which cause rapid clogging of the equipment so the efficiency required of them is therefore low. The considerable benefits offered by high efficiency filters too often are completely ignored.

Filters of higher grades can remove pollens and other allergens which may be present in the air. They can intercept and catch bacteria, even viruses, and they can take out irritants such as tobacco smoke. Carbon filters will remove odours and the chemicals, solvents, etc. given off by the building fabric, the furnishings and the internal equipment.

However, better quality filtration has an economic penalty in terms of greater initial cost, greater operating cost due to the increased resistance of high efficiency filters absorbing more fan power, and greater replacement cost since high efficiency filters are inevitably more expensive to buy than low efficiency filters. So for economic reasons the very positive benefits that good air filtration contributes towards IAQ are more often than not ignored.

Filters can also make a negative contribution to IAQ, even though this is minimal compared with the positive benefits.

Capturing bacteria and viruses leads to a potential concentration of these organisms in the one place. However, conditions within an air filter are not conducive to their multiplication or indeed survival, so under all normal circumstances there is no risk posed to health. Work on this, though, is needed, particularly since the interpretative document covering the 'Essential Requirements of Hygiene, Health and the Environment' within the E.E.C's Construction Products Directive refers to a product characteristic of air filters as being their 'susceptibility to the growth of harmful organisms'.

Pocket filters - whose media is normally composed of ultra-fine fibres bonded together, can suffer to a certain very limited extent from the shedding of fibres (normally only when the filter is new). Studies, though, have indicated that there is no risk to health from the inhalation of these fibres.

Once filters start collecting dirt and dust they become a source of odours. Studies are currently being conducted in Denmark on this aspect, including the odour potential of new filters. But particularly in the case of filters which are in service, it is not possible to prevent odour emission, it can only be limited by timely replacement.

Most important of all, filters are percentage devices: they will all let some dirt particles through, the higher the efficiency the less that will penetrate them. Over a period of time this dirt will build up within the ducting, etc. downstream of the filters and also lead to staining of the decor. The lower the overall filtration efficiency the quicker the build-up, something which should be taken into account when considering the impact of contaminated ducting and equipment on IAQ.

The cost of cleaning contaminated ducting and equipment is substantial, assuming that it is in fact possible in the first place. So purely from an economic viewpoint, let alone from a health viewpoint, there are benefits to be gained from higher filtration standards. Little research has been conducted on the effect of filtration standards on economy, hygiene and health, so there is much scope for work here.

HEAT EXCHANGERS

The type and application of a heat exchanger greatly affects its potential, if any, for contributing towards IAQ problems, apart from those connected with poor control of temperature and humidity, which purely affect physical comfort. The three main categories of heat exchanger within heating or air conditioning units are heating coils, cooling coils and heat recovery units.

Heating Coils

The only potential problem with heating coils is that of odours. These are caused by dirt build-up on the surfaces of the heat exchanger and to some extent are influenced by the temperature of the heating medium, i.e. electric coils or coils using steam as the heating medium tend to give off more odours than hot water coils. Filters upstream of the heat exchangers help limit the rate of dirt build-up and hence help to reduce the problem.

Coils should be regularly cleaned by brushing or vacuuming to help minimise any production of odours, but regrettably access to do this is not always provided.

Cooling Coils

The finned surfaces and drain trays of cooling coils that dehumidify can become covered with bacterial slime. This can be particularly a problem with water left lying in drain trays.

All drain trays should therefore be sloped to prevent stagnant water and sufficient access should be made available for cleaning and disinfecting the coil and its drain tray. The latter should either be removable or completely accessible for cleaning. In addition, drain trays should be protected against corrosion or better still, made from corrosion free material e.g., stainless steel, because corroded surfaces are impossible to clean completely.

Attention should also be given to the arrangements for trapping the condensate drain from the cooling coil. If this is inadequate, or incorrectly designed, it is possible for an aerosol of infected droplets to be distributed into the airstream.

Heat Recovery Units

Devices such as thermal wheels and plate heat exchangers have to be applied with care if for health or hygienic reasons cross-contamination between air streams has to be avoided. They cross-connect between the exhaust and supply airstreams, so air leakage, which is almost inevitable, must always be designed to be from the clean to the contaminated airstream.

This can be achieved by balancing the pressures of the two airstreams, arranging that the clean air side of the heat recovery unit is always at a higher pressure relative to the contaminated side. This is particularly important in the case of thermal wheels, as considerable air leakage does occur; indeed it is normal to deliberately purge the wheel to reduce cross-contamination. Studies have demonstrated that when thermal wheels are properly applied the carryover from the exhaust to the supply airstream is less than 0.05% and more importantly, that there is no bacterial contamination.

HUMIDIFIERS

A considerable amount of attention has been paid, particularly by the medical profession, to the illnesses which are associated with humidifiers. In fact the list of references, if quoted, would be almost as long as this paper, hence the reason for not listing references.

The main problem associated with humidifiers is so called 'humidifier fever', a respiratory illness caused by inhaling water droplets contaminated with organisms. Precisely which organisms are responsible has yet to be authoritatively identified, investigations having linked humidifier fever to a whole variety of them. Humidifiers have also been linked with allergies such as asthma, but not, as far as is known, Legionnaires Disease.

There are various types of humidifier, not all of which involve the same risk of infection.

Spray humidifiers and spinning disc humidifiers introduce a spray of droplets into the airstream, therefore there is risk of infection. Cases of humidifier fever have been associated with both types, especially when water is recirculated by taking it from a sump in the base of the unit. A more recent variation on this theme is the use of compressed air or ultrasonic atomisation to produce much finer droplets. Water may be supplied from mains or a tank and no cases are known to have been attributed so far to these types. However, this could be due to the comparative lack of installations.

Cold water evaporators which rely on water being trickled over porous or fibrous elements have not been associated with humidifier fever, although they have been shown to be capable of releasing organisms.

The only totally safe type would appear to be steam injection humidifiers, but there are still potential problems from the release of feed water treatment chemicals into the airstream and of odours.

Whilst there has been a great deal of research work identifying the problems caused by humidifiers there does not appear to be any research into how these problems can be overcome. Humidification is essential for many applications e.g. control of humidity levels within hospital operating theatres in order to minimise static electricity which can cause explosions/fires, control of humidity in art galleries and museums to protect paintings, costumes and books. It is therefore important that research attention be given to how the drawbacks can be overcome.

MIXING SECTIONS

The item of equipment I would particularly like to concentrate on is the mixing section. This is where, in the case of recirculated air systems, the extract air is combined with outdoor air to provide maximum energy recovery consistent with maintaining adequate outdoor air ventilation rates. The mixing section controls the relative amounts of outdoor air and recirculated air, ensures that the two airstreams are thoroughly mixed so that stratification does not occur and provides an even velocity profile downstream across the duct section. Or does it?

In my experience, mixing sections do not perform any of these three objectives in a satisfactory manner. A recent pilot study conducted in Britain by BISRIA has served to confirm this view.

The main problem is with the characteristics of the actual dampers. These dampers, if mounted within air handling unit mixing sections, typically operate at velocities in the range 3-5 m/s when fully open. This range is far too low for effective control or for effective authority, with the result that the relationship between angular opening position and percentage volumetric flow is anything but linear. As figure 1 indicates, there is a disproportionately large increase in flowrate as the damper begins to open, and at the other extreme, towards the end of its travel there is little change.

Figure 2 shows a typical air handling unit with mixing section. It is normal to mount the outdoor air damper on the front or side of the mixing section, and the recirculation damper on top. This, however, can lead to stratification, as cold, denser air coming through the outdoor air damper can drop to the bottom of the section without mixing. Heat exchangers downstream can freeze as a result.

There is always great pressure to make an air handling unit as short as possible, not just from commercial considerations (shorter = cheaper) but more often due to limited space in plantrooms. The mixing box is therefore shortened, and hence problems with high velocity spots can occur, with detrimental effect on the components immediately downstream, such as air filters and heat exchangers, e.g. high velocities or turbulence can lead to filters breaking up and shedding fibres down the duct, into the room, which is not conducive to good IAQ!

The way the air handling unit is connected with the system can also have a great effect on mixing performance. Figure 3 shows a simple system utilising the one fan to supply air into the room, the return air being forced out by the positive pressure it creates. The amount of recirculated air is controlled by the relative interaction between the air handling unit's recirculation damper and the gravity operated flap damper on the exhaust outlet to atmosphere. This is very crude and clearly there are even greater problems with obtaining proportionality between control settings and outdoor air ventilation rates.
The two openings, outdoor air intake and exhaust outlet, are very often located as shown, giving rise to the possibility of exhaust air being brought back in through the inlet. On the other hand, siting the two openings on different sides of a building will make the system prone to wind effects which can create havoc with relative pressure balances.

Either way, there is yet more potential for not achieving the design outdoor air ventilation rate.

A better arrangement is that shown in figure 4, where the extract rate is controlled by a separate extract fan and the flap damper is replaced by a modulating damper. The dampers - outdoor air, exhaust and recirculation - are all linked together by the controls so that they (should) work in conjunction, i.e. the latter opens as the other two close, and vice versa. Whilst this gives better balance, it still potentially suffers from all the problems already outlined, of non-linearity, stratification, high velocities, short-circuiting of exhaust air and wind pressurisation effects, but to a lesser degree.

Often the extract fan is incorporated into the air handling unit, as shown in figures 5 and 6. It can be seen that there is a natural tendency in the case of the 'piggy back' arrangement (figure 5) for the extract air to be blasted out by the fan through the exhaust damper as soon as it cracks open, since the discharge from the fan is directed straight at it. Similarly, in the case of the in-line unit (figure vi) the extract air will preferentially go through the recirculation damper. With this arrangement it is hard to believe that outdoor air will be drawn in because as soon as the recirculation damper starts to open the supply-side of the mixing section will become positively pressurised.

The last figure, figure 7, sums the situation up. It depicts the site measured relationship between the controller setting of percentage outdoor air and the actual percentage of outdoor air. All that can be said is that from an IAQ viewpoint this is fine, since the outdoor air ventilation rates are roughly double those intended. But this situation is totally unacceptable in terms of energy usage.

I therefore believe that there is a great need for research into the subject of mixing sections - how effective they are, how can they be improved, what are the minimum parameters, etc. This would provide a basis for guidelines and standards. At the moment no such documents exist. Without this work we will all continue to delude ourselves over the outdoor air ventilation rates within our mechanically ventilated buildings, making mockery of all the attempts to set down acceptable levels.

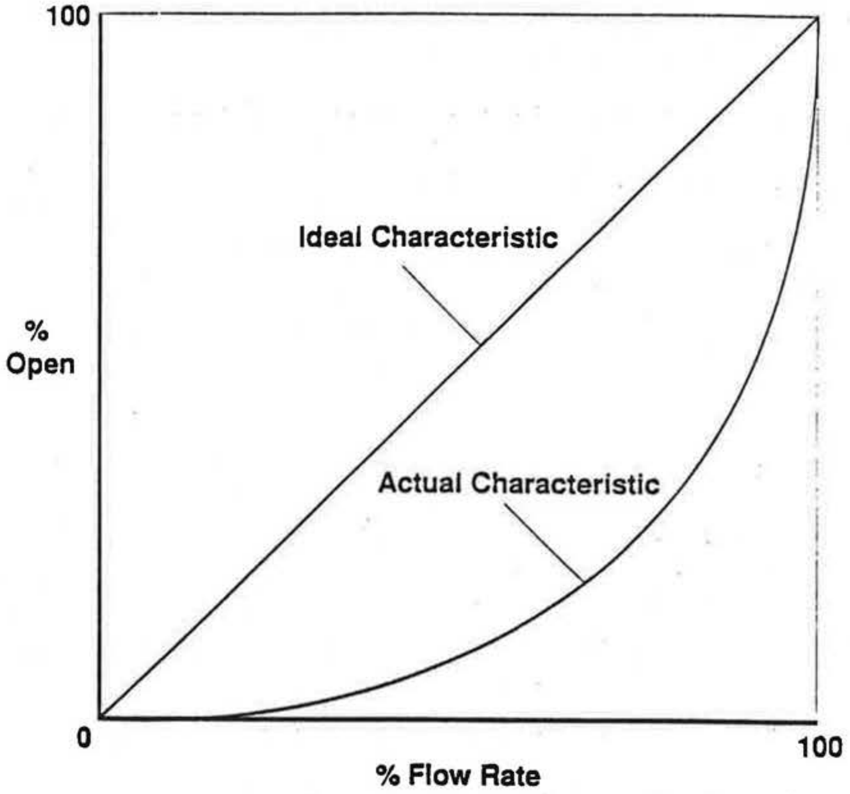

FIG. 1 DAMPER CHARACTERISTIC

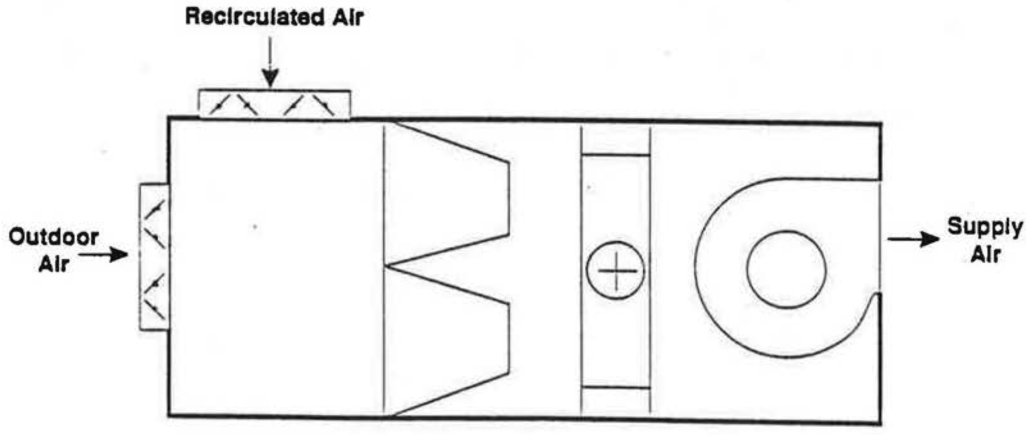

FIG. 2 AIR HANDLING UNIT WITH MIXING SECTION

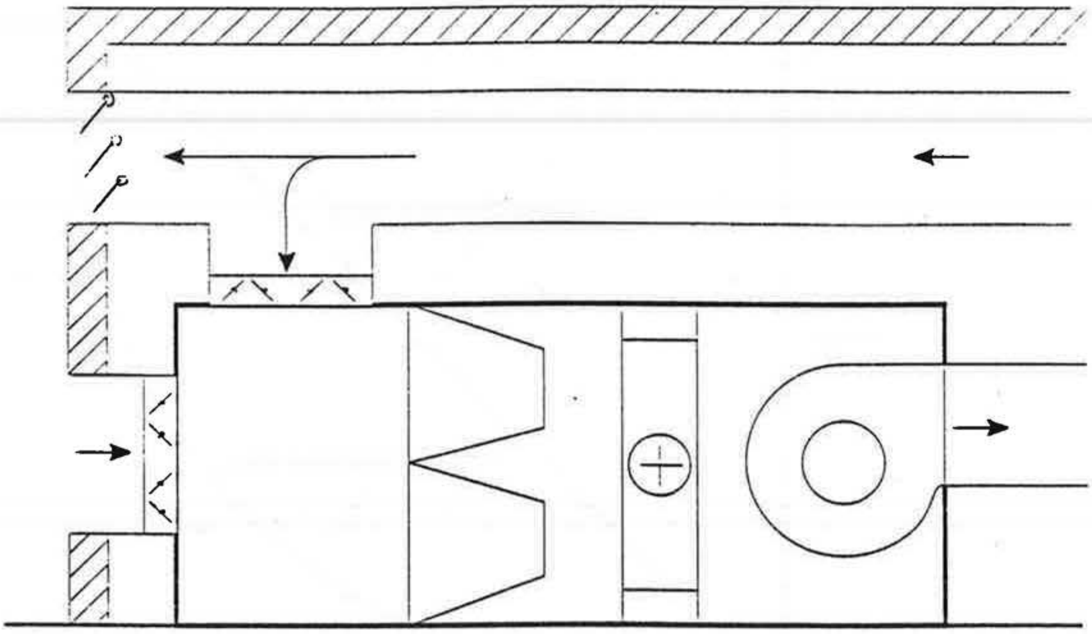

FIG. 3 SIMPLE RECIRCULATION SYSTEM

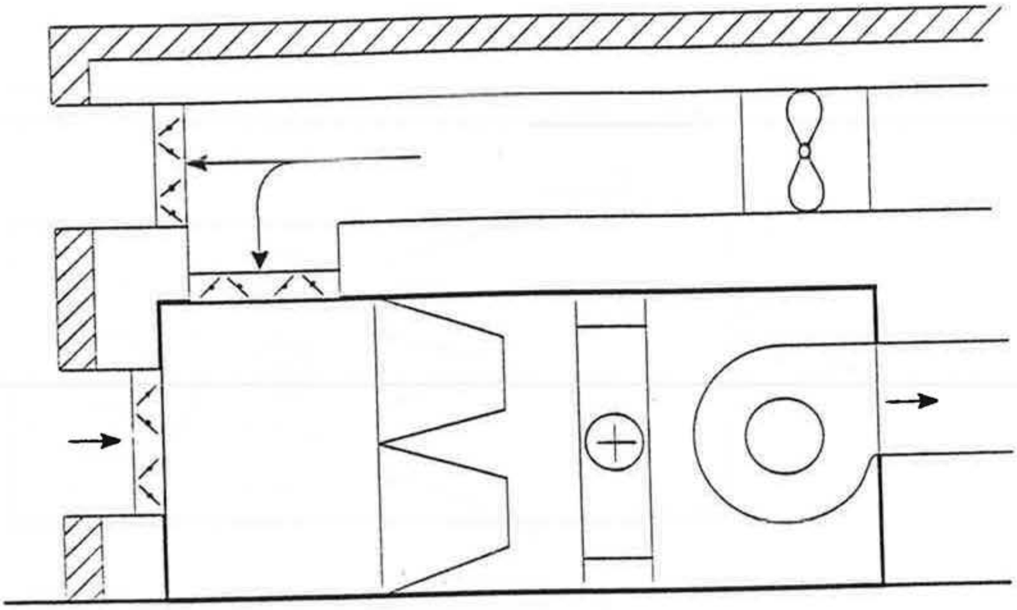

FIG. 4 RECIRCULATION SYSTEM WITH EXTRACT FAN

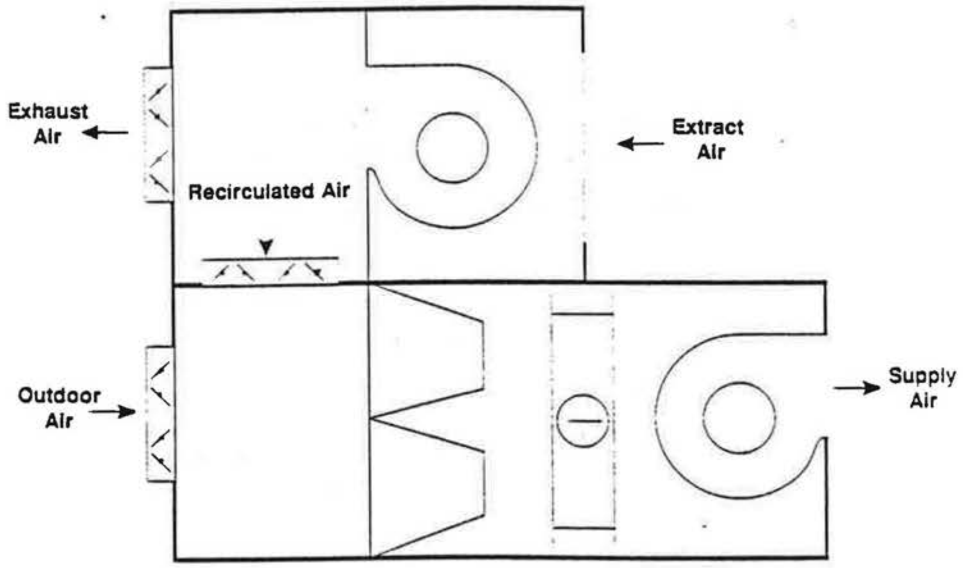

FIG. 5 COMBINED SUPPLY / EXHAUST AIR HANDLING UNIT

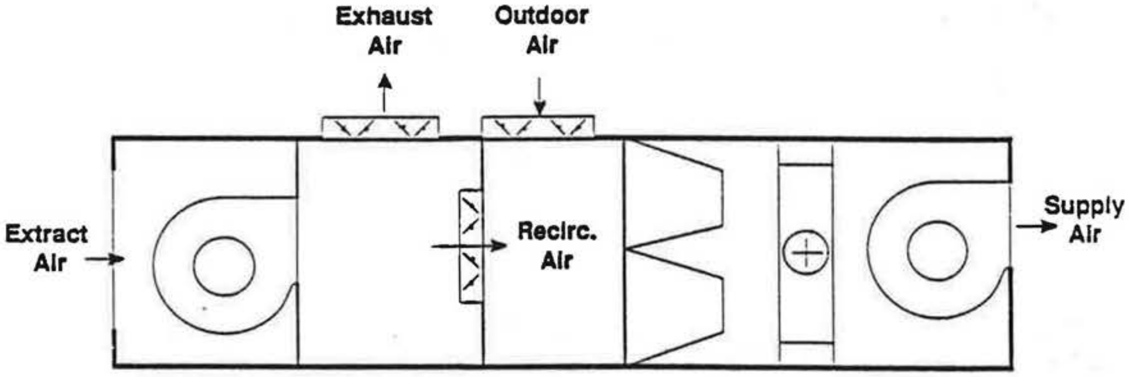

FIG. 6 COMBINED SUPPLY / EXHAUST AIR HANDLING UNIT

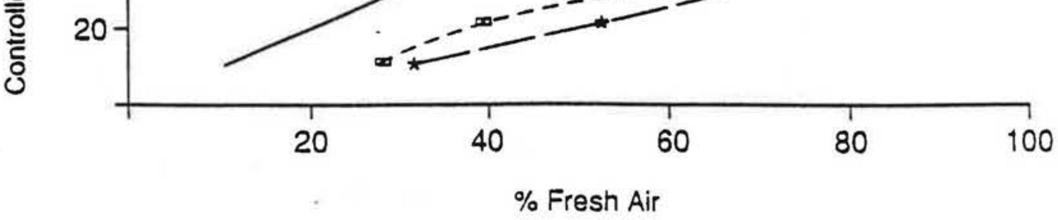

FIG. 7 ACTUAL EXAMPLE OF NON - LINEARITY

Decreased Ventilation Requirement through Control of Indoor Pollution Sources

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ABSTRACT

It is documented that the building in itself is the major source of air pollution in many buildings. The pollution sources are found in building materials, furniture, carpeting and in the ventilation system. These hitherto ignored sources increase the ventilation requirement and energy consumption whether they occur in naturally or mechanically ventilated buildings. Data for the pollution source strength in offices, schools and kindergartens are presented. The reduction of these unnecessary sources may provide the most promising potential for energy conservation in European buildings. The IAQ Mangement by control of pollution sources has the appealing characteristic that energy conservation can be accomplished without jeopardizing human comfort. A European field study of pollution sources caused by the building itself is recommended. A study of pollution sources from individual components in ventilation systems is also suggested as well as research to develop a simple method of determing the pollution source strength of building materials and a study of the effect of redecorating high-polluting buildings with low-polluting materials.

INTRODUCTION

The principal aim of ventilation standards for non-industrial buildings is to provide an indoor air quality which is perceived by the occupants as pleasant and acceptable. How does man react when he perceives that the air quality is poor? When the air is perceived as stale, stuffy and irritating? If possible, he will increase the ventilation for instance by opening a window. This behaviour is the common way of improving conditions in dwellings, offices or schools. whether they are mechanically or naturally ventilated. If it is impossible or inconvenient to open windows (e.g. due to traffic noise or draught), the occupant will be uncomfortable and may complain. With the object of saving energy a great deal of effort has been exerted over the past decade to make buildings tight. This is in itself useful but is has little effect on the energy consumption if people open windows instead.

The obvious way of reducing the ventilation requirement is to control the indoor pollution sources. If the pollution sources are small, the ventilation requirement is low. If the pollution sources are excessive, a high and energy-consuming ventilation rate is necessary.

What kind of pollution sources **do** we have in our buildings? Since Pettenkofer's (1) and Yaglou's (2) classical studies, it has been assumed that people were the only polluters. This belief is reflected in standards prescribing a certain ventilation rate **per person.**

But numerous studies over the past decade have indicated that many other sources were present in buildings (3,4,5,6). If people were the only polluters, it follows that the indoor air quality should be as fresh as the outdoor air when no persons are present in the building. This is obviously not the case. Other studies have shown widely differing air qualities in buildings with the same ventilation rate per person (7).

SENSORY UNITS FOR AIR QUALITY

The problem was that there were no common sensory unit by which the many indoor pollution sources could be expressed.

In the fields of lighting and sound sensory units had been available for a long time. Light sources are quantified in lumen independent of the type of light. Sound sources are quantified in watts independent of the type of noise. Perceived light is expressed in lux and perceived sound level in decibel. These sensory units have been most useful for calculating and predicting light and sound in buildings (Table I).

Table I. Units used to quantify source strength and perceived level of light, noise and air quality

	Light	Noise	Air Quality
Source Strength	lumen	watt	olf
Perceived Level	lux	decibel (A)	decipol

A few years ago analogous units were introduced for perceived air quality (Table I) (8). The new sensory unit for source strength is one olf, defined as the air pollution from one standard person. Perceived air quality is measured in decipol, one decipol being the air quality in a space with a pollution source of one olf ventilated by 10 l/s of clean air. There is a direct relation between decipol and percentage of dissatisfied persons (Figure 1).

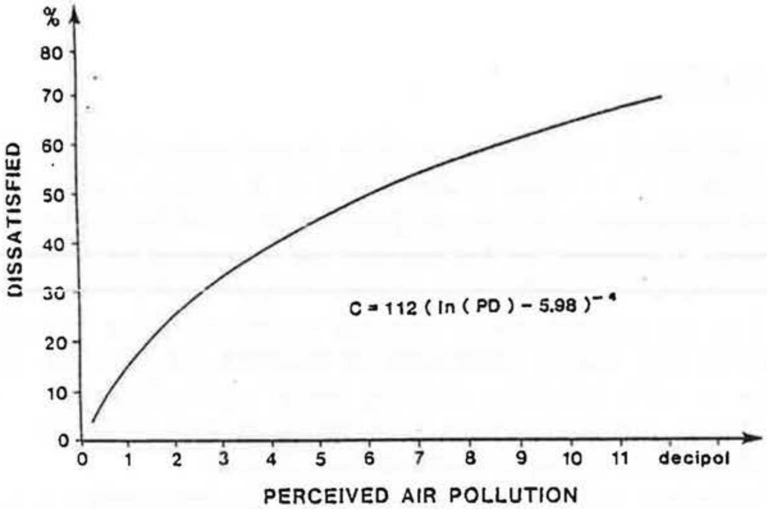

Figure 1. Perceived air quality as a function of the percentage of dissatisfied

Utilizing the new sensory units it is possible to predict the perceived air quality or the required ventilation from this model:

$$Q = 10 \frac{G}{C_i - C_o} \cdot \frac{1}{\varepsilon_v}$$

where

Q = Ventilation rate required (l/s)
G = Total pollution load (olf)
C_i = Perceived indoor air quality, desired (decipol)
C_o = Perceived outdoor air quality (decipol)
ε_v = Ventilation effectiveness

The required ventilation is proportional to the pollution load. To decrease the required ventilation it is therefore essential to avoid unnecessary pollution sources. The question is how large is the pollution load in real buildings?

POLLUTION LOAD IN REAL BUILDINGS

The pollution load has been measured in more than 40 buildings of different types (9,10,11,12). The load originates partly from human beings and partly from the building. The load from the person is well-known. One standard person provides per definition one olf. The load of children, athletes and smokers are listed in Table II.

Table II. Pollution load caused by the occupants in buildings

	olf/occupant
Sedentary, 1-1.2 met*	
0% smokers	1
20% smokers**	2
40% smokers**	3
100% smokers**	6
Physical Excercise	
Low level, 3 met	4
Medium level, 6 met	10
High level (athletes), 10 met	20
Children	
Kindergarten, 3-6 yrs, 2.7 met	1.2
School, 14-16 yrs, 1.2 met	1.3

* 1 met is the metabolic rate of a resting sedentary person (1 met = 58W/m² skin area, i.e. approximately 100 W for an average person)
** average smoking rate 1.2 cigarettes/hour per smoker

The pollution load for offices, schools and kindergartens caused by the building in itself is shown in Table III. It is remarkable how large the variation is from building to building. It is also surprising how high the average load from the building is. Figures 2, 3 and 4 illustrate this in a dramatic way by showing how many unnecessary hidden olfs there were per person present.

Table III. Pollution load caused by the building in itself, including furnishing, carpets and ventilation system

	olf/(m² floor)	
	mean	range
Existing Buildings		
Offices*	0.3	0.02-0.95
Schools (class rooms)**	0.3	0.12-0.54
Kindergartens ***	0.4	0.02-0.74

* Data for 24 office buildings (9,10)
** Data for 6 schools (11)
*** Data for 10 kindergartens (12)

For 24 office buildings (9,10) there were on average 5 hidden olfs per occupant, see Figure 2. The average ventilation rate per person was high (25 l/s · person) and much higher than present ventilation standards prescribe. Still, the average ventilation rate per olf was quite small (4 l/s · olf) which explains why there were quite widespread complaints in many of the buildings.

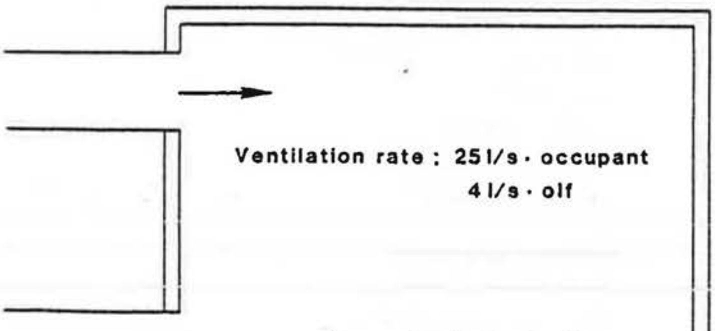

Figure 2. Hidden olfs per occupant in 24 office buildings (9,10)

In the schools (11) there were 1.5 hidden olfs from the building per student, see Figure 3. Although there were only 14 students in each classroom, the hidden sources contributed 21 olfs; thus the total load corresponded to a load produced by 35 students in each classroom. The ventilation rate was 5 l/s· student but only 2 l/s· olf.

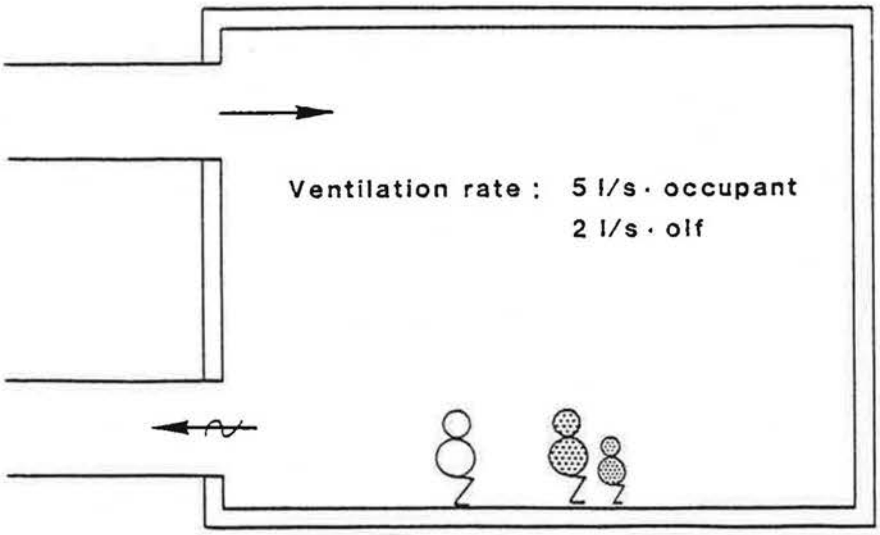

Figure 3. Hidden olfs per occupant in 6 schools (9,10)

In the kindergartens (12) the building contributed on average one hidden olf per child, see Figure 4. The ventilation was 7 l/s per child but only 4 l/s· olf.

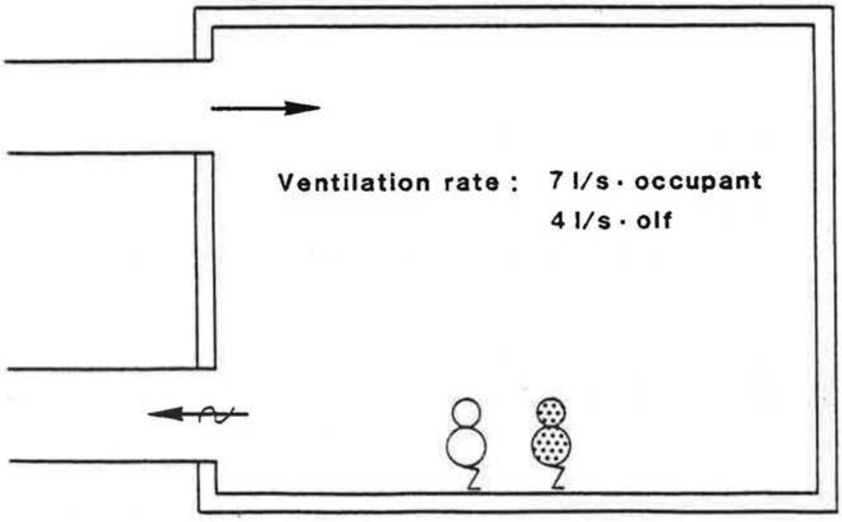

Figure 4. Hidden olfs per occupants in 10 kindergartens (12)

A split-up of the sources were done in most of the buildings. This is shown for 15 of the office buildings in Figure 5. It can be seen that the pollution from the building was caused in part by building materials and furniture but mostly by the ventilation system.

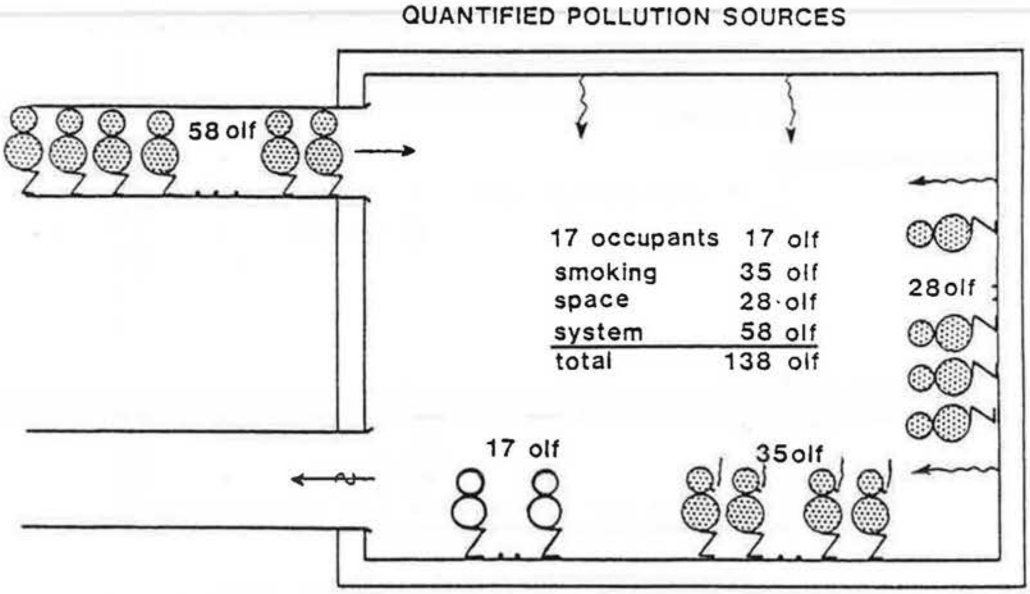

Figure 5. Quantified pollution sources in 15 office buildings

A pilot study of pollution sources was made in 8 ventilation systems (13). One example is shown in Figure 6. It is obvious that the perceived air quality deteriorates while passing the ventilation system.

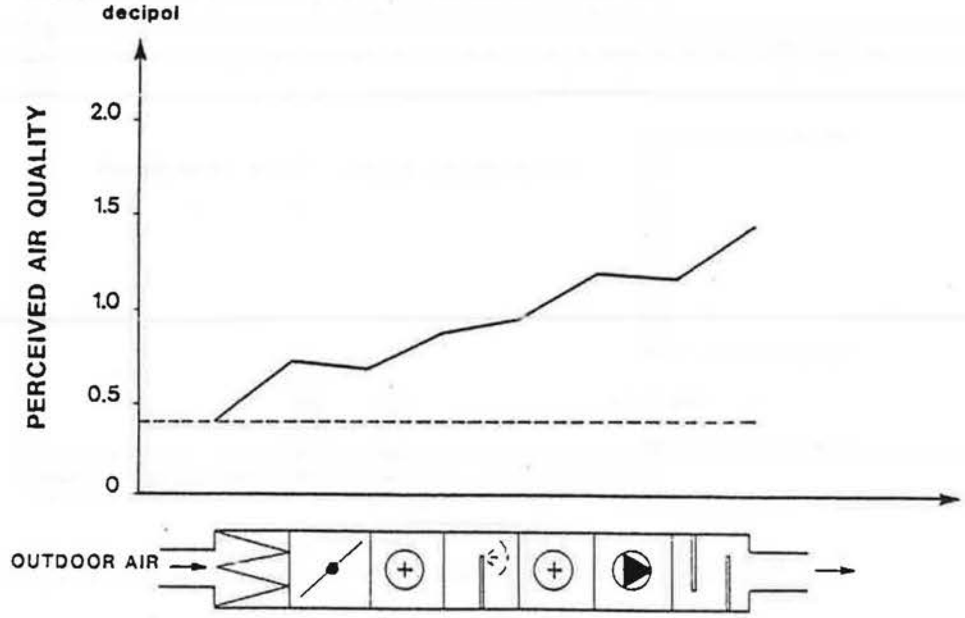

Figure 6. The perceived quality of air passing through a ventilation system

The abovementioned studies document that the building in itself in many cases is a major source of pollution, often much more important that the occupants acknowledged in the present standards. These sources situated partly in building materials, furnishing etc. and partly in the ventilation system are unnecessary. To handle these hitherto ignored pollution sources, a high ventilation rate is required. The reduction or avoidance of these superfluous sources may represent the greatest potential for energy conservation in many existing and future buildings.

FUTURE RESEARCH

IAQ Management by control of pollution sources has the appealing characteristic that energy conservation can be accomplished without jeopardizing human comfort. The aim of the following research recommendations is to identify such pollution sources in European buildings and to demonstrate how they can be reduced or avoided in existing and future buildings.

- Pollution Caused by the Building
  A field study in a variety of buildings in different parts of Europe to identify the pollution load caused by the building in itself.

- Pollution Sources in Ventilation Systems
  Study of the pollution source strength of individual components in ventilation systems. The research involves a field study in a variety of European ventilation systems and a detailed lab study on how to avoid pollution from selected types of components.

- Pollution from Building Materials
  Development of a simple test method to determine the pollution source strength of building materials in chemical and sensory units.

- Renovation of High-Polluting Buildings
  A study to demonstrate the impact on indoor air quality and energy consumption of renovating existing high-polluting buildings. The renovation involves the replacement of high-polluting materials in buildings and ventilation systems by low-polluting materials, the elimination of high-polluting processes etc.

REFERENCES

(1) M.V. Pettenkofer (1858) Über den Luftwechsel in Wohngebäuden. Cottasche Buchhandlung, München.
(2) E.C. Yaglou, E.C. Riley, and D.S. Coggins (1936). 'Ventilation Requirements'. ASHVE Trans. 42, pp.133-162.
(3) L. Mølhave (1986). 'Indoor Air Quality in Relation to Sensory Irritation due to Volatile Oganic Compounds'. ASHRAE Tans. 92(1):paper 2954.
(4) D.A. Sterling (1985). 'Volatile Organic Compounds in Indoor Air: an Overview of Resources, Concentration and Health Effects. In: R.B. Gammage, S.V. Kaye eds Indoor Air and Human Health, Chelsea, MI, pp.387-402.
(5) H.V. Wanner, M. Kuhn (1984). 'Indoor Air Pollution by Building Materials'. Proc. of Indoor Air 1984, **Vol. 3**, pp.35-40.
(6) WHO Indoor Air Pollutants: Exposure and Health Effects (1982). World Health Organization EURO-Reports and Studies No. 78 Working Group Report, Nördlingen, WHO-Regional Office, Copenhagen.

(7) O. Nielsen, H.P. Bredsdorff (1987). 'Luftkvalitet og udelufttilførsel i 11 skoler'. SBI-rapport 166. Danish Building Research Institute. (In Danish).

(8) P.O. Fanger (1988). 'Introduction of the olf and the decipol to quantify air pollution perceived by humans indoors and outdoors'. Energy and Buildings **Vol. 12**, pp.1-6.

(9) P.O. Fanger, J. Lauridsen, P. Bluyssen, G. Claussen (1988). 'Air Pollution Sources in Offices and Assembly Halls Quantified by the olf Unit'. Energy and Buildings, **Vol. 12**, pp.7-9.

(10) J. Pejtersen, L. Øie, S. Skar, G. Clausen, P.O. Fanger (1990). 'A Simple Method to Determine the olf Load in a Building. Proc. of Indoor Air '90, Toronto, **Vol. 1**, pp.537-542.

(11) E. Thorstensen, C. Hansen, J. Pejtersen, G. Clausen, P.O. Fanger (1990). 'Air Pollution sources and Indoor Air Quality in Schools. Proc. of Indoor Air '90, Toronto, **Vol. 1**, pp.531-536.

(12) J. Pejtersen, G. Clausen, J. Sørensen, D. Quistgaard, G. Iwashita, Y. Zhang, T. Onishi, P.O. Fanger (1991) 'Air Pollution Sources in Kindergartens' Healthy Buildings '91, Washington (submitted)

(13) J. Pejtersen, P. Bluyssen, H. Kondo, G. Clausen and P.O. Fanger (1989). 'Air Pollution Sources in Ventilation Systems. Proc. of Clima 2000, Sarajevo, **Vol. 1**, pp.139-144.

THE IAQ CONTROL

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ABSTRACT

Traditionally, occupants have always been entrusted with the task of controlling IAQ, and this task was usually carried out by opening the windows, at the expense of heating (or cooling) energy. When mechanical ventilation started to be adopted as a common technique, the amount of fresh air was established according to design values, in their turn usually based on peak ventilation loads.

Only recently the concern for energy on one side, and the renovated interest for air quality on the other side, have given rise to a variety of applications of ventilation systems controlled by IAQ levels. This kind of systems has been termed by the International Energy Agency, which promoted a working group (Annex XVIII) under this heading, "Demand Controlled Ventilation" (DCV) systems, i e, systems which should be able to maintain always acceptable IAQ levels at the lowest possible energy costs.

A number of DCV systems are already commercially available. Their application ranges from natural to mechanical ventilation, from new buildings to existing ones, from dwellings to schools, or any other type of buildings and climate. A variety of different IAQ "indicators", and suitable sensors are also used. In order to avoid future disappointments, the choice of the right DCV system requires a careful analysis of the problem, which not always can be provided by installators, due to the novelty and intrinsic complexity of these systems.

After a general evaluation of DCV systems, related to their energy saving potential and IAQ improvement, a number of typical examples of applications are shown, derived from the preliminary results of IEA Annex XVIII, stressing the benefits which were achieved, but also the problems which were encountered. Areas for future research are also indicated (improved sensors, field and laboratory tests, etc.).

1. Introduction

The term "ventilation" of a building usually means the exchange of indoor air with outdoor air. By definition, we will assume that the sources of pollution are only indoors and therefore that indoor air is more polluted than outdoors (which is, by the way, not always true). Moreover, we will not consider ventilation as a mean to carry out a thermal function (air conditioning).

Under these assumptions the reasons for ventilating a building are merely related to hygienic matters. There are indoor sources of pollution in buildings which can produce stuffy air (odours), health risks (VOC, radon, formaldehyde, etc.), or damage to the building (moisture). Whenever these sources show a rather constant emission rate, an ordinary ventilation system may realize acceptable Indoor Air Quality (IAQ) indoors. When, on the opposite, the emission rate is strongly variable, the possibility of installing a Demand Controlled Ventilation (DCV) system should be taken into consideration.

According to the definition provided by IEA Annex XVIII "Demand Controlled Ventilating Systems" subtask A Report (Raatschen, ed., 1990), a DCV system may be defined as **"a ventilation system in which the air flow rate is governed by airborne contaminants"**, either by an automatic control device, or directly by the intervention of the user. We will consider in this context only automatic DCV systems.

This kind of ventilation systems are not widely spread, not even in those countries where mechanical ventilation is already a traditional technique. On the opposite, thermostat control of indoor climate is practised anywhere, and is often made compulsory by law.

Then, a question arises spontaneously: why is heat released according to the actual demand, while air flow rate provided by mechanical ventilation is usually constant ?

A tentative answer may be provided by the parallel between indoor climate control and IAQ control as shown in Table 1.

Table 1 - Parallel between Indoor Climate and IAQ control.

	Indoor Climate (IC)	IAQ
Reason to control	Subjective (thermal sensation) & objective: 1) Health related 2) Building related	Subjective (smell) & objective: 1) Hygiene related 2) Health related 3) Building related
Influencing factor	1) Outdoor factors (weather) 2) Indoor factors (people, equipment)	1) Indoor factors (human activity, building sources) 2) Outdoor fact. (infiltration)
Physical quantities (PhQ) defining IC/IAQ	1) Air temperature 2) Radiant temperature 3) Air humidity 4) Air speed	Concentration of VOC, H_2O, CO, smoke, Radon, Formaldehyde, etc.
Relationship between PhQ and perception	Exists and is well known (see, e g, Fanger equation)	Exists for some PhQ (see Fanger equation), does not exist for others.

Proceeding further in the comparison we will refer to control systems, as shown in Table 2.

Table 2. Main features of Indoor Climate and IAQ control systems.

	Indoor Climate (IC)	IAQ
Type of control possibilities	1) Feed-forward 2) Feed-back	Feed-back only
Control variable for feed-back control	Air temperature	VOC, H_2O, CO_2, ...
Relationship between control variable & IC/IAQ	Very close	Depends ...
Typical time constant of control variable dynamics	hours	seconds
Space distribution of control variable	rather uniform	widely variable
Control feasibility	easy	difficult
Control sensitivity	1°C ⇒10% PPD	100 ppm CO2 ⇒2% PD
Potential energy savings	1°C ⇒5-10% of total losses	100 ppm ⇒ 15% of ventilation losses

The conclusion which may be drawn from the Table above is that controlling IAQ is much more difficult than controlling Indoor Climate. If one adds that a large part of the perceived poor air quality is not due to bioeffluents and people related activities, but to materials in ventilation systems themselves (Fanger, 1989), the picture becomes even more fuzzy...

2. Suitability of DCV systems

Despite the difficulties in realizing a well designed DCV system, the possibility to adopt one of these systems should be (carefully) considered according to the following fundamental factors:

i) The characteristics of contaminant production within the building

ii) The building features

iii) The HVAC installations

iv) The climate

2.1 Characteristics of contaminant production within the building

There are many pollutants produced within the building, each one requiring a certain level of ventilation rate. They may be considered as belonging to three categories:

a - **building pollution sources**, showing a rather steady source strength,

b - **event related sources**, and

c - occupant related sources

One of these pollutants should be chosen to drive a DCV system: this will be called the **driving (or dominant) contaminant**, and it will be the contaminant, the level of which is such as to require the highest ventilation rate, as an average. Moreover, the driving contaminant should have an emission rate, which is

i) high enough as to require the installation of additional (natural or mechanically assisted) ventilation in addition to that provided by natural infiltration

ii) strongly variable in time (variations of at least 100 % should be considered)

iii) unpredictable as to time and location of the source.

It is obvious that none of pollutants of categories a and b show all above properties. Building related pollutants do not owe properties ii) and iii). Event related pollution usually do not owe property iii). They should be rather reduced by exhausting them at the source: if the time when a strong increase of pollutant emission rate (PER) will take place is known in advance, a simple clock-control system may be adopted. If, on the other hand, the location of pollutant emission is well known and localized in a small area within the conditioned space, it may be preferable to adopt local exhaust systems (e.g., hoods), which are much more efficient in the removal of contaminants than are even well designed central systems.

A decision diagram taking into account these factors is shown in Figure 1.

2.2 Building-related factors

There are at least three major building- related factors which may be relevant for the adoption of a DCV system:

a - the air tightness of the envelope of the building

b - the building use and destination

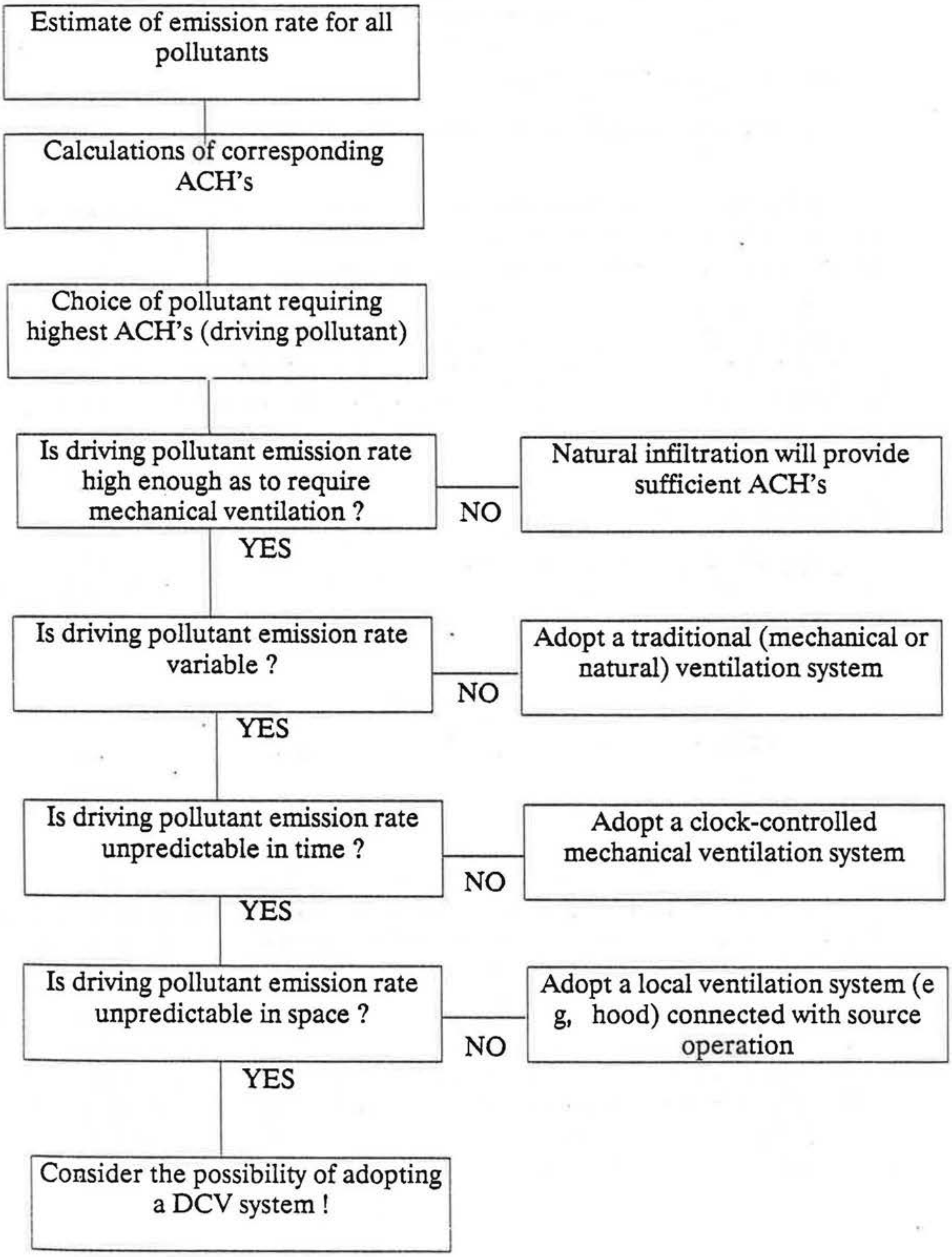
c - emission and absorption of pollutants by building materials

a) Air tightness

If a building is so leaky that natural infiltration generally provides sufficient ventilation, then a DCV system is clearly not applicable. The tighter the building, the more efficient the control of ventilation by the DCV system, and the greater the energy savings will be. As a rule of thumb, if normally more than 50 % of outdoor air comes from uncotrolled natural infiltration, the performance of DCV systems will be rather ineffective.

However, where a mechanical system is already installed, even in leaky buildings the installation of DCV systems will result in some energy savings, because it will "sense" the effect of natural infiltration in terms of IAQ improvement.

Figure 1 - Decision diagram for choosing a DCV system according to Pollutant Emisssion Rate characteristics



- IAQ levels (i e concentrations)
- Ventilation loads

Once the total energy losses are calculated, these will be compared to ventilation energy losses induced by competing systems (e g constant flow rate ventilation systems). The energy savings and the extra costs for DCV will have to be compared in order to evaluate the return on investment, profitability or Life Cycle Cost.

5. Experiences with DCV systems

Experience with DCV is still very limited, and cannot bring to definitive conclusions.

In general, IAQ improvements are always observed when DCV is compared to natural ventilation. In some cases, incorrect positioning of sensors may lead to underventilation of certain areas of the building.

Theoretical evaluation of energy savings may induce optimistic conclusions, and cannot be generalized. As an example, a calculation performed in a classroom (Raatschen, 1990) showed that the installation of DCV would lead to a reduction from 1.19 ach to 0.64 ach with a maximum carbon dioxide level of 1,400, and from 1.92 to 1.05 ach when the CO_2 set-point was lowered to 1,000 ppm. In both cases the ventilation load reduction was 46 %.

Measured savings were in the range of 8 % in a Bank (Gabel, 1986) up to 17 % in a Cinema (Anon, 1986) of the total fuel consumption.

Respect to ventilation load, 20 % savings were estimated in a theatre (Warren, 1982), and 40% in an office building (Södergren and Punttila, 1983). Payback times from less than one year in an entertainement building (Lyons, 1983) to more than 6 years in a library (Smith et al., 1984) were reported.

6. Need for further research and conclusions

As this technology is rather new, many items should need further research both in the field and in the laboratory:

a) Control strategy

Differently from indoor climate feedback control, in which the controlled quantity and the controlling (driving) quantity is the same, i e air temperature, IAQ control may make use of as many driving quantities as there are pollutants in the air, none of which is completely reliable in all situations.

Moreover, some investigations show that a large part of perceived pollution is not due to the occupant-generated pollutants (smoke + bioeffluents + CO_2 + humidity), but to those emitted by the building, the furniture or by the ventilation system itself (Fanger, 1989). Therefore it is not clear which should the best quantity to be monitored in order to keep an agreeable IAQ. CO_2 is often considered to be the best indicator of bioeffluents, but this is no longer valid when smoking is allowed.

condensation on walls surfaces (a rather frequent case for residential buildings in humid winter climate regions).

3. Types of DCV systems

Most DCV systems are designed in order to keep under control:

- air quality (in general)
- odours
- tobacco smoke
- humidity

This can be accomplished adopting monitorable indicators as:

a - water vapour

b - carbon dioxide

c - mixed gases (volatile organic compounds - VOC)

The cross-correlation matrix between controlled quantities and their indicators is shown in Table 3.

Table 3 - Controlled quantity and indicator

Controlled quantity	VOC	CO_2	Water vapour
Air quality	x	x	(x)
Odours	x	x	(x)
Tobacco smoke	(x)	(x)	-
Relative humidity	-	-	x

3.1 Humidity controlled ventilation (HCV) systems

This type of DCV is generally adopted in residences, where large and sudden increases of RH are often observed, causing moisture problems to the building fabric.

Particularly interesting appear those HCV systems making use of self-regulating grilles, whose opening section varies according to the dwelling humidity. These systems may be adopted either with mechanical ventilation or with natural ventilation ducts ("shunt" system). The rationale behind these systems is shortly described below.

Because there is always a certain amount of water vapour in outdoor air, the amount of this air required to keep indoor air relative humidity (RH) below limit values will vary according to outdoor air moisture content. The theoretical number of ach, derived from the general equation of continuity under the hypotheses of perfect mixing, steady-state, taking into account absorption/desorption phenomena, will be:

$$n = \frac{P + B \cdot S \cdot (x_{\max} - x_i)}{\rho \cdot V \cdot (x_i - x_o)}$$

where

P = moisture production rate (kg/h)

x_i = moisture content in indoor air

x_{max} = maximum moisture content on the surface (kg/kg), corresponding to saturation conditions at the surface temperature

x_o = outdoor moisture content (kg/kg), varying with temperature and RH of outdoor air

B = moisture absorption or desorption resistance (kg/m^{2}h), equal to zero when x_i x_{max} and no condensation is left on the surfaces

S = Surface area of walls and furniture (m^2)

When the goal is to maintain a constant indoor RH (e.g. 50 % RH at 20 °C, corresponding to 7 g of water per kg of dry air) x_o tends to diminish with decreasing outdoor temperature and therefore the amount of outdoor air needed to maintain a constant indoor RH will also diminish (Fantozzi et al, 1990), thus tending to compensate for the increase of ventilation loads with increasing temperature difference (see Figure 2).

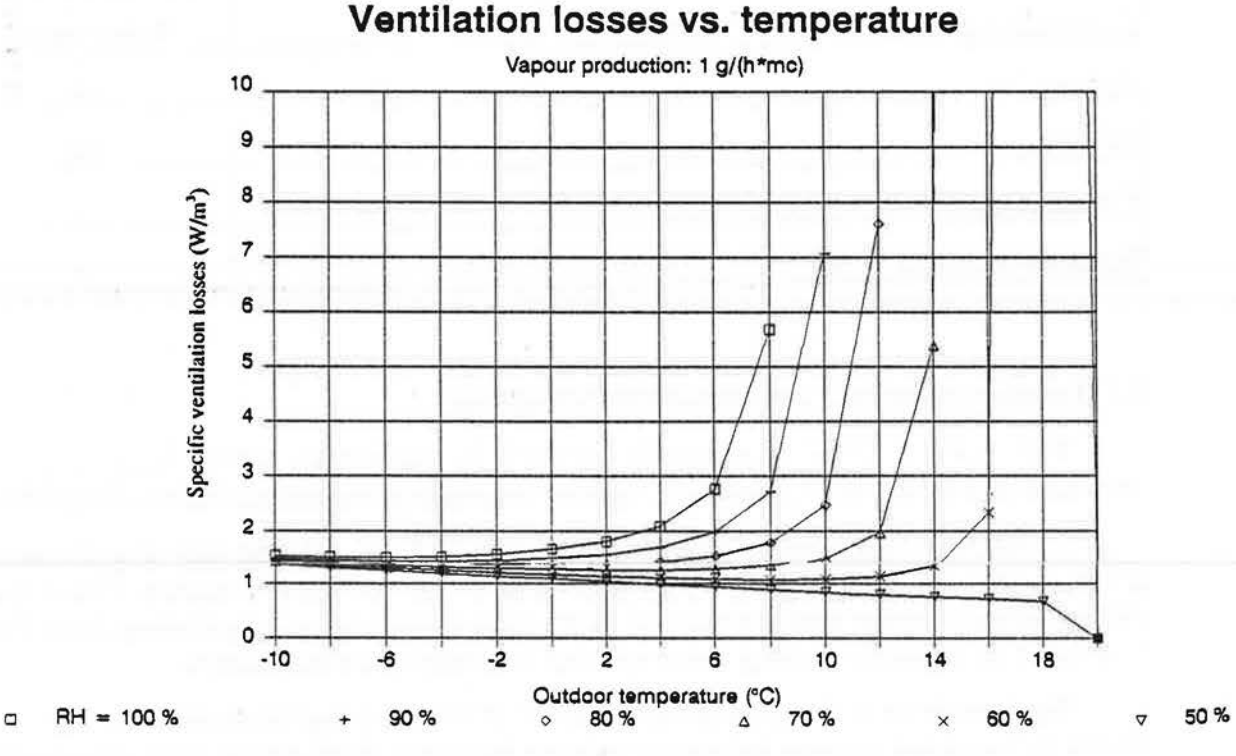


Figure 2. Ventilation losses versus temperature. Vapour production: 1 g/(h.m3). Indoor air conditions 20 °C, 50 % RH.

However, if the aim is to maintain the dew-point temperature of the air below the surface temperature of the coldest spots in the walls, the maximum allowable moisture content indoors will also decrease with decreasing outdoor temperature, partially counterbalancing the above effect.

In extremely cold climates these systems may have problems such as freezing of the grille tissue with chilly air and snow entering pushed by strong winds. Moreover, if the air inlet grilles are not correctly sized, they may induce such a large air flow that, in extreme conditions, indoor air temperature will decrease, leading to an increase of indoor RH, with a dramatically divergent result.

3.2 CO_2 controlled ventilation systems

Carbon dioxide seems to be a rather trustworthy driving contaminant for schools, offices, auditoria, where the main pollution problem is related to occupants, and the occupant load shows strongly variable trends.

It should be borne in mind that CO_2 in no way represents a harmful contaminant. It is, on the opposite, a good indicator of IAQ, when this is mainly put at risk by bioeffluents.

CO_2 sensors are usually sufficiently accurate to carry out their task. As CO_2 is usually emitted together with heat it is recommendable that the exhaust terminal are placed at a high level, and the sensors are placed in the exhausts.

3.3 VOC controlled ventilation systems

Volatile Organic Compounds are also good indicators of IAQ, but the sensors available on the market (often termed "mixed gas sensors", or "IAQ sensors") are not as reliable as CO_2 sensors, due to their weak stability and accuracy. Furthermore, "there is no direct relationship between the sensitivity of the sensor to a certain gas and the effect of this gas on IAQ" (Fahlén, 1991).

4. Evaluation of potential energy savings

Pre-evaluation of energy savings is needed to make a cost-benefit analysis upon deciding on the application of DCV. This will require the use of simulation techniques.

In order make a cost-benefit analysis the system performance will have to be analysed under typical (and not design) climatic conditions. The following data are needed to predict the operation of the system:

- meteorological data
- PER data
- features of the mechanical ventilation system
- geometrical and technical characteristics of the building
- absorption and desorption features of building walls and furniture

The following quantities will be calculated as a function of time:

- Air flow rate

- IAQ levels (i e concentrations)
- Ventilation loads

Once the total energy losses are calculated, these will be compared to ventilation energy losses induced by competing systems (e g constant flow rate ventilation systems). The energy savings and the extra costs for DCV will have to be compared in order to evaluate the return on investment, profitability or Life Cycle Cost.

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Moreover, some investigations show that a large part of perceived pollution is not due to the occupant-generated pollutants (smoke + bioeffluents + CO_2 + humidity), but to those emitted by the building, the furniture or by the ventilation system itself (Fanger, 1989). Therefore it is not clear which should the best quantity to be monitored in order to keep an agreeable IAQ. CO_2 is often considered to be the best indicator of bioeffluents, but this is no longer valid when smoking is allowed.

b) Sensors

Sensors are a key point for the good performance of DCV. The following crucial features have to be considered (Fahlén, 1991):

- low cross-sensitivity
- good stability
- immunity to climatic, mechanical and electro-magnetic interference

Some "special features", such as e g the possibility to display the measured signal may well help to improve the acceptability of DCV.

Another important matter is the correct positioning of sensors. It is maybe difficult to provide practical "rules-of-the-thumb" of general validity; improvement of DCV design should have recourse to simulation techniques, for example, to determine the correct position of sensors, grilles or extraction hoods. This can be accomplished by using rather sophisticated Computer Fluid Dynamics (CFD) models, simultaneously solving the three-dimensional equation of continuity and momentum for each room. Many of the CFD programmes available on the market, such as PHOENIX, FLOVENT, FLUENT, FIDEP, and others, are listed in an AIVC paper by Liddament (1991).

REFERENCES

Anon, Ventilation control by meas. of carbon dioxide levels in public entertainement buildings, ECD Partnership, Final Report ED/85/172, ETSU, Harvell, 1986.

Fahlén, P., Private communication, 1991.

Fanger, P.O., The new comfort equation for indoor air quality, IAQ '89, ASHRAE, 1989.

Fantozzi, Fracastoro G V, and Masoero M, "Assessing the performance of passive humidity controlled ventilation systems", XI AIVC , Belgirate (Italy), 1990.

Gabel, S.D., Janssen, J.E., et al., Carbon dioxide based ventilation control system demonstration, DOE, Bonneville Power Administration, Engineering Branch, Division of Resources Engineering, 1986.

Goodfellow, H.D. (Ed.), Advanced Design of Ventilation Systems for Contaminant Control. Elsevier, Amsterdam, 1985.

Liddament, M. W., A Review of Building Air Flow Simulation, AIVC Technical Note 33. March 1991.

Lyons, M., The Breathaliser Test, Energy Manager, Vol. 6, No. 10, p. 59-61, 1983.

Raatschen, W. (Ed.), Demand Controlled Ventilating Systems - State of the Art Review, International Energy Agency. Published by Byggforskningsrådet, D9:1990, Stockholm, Sweden, 1990.

Smith, B. E., Prowse, R.W., Owen, C.J., Development of occupancy-related control for Brunel University Library, Proc. of 5th AIC Conference, Reno, Nevada, 1984.

Södergren, D., Punttila, A., A CO_2 controlled ventilation system. Pilot study. Swedish Council for Building Research Document D7:1983.

Warren, B.F., Energy saving in buildings by control of ventilation .., Building Services Engineering and Technology, 1982, Vol. 3, No. 1.

IAQ-Management by Demand Controlled Ventilation

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Abstract

Research results of the last 2 years clearly showed, that the pollution load in a room originates from a variety of sources. Main sources of concern are emissions from building material, emissions from filters, emissions from dirty ducts, and emissions from occupants according to their activity level. It depends on the building itsself, whether the occupancy load dominates the pollutant level or not.

Demand Controlled Ventilation offers the possibility to control the airflow rate according to the pollution level in a room. The abundance of indoor air pollution gases leads to a classification of control strategies into 3 groups: humidity, carbon dioxide, and volatile organic compounds.

In addition to an effective extraction of the contaminant the detection with a reliable IAQ-sensor is of fundamental interest. This paper focusses on the requirements to IAQ-sensors, compares this with their current performance and highlights new areas of research.

Introduction

Indoor air quality is becoming a bigger and bigger issue in the countries of the European Community. Thightning of the building's envelope and efforts to decrease fresh air intake and energy demands for conditioning the supply air led to the conflict between indoor air quality and energy savings. Enourmous efforts to ensure a good thermal comfort environment in ventilated buildings of today let people (occupants, hygienists, housing authorities, engineers, building managers, etc) now pay more attention to gaseous substances in the air. Due to longer duration of people in indoor air symptoms of poor IAQ like discomfort, irritations, annoyance, and health risks of occupants were placed into the foreground. On the way of solving the sick building syndrom IAQ-analysis is regarded to be one key.

The awareness of material emissions led to a selection of building materials with low source strengths. Deposition of dust in filters and ducts can become another odour source. Furthermore, there are other pollutants in buildings, which generate from people and their activities and from machines (laser printer, copy machines, etc.).

If possible, an extraction at the source is favourable. Many sources move, people walk around, machines were used by several users and displaced from time to time. Where source extraction is not possible, emissions have to be effectively extracted via the ventilation system, either by dilution or by directed airflow (displacement flow).

Excessive ventilation leads, in general, to improved IAQ with the disadvantage of complains about draught and higher energy consumption for the ventilated air. One approach to solve this conflict is to use *Demand Controlled Ventilation* (DCV).

Demand Controlled Ventilation

We talk about Demand Control, when the ventilation rate for a room is governed by airborne contaminants. One can have an automatic DCV system, in which the airflow rate is governed by an automatic control device. Or one can have a manual DCV system, in which the airflow rate is governed by the user (a person acts as an indicator).

One has to be aware of the fact that, depending on a given situation, DCV should only take care of emissions of occupants and emissions according to activities in a room. As Fanger has shown, occupants and occupant related emissions can be only a small percentage of sources inside a building; there are often other sources e.g. filters, ducts, walls that may cause the real problems. The diverse pollution sources are not DCV specific; they apply to every ventilation system and building. Before installing a DCV system the designer should carefully examine the location and quantity of pollution sources with regard to occupants and other subjects. This is necessary to quantify the improvement of IAQ by a DCV system. A sick building cannot be cured with a DCV system.

The decision towards DCV should be made with regard to all pollution sources. DCV systems are likely to be cost-effective, when the emission rate of sources is unpredictable and with high fluctuations.

In dwellings often ventilation systems are not designed to cover peak loads. They usually run on a constant air exchange rate between 0.5 and 1.0 h^{-1}. Here a DCV system can lead to a better IAQ, as the peak flow rate can be designed to be above the usual flow rate, as internal supply airflows can be linked to one room without increasing the total air intake.
Detailed observations in auditoria and kindergarten proof, that ventilation systems often run on full speed regardless whether the room is fully occupied or not. Time control often failes, because the time schedules change and the real person load is difficult to predict. Presence control is only applicable in rooms with very low changes in occupancy. Manual control turned out to be nearly always insufficient. To operate a

ventilation system according to the quality of air would therefore be a promissing way to cover both: good IAQ and a minimum of energy consumption.

One assumption, which is made in the design of a ventilation system is, that outdoor air is always looked upon as to be fresh and clean (what in reality is not always true). The saying, that Demand Control improves IAQ, has to be used with care. As pointed out before, only an increase of supply air improves IAQ; but: if one accepts for example, a CO_2 concentration in indoor air of 800 ppm to be of acceptable quality and the current CO_2 concentration is 600 ppm, a decrease of the ventilation rate will lead to an increase of the CO_2 level and therefore to a poorer IAQ, but the air is still regarded to be of good quality as long as it's below 800 ppm. Figure 1 shows a decision diagram to check whether CO_2 control is adequate or not.

IAQ-Sensors

As mentioned above, manual control often failes, presence control e.g. in an auditorium is not a good choice, and the effective application of indirect IAQ-control via a time relay is quite limited. A direct IAQ-control is desirable.

Compared to other control parameters in HVAC systems, IAQ-control is difficult. Control of room temperature is straight forward. Some more complex is to achieve thermal comfort. This was possible, since researchers found that not only the air velocity and temperature, but also turbulence and the direction of airflow has an influence on thermal comfort. IAQ is much more difficult to control, since nobody yet knows, what IAQ is. The substances in indoor air which cause problems are numerous and listed elsewhere. They will not be repeated here. About cross

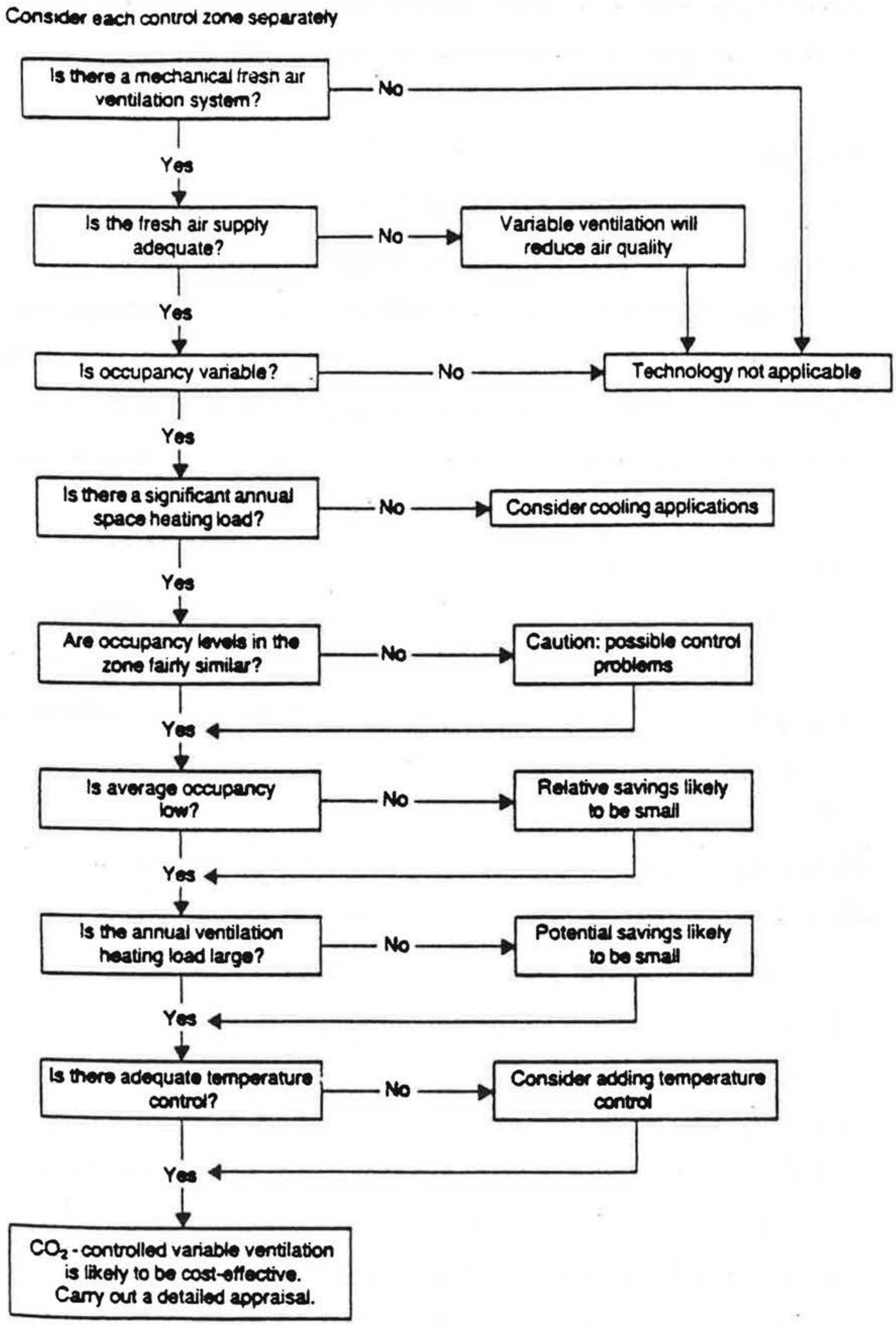

Figure 1 *Decision Diagramme for Suitability of CO_2 controlled variable ventilation (from: Annex 18, State of the art report)*

influences almost nothing is known. In a first approach, a rugh classification of pollutants with regard to Demand Control can be made within 3 classes:

Humidity

Of main concern in dwellings in European Countries are moisture damages, which deteriorate the building fabric. The growth of mould leads to allergenic reactions and health risks. Appropriate actions (better insulation, adequate occupant behaviour, humidity controlled ventilation) solves this problem. As occupants emit odours **and** water vapour, the control of room air humidity also leads to some extend to an improvement of IAQ in general, as increased ventilation always leads to better IAQ.

CO_2

Low energy houses are usually of very good insulation quality. The likelyhood of moisture problems is reduced and other pollutants will play a more dominant rule. One attempt to cover other airborne pollutants is to look for surrogates or indicators of IAQ, which are more easily to measure than the pollutant itself.

Carbon dioxide is almost accepted to be a reliable indicator for emission of humans, if they do not smoke. The detection of CO_2 with a CO_2 sensor is state-of-the-art. There are sensors on the market which selectively measure CO_2 between 300 and 2000 ppm with an accuracy of ±100 ppm. Prices range from 700 to 2500 $.

Mixed Gases

Mixed-gas sensors don't selectively measure one gas, they show responses usually against numerous gases. The sensitivity of mixed-gas sensors often corresponds to a chemical group of compounds: oxidized gases, non-oxidized gases, etc.
There are 10 to 15 mixed-gas sensors on the European market. They are sold under names like IAQ-sensor, odour detector, smoke sensor, CO sensor. They all use sensor

elements from the Japanese company Figaro. 3 different sensor element types are to be found in IAQ-sensors. Due to a different heating voltage, different amplification and other electric circuits they show very different performances against gaseous substances in the air.

CO_2 versus mixed-gas sensors

Discussions about CO_2 vs. mixed-gas sensors are very actual today, not only between sensor manufacturers but also in the research world.

Arguements pro CO_2-control are, that

- CO_2 can be selectively measured
- CO_2 correlates with emission of occupants
- CO_2-sensors can easily be calibrated.

Arguements against CO_2-control are

- no unique relationship between CO_2 and air quality, sensed by the human nose
- dominant gases which determine the level of odour sensed by the nose vary in space and time.

This leads to the opinion that selective measurements are only a very small part of the truth and a non-selective measurement allows to have more constituents under control.
In general, mixed-gas sensors react quite sensitive against tobacco smoke. In rarer cases they also react against body odour, but very less sensitive than against tobacco smoke.
Calibration is often heard to be an arguement against mixed-gas sensors, because there is no defined value against to calibrate. On the other hand, a mixed-gas sensor is an attempt to simulate the human nose. Why not take the nose, if IAQ is poor and turn the knob of the sensor to higher sensitivity, til an appropriate setpoint is found?

Mixed-gas sensors show a good reaction against carbon monoxide, a hazardous odourless gas. Therefore, an increase of CO inside a building would cause the ventilation system to increase the flowrate. If the CO source is inside, the use of an mixed-gas sensor would lower the health risk to occupants. The sensor test reveilled another fact: during testing of sensors in a climate box with fixed airflow rate the mixed-gas sensors suddenly reacted. The reason was, that always around 4pm the employees of the testing institute left in their cars. The carbon monoxide of the exhaust gas of the cars migrated via the ventilation system into the building. In this case a mixed-gas sensor would have reacted in a wrong way; an increased airflow rate would worsen IAQ. In this respect however, the checking of fresh air intake could be another application for mixed-gas sensors.

Keeping the various advantages and disadvantages of CO_2 and mixed-gas control in mind, the performance of sensors has to be looked at. The IEA-Annex 18 sensor test reveilled, that mixed-gas sensors are very sensitive to changes in r.h. of the room air. Sometimes they seem to be more sensitive against humidity than against VOC. Figure 2 shows the performance of 6 tested mixed-gas sensors when, at constant temperature of 20° C, the r.h. increases from 40% to 60% and decreases again to 20% at 10° C. The change of the output signal of all sensors is substantial. To use such a sensor for ventilation control is not recommended. The mixed-gas sensor IAQ 1 showed no humidity drift but this sensor also showed no reaction in a smoking room with 30 smokers present.

CO_2 sensors are more expensive, but have low cross sensitivity with little temperature and humidity drift.

From a total of 17 sensors tested during the environmental test (9 humidity-, 2 CO_2-, 6 mixed-gas sensors), one was destroyed by the dry heat test at 55° C. Dry cold and humidity was o.k. for all sensors. The vibration test killed 4 sensors. Transient burst killed a couple of sensors, electrostatic discharge killed one. At the end 2 humidity sensors and one mixed-gas sensor survived the test.

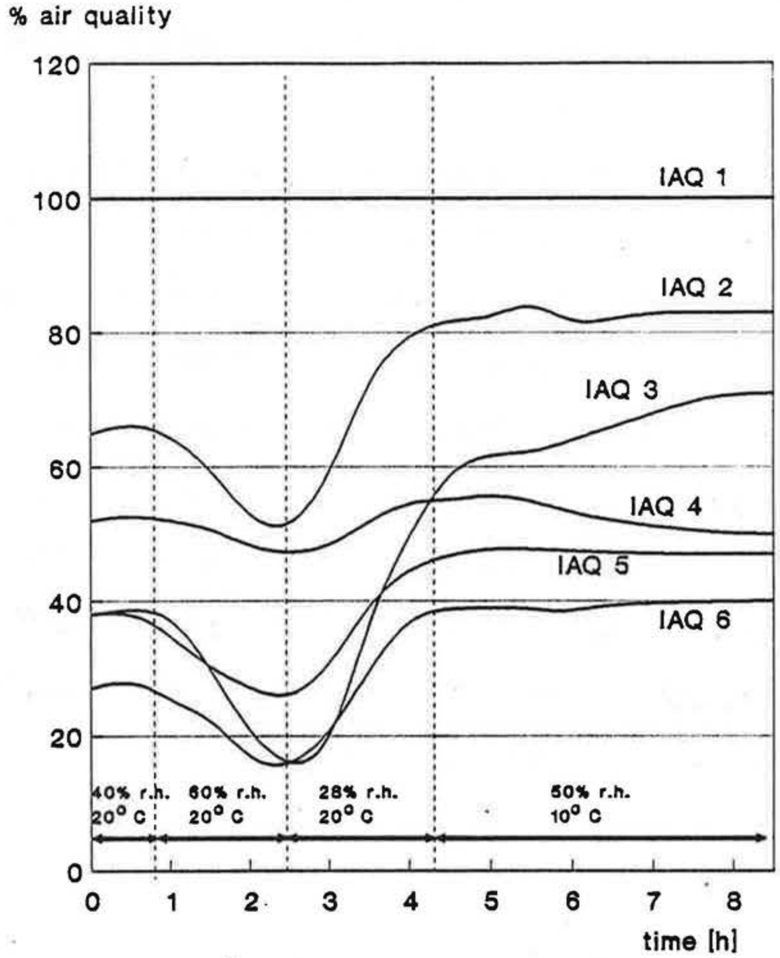

Figure 2: Drift of mixed-gas sensors against humidity changes
IAQ1-IAQ6 represent sensors from different companies

The unpredictability of the reaction of mixed-gas sensors makes its application to an experiment. Humidity dependance and long-term drift are facts. Today mixed-gas sensors are installed with success in pubs and restaurants, preferably for tobacco smoke control.

Discussion

Although big efforts are currently undertaken by some companies to improve the performance of mixed-gas sensors, there is one fact that makes all further research questionable:

> How can an IAQ-sensor be developed, if no sufficient definition exists, how IAQ is defined in terms of compositions and concentrations?

Necessary requirements. for further developments are, that indoor air constituents and their compositions are investigated with respect to the perception of the human nose. IAQ-sensor developments can only make progress when IAQ is a defined and measurable quantity. Sensor companies of today are able to develop every gas sensor which is demanded; however the necessary assumption is, that the performance of such a sensor is specified. Side effects and cross sensitivities can electronically easily be compensated, multi-sensor elements are on the market but without detailed knowledge of IAQ any progress in this field will be by accident.

Summary

The prerequisites for installing a Demand Controlled Ventilating System have been discussed. Other control strategies like time relay control, presence control, and manual control have been briefly commented. Direct IAQ-control with gas sensors is outlined. It is focussed on humidity, CO_2, and VOC-control. Sensor performance has been discussed as well as the problems in future IAQ-sensor development. The conclusion is that IAQ has to be investigated in much more detail. One goal should be to quantify IAQ in terms of constituents and concentrations with regard to the perception of the human nose, not only for single substances but also including influencing effects among substances.

ASSESSING INDOOR AIR QUALITY IN EXISTING BUILDINGS

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ABSTRACT. This paper is concerned with the information needed for planning indoor air quality (IAQ) improvements in existing buildings. This information may be obtained by IAQ measurements in a random sample of houses. In Sweden such a survey is presently being carried out. Both subjective and objective IAQ-measurements are performed. The seleced houses are also inspected on site. The statistical survey design makes it possible to obtain results from the individual houses studied with as general interpretation as possible. Moreover, the survey design gives unique possibilities for analyses of interrelations between IAQ-variables and between IAQ-variables and the technical characteristics of the houses. The experience gained in the design and execution of this survey is relevant to the CEC IAQ-research programme.

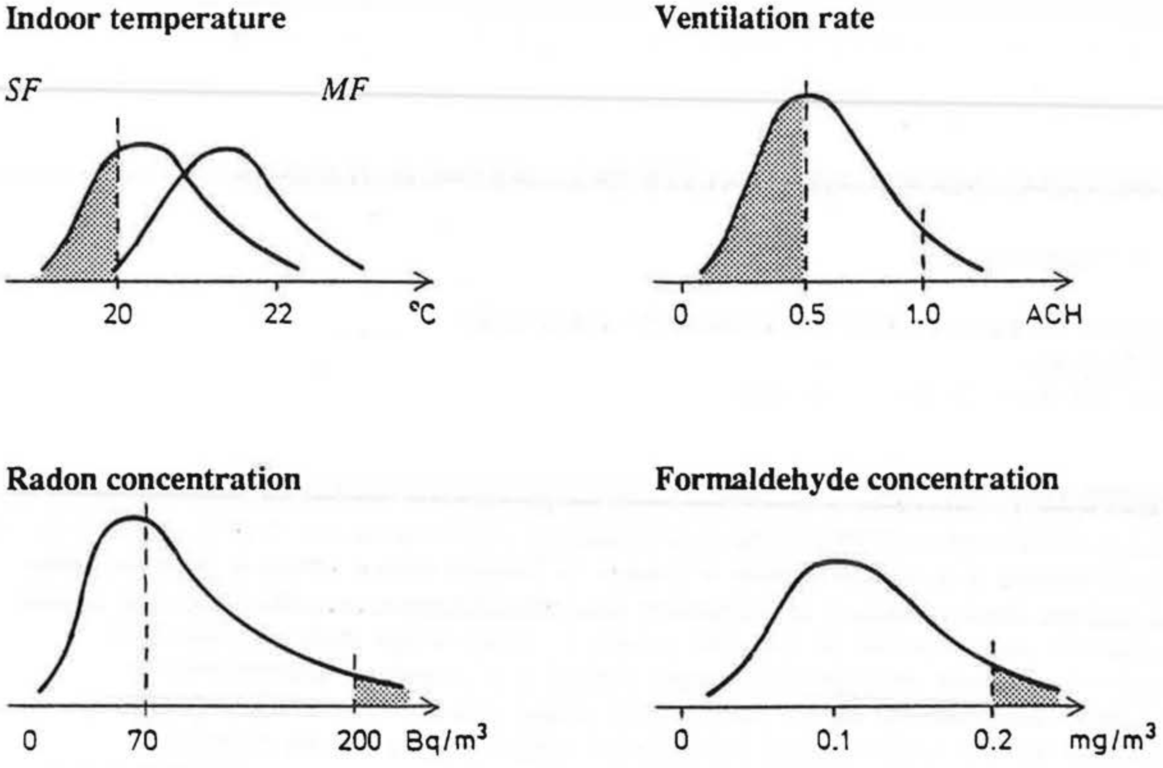
1. INTRODUCTION

In a rational system for improving IAQ in existing buildings five levels can be distinguished, *viz*. that of: (1) measurement, (2) description, (3) explanation, (4) prescription, and (5) decision making. The first level includes the whole system of different ways to collect data. The second level corresponds to the description of IAQ phenomena using measurements within a study design. At the third level one seeks to explain the phenomena, often best achieved by using a new set of measurements within another study design. The fourth level concerns medical, technical and cost considerations. At the fifth level the decisons take place.

This paper discusses the second level, that of describing IAQ. It is selfevident that all five levels closely interact. By discussing the level of description we avoid the temptation to look for a direct explanation on the basis of measurements, which would reduce the attention to systematic description.

The descriptive information required about a number of indoor climate variables might look like figure I. In the Swedish regulations it is prescribed or recommended that a number of particular IAQ-variables should not exceed, fall below or be kept within certain levels. Some of these levels are presently being discussed, *e.g.*, the prescribed ventilation level of .5 air changes per hour. For a number of variables there are no levels prescribed at all. Two resons for this are insufficient knowledge of occuring levels and dose-response relationships. The harmful health effects are known for just a few chemical substances like radon och formaldehyde. The interaction effects are often not known at all.

Figure I. Hypothesized distributions of number of houses by level of IAQ-variables. Indicated are levels presently prescribed or discussed in Sweden. SF = Single-family houses. MF = Multi-family houses



Indoor temperature

Ventilation rate

Radon concentration

Formaldehyde concentration

Additional questions to be answered in descriptions are: "Which types of houses have too high or too low levels of IAQ-varibles ?", "In which parts of the country are they located ?", "How is the level related to the ventilation level and to the technical characteristics of the house such as type of ventilation system and foundations ? ", "How is the indoor climate perceived by the residents ?", and "Which are their symptoms ?"

Thus, one should seek to combine factual information as illustrated by figure I with appurtenat information in the form of indoor climate assessments by the residents and technical characteristics of existing houses. The physical IAQ-measurements should be aggregated and broken down by, *inter alia,* type of house, age of house and type of region. The physical measurements should also be related to the type and status of the ventilation, heating and control systems and to subjective assessments of the indoor climate by the residents.

Indoor variables of prime concern are levels of indoor air temperature, ventilation, air humidity, volatile organic compounds, formaldehyde and radon.

In Sweden, indoor temperature measurements were carried out in 1982 in 144 randomly selected houses in nine municipalities. This survey showed that the indoor temperature was on the average 20.4°C in single-family houses and 21.8°C in multi-family houses (Holgersson and Norlén, 1984). A compilation of 900 ventilation measurements carried out by the National Swedish Institute for Building Research (SIB) in the 70-s and the 80-s shows that the ventilation levels are alarmingly low. On average, it takes four hours to replace the indoor air according to the measurements, which is twice as long as the time prescribed (Boman and Lyberg, 1984). Radon measurements in 750 houses, built before 1976, selected at random from the Swedish housing stock showed that the radon level was on the average 122 Bq/m^3 in single-family houses and 85 Bq/m^3 in multi-family houses (Mjönes *et al.*, 1984). Both these averages exceed the level 70 Bq/m^3 prescribed for new houses in Sweden. Besides these surveys, no other nation-wide indoor climate measurements have been carried out in Sweden.

2. THE 1991 ENERGY AND INDOOR CLIMATE SURVEY

A number of recent Swedish governmental commissions have noted a lack of descriptive information about existing houses. Specific attention is drawn to the need for improved information about their technical status, indoor climate problems and energy conservation possibilities.

To obtain one such description, a research program "Conservation of electricity in existing buildings" (ELIB) is presently being carried out by the SIB in cooperation with the Department of Occupational Medicine in Örebro and the National Institute for Radiation Protection (Andersson *et al.*, 1989).

The data requirements for this research have been integrated in a common statistical sample survey framework. The indoor climate part of the survey is discussed in this paper.

3. STUDY OBJECTIVES

Our point of departure is that the survey should produce results useful for both technical and medical evaluations of indoor climate:

For technical evaluations we are concerned with *all houses in Sweden* completed before 1989, the main volume of which serve as principal residences used for the greater part of the year. Vacant, seasonally occupied and occasionally used houses are excluded. A special operational definition of the term 'house' is used to classify each structure as consisting of one or more houses. This population of houses is divided into eight domains of study according to type of house (single-family, multi-family) and age (erected before 1940, 1941-60, 1961-75 and 1976-88). We are interested in distributions of indoor climate variables and variables describing the technical characteristics of houses.

For medical evaluations we are concerned with *residents in Sweden* living in the population of houses studied. This population of residents is divided into domains of study according to age, sex, atopic constitution, type of house and region. We are interested in distributions of their assessments of indoor climate and their symptoms.

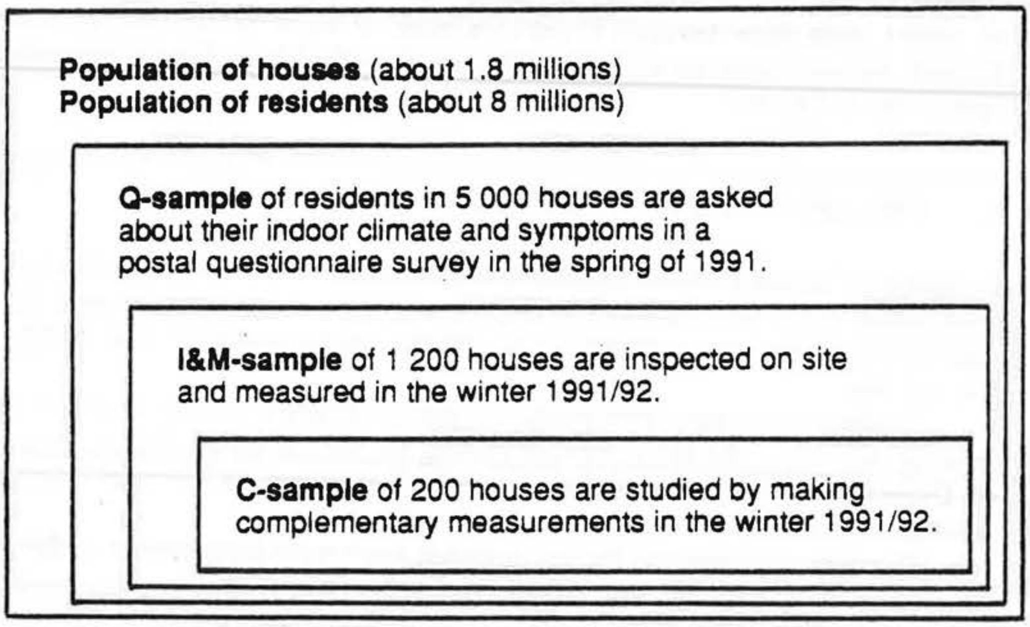
We are also concerned with inter-relations between indoor climate variables and variables describing the technical characteristics of a house.

4. SAMPLING DESIGN

The survey has been designed as a series of data-collections carried out within a statistical multi-stage sample (Norlén *et al.*, 1991). First 60 municipalities were randomly selected from the population of 284 municipalities in Sweden. A sample of 5 000 houses was then randomly selected within these 60 municipalities. Sub-samples consisting of some 1 200 and 200 houses, respectively, were then randomly selected.

The residents in the 5 000-house sample constitute a sample of individuals for a postal questionnaire. The sub-samples are used for the other data collections as described by figure II.

Figure II. Investigated populations and samples of houses and residents in the Swedish 1991 indoor climate survey.



Population of houses (about 1.8 millions)
Population of residents (about 8 millions)

Q-sample of residents in 5 000 houses are asked about their indoor climate and symptoms in a postal questionnaire survey in the spring of 1991.

I&M-sample of 1 200 houses are inspected on site and measured in the winter 1991/92.

C-sample of 200 houses are studied by making complementary measurements in the winter 1991/92.

5. SUBJECTIVE MEASUREMENTS OF THE INDOOR CLIMATE

The postal questionnaire used has been developed by Andersson *et al.* (1988). This questionnaire includes questions about the indoor climate in terms of different environmental factors and about particular symptoms.

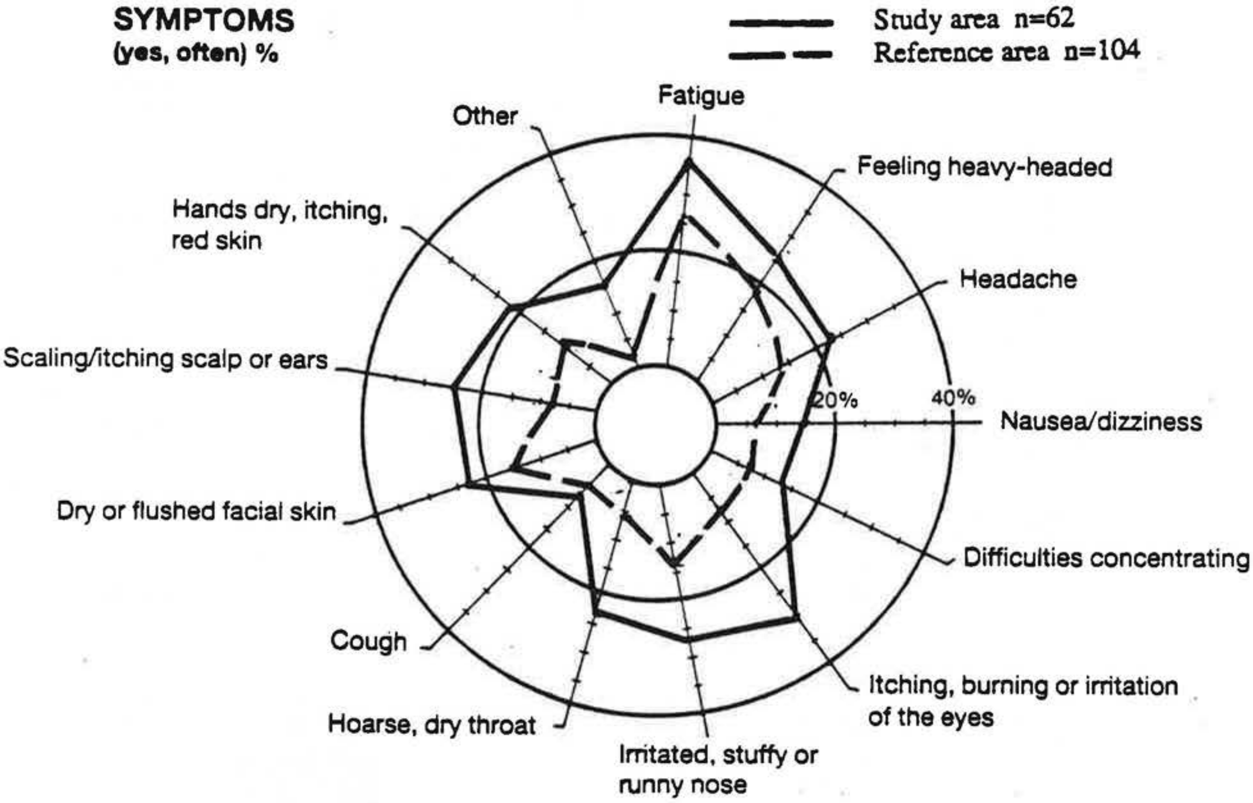
The environment questions ask: "Have you been bothered during the last three months by any of the following factors in your apartment ?" The possible categories of answers are "Yes, often" (every week), "Yes, sometimes" and "No, never". The factors queried include temperature factors, air quality factors such as "Stuffy bad air", "Dry air" and "Unpleasant odour" and more general physical factors like noise and lighting.

The symptom questions ask: "During the last three months have you had any of the following symptoms ?" The symptoms include general symptoms, mucuos membrane irritations and skin problems. The categories of answers are the same as described for the environmental questions. In connection to each symptom question, the respondent is asked to answer by "Yes" or "No" the question: "Do you believe that it is due to your residential environment ?"

Questions about medical history of atopic diseases (asthma and hey-fever) are also put. These questions are used as indicators of the atopic constitution of the respondent.

The questionnaire has been used in a large number of case studies. Figure III illustrates results from one such study.

Figure III. Results from an investigation of symptoms using a postal questionnaire. The graph illustrates a typical pattern for a "sick building" with emissions of ammonia and 2-ethylhexanol from self-levelling concrete containing casein (Andersson et al., 1990).



6. TECHNICAL MEASUREMENTS OF THE INDOOR CLIMATE

The technical measurements are all of the passive integrating type giving monthly averages of the variables. The chosen techniques are relatively inexpensive and considered to be simple and accurate enough to be used in the present large-scale survey.

The design of the instruments are shown in Figure IV. Table 1 gives some characteristics of and references to more detailed descriptions of the methods.

Indoor temperature, ventilation rate, relative humidity and radon concentration are planned to be measured in 1 600 apartments in the 1 200-house sample. Formaldehyde and VOC concentrations are planned to be measured in a 200-house subsample.

In each apartment, the variables will be measured in a number of room-units, in the living-room, in the largest bedroom and/or in the kitchen, according to detailed instructions given by the survey staff. The tubes containing tracers for the ventilation measurements will be installed close to the largest air inlets, also according to instructions.

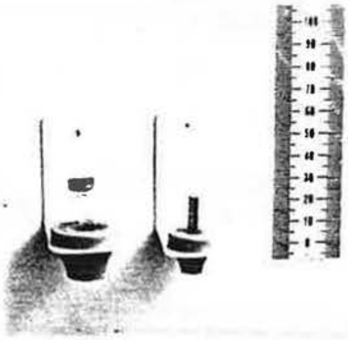
Figure IV. Measurement instruments in the 1991 Swedish indoor climate survey.

Indoor temperature [°C]

Electronic device:

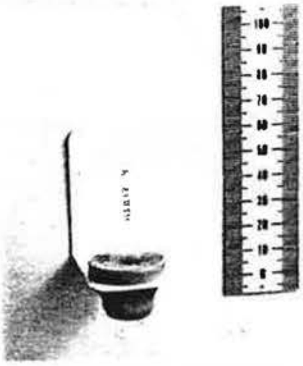
Ventilation rate [ACH]

Tube emitting the tracer (left) and diffusion sampler (right):



Relative humidity [RH]

Diffusion sampler:

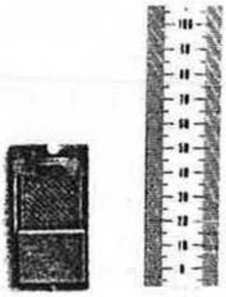


Radon concentration [Bq/m^3]

"Track sampler":

Formaldehyde concentration [mg/m^3]

Diffusion sampler:



VOC concentration [mg/m^3]

Diffusion sampler:

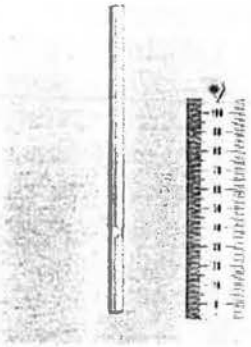


Table 1. Measurement methods in the 1991 Swedish indoor climate survey.

Variable	**Measurement method**	**Sensor, sampler**	**Comments, reference**
Indoor temperature [°C]	Continuous sampling. The total number of pulses in a register is divided by the total sampling time and converted to a temperature.	RC-oscillator circuit with an NTC resistor (in a battery driven electronic device).	The temperature dependency of the oscillator frequency and a device dependent calibration constant are used.
Ventilation rate [ACH]	Passive tracer gas method. A perflourocarbon tracer is emitted at a constant rate from a permeation tube. The absorbed amount of the tracer is analyzed on a gaschromatograph after liquid extraction.	Diffusion sampler (glass tube with charcoal).	The average ventilation rate is calculated from the absorbed amount, the known sampling rate and the tracer source strength (Stymne and Eliasson, 1991).
Relative humidity [RH]	Passive sampling of water vapour with analysis by weighting the absorbed amount of water.	Diffusion sampler (polypropylene tube with lithium chloride monohydrate).	A known linear relationship between sampling rate and RH is used (Stymne *et al.*,1991).
Radon concentration [Bq/m^3]	Passive sampling with automatic image analysis for counting of the the number of tracks.	"Track sampler" (plastic holder with CR-39).	Detectors are calibrated by exposure to an environment with known radon concentration (Mellander and Enflo, 1991).
Formaldehyde concentration [mg/m^3]	Passive sampling with analysis by liquid chromatography.	Diffusion sampler (an impregnated glass fibre plate in a plastic holder)	The principle is based on chemisorption of aldhydes on 2,4 dinitrophenyl hydrazine (Levin *et al.*, 1986).
VOC concentrations [mg/m^3]	Passive sampling. Gaschromatographic . separation after thermal desorption. Qualitative and quantitative analysis with a connected mass spectrometer.	Diffusion sampler (glass tube with Tenax).	Results are expressed in toluene and decane equivalents. The five most abundant VOCs are identified. The sum of all VOCs is also determined (TVOC).

7. INSPECTIONS ON SITE OF TECHNICAL CHARACTERISTICS

The inspections on site are based on a special inspection form. The variables recorded are type and age of the house; the heated floor area and building-volume; areas and U-values of the floor structure, the external walls, the windows and the attic; type and status of the roof, wall and foundation constructions, the ventilation system, the heating system, and the control system.

Consultants with a suitable technical background have been engaged to perform the field work. They are given training consisting of instructions on how to perform the inspections and measurements. They also perform a trial inspection and trial measurements in a house.

The average time required for an inspection, including travelling and installation of measurement instruments, is about a whole day for a multi-family house and half a day for a single-family house.

8. FIELD WORK

The field work started with the postal questionnaire survey.

According to present plans, survey inspectors then perform the inspections on site and install measurement equipment. Monthly averages of the variables are recorded. To accomplish this, the meters are demounted by the house owners after about one month and sent back to the survey staff for further processing.

The complementary measurements of ventilation rates and air tightness in the 200-house sub-sample are carried out by the energy and indoor climate measurement unit at SIB.

9. CONCLUDING COMMENTS

The survey described in this paper is an attempt to follow sound statistical and scientific methods for making inferences: (i) The sampled houses and residents are obtained by using statistical sample survey theory, (ii) the subjective measurements are carried out by using a postal questionnaire form, which have been used extensively in recent years, but not in such a large scale as in this survey, and (iii) the objective measurements are carried out by using a number of new and promising measurement techniques, which have been recently developed, but have not until now been applied in such a large scale as in this survey.

Some decisive steps in the survey are: (i) The consent of the residents to participate in the postal questionnaire of their perceived idoor climate, (ii) the interest of house owners to help the inspectors to investigate their houses and to allow allow them to install measurement instruments, and (iii) the function of the measurement instruments in residential environments.

The experience gained in the design and execution of this research is relevant to the CEC IAQ-programme. Wouters (1990) has in his proposal for this CEC-programme stressed the lack of quantitative data about IAQ. The survey described in this paper is an attempt to obtain such data.

The results from the survey in the form of: (i) Identified indoor climate problems, and (ii) relations between IAQ-problems and building technical characteristics are also of interest.

REFERENCES

Andersson G., Boman C.A., Engebeck L., Glauman M., Hammarsten S., Norlén U. and Tolstoy N. (1989): Research program for electricity conservation in existing buildings (ELIB). PM 1989-02-06. The National Swedish Institute for Building Research, Gävle /In Swedish/.

Andersson K., Fagerlund I., Bodin L. and Ydreborg B. (1988): "Questionnaire as an instrument when evaluating indoor climate". In: *Proceedings from Healthy Buildings '88.* **1.** Stockholm: Swedish Council for Building Research.

Andersson K., Fagerlund I., Löfman O. and Erlandsson B. (1990): "A follow-up questionnaire study after restoring modern dwelling with SBS problems". In: *Proceedings from Indoor Air '90.* Ottawa: International Conference on Indoor Air Quality and Climate, **1.**

Boman C-A. and Lyberg M. (1984): "Measured and building code values of air change rates in residential buildings". *Proceedings from 5th AIC conference on the implementation and effectiveness of air infiltration standards in buildings.* Oct. 1984, Reno.

Holgersson M. and Norlén U. (1984): "Domestic indoor temperatures in Sweden." *Building and Environment,* **19**, *No. 2.*

Levin J-O., Lindahl R. and Andersson K. (1986): A passive sampler for formaldehyde in air using 2,4-DNF-coated glass fibre filter. *Environ. Sci & Technol.* **20**, No. 12.

Mellander H. and Enflo A. (1991). The accuracy of the radon detectors used in the Swedish radon epidemiological study. Forthcoming in proc. from: *Fifth Int. Symposium on the natural radiation environment.* Salzburg, Austria.

Mjönes L., Burén A. and Swedjemark, G.A. (1984): Radon levels in Swedish dwellings. Report a 84-23. Statens Strålskyddsinstitut, Stockhom /In Swedish/.

Norlén U., Högberg H. and Andersson K. (1991): "A survey of the indoor climate in the Swedish housing stock". Submitted for publication in *Proceedings from Healthy Buildings-IAQ '91 Conference,* September 4-8, 1991, Washington, DC.

Norlén U., Högberg H. and Tolstoy N. (1991): "Design of a Swedish energy and indoor climate survey". Submitted for publication in *Journal of Official Statistics.*

Stymne H. and Eliasson A. (1991): Development of a new PFT-method for ventilation rate measurements. In Säteri J (ed.): *The development of the PFT-method in the Nordic countries.* Document D9:1991. Swedish Council for Building Research, Stockholm.

Stymne H., Boman C.A., Melander H., Norberg P. and Stridh G. (1991): "Methods for indoor climate measurements in large-scale surveys". Submitted for publication in *Proceedings from Healthy Buildings-IAQ '91 Conference,* September 4-8, 1991, Washington, DC.

Wouters P (1990): Proposal for a CEC DG XII programme on indoor air quality management. First draft, Dec 1990. Belgian Building Research Institute, Limelette.

Use of Tracer Gases to Assess Indoor Air Quality

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ABSTRACT: various quantities, often used to qualify the performance of the ventilation system with respect to the indoor air quality are defined, and measurements methods, using tracer gases to assess these quantities, are described. A handbook, giving the state-of-the-art of these methods is presented. Finally, some lacks of knowledge and possibilities of development are listed.

1. Introduction

The indoor air quality (IAQ) can be directly defined either through the health of the inhabitants, or by collecting their opinions, or by measuring the concentrations of the main contaminants. However, it is not acceptable to wait until a statistically significant number of inhabitants are ill before acting against a bad IAQ. On the other hand, these experiments are either too expensive or very difficult to perform. Finally, the main contaminants are often not known or not easily measurable. For all these reasons, it is useful to define indirect ways to assess the IAQ or the chances for obtaining an acceptable IAQ.

The ventilation itself can be characterized by the air flow rates or the air change rate, but the relation with the IAQ is not straightforward *[Fanger, 1988]*.

Several other physical quantities, like the age of the air or the ventilation efficiency, are used to qualify the IAQ and the performance of the ventilation system, but they are also indirectly related to the IAQ: the relation depends on the locations and strengths of contaminant sources.

Going closer to the IAQ problems, contaminants can be simulated by non-toxic, easily measurable, tracer gases. Their source strength can also be easily measured or controlled and the spreading of the contaminant can be determined.

The contaminant removal effectiveness, which tells how efficiently the contaminants are removed from a given zone, can be deduced from such simulations, as well as from direct measurement of real contaminants concentrations.

	⇓	Air change rate	⇓	
	⇓	Air flow rate	⇓	
Growing	⇓	Age of air	⇓	Growing
difficulty	⇓	Ventilation efficiency	⇓	relevance
of measurement	⇓	Ventilation effectiveness	⇓	to IAQ
	⇓	Contaminant simulation	⇓	
	⇓	Analysis of actual contaminants	⇓	
	⇓	Satisfaction of inhabitants	⇓	
	⇓	Health of inhabitants	⇓	

Figure 1: Physical quantities related to the IAQ.

Figure 1 summarizes the situation. All these quantities are measurable using tracer gases, and, since measurement methods exist, why do research in that topic? In fact, the principles of the measurement methods are known, some of them are used since years *[Dick, 1950]*, and the ventilation was measured in hundreds of dwellings. But, hundreds of dwellings are not much, the ventilation rate is not the IAQ, and measurements of quantities more directly related to IAQ are not many. Therefore, R & D is still required as well to develop the usability of the measurement techniques as to use them extensively.

2. Tracer gases

Tracer gases are gases, used in low to very low concentrations together with a suitable analyzer, to mark some air in order to differentiate it from other masses of air, or to simulate a contaminant and follow its spreading.

Good tracer gases are easily measurable in small quantities, and neither toxic nor flammable at the practical concentrations. They should preferably be cheap and not present (or only in trace amounts) in the atmosphere. An important advantage is that their source strength can be measured.

When used to mark the air, the tracer should mix easily with the air, that is should have a density close to 1 kg/m^3 and should not adsorb on building surfaces or furnitures. If the tracer is used to simulate a contaminant, it should have, as far as possible, the characteristics of the simulated contaminant, i.e. the same density and similar adsorption/desorption characteristics. The most commonly used tracers are listed in Table 1, but, since no tracer presents all the required qualities, the choice of the most appropriate tracers is always a compromise.

Tracer name	Chemical formula	Density /air @NT	Analyzer (besides MS)
Helium	He	0.14	
Neon	Ne	0.69	
Carbon dioxide	CO_2	1.53	IR
Nitrous oxide	N_2O	1.53	IR
Sulfur hexafluoride	SF_6	5.03	ECD (IR)
Freons	$C_xCl_yF_z$	3 to 7.6	ECD (IR)
Halons	$CF_xBr_yCl_z$	5 to 5.5	ECD (IR)
Perfreons or PFTs	C_xF_y	6.4 to 14	ECD

MS	Mass spectrometer
IR	Infrared absorption spectrography or photoacoustics
ECD	Gas chromatography and electron capture detector.

Table 1: Properties of the most common gases used as tracers *[from Charlesworth, 1988]*.

3. Quantities related to ventilation and their measurement techniques

3.1 Air Flow Rate, Air Change Rate and Nominal Time Constant

The air flow rate is the quantity of air flowing through a boundary (e.g. the building envelo) or in a ventilation duct during a unit period of time. Depending on the way the quantity s expressed, the volumetric or mass air flow rates can be defined. Their units are respectively [m^3/s] or [kg/s].

To measure the air flow rates, known amounts of tracer gas, S, are injected at suitable locations. When the tracer gas is well mixed to the air, its concentration, C, is directly related to the air flow rate, Q, by a mass conservation equation. In a single zone, using one tracer, this equation is:

$$\rho V \frac{\mathrm{d}C}{\mathrm{d}t} = S - \Delta C\, Q \qquad (1)$$

where:

ρ is the indoor air density,
V is the volume of the zone
ΔC is the difference in tracer concentration between the indoor and the outdoor air

The air flow rate could directly be deduced from measurements using this equation. However, since concentration, temperature and volume measurements always contain random errors, it is numerically more accurate to integrate the measurements during a time period, Δt, which is equal to one or more measuring intervals, and to calculate the average air flow rate, $\langle Q\rangle$, by:

$$\langle Q\rangle = \langle \frac{S}{\Delta C} \rangle - \frac{V}{\mathrm{d}t} \ln \left[\frac{\Delta C(t)}{\Delta C(t+\Delta t)}\right] \qquad (2)$$

where ln is for the Neperian logarithm.

Various techniques, based on that equation, are used depending on the way the tracer is injected. When $S = 0$, and using the definition of the **air change rate**†, $n = Q/\mathrm{r}V$, equation (2) simplifies and gives an unbiased estimate of an average air change rate $\langle n\rangle$ between two measurements, one at time t and the other Dt later:

$$\langle n\rangle = \frac{1}{\Delta t} \left\{ \ln \left[\frac{\Delta C(t+\Delta t)}{\Delta C(t)}\right] \right\} \qquad (3)$$

This **decay technique** is also known as the **container method.** Note that it is not necessary that the decay be exponential or that the flow rate remains constant during the measurement.

The inverse of the air change rate is the **nominal time constant** of the air, τ_n, and is equal to the time constant of the exponential decay of the concentration when the air change rate is constant.

If the tracer is injected at constant flow rate (**constant injection technique**), either the concentration growth curve or the steady state concentration, $\Delta C(\infty)$, can be used. In the last case:

$$Q = \frac{S}{\Delta C(\infty)} \qquad (4)$$

This direct solution gives the correct answer if the air flow rate is constant.

With passive samplers, accumulating by adsorption on activated charcoal the tracer contained in the air, the average concentration over a large period of time is directly measured *[Dietz, 1988]*. In this case, equation (2) is used with an average concentration at the denominator:

$$Q = \frac{S}{\langle \Delta C \rangle} \qquad (5)$$

Q is a biased estimate of the average air flow rate, this estimate being lower than the true value if the air flow rate changes with time. It is, however, an unbiased estimate of the average purging flow rate, which is the average flow rate at which the tracer is removed *[Sherman and Wilson 1986]*.

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† The air change rate is also called **specific air flow rate.** This denomination is justified by the fact that, in most cases, the air in a room is completely changed within a time period larger than the nominal time constant.

Provided the concentration remains exactly constant throughout a **constant concentration** measurement, equation (2) becomes:

$$\langle Q\rangle = \frac{\langle S\rangle}{\Delta C} \tag{6}$$

3.2 Age of Air

The particles of fresh air coming from outside or from the ventilation system arrive at a given location **r** in a room after a time τ_r which will vary from one particle to the other. τ_r is called the age of the particle, as if it were born when entering the room. Since there is a large number of air particles, we may define a **local mean age of air,** τ_r at a point r by the average age of all the air particles arriving at that point.

The **room mean age of air** $\langle\tau\rangle$ is defined by the average of the ages of all the air particles in the room.

If the air leaves the zone by a single exhaust, which is likely to be the case in exhaust ventilation systems, it is shown that the nominal time constant is equal to the mean age of air at the exhaust *[Sandberg, 1984]:*

$$\tau_n = \bar{\tau}_e \tag{7}$$

The time, τ_a, required on average to replace the air present in the space is given by:

$$\tau_a = 2\langle\tau\rangle \tag{8}$$

It has been shown that the age of air can be measured by recording the time history of the tracer concentration, $C_r(t)$, at any point, r, by either of three strategies as follows *[Sandberg and Sjöberg, 1982]:*

- uniform concentration of tracer is achieved at the beginning of the test and no injectio during the test (decay),
- the tracer is injected at a constant rate throughout the test at the air inlet,
- a short pulse of tracer is released at the air inlet.

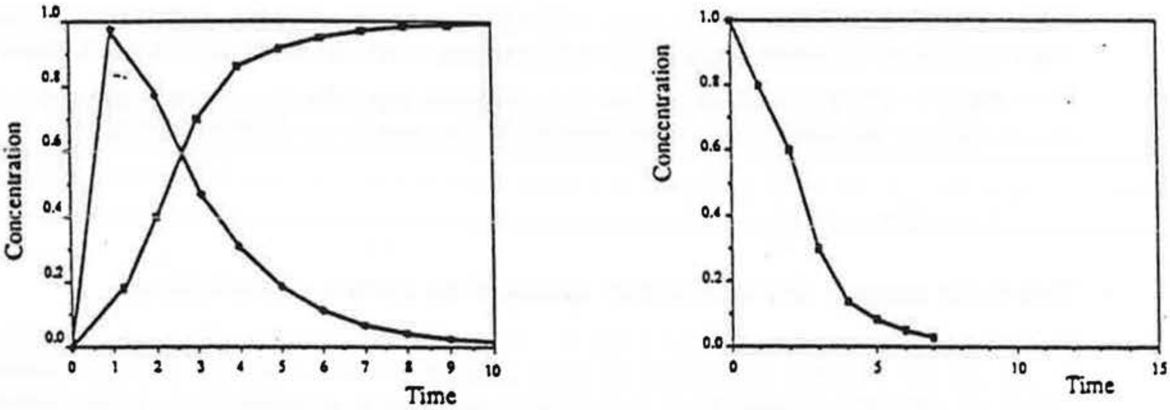

Figure 2: Concentration versus time for an age of air measurement using the pulse and t constant injection method (left) or the decay method (right).

The last two methods assume a single, known, air inlet. The tracer concentration in the supp air should also be measured. The local mean age at a given measurement location is obtain by numerical integration of the concentration histories.

3.3 Air Exchange Efficiency

This efficiency expresses how the fresh air is distributed in the room. At a given flow rate and space volume the shortest time required to replace the air within the space is given by the nominal time constant.

The air exchange efficiency, η_a, is calculated, from measured values of τ_n and $\langle\tau\rangle$ by:

$$\eta_a = \frac{\tau_n}{2\langle\tau\rangle} = \frac{\tau_n}{\tau_a} \qquad (9)$$

The air exchange efficiency is equal to one for piston-type ventilation whereas for complete mixing it is equal to 0.5. Short circuiting of air will give rise to an efficiency which is lower than 0.5.

A more detailed review of the concepts described above is given by Sutcliffe *[1990]*.

4. Quantities related to IAQ and their measurement techniques

The relation between the age of air or the air exchange efficiency and the IAQ is not straightforward, but it is likely that the older the air or the lower the air exchange efficiency, the worse is the IAQ. In order to assess more directly the IAQ, quantities closely related to contaminant concentrations should be defined and measured. These concepts are reviewed in very details by Brouns *[1991]*.

4.1 Turn-over Time of a Contaminant

This time constant is defined in a way similar to the nominal time constant. Given a contaminant source of strength S and a volume of contaminant in a zone, v, the turn-over time of this contaminant is:

$$\tau_c = \frac{v}{S} \qquad (10)$$

The equilibrium volume of contaminant, v, is related to the concentration at steady state, $\langle C_\infty\rangle$, and to the volume of the zone, V, by:

$$v = \langle C_\infty\rangle V \qquad (11)$$

4.2 Ventilation Effectiveness

The ventilation or pollutant removal effectiveness expresses the efficiency in extracting the contaminants generated in the rooms, and is generally defined as the ratio of two net concentrations:

$$\varepsilon_c = \frac{C_e - C_o}{C_r - C_o} \qquad (12)$$

where

C_e is the contaminant concentration in the exhaust air,
C_o is the contaminant concentration in the outdoor air, and
C_r is the contaminant concentration at the location of interest, $\boldsymbol{r}$.

The location of interest can be:

- any particular location $\boldsymbol{r}$, the result being $\varepsilon_c(\boldsymbol{r})$
- the location with the highest contaminant concentration, which gives the lowest ventilation effectiveness, $\varepsilon_{c,min}$

- all the space, by taking the average concentration $\langle C_r \rangle$ over the space. The result will then be the average ventilation effectiveness, ße$_c$

The ventilation effectiveness is zero if there is a short cut between exhaust and inlet grilles ($C_e = C_o$), it is equal to one for complete mixing ($C_e = C_r$) and is infinity at the locations reached by pure fresh air ($C_r = C_o$).

It is shown that the average ventilation effectiveness is also the ratio of the nominal time constant to the contaminant turn-over time *[Sandberg and Sjöberg, 1984]:*

$$\langle \varepsilon_c \rangle = \frac{\tau_n}{\tau_c} \tag{13}$$

4.3 Contaminant Removal Efficiency

This efficiency is directly derived from the ventilation effectiveness:

$$\eta_c = \frac{\langle \varepsilon_c \rangle}{1 + \langle \varepsilon_c \rangle} \tag{14}$$

$\eta_c = 0.5$ for complete mixing, has a maximum value of 1 for perfect piston flow and is less that 0.5 in case of short circuits.

4.4 Purging Flow Rate

The purging flow rate is the flow rate, U, at which the contaminant is eliminated *[Sandberg, 1984]:*

$$U = \frac{S}{C} \tag{14}$$

Depending on the location where the concentration is measured, this flow rate can be estimated instantaneously and locally, or averaged over the space of interest, giving $\langle U \rangle$, or over time, giving $\bar{U}$.

Using the definitions of τ_n and τ_c:

$$\langle \varepsilon_c \rangle = \frac{M}{Q} \frac{S}{m} = \frac{\langle U \rangle}{Q} \tag{15}$$

since, by definition, $\langle C \rangle = m/M$. So the average ventilation effectiveness is also the ratio of the room average purging flow rate to the fresh air flow rate. In other terms, the purging flow rate is the air flow rate multiplied by the ventilation effectiveness.

5. Measurement Techniques Handbook

The state of the art of the measurement methods using tracer gases (as well as other methods like those detecting and measuring leakages or measuring air flow rates in ducts or in buildings) is presented in a comprehensive handbook presently drafted within the IEA-ECB research program, Annex 20. This 300 pages handbook is divided into six parts:

Part I defines the important parameters, presents the reasons why they should be measured and gives a guide to the selection of techniques for particular applications. Summaries of the main techniques available are presented, which are cross referenced with the main body of the guide.

Part II presents the theory and practice of measuring the airtightness of the building envelope and its components. Leakage location and leakage path distribution within the building is also examined.

Part III presents the theory and practice of measuring air flow rates and the related contaminant flow rates. Air exchange between a building and the external environment is examined, as is the air exchange between the various internal spaces of a building.

Part IV presents some measurement methods which may be useful to qualify the indoor air and the efficiency of the ventilation system. This part is the most directly related to IAQ.

Part V describes measurement methods to measure the flow rates in ventilation networks and to control their tightness.

Finally, appendices are provided either to give informations on general tools - as units transformations, error analysis, identification methods - or to lighten the main text of informations which may be useful only to specialists.

A CEC IAQ project could start from this base and improve the usability of selected methods, those which can help in detecting and solving IAQ problems.

6. Lacks of Knowledge and Possible Improvements

6.1 Knowledge of the Ventilation Performance in Buildings

The lack of proper ventilation is often mentioned as an important cause of the sick building syndrome or of poor indoor air quality. However, until now, only a few buildings or dwellings were measured for the performance of their ventilation systems[‡], and most of these are located in Nordic countries *[Kvisgaard, 1985, Säteri et Al, 1991, Bergsoe, 1991]*. Therefore, no statistically significant information is available at the European scale.

Moreover, it should be mentioned that most of the few mechanical ventilation systems on which measurements were performed were not functioning as planned *[Kvisgaard & Collet, 1987, Roulet et Al, 1990]*. The potential in improving IAQ and energy saving seems to be very important in that domain. In order to be able to improve such systems, one should first know how they perform. Measurement techniques may be of great help in this task.

6.2 Implementation of Measurement Techniques

During the last 5 years, considerable improvements were brought to tracer gas measurement techniques. These improvements are as well theoretical, such as sophisticated techniques for interpreting the measurements, as at a practical level, like the development of new instruments or analysis techniques.

This great but fast development has its counterpart: not much time and effort was left to the applications. Very few instruments were built in series and applied on a large scale. In fact, most of the instruments and techniques were developed for research use, and it appears that only one tracer technique is cheap enough to be applied on the field at a large scale, i.e. for thousandth of measurements. This is the passive technique using PFTs.

6.3 Passive Tracer Gas Technique

This techniques uses a sampler containing an adsorbent trapping the tracer diluted in the air around the sampler. After a given period of time, this sampler has accumulated a dose of tracer, which is analyzed and quantified in the laboratory using a gas chromatograph with an electron capture detector *[Dietz, 1988]*.

[‡] In this contribution, a ventilation system is any system used to air the building. Natural ventilation is also included as a "system".

The tracers used are perfluorocarbons (PFT), which can be analyzed in minute amounts (10^{-14} g) and the background concentration is of the same order of magnitude. The required tracer concentration in the air is therefore very small, and the material cost are very low. Since there are several such PFTs, as well inter-zonal air flows measurement as multiple contaminant simulation can be performed.

These tracers can be injected in a pulse with a syringe or, for long term measurements, can be diffused at nearly constant injection rate by passive effusion cells. Both effusion cell and passive samplers can be mailed, but separately.

For all these reasons, the PFT technique appears to be the only one which can be applied in the field on a large scale. The laboratory analysis, however, requires not only a special, sophisticated material but also skilled and trained personal.

6.4 For an European PFT Network

Few European laboratories will perform or are performing measurements using the PFT techniques. These are located in the following countries: Denmark (Building Research Institute), Finland (Helsinki University of Technology), France (Laboratoire National d'Essais), United Kingdom (Building Research Establishment), Sweden (National Swedish Institute for Building Research) and Switzerland (LESO-EPFL). The state of development is however much more advanced in Nordic countries and some of these labs, like the Swiss one, are still developing the technique.

Following P. Wouters *[1990]*, it is proposed to organize the European "PFT laboratories" in a cooperating network, maybe with the addition of one or two more locations. This coordination will help to fill-up the lack of knowledge mentioned under 6.1, since:

- the techniques of these laboratories will be improved by exchange of knowledge in very detail,
- the laboratories which are still under development will reach a performing level earlier,
- inter-laboratory comparisons will increase the confidence in calibration of the instrumentation,
- each European country or region will have a laboratory able to perform such measurements at a reasonable price (order of magnitude: 100 ECU for one measurement),
- within a few years, much statistical knowledge will be collected and should be stored and analyzed in a central place.

7. Conclusions

Tracer gas measurement techniques have proven to be useful for assessing physical quantities related to indoor air quality. Moreover, harmless, easily analyzable tracer gases can be used to simulate more dangerous and difficult to measure contaminants.

These techniques are however not enough implemented and not broadly used and, therefore, ventilation systems are not properly commissioned, actual ventilation in buildings is not really well known and the causes invoked to explain a poor IAQ may be the wrong ones.

As a small contribution to improve that situation, it is proposed to create a European network of laboratories, able to perform numerous and relatively cheap measurements of air flow rates and to simulate the spreading of contaminants within buildings.

8. References

ASTM E 741-83: Standard Test Method for Determination of Air Leakage Rate by Tracer Dilution. *Annual Book of Standards, American Society for Testing Materials, Philadelphia, PA, 1988.*

Bergsoe, N. [1991]: Investigations on Air Change and Air Quality in Danish Dwellings. *in: The Development of the PFT Method in Nordic Countries, J. O. Säteri, ed. Swedish Council for Building Research, Stockholm, 1991.*

Brouns, C. [1991]: A Guide to Ventilation Effectiveness. *Technical Note, AIVC, Bracknell, Berkshire RG124AH, GB, 1991.*

Charlesworth, P. S. [1988]: A Guide to Air Exchange Rates and Airtightness Measurement Techniques. *Air Infiltration and Ventilation Center (AIVC), Warwick (UK), 1988, # 2682.*

Dick, J. B. [1950]: Measurement of Ventilation Using Tracer Gas. *Heating, Piping and Air Conditioning 22, No 5, 1950, # 149.*

Dietz, R. N., [1988]: Overview of Tracer Technology Instrumentation for Short-term and Real-time Building Ventilation Determinations, *AIVC Measurement Techniques Workshop, Technical Note AIVC 24, Bracknell, UK, 1988.*

Fanger, P. O. , Lauridsen, J., Bluyssen, P. and Clausen, G. [1988]: Air Pollution in Offices and Assembly Halls Quantified by the Olf Unit. *Energy and Buildings, 12 (1988), pp 7-19.*

Kvisgaard, B. [1985]: The User's Influence on Air Infiltration. *Air Infiltration Review 6, pp 1-4, 1985. AIVC, Bracknell, UK.*

Kvisgaard, B. and Collet, P. F. [1987]: Tracer Gas Used to Evaluate HVAC Equipment. Proc. of the 8th AIVC Conference. *AIVC, Bracknell, UK, 1985.*

Roulet, C.-A. and Vandaele, L. [1991]: Air Flow Patterns in Buildings-Measurement Techniques. *Technical Note, AIVC, Bracknell, UK. 1991.*

Roulet, C-A., Compagnon, R., Jakob, M. [1990]: Planning of Experiment to Measure Ventilation Efficiencies. *IEA-ECB Annex 18 report, LESO-EPFL, Lausanne, 1990.*

Säteri, J. O., Ruotsalainen, R. O., Jyske, P. [1991]: Integrating Ventilation Measurements in Finnish Residences. *in: The Development of the PFT Method in Nordic Countries, J. O. Säteri, ed. Swedish Council for Building Research, Stockholm, 1991.*

Sandberg, M. and Sjöberg, M.[1982]: The Use of Moments for Assessing Air Quality in Ventilated Rooms. *Building and Environment 18, pp 181-197, 1982.*

Sandberg, M. [1984]: The Multi-Chamber Theory Reconsidered from the Viewpoint of Air Quality Studies. *Building and Environment 19, pp 221-233, 1984.*

Sherman, M. H. and Wilson, D. J. [1986]: Relating Actual and Effective Ventilation in Determining Indoor Air Quality. *Building and Environment 21, pp 135-144, 1986, #2456.*

Sutcliffe, H. C. [1990]: A Guide to Air Change Efficiency. *AIVC technical note 28, Bracknell, Berkshire RG124AH, GB, 1990.*

Wouters, P.: Proposal for a CEC DG XII Programme on Indoor Air Quality Management. *First draft, December 1990, presented at a CEC preparatory meeting in Brussels, on 11 Feb. 1991.*

CEC WORKSHOP ON INDOOR AIR QUALITY MANAGEMENT
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HOW TO MEASURE INDOOR AIR QUALITY?

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Abstract

Indoor air is a complex phenomenon and difficult to measure or describe. Several measuring techniques are available to assess parameters of the indoor environment which are suspected to influence Indoor Air Quality (contents and characteristics of indoor air, indicators of latent sources, ventilation measuring techniques). Other measuring techniques are developed to register the consequences that Indoor Air Quality can have for people (questionnaires, medical examination, clinical studies). A technique which has been developed the latest is the use of an untrained or trained panel to evaluate perceived air quality. In this technique the human nose serves as the instrument to quantify Indoor Air Quality.

The state-of-the-art of methods to assess Indoor Air Quality is presented and future research is proposed.

Introduction

Indoor air is a complex phenomenon and many variables of the indoor environment as well as the outdoor environment determine the contents and characteristics of indoor air.

To define the quality of indoor air is a difficult task. ASHRAE (1) defines acceptable Indoor Air Quality (IAQ) as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction". This definition approaches IAQ from the human as well as the air point of view. Quality is here a combination of the contents of the air and the response from people exposed to that air.

The quality of indoor air has been determined with different measuring techniques which can be divided in three main categories:

a. measuring techniques concentrating on the human being,
b. measuring techniques considering the air,
c. and measuring techniques combining a and b.

Besides these measuring techniques other methods have been used. For example the indication of latent sources of pollution and ventilation measuring techniques.

STATE-OF-THE-ART

The human being

Several measuring techniques which are concentrated on the human being are available. These techniques registrate the response of exposed people or examine the human body and its fluids. An indication of the air quality the persons were exposed to can be given in the form of prevalence of symptoms, acceptability, measurable contaminants in the body fluids or prevalence of exposure to specific sources.

Questionnaires given to occupants of the investigated buildings, medical examination and biological monitoring of body fluids of exposed people, and the response of visitors of the investigated buildings, all belong to this group of measuring techniques.

Questionnaires

Many questionnaires have been used to investigate the working conditions of the office environment. A questionnaire generally comprises questions about the indoor air quality and the symptoms which might be caused by the indoor air (e.g. SBS symptoms). A.Hedge compared eight questionnaires on their defining symptoms as work-related, on their scaling of responses and on their range of symptoms (2). He concluded that there is a considerable variation in the range of symptoms covered by the 8 questionnaires, in whether symptoms are defined as work-related, and in the type of response scales used. Comparisons of prevalence between studies can therefore be misleading. A standardized questionnaire for evaluating SBS symptoms in offices is however under development (2).

According to Berglund and Lindvall (3) two principle approaches of questionnaire surveys exist. A list of questions constituting an attitude scale to obtain e.g scores of annoyance or discomfort, or self-rating questions to obtain direct estimates of perceptions or symptoms. They advise to adopt a master scale based on defined reference stimuli and an adequate stimulus calibration procedure.

An interview per telephone is a questionnaire as well. Jenkins et.al. (4) made telephone interviews with 1780 respondents (11 years and older) in which a 24-h recall diary of activities and locations, and the use and proximity of potential pollutant sources was determined. With this information it is possible to determine exposure estimates by population subgroups (age, gender, employment, status, income, ..) which can lead to more effective strategies for risk estimation.

Medical examination

Medical examination of an exposed person can be a diagnosis of allergy, hyper-reactivity, irritation, or a diagnosis of a characteristic disease (lungcancer, influenza, etc..). Diagnosis of headache, fatique and general malaise are difficult to determine with a medical examination. When a diagnosis is made a possible cause can be determined and therefore an indication of the indoor air quality the person was exposed to.

A diagnosis of allergy and hyper-reactivity can be established by several tests (5). Exercise-induced asthma as a measure of bronchial hyper-reactivity can be used to confirm the diagnosis in suspected asthmatics (examined in a symptom-free period). Bronchial provocation with metacholine or histamine can be used as a test for non-specific hyper-reactivity (in a symptom-free period). The number of blood eosinophils can depict the severity of an allergic inflammation and the size of the organs involved (eosinophilia is highly characteristic of allergy and allergic-like

diseases but is not pathognomonic). And the level of serum IgE can predict the development of allergy in the first years of life. Another test is the immediate wheel and flare reaction to an allergen tested on the skin. This is a measure of mast-cell fixed IgE antibody. The radio allergo-sorbent test (RAST) is a laboratory test for the determination of circulating IgE-antibody (when a confirmatory test is indicated, RAST is prefarable to skin testing), and bronchial allergen provocation testing is used when an extract is not available for skin testing and RAST.
A diagnoses of sensory irritation, due to chemical activation of the trigeminus nerve located in the eye and the nose, can be made by reflex-induced tear production, eye blinking and respiratory frequency (6). Further external eye examinations can be the appearance of foam at the eye lid or corner of the eye, semi-quantitative measurements of the pre-corneal superficial lipid layer, time interval registration from the conclusion of a blink to the occurence of tear film fracture (break-up time), and lissamine green stinging of conjuctival epithelial damage (7).
Lung function measurements can be vitalograph spirometry measurements (forced expiratory volume in first second, forced vital capacity) and mini-Wright peak expiratory flow measurements (7).

Body fluids
Analysing body fluids of a person to detect previous exposure to pollutants is another way of determining the indoor air quality. Breath, blood, hair, feces and urine samples have been investigated. Breath measurements can reflect long-term repeated exposure but also short-term peak exposures to volatile organic chemicals (8). Urine samples have been taken to detect nicotine and cotinine as markers for exposure to tobacco smoke (9) but also to measure the chromium content as an index of exposure (10). Blood collection is an invasive and more complex procedure than breath or urine sampling (8).
Measurement of antigenes in surrounding air is done by analysing serum of a patient. With immuno-chemical techniques, e.g. radio immuno-assay (11) or ELISA-inhibition (12), it is possible to measure the exposure to specific allergens in the air. These techniques are better in determining the actual exposure to allergens then the amount of dust in the air or microorganisms per m^3. They are still however, in the stage of development and not usuable unless a specialised laboratory is available.

Response of visitors
The response of visitors when entering a building can determine the indoor air quality either in acceptability or in decipol. Untrained visitors can judge the air on its acceptability (13) while trained visitors can judge the air in decipol (14).
According to ASHRAE (1) the air can be considered free of annoying contaminants if 80% of a panel of at least 20 untrained observers deems the air to be not objectionable under representative conditions of use and occupancy. An observer should render a judgement of acceptability within 15 seconds. Each observer should make the evaluation independently of other observers and without influence from a panel leader.

Air

Measuring techniques which consider the air can be divided into those which measure the contents of the air and those which characterize the air.
The physical characteristics of air are mainly the temperature, the

velocity and the relative humidity. Methods and instruments to measure these physical quantities are well described in the International Standard ISO 7726 (15).
In Table 1 the main groups of pollutants found in the indoor air are presented. For each pollutant group different measuring techniques are available.

Table 1 Main groups of Indoor Air Pollutants

chemical:	gases and vapours inorganic: NO_x, SO_x organic: VOC, CO, formaldehyde particulate matter: asbestos, RSP, PM10 radioactive particles/gases (radon & radon daughters)
biological:	microorganism, mould, fungi, pollens, mites, spores, allergens, bacteries, airborne infections, droplet nuclei, house dust, animal dander

Depending on the pollutant sampled a sampling procedure has to be selected. Parameters as sampling duration, sampling points, location, frequency and time of sampling are hereby important (16). Continuous monitoring and integrated sampling of the pollutant(s) during normal exposure conditions or during "worst-case" conditions (e.g. minimum ventilation or maximal source contribution), and short term sampling during "worst-case" conditions, are generally applied procedures (17). The sampling objective determines the procedure to be followed (16).

Particles

Particles are defined as aerosols (dust) when they are smaller than about 200 µm and larger than 0.01 µm. Smaller particles have the characteristics of gas. Larger particles are too heavy to stay suspended and will not be inhaled. The applied sampling method depends on whether the concentration is expressed gravimetric (mg/m^3, $\mu g/m^3$) or numerical (e.g. $fibers/m^3$), on which part of the particle spectrum has to be measured, and on the required average sampling time. Inhalable particles which can reach the pharynx have a maximum size of 200 um. Particulate matter smaller than 10 um (PM10) can reach the larynx and the thorax, and respirable particles can go as far as the alveoli in the lungs (e.g. asbestos fibers) (18).
To determine the gravimetric concentration of dust a specific air quantity is led through a filter. The amount of dust that remains on the filter is determined by weighing the filter on a micro-balance before and after the sampling. The difference in weight divided by the total amount of air that has passed the filter results in the dust concentration. Filters used the most are glass-fiber filters, polystyrene-fiber filters, membrane filters and nucleopore filters. The air flow through the filter, the amount of air, the shape of the suction opening, the orientation of the opening and the air velocity and flow direction of the air in the sampled space, are all parameters which can influence the determined dust concentration.
When the respirable fraction of dust has to be sampled a separator is used to remove 50% of the particles larger than or equal to 5 µm and all particles larger than or equal to 7 µm. A small change in the air flow rate will however change the penetration effect of the separator. Another separator is used when the particulate matter (PM10) has to be sampled.
The numerical concentration of for example asbestos fibers can be determined with the use of a membrane filter. After the sampling the filter

is made transparent and the particles are counted using a microscope.
The continuous monitoring dust meters which are used most widely are the aerosol-photometer or tyndall-meter (based on light scattering by particles; light pulses are transformed into an electrical signal depending on particle size and other characteristics of the particles), the beta-particle monitor (which measures the attenuation of beta radiation by a filter before and after sampling with that filter; the difference in radiation is directly related with the mass of the collected particles), and the piezo-balance, which contains a quartz cristal brought into resonance with an oscillator (the frequency adjustment required to bring the cristal into resonance is directly related to the amount of dust collected on the cristal). The last monitor is also available as a portable version.
Recommended conditions for sampling asbestos fibers and suspended particulate matter are given in (16).

Bioaerosols

Bioaerosols are usually sampled on a solid medium (morphiological determination). During the incubation the living microorganisms can grow into countable colonies. Different organisms require different incubation conditions so several methods are available. Non-colony forming bioaerosols require other biochemical methods (19). Malt Extract Agar (MEA) is a common used medium in aerobiological studies (20). Depending on the expected pollution other media can be used.
Suction devices with different kinds of filter materials are frequently used for the sampling of airborne allergens. The sampled particle size depends on the cut-off (seperator) for the filter material. Some suction devices combine suction with the principle of adhesion to a sticky surface (especially used in sampling of pollens and spores). The air sampling devices which are used most widely are the Andersen N-6 sampler and the Reuter Centrifugal air Sampler (RCS) (21).
Another method for sampling of indoor allergens is vacuum cleaning together with extraction of the dust samples. This method gives an indirect description of the possible aeroallergens in the environment and has been widely used in the detection of house dust mites and allergens of animal origin.
In general three basic techniques are used to describe the sampled material (22). Recognition of complete particles by light microscopy (e.g. whole house dust mites, whole pollens and whole mould spores), immuno-chemical analysis of sampled materials by radio immuno-assays or enzyme immuno-assays (an exposed person provides some grams of vacuum cleaner dust for the laboratory, where the allergenic molecules are extracted and identified (5)), and the measurement of the enzymatic activity of the sampled materials itself (e.g. guanine or protease activity in house dust mite samples).

Gases

Many gases are present in the indoor air. Some of them organic, others inorganic. Depending on the sampling objective these gases are monitored following different procedures. For some of them threshold limit values have been determined (23) and the measured concentrations can therefore be compared to those.
The most common measured gases will be discussed here.
Carbon monoxide (17) can be monitored continuously with electrochemical oxidation and with the measurement of the extinction of light with a specific wavelength in the infrared spectrum (infrared spectrophotometry

and MIRAN-broad spectrum infrared analyser). Gas detection tubes will result in a concentration at a specific moment.

Nitrogen oxides (17) can be monitored continuously with monitors based on a chemo-luminescention principle, and by infrared methods (f.e. MIRAN). Week averages can be determined with Palmes-diffusion tubes (NO_2 is sampled in the coating of a raster that is placed in a plastic tube and colorimetric analysis is performed in the laboratory). In The Netherlands the determined concentration is compared with reference values to see if the determined value deviates from normal (24). For detection at a specific time gas detection tubes can be used (relatively high detection level). Recommendations on sampling conditions for nitrogen oxides are given by (16).

A working group of WHO categorized the entire range of organic indoor pollutants in four groups (25): Very Volatile Organic compounds (VVOC) (boiling point < 0 to 50-100 degree Celcius), Volatile Organic Compounds (VOC) (boiling point 50-100 to 240-260 degree Celcius), Semi Volatile Organic Compounds (SVOC) (boiling point 240-260 to 380-400 degree Celcius) and particle bound organic matter (pom) (boiling point > 380 degree Celcius).

Three different principles have been applied to sample VOC (26). The grab method in which a whole-air sample is taken by either opening the valve of an evacuated cylinder or pumping air into it. Active sampling in which a specific amount of air is drawn by a pump through a solid or liquid sorbent. And passive sampling which is based on the diffusion of VOC from the entrance opening of a sampling cylinder to the surface of a sorbent.

The most widely used procedure for sampling VOC is to pass a suitably large volume of air through a solid sorbent material that retains the compounds of interest. The types of sorbents used most are organic polymer resins (e.g. Tenax) and carbon based sorbents (e.g. activated charcoal). Cleaning of sorbent samplers is hereby important. However, even after careful cleaning artifacts may occur due to impurities or thermal decomposition of the sorbent or due to reactions of sampled species among themselves or with the sorbent. Because of increased concerns over the reliability of tenax-based VOC data, the U.S. Environmental Protection Agency (EPA) is adopting integrated whole air sample collection systems for VOC analysis. Whole air samples are collected in stainless steel canisters with highly polished inner walls to prevent adsorption of impurities and degradation of collected components (26).

Recommendations for sampling VOC are given by (16).

Identification of VOC, usually including the separation of a mixture of pollutants, is mostly performed in the laboratory and therefore complex and expensive instrumentation may be used like high resolution gas chromatography (HRGC), high performance liquid chromatography (HPLC) and mass spectrometry (MS) (26). Three ways to introduce samples to the separation/identification equipment are generally available: direct injection of a part of a grab sample or an absorption liquid into a HRGC or HPLC system; solvent extraction of VOC from an absorption liquid or a solid sorbent and injection of a fraction of the extract into the HRGC or HPLC system; and thermal elution of the sorbed VOC from a solid sorbent by means of a pure carrier gas, usually helium.

Most SVOC are very toxic compounds. Sampling devices with low detection levels are therefore required. Tenax and activated carbon are not suitable as sorbents for SVOC. Specially manufactured polyurethane foam (PUF) which has good absorption characteristics can be applied (17).

Pom compounds are usually sampled by glass-fiber- or paper filters (17).

Sampling of VVOC is difficult. A bag of aluminium with an inert inside

(teflon) is sometimes used. An alternative is the use of a portable gaschromatograph (17).
Formaldehyde is a polar organic compound and an aldehyde. Other aldehydes of interest are acroleine, acetaldehyde and benzaldehyde. A standardized sampling procedure for formaldehyde exists in The Netherlands (27). All used sampling methods are based on wet gas cleaning with a liquid in which formaldehyde reacts with an organic compound. Some methods then determine the concentration colorimetric. Others seperate the different aldehydes with gaschromatography or HPLC. Recommendations for the conditions under which the sampling of formaldehyde vapours in indoor air should be carried out are given in (16). A guideline for the determination of the emission of wood based materials is available (28).

Radon originates from the radioactive decay of uranium. Radon can be measured by integrating methods, like solid nuclear track detectors in a filtered cup, charcoal with/without TL-dosemeters and passive radon monitors, by continuous monitoring of radon daughters on a filter measured by a semiconductor, and by equipment for instantenuous measurement of radon daughters (29). Recommendations on the conditions for sampling radon in indoor air are given by (16).

Air and the human being

Epidemiological and clinical studies are measuring techniques which consider the air and the human being. Epidemiological studies study the incidence of disease in a population and its relation to environmental factors. Clinical studies generally establish acceptable levels of exposure of humans to air pollutants (30).
An example of an epidemiological study is the Danish Town Hall study (31). It contained a questionnaire study, a medical examination and an indoor climate study in which the characteristics and contents of the air were determined. Such investigations make it possible to determine relations between prevalences of work-related symptoms and the contents of the air.
Interpretation of the results is however complicated. It is often difficult to attribute effects observed in populations exposed to air pollution, to one contaminant. Exposure burden can vary greatly between individuals. Confounding variables as socio economic status, smoking and meteorological factors play a role as well.
Clinical studies are generally conducted in laboratory environments and are most suitable for developing short-term exposure limits. Olfactometry, the controlled presentation of odorants and the registration of the resulting sensations in humans (32), is an example of a clinical study. Olfactometry has several objectives. Two of them are: to determine the power of the human sense of smell, with known concentrations serving as defined stimulus intensities, and to determine unknown odorant concentrations with the human sense of smell as the detector. Odour annotated chromatograms, odour characterisation, odour intensity determination, determination of odour acceptability and odour threshold, are different techniques of olfactometry (33). Animal studies, another form of clinical studies, are useful for the prediction of irritating effects in humans. The results can help in the identification of target organs and systems, in the clarification of mechanisms of toxity and in the assessment of carcinogenicity. Irritating effects in animals can be measured by the electrical activity in the trigeminal nerve branches, by escape behaviour or by the reflex-induced decrease in respiratory rate (6).

Other methods

Other methods of measuring or indicating indoor air quality are indicators of latent sources, general "indicators" of Indoor Air Quality, visual inspection of the building with the help of a checklist, and theoretically proposed indicators or models of Indoor Air Quality.

Two indicators of latent sources were proposed by Nielsen (34): the fleece-factor, defined as the area of all textile floors, curtains and seats divided by the volume of the room, and the shelf-factor, defined as the length of the all open shelves and cupboards divided by the volume. Another indicator of latent sources is the olf-load of a building (13), which is directly related to the response of visitors of that building.

A checklist can be of help when a visual inspection of a building is made.

During an inspection moulds might for example be detected. Moulds have the potential to grow on practically any organic material providing there is enough water. They are capable of producing large quantities of spores as well as mycotoxins (toxic to humans, carried on spores), synergizers (increase potency of toxins) and VOC. Sampling of air may not always show that a fungal contaminant is present (35).

General "indicators" of Indoor air quality are carbon dioxide and water vapour.

According to Molhave (36) VOC's may be important to indoor air quality in the form of discomfort due to odours, of irritation of eyes, nose and throat, and of headache. Molhave defined therefore comfort ranges of TVOC-concentrations and defined the TVOC-indicator as a first approximation of a comfort predictor, indicating the perceived unspecific stimulation of nerves caused by a multicomponent air exposure at low levels (e.g. a few ppm or lower). This indicator cannot be used to predict other type of effects for example effects on CNS, tissue changes or cancer.

Berglund (3) however, claims that the pattern of chemicals rather than the concentration of a chemical carries the information of perceived air quality or symptoms. According to her, it is probable that the chemical senses perform a pattern analysis on exposure to complex air pollution. It is therefore possible that the concentration of numerous compounds is less important than the addition or subtraction of a few specific compounds to a gas mixture.

Discussion

Indoor Air Quality is difficult to define. Many measuring techniques are available to give an indication of the Indoor Air Quality. Measuring techniques which determine the indoor air pollutants are numerous, since the number of indoor air pollutants is numerous. Many things can go wrong when sampling, identifying and quantifying those pollutants. This makes the reproducibility and credibility of the results questionable. In a Round Robin test with formaldehyde 16 institutes of the EC measured the concentration of formaldehyde following the same procedure (28) and using a sample of particle board cut from the same piece. A concentration range from 0.06 to 0.44 mg/m^3 was found (J.F. van der Wall, personal communication).

When it comes to identifying pollutants which have carcinogenic or other health effects, measuring techniques which are concerned with the contents of the air are however necessary. Threshold limit values based on epidemiological and clinical studies can then be used to indicate the Indoor Air Quality. This health procedure needs however further development. Not for all pollutants causing health effects limits of exposure have been determined and all pollutants causing health effects might not have been identified yet. For example, for indoor air allergen contents one does not know yet which doses causes allergic diseases in the exposed people after some period of time (20). Identification of allergens and medical examination of exposed persons is as far as one can go. Exposure to certain pollutants seems to be measured the most accurate by examining the exposed persons (contents of body fluids).

This health procedure can not be followed when the comfort aspect of Indoor Air Quality has to be determined. Quantification and identification of each of the hundreds of compounds present in the indoor air is with the instruments developed so far impossible. A threshold limit value (odour and/or irritation) is not available for each of the identified compounds. And on effects of mixtures of pollutants is little or no knowledge available. It seems that measurement of the whole contents of the air by chemical/physical methods in relation to the response of people is not adequate to indicate or define the comfort aspect of Indoor Air Quality.

According to Molhave (36) measuring the TVOC-concentration can be enough to indicate the comfort level of the Indoor Air. This concept is however still a postulate. The widely used CO_2-concentration is only an indicator of the occupants present and ignores all other pollution sources in a non-industrial environment.

Since no other indicators of "Air Quality" have proved to be adequate, it seems that the best indicator for now is the human being. The response of exposed people can give an indication of Indoor Air Quality. This response can be from people who are occupants of the building or people who are visitors of the building. The first group of people, the occupants, can response through questionnaires, interviews or medical tests. However, their responses might be influenced by many confounding factors, making a direct indication of the Indoor Air Quality difficult. The response of independent visitors to a building seems therefore the best indication of Indoor Air Quality.

The latest developed method to measure Indoor Air Quality is based on the use of independent visitors. The human nose serves hereby as the instrument to quantify Indoor Air Quality. This method, developed by Fanger (37), requires a panel of subjects who evaluate the air quality on its acceptability or directly in decipol immediately after the panel enters the building or space. The theory behind this method is that in principle any perceived air pollution can be expressed in a grade of dissatisfaction caused by that pollution. The unit of this dissatisfaction is expressed in decipol. One decipol is defined as the perceived air pollution caused by a one standard person (one olf) ventilated by 10 l/s of unpolluted air. A standard person is the average sedentary occupant in thermal comfort. The source strength of a pollution source is expressed in olf. One olf is defined as the emission rate of air pollutants (bioefluents) from a standard person. Any other pollution source may be quantified by the number of standard persons (olfs) required to cause the same dissatisfaction as the actual pollution source.

When the ventilation rate of the evaluated building or space is determined, besides the evaluation of the perceived air quality, an indication of the total olf-load of that building (olf/m^2) can be established.

This <u>comfort procedure</u> does not indicate the effect of longterm exposure on the occupants. However, in a study of 10 schools (602 students, 14-16 years) a correlation was found between the prevalence at school of both mucosal irritation (in eye, nose and/or throat) and general symptoms (i.e. headache, abnormal fatique and/or malaise) among the students, and the perceived air quality in decipol evaluated by a trained panel (38). Untrained panels can evaluate the perceived air quality on its acceptability using an acceptability scale (13). An alternative is the use of a trained panel who evaluates the perceived air quality directly in decipol (14).

Air quality evaluated by a trained panel (14)

A panel of subjects trained in sensory evaluation is a panel whose subject's evaluations are standardized by training. The purposes of panel member training is to familiarize an individual with a standard procedure, to improve an individual's ability to evaluate according this procedure and to improve an individuals' sensitivity, so he or she can provide precise, consistent and standardized sensory evaluations, which can be reproduced. Trained panels for sensory evaluation have been used and are used, for example in the food industry, cosmetics and perfumery, distillation industry, industrial odour control and in other air quality fields.

Selection of subjects who can be trained to evaluate air quality in decipol is the first step to be taken. The second step is the development of a training procedure.

The two units, olf and decipol, were introduced to quantify air pollution sources and perceived air pollution with human bioeffluents from a standard person as the reference. In practice it is hard to produce such a reference since human bioeffluents comprise a large number of chemical compounds and varies considerably from person to person.

A reference gas which is easy to measure and to produce was therefore selected through a literature survey and several laboratory tests. The gas 2-propanone was found to be the best candidate, since it is cheap, common and readily available, not unfamiliar to people, easily detectable, and not dangerous, explosive or poisonous in the concentrations used. The production is based on passive evaporation and is introduced to the human nose by a constant airflow coming out of the so called decipolmeter (Figure 1). The concentration of 2-propanone is measured with a toxic-gas monitor (Bruel&Kjaer 1306) based on photoacoustic spectroscopy. To use the chosen compound, 2-propanone, as a reference gas instead of human bioeffluents the relation between the perceived air quality in decipol and the concentration of 2-propanone in air has to be known. This relation was determined by an untrained panel of 265 persons who each evaluated the acceptability of eight different levels of 2-propanone produced by eight different decipolmeters.

Figure 1 The decipolmeter: An instrument to expose a human subject to a certain 2-propanone concentration. By varying the number of bottles with 2-propanone and the diameter of the hole in the top of these bottles, different concentrations can be established.

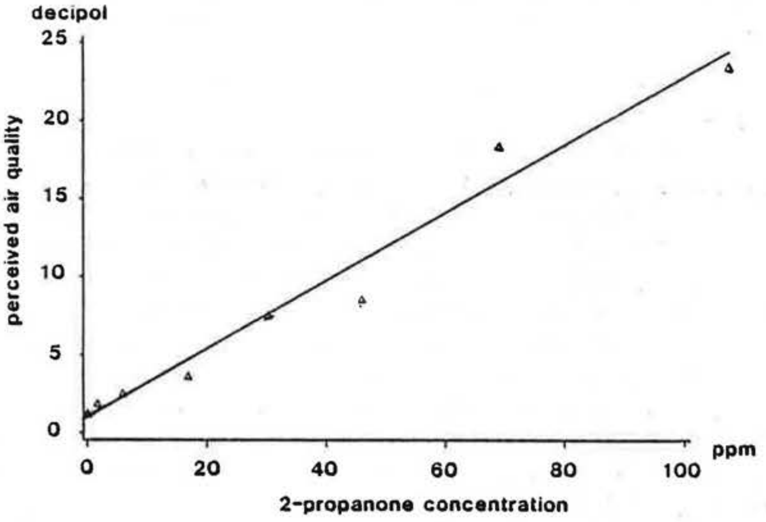

Figure 2 The relation between the perceived air quality in decipol and 2-propanone concentration (ppm). Each point is based on votes of 265 untrained subjects. (decipol = 0.84 + 0.22xppm; R^2=0.97)

The mean acceptability vote of the untrained panel for each concentration was transferred to decipol using the definition curve of decipol (13). This resulted in the relation between the decipol and the 2-propanone concentration (Figure 2).
It was found that <u>selection</u> of persons for a panel to be trained to evaluate perceived air quality in decipol can be based on an entrance test determining the ability to evaluate 2-propanone.

<u>training</u>
Several selected panels have been trained to evaluate air quality directly in decipol. Four different 2-propanone concentrations (2, 5, 10 and 20 decipol) produced by four decipolmeters, called the "milestones", served as the reference for the panel members. Several unknown decipol levels were evaluated several times using the four milestones as a reference. The procedure of judging was as follows: A panel member was exposed to an unknown decipol level and then asked to compare with the milestones and to determine the decipol value for the unknown level. The panel member was allowed to go back and forth between the unknown and the milestones as much as he or she wanted. However, one sniff had to be followed by at least two breathings of room air before another sniff was taken. The procedure should prevent the panel member from being adapted. After the evaluation the correct answer was given and the panel member was asked to go back to the unknown level to compare the correct answer with his/her own answer.
During the training, the panel members were also exposed to other pollution sources then 2-propanone, comprising several common materials from buildings and ventilation systems. The same procedure of judging was followed with the exception that no correct answers were given.
From studies with three panels of subjects it was found that training of a selected panel in groups of four requires at least 30 minutes per day

during three days. Each panel member has to evaluate seven unknown 2-propanone levels per day and several other pollution sources. This finding was based on the performance of a panel expressed by the given decipol votes compared to the correct decipol values for the unknown 2-propanone levels, and by their reproducibility when exposed several times to other pollution sources then 2-propanone.

performance

After three days of training (7 unknown levels per day) of a panel of eigth persons linear regression of all given votes versus the correct values for the unknown 2-propanone levels evaluated per day, resulted in a regression line with an intercept of 1.3 and a slope of 0.8 decipol.

The performance index, defined as the mean difference between the voted decipol and the correct decipol divided by the correct decipol for all evaluated levels per day, together with the standard deviation show how the votes were distributed around the line voted=correct. A performance index lower than 20% with a standard deviation lower than 40% was reached by a trained panel of eight persons after three days of training (7 unknown levels per day). The trained panel was less than 20% wrong in their vote for a given 2-propanone level.

Several judgements of the same pollution source provide information on the reproducibility of a panel. The standard deviation around the mean of two or more replicas of a source divided by the mean vote of that source determines the reproducibility. The reproducibility for other pollution sources than 2-propanone was found to be about 8%.

The reason for using a trained panel instead of an untrained panel is that a trained panel requires less people than an untrained panel. It was found that to establish the same standard error on a mean vote with an untrained panel as a trained panel, at least 8 times as much people are required. An untrained panel of 265 persons had a standard error of 2.2% dissatisfied, while a trained panel of eight persons had a standard error of 4.5% dissatisfied (transferred from decipol) when judging 2-propanone at a level of 1.4 decipol (20% dissatisfied).

use of a trained panel

A trained panel makes it possible to determine the perceived air quality in a building directly in decipol. The developed training procedure needs nevertheless further development in the low decipol values. The decipolmeter without any pollution source results in a perceived air quality of around 1 decipol (Figure 2). The panel members can therefore not be trained between 0 and 1 decipol. Knowing that a decipol value of 1.4 decipol equals 20% dissatisfied makes the use of a trained panel in buildings with a perceived air quality between 0 and 2 decipol difficult.

However, the so far developed method can be used very well when comparison of different pollution situations has to be made. In other words the selection of the lowest polluting materials or the best perceived air qualities. Trained panels are very useful when it comes to labstudies. It was found for example with the use of a trained panel that addition of olfs from different pollution sources occuring in a space is, as a first approximation, a good prediction of the total olf-load of that space (39). Further more it was found that used filters can pollute the air instead of cleaning it, even when the filters have been used for only two months (14).

The training of a panel is so far mainly based on the ability to evaluate different 2-propanone concentrations in decipol. The description method was an additional training procedure, in which the panel members were exposed to several pollution sources and were asked to describe what they were perceiving. Every time a source was evaluated the source was shown and made known to the panel members. By repeated exposures to the same material (and mixtures of materials) the panel members were taught to recognize materials common in buildings and what specific perceived air quality they generate. This knowledge may help to recognize the main sources of pollution in a real-life situation, for example an office. A step further could be to have standard pollution sources with fixed decipol levels.

Source strengths of single materials are not known yet, which makes prediction of the air quality based on the used materials alone impossible. This source strength depends on several variables: the relative humidity, the temperature, the velocity around or through the source and the age of the perceived pollutants emitted by the source. Study has to be done on how these variables influence the source strength. A standard method to obtain the source strength of materials and components of and in buildings combined with a model that predicts the source strength in any other environment, is required to make prediction of Indoor Air Quality possible. A trained panel can serve hereby as "the instrument".

To make the use of a trained panel the same in every country the existing training method needs to be further developed and standardized. Since several EC countries are already working with trained panels or are planning to do so (Denmark, Germany, Norway, The Netherlands), the organization of a working group out of those countries which can provide a standard method of training a panel is a possibility. After a standard training method is developed trained panels can be used to obtain a standard method to determine olf values of pollution sources. This could result in an olf-catelogue which can be used to select low polluting materials and can help to predict the air quality in a building.

Conclusions & Recommendations

- Two procedures can be used to measure Indoor Air Quality: The health procedure in which the air quality is based on the concentration of pollutants which may have a health risk, and the comfort procedure in which the perceived air quality is determined by the human nose and is based on the dissatisfaction/satisfaction of visitors of a building.

- The health procedure needs further development. Not for all pollutants causing health effects limits of exposure have been determined and all pollutants causing health effects might not have been identified yet.

- Exposure to certain pollutants seems to be measured the most accurate by examining the exposed persons. Monitoring at the location of exposure leads to many confounding factors.

- A trained panel can be used to determine the perceived air quality directly in decipol, with 2-propanone as the reference gas. A standard training method is required.

- A standard method to obtain the source strength of materials/ ventilation systems is necessary for the establishment of an olf-cataloque. Standardized trained panels can be used to determine this method.

References

(1) ASHRAE (1989), ASHRAE Standard 62-1989, Ventilation for acceptable Indoor Air Quality

(2) A.Hedge, Questionnaire design guidelines for investigation of sick buildings, Indoor Air'90, Toronto, vol.1, pp.605-610.

(3) B.Berglund, T.Lindvall, Sensory criteria for healthy buildings, Indoor Air'90, Toronto, vol.5, pp.65-79.

(4) P.L.Jenkins, T.J. Phillips, E.J. Mubog, Activity patterns of californians: use and proximity to indoor pollutant sources, Indoor Air'90, Toronto, vol.3, pp.465-470.

(5) N.Mygrind, Essential Allergy, Blackwell Scientific Publications, 1986.

(6) G.D.Nielsen, Exposure limits for irritants, Ann.Am.Conf.Ind.Hyg., vol.12, 1985, pp.119-135.

(7) C.R.Johnson, et.al., Controlled human exposure to building materials in climate chambers, part I: performance and comfort, Indoor Air'90, Toronto, vol.1, pp.269-274.

(8) L.Wallace, E.Pellizari, S.Gordon, The use of breath analysis to determine accent or long-term exposure to indoor sources of volatile organic chemicals, Indoor Air'90, Toronto, vol.2, pp.127-132.

(9) Proceedings of Indoor Air'87, Berlin.

(10) W.A.Coniglio, J.Faglinno, Urinary excretion of chromium, an index of exposure, Indoor Air'90, Toronto, vol.2, pp.139-144.

(11) C.E.Reed, Indoor allergens, Indentification and quantification, proceedings of the 3rd conference on Indoor Air Quality and Climate, Stockholm, 1984.

(12) H.J.Finnegan, C.A.C.Pickering, P.S.Davies, et.al., Factors affecting the development of precipitating antibodies in workers exposed to contaminated humidifiers, Clinical Allergy 15, 1985, pp.281-282.

(13) P.O.Fanger, Introduction of the olf and decipol units to quantify air pollution perceived by humans indoors and outdoors, Energy and Buildings, 12, 1988, pp.1-6.

(14) P.M.Bluyssen, Air quality evaluated by a trained panel, Ph.D.thesis, Laboratory of Heating and Air Conditioning, Technical University of Denmark, lyngby, Denmark, Oktober, 1990.

(15) ISO, International Standard ISO 7726, Thermal Environments - Instruments and methods for measuring physical quantities, 1985.

(16) B.Seifert, et.al., Strategy for sampling chemical substances in Indoor Air, report no.6, Community COST- Concertation Communittee COST project 613, Environment and Quality of life, december 1989.

(17) J.J.Kliest, Binnenmilieumetingen chemische agenten, Seminar, Maastricht, november, 1990.

(18) J.F. van der Wall, Stof in het binnenmilieu, Seminar, Maastricht, november 1990.

(19) A. van der Meer, Seminar, Maastricht, november 1990

(20) H.A.Burge, Bioaerosols: Guidelines for assessment and sampling of saprophytic bioaerosols in the indoor environment, Applied Industrial Hygiene 2, 1987, R10-16.

(21) Tj. Smid, et.al., Schimmels in arbeidssituaties, een vergelijking van meetmethoden, 19878, L.H. Wageningen.

(22) C.Johnson, Aeroallergens, NIVA Course on "The Sick Building Syndrome", Copenhagen, oct. 1989.

(23) WHO, Air Quality quidelines for Europe, WHO Regional Publications, European Series no.23, 1987.

(24) E.Lebret, Air pollution in Dutch Homes. An exploratory study in

environmental epodemiology, L.H. Wageningen.

(25) World Health Organization (WHO), Indoor Air Quality: Organic pollutants, report on a WHO-meeting, Euro reports and studies 111, WHO Regional office for Europe, 1989, Copenhagen, Denmark.

(26) H.Knoppel, Sampling of volatile organic compounds, NIVA-course, october 1989,

(27) Interdepartementale Beleidsgroep Formaldehydeproblematiek, Bepaling van formaldehyde concentraties in binnenlucht, Beleidsadvies Woonmilieu, Rotterdam, 1983.

(28) COST, Formaldehyde emissions from wood based materials: guidelines for the establishment of steady-state concentrations in test chambers, report no.2.

(29) G.A.Swedjemark, H.Wahnen, A.Makitalo, W.Tell, Experience from indoor Radon-daughters limitation schemes in Sweden, 1989, Environmental Int.

(30) International Health Directoriate Health Protection Branch, Authority of the Minister of National Health and Welfare, Exposure Guidelines for residential indoor air quality, April 1987.

(31) P.Skov, O.Valbjorn, DISG, The "sick" building syndrome in the office environment: The Danish Town Hall study, Env.Int., vol.13, 1987, pp.339-349.

(32) VDI-Richtlinien, VDI 3881, Part 1/ blatt 1, Olfactometry - Odour threshold determination, Fundamentals, may 1986.

(33) J.D.Spengler, et.al.,Indoor Pollutants, National Academy Press, Washington D.C., 1981.

(34) P.A.Nielsen, Potential pollutants- their importance to the sick building syndrome and their release mechanism, vol.2, Indoor Air'87, Berlin, 1987, pp.598-602.

(35) J.D.Miller, Fungi as contaminant in indoor air, Indoor Air'90, Toronto, vol.5, pp.51-64.

(36) L.Molhave, Volatile organic compounds, Indoor Air Quality and Health, Indoor Air'90, Toronto, vol.5, pp.15-33.

(37) P.O.Fanger, The new comfort equation for indoor air quality, ASHRAE Journal, october 1989, pp.33-38.

(38) E.Thorstensen,et.al., Air pollution sources and indoor air quality in schools, Indoor Air'90, vol.1, pp.531-542.

(39) P.M.Bluyssen, P.O.Fanger, Addition of olfs from different pollution sources, Indoor Air'90, Toronto, vol.1, pp.569-574.

Session 9 : Building Performance Specifications

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REQUIREMENTS ON INSTALLATION PERFORMANCE

ABSTRACT

The paper deals with two main items:

* Important parts of the installation in the Process of Design, Contracting, "Commissioning", Use and Maintenance of the Installations in the building.

* Social Factors in the Process. The Built Environment in the Commercial Market. Parties involved, and their power. A proper balance of quality and price?

The paper will conclude into white spots in the knowledge which could bring us to a specification of future research in the field of the built environment.

CONTENTS.

REQUIREMENTS ON INSTALLATION PERFORMANCE

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1. INTRODUCTION

Indoor Air Quality and the Management of it, is certainly an important part of the complicated and much wider **Quality of the Indoor Environment.** This indoor environment is the result of a complex interaction between the Building itself, the Installations and the User and its specific qualities. The User (human beings, an industrial process or both) determines the specification of the Building-and-its-Installations as **one single unity.**

The results can be judged by factors as **Thermal Comfort** [ambient temperature, (mean) radiant temperature, mean value of the air velocity and degree of turbulency, (relative) air humidity], **Sound and Noise, Daylight and Artificial Lightning,** and **Indoor Air Quality.**

During this workshop we will focus on **Indoor Air Quality Management,** but we will have to realize that IAQ is not an effect on itself but also the result of a complex of factors. And in this presentation there will be an emphasis on the **Installation and its Requirements** in a close relation to all other factors involved.

2. CLEAN AIR

A good Indoor Air Quality begins with a good Outdoor Air Quality. The best we can have is good outdoor air, generally spoken. If the outdoor environment is totally satisfying, we have no problem at all for the location of the air intake in the building. If the outdoor air is not perfect, we can have gaseous and particulate pollutants, and odours. The pollutants can cause "only" comfort problems (harmless odours), or we can have pollutants causing possible health risks. The removal of particulate pollutants from the outdoor air may be not too complicated, but the removal of gaseous pollutants and odours can be very complicated and costly, specially if there is a severe health risk. Normally spoken, the situation of a building in such a risky environment should be avoided. Exceptional cases can be covered by closing the building fully air tight and give the air a special processing: In military applications, NBC-filters (Nulear, Bactereological, Chemical) are used; airport buildings are protected by processing of the outside air over active coal filters to avoid a kerosine smell in the indoor air. But under normal conditions this is an impossible option from an operational and an economical point of view.

If there are differences in the level of air pollution around the building, we can optimise the situation of the air intake. In a built environment, the air at ground level (car park!) can be much more polluted than at roof level. Even a stack for the intake of fresh air is an option.

From the 1980's the discussion of the quality of the indoor environment got an emphasis to the **Sick Building Syndrome.** In these days, the research to this new item had priority, but from 1988 we switched over to a more positive approach and started to talk about **Healthy Buildings,** trying to get practical solutions for our problems. Certainly the IAQ is one of the main items of the Healthy Building, but we must be aware that HB quality is much more complicated than IAQ alone. But there is a strong interaction.

3. THE BUILDING AND THE USER

Other contributions in this workshop will certainly report in detail about the building and the user, but some basic remarks have to be made now, to provide a background for the discussion of **Requirements on Installation Performance.**

If we look at the **Building** and focus to an occupied area,a room, we will find an air volume separated from the surroundings. By a number of factors, this volume of air will be (or at least can be) polluted. All building materials, giving the room its partition, can show an emission of pollutants in the form of particals, gases and odour. Also paint, wall paper and tapestry must be noticed.

The **User** of the building will bring other elements in the room, such as furniture, equipment, animals, plants and don't forget: themselves! All these elements cause their specific pollution.

The **HVAC-Installation** as a third main parameter is supposed to satisfy not only the thermal specifications but also to maintain the level of IAQ within given restrictions, interacting with the Building and the User. The ventilation (i.e. the supply of "new" air to the occupied space) could be used to **dilute** the pollution, and will be in many cases, but it is better to think of the labor-hygienic philosophy in which we first try to **avoid** a pollution, then **restrict** it, further attack the **source** of the pollution directly, before giving the pollution a free way to the ambient air so that dilution is the only way to go.

Some pollutions may be so dangerous that even a strong rate of dilution is not tolerable; some odours (even if not risky to the health) could be so strong that dilution is practically not possible from technical or economical points of view.

Apart from the hygienic behavior of people and the development of social habits in this field, the odour caused by human beings is a given fact; it can not be avoided nor restricted, it can only be diluted. So the **lowest possible airflow** for this dilution will be determining for the ventilation. It is preferable not to increase this flow more than necessary, and look for alternative ways for the supply of heat or cold than by the air alone. The improvement of such means is under development: supply by radiation and/or convective heat transfer (see chapter 5.2).

4. NATURAL VENTILATION versus MECHANICAL VENTILATION.

With the application of **natural ventilation** we cause a **direct exchange** of air from outside the building and air from inside the building. There is no interference from an installation whatsoever. Only an aperture in the facade of the building is needed to provide the possibility of the air exchange.

Supposed that the outside air is of good quality, we have an unlimited reservoir for the exchange of fresh air. If a window is totally opened, the velocity of the exchange is almost unlimited. We can provide a sudden effect of freshness. This is a very positive factor on human experience.

To control the natural ventilation, the window can be closed more or less. But the flow of ventilation is progressively dependent on a variable wind force and direction. ((1)).

It is an old proposition that natural ventilation in a multi-story building is only acceptable up to a certain height of the building. A limit of 4 to 15 stories is often stated. Recent studies give a contrary opinion.[1]

The control of the indoor temperature is difficult. The temperature difference outside-inside can easily be more than 30 K, so a limited flow can cause an extreme thermal load, positive or negative. The mixing of cold and warm air can be difficult; therefore inacceptable differences in indoor air temperarure can occur. The mixing process is poor.

The natural exchange of cold and warm air makes it impossible to exchange heat between the two air flows. So the thermal efficiency of the heating system will be extremely low.

The wind force on the facade can cause an important pressure-difference over two opposite facades of the building. So an unacceptable air flow through the building can occur. If the window is open, the door to the corridor must be closed. It is impossible to operate a landscape office.

The size of the building, perpendicular to the facade, is restricted with natural ventilation. Often a depth of 6 meters for an occupied space is stated as a maximum.

Natural ventilation shows many positive features, as simplicity, low cost level and direct accessability for inhabitants, but the possibilities for application are rather restricted. But in moderate climates it will be possible to open the windows when the outside conditions are near the preferred inside conditions. Slightly lowered outside temperatures can provide cooling in case of excess sun radiation.

The application of **mechanical ventilation** shows other advantages. The system provides the possibility for a perfect **control** of air flow, thermal conditions and IAQ conditions of the ambient air.

If the outside air conditions are poor or cause health risk, and the windows must be kept closed, the air can be processed in the installation before the supply into the interior. If the acoustical conditions outside are unacceptable, the windows can also be kept closed.

Apart from health risk, other than chemical properties of the air can be controlled by mechanical ventilation, and can't by natural ventilation. That applies to the filtering of dust and the control of the humidity. The HVAC installation can raise or reduce the humidity level to satisfy any specification. ((2)),((3))

Only with mechanical ventilation, the level of thermal comfort can be assured at any level of heat load or heat gain of the office. With the present (high) level of specifications for indoor climate and use of buildings (i.e. a high density of people and machines, reduced story height and a design of extended buildings), mechanical ventilation gives enlarged possibilities in the design. But this statement does not give the way free to unlimited variation of parameters. Only if there is a proper balance between the building, the use and the installation, a really satisfying indoor climate and good IAQ can be realized.

Mechanical ventilation will also have its negative consequences. The total investigation for a HVAC installation can be as high as 40% to 50% of the cost level of the project. And the life cycle of the technical installations is normally much shorter (15 to 20 years) than the life cycle of the building. The HVAC installation with its duct system takes an important part of the volume of the building, which also increases the total cost of the project.

As to the IAQ, there can also be a negative effect from the air handling part of the installation. Caused by a wrong selection of materials or parts, or a lack of maintenance, the installation itself can produce a certain level of pollution or odour.

5. THE HVAC INSTALLATION

The choice of the elements of the HVAC installation and their interaction determine the quality of the indoor climate, and specially the Indoor Air Quality in the building. Fig.1 shows the main parameters of the building and the installation.

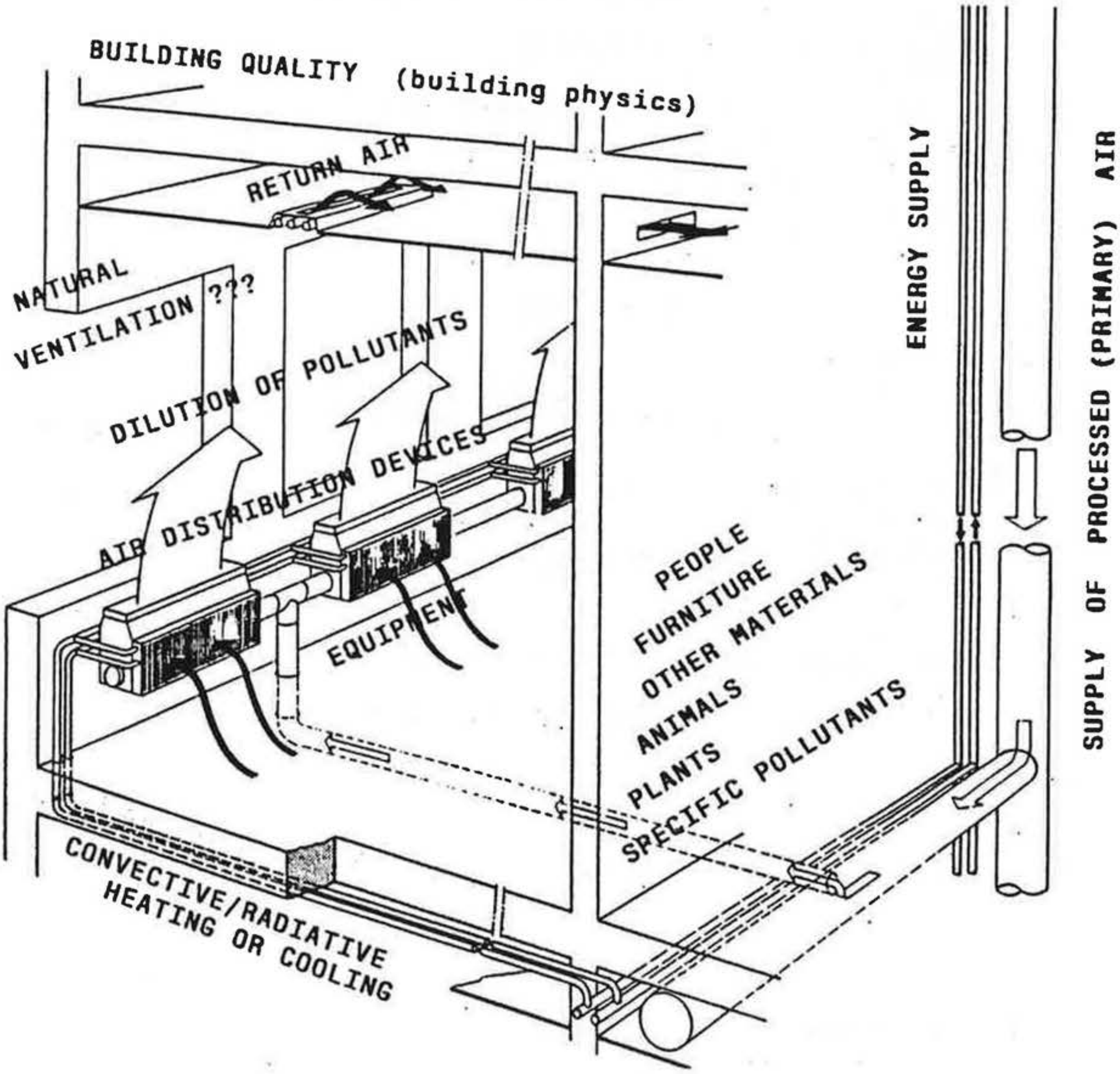

Fig.1. The building and the HVAC installation

5.1 Elements of the HVAC Installation

A traditional HVAC installation will normally content the following elements (see fig.2):
- registers for outside air and return air
- mixing box
- pre-filter
- fine filter
- fin-pipe heat exchanger for heating
- fin-pipe heat exchanger for cooling and de-humidifying
- humidifier
- ventilator

- sound attenuator
- duct system
- valve, constant/variable volume box
- air distribution device (grille, air terminal)
- device for radiative/convective heating or cooling
- device for heat recovery

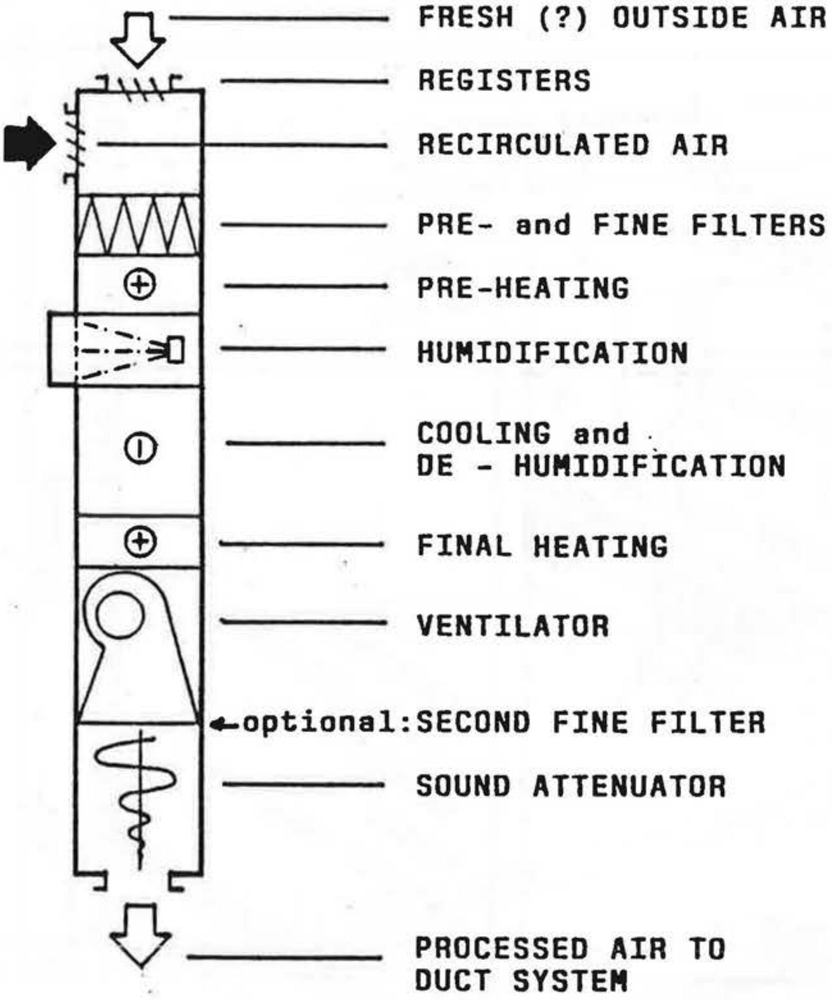

Fig.2. Elements of a traditional air-processing installation

These elements themselves could be a source of pollution.((4)) Porous materials can easily emit odours from their (own) material or absorb/adsorb and desorb gaseous pollutants or odours. This mechanism applies for filter material, for the baffles in a sound attenuator, for the thermal isolation inside ducts (better don't use internal isolation), for the heat recovery "wheel" especially if porous material is used for the "latent" recovery. (5)) For many other elements sheet metal is used. During the processing of this sheet metal in special machines additional materials are often used, for instance oily fluids, adhesives or plastic materials for tightening of seams. This applies specially for fin pipe heat exchangers.

Humidifier devices can sometimes use water with special additives for the prevention of corrosion or biologically active substances. These substances can be odourous or chemical active.

The elements of the installation should be **prevented** for being polluted. The chain of elements should start not only with a pre-filter but also with a fine filter. And, to be sure of preventing the duct system from pollution, another fine filter should be provided at the beginning of the duct system (the part of the system "before" the ventilator is at a lower pressure then the surrounding so could be polluted from outside).

Filters can be a source of pollution. For instance, when moisture plays a role, the collected dust could carry substances which are biologically active, and pass the filter. If mould growth occurs on the filter, the spores can penetrate the filter, and stimulate mould growth on other places if these places are (temporary) moist. ((6))

Humidifiers, if not in a state of perfect maintenance, will be a source of pollution. Specially if liquid water plays a role, pollution is hardly to avoid: "natural" water will develop biologically active substances after some time and bring them in the ventilating system, or when the water is processed for the prevention of these effects, the chemicals which are diluted in the water will disperse in the system. If humidification is an absolute necessity, steam is the best alternative.

Heat exchangers of the fin pipe type could also be dependent of regular maintenance. This applies strongly for batteries with a cooling and de-humidifying task. For de-humidifying the batterie needs many rows of pipes (6 to 10 rows) to attend a dew point low enough for our purpose and of course condensation will occur. These temporarily wet surfaces deep inside the device have a pollution risk. So these batteries must be perfectly accessible for maintenance.

Air distribution devices, as grilles, are in direct contact with potentially polluted room air. These grilles introduce processed air in the room by means of a mixing process, called induction. So room air can penetrate the grill(-box) and cause the collection of dust in the device. Even if the primary air is absolutely clean, supply grilles must be in regular maintenance anyhow. ((7))

In general, machine rooms and comparable spaces should have dimensions that allow a sufficient accessibility for repair and maintenance, and all the components must have a possibility for easy exchange.

5.2 Systems for HVAC

Generally spoken, the building, the use and the installation must be in good balance in the design process. But we must start with a good definition of the use, and avoid to translate our doubts in specifications that double or even triple any normal level. The second step is a provisional building design in which we try to satisfy the specifications from the user as good as possible, within certain limitations. Here we deal with fundamental decisions about the building (i.e. thermal specifications and other decisions in the field of building physics). During this provisional stage in the building design, fundamental discussions about installations must start. From this moment on we should assure the balance between building and installations, looking at the realisation of thermal and other specifications against, on the other hand, the total cost level of the project. This certainly is a circular process. An extreme emphasis on trying to avoid installations, nor an extreme neglect of building physics (which can make the buiding too dependent on installations) will lead us to a well balanced design.

Focussing again on Indoor Air Quality, a number of useful statements on system design can be made.

It seems useful or even desirable to assure the possibility of **windows that can be opened**, and give the inhabitants the option for natural ventilation if they like it. Also the option of combining a HVAC installation and windows to open, must be considered with certain restrictions. Under certain atmospheric conditions it is an attractive alternative, and it gives people the chance to escape from the given indoor climate. But we will have to assure that the system will work even if the wind force changes the air pressure in the room. Dramatic chances for malfunctioning occur. Return grilles can alter to supply grilles at the lee side of the building. ((8)).

In traditional system design the principle of **air recirculation** is ofen used. In the machine room a large percentage of the return air from the occupied spaces is mixed with a relatively small percentage of outside (processed) air and supplied to the building again. ((9))

Looking at the energy consumption there is an advantage: The quantity of outside air to be processed is far less (20% to 40%) and specially during winter conditions we avoid the need for heating the air over a span of 30K. The same applies for the latent load. The humidification during winter or the de-humidification under summer conditions takes a lot of energy.

Using recirculation, there is much more air-**circulation** in the building than **ventilation** (air rate, expressed in airchanges per hour). If the air flow for ventilation is used in a traditional **mixing system** this air quantity can be too low to assure a good air distribution in the room, and a sufficient supply of fresh air and/or a good temperature distribution through the occupied space is not realised. Furthermore the enlarged air quantity using recirculation can be a necessity if the air is the only means of transport of energy for heating or cooling (all air systems).

The transportation of much more air than we need for ventilation has severe disadvantages. All air handling devices will be much larger, and this does not only apply to the machine room, but even worse to the duct system in the building. The installation will cost more, and the enlarged space need is costly in building volume. Besides that, the energy use and cost for air transport (the ventilator) can cover a high percentage of the total running cost for the installation (up to 40%). The reduction of the air volume to the ventilation rate only will cause a severe reduction in energy use and cost for this transport. It will depend on the details of the specific installation, in which direction the energy saving will come out.

But the main disadvantage of recirculation is the mixing of pollutants through the building as a whole. The recirculated air is again filtered from dust, and humidity and temperature will be at a correct level again, but gaseous pollutants and odours will remain. In this way inhabitants of the building are oblidged to breathe the tobacco smoke of their neighboor, be it in a diluted condition. Air recirculation should be forbidden, at least in office buildings and comparable projects.

If we now reduce the air volume to the ventilation rate alone, we intoduce, as said before, two problems. The first problem of the energy transport is easy to solve: if we take water for the energy transport, this liquid is 2000 times better than air, looking at the volumetric heat transport capacity, at normal temperature differences. This argument moves against the all air systems.

The second problem was the air quantity for ventilation being too small to ensure a good mixing and distribution. There are two possible solutions. The first, in the discipline of the traditional mixing systems, is the well known **induction unit** (see fig. 3).

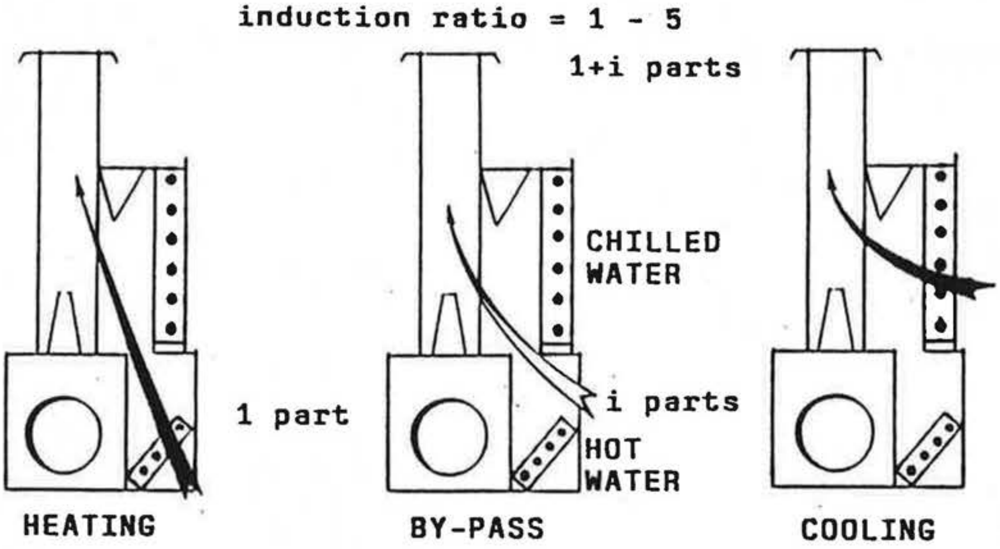

Fig.3. Induction unit (damper operated)

A reduced volume of ventilation air ("primary air") from the duct system mixes up with room air ("secundairy air"), and the mixed quantity ciculates in the room. The secundairy air passes a heat exchanger in the same device, providing heat or cold transport to the room. In this concept, only original room air circulates through the room; there is no mixing or recirculation through the building. ((10)

A second possible solution for a reduced air quantity is the system of **displacement ventilation.** Fresh air for ventilation is dispersed with low velocity at floor level and with a temperature 2K or 3K below room temperature. A "lake" of fresh air on the floor works as a reservoir, and the driving force for the air transport is the production of heat by people or machines. So the heat production determines the quantity of transported air. A human being is supposed to displace by convection an air quantity sufficient for his ventilation need (say 40 m3/h). The pollution (odour) and the excess heat does not mix up and is directly transported to ceiling level. As there is no mixing, an enlarged **ventilation efficiency** and a better **temperature efficiency** is claimed from the system. This is a contribution to an improved IAQ level; with a reduced air quantity the same level of IAQ can be realized. The thermal capacity, notwithstanding the improved temperature efficiency, is very restricted. So the system has to be completed with some kind of a low velocity thermal system; a cold ceiling is claimed to give an extra thermal capacity by radiation and natural convection.((11)) It seems that this system provides good possibilities for adequate solutions. But there is not much experience and hardly any laboratory research to prove the claims.

If we reject the air recirculation as an option for energy saving in the system, an other method can be found with **heat recovery**, by which the energy content of the return air is (partially) transferred to the outside air to be processed (see fig. 4). Several systems can be used: direct transfer via a plate heat exchanger, liquid systems with two heat exchangers or heat pipes. The heat recovery by means of a slowly rotating "wheel" could be risky.

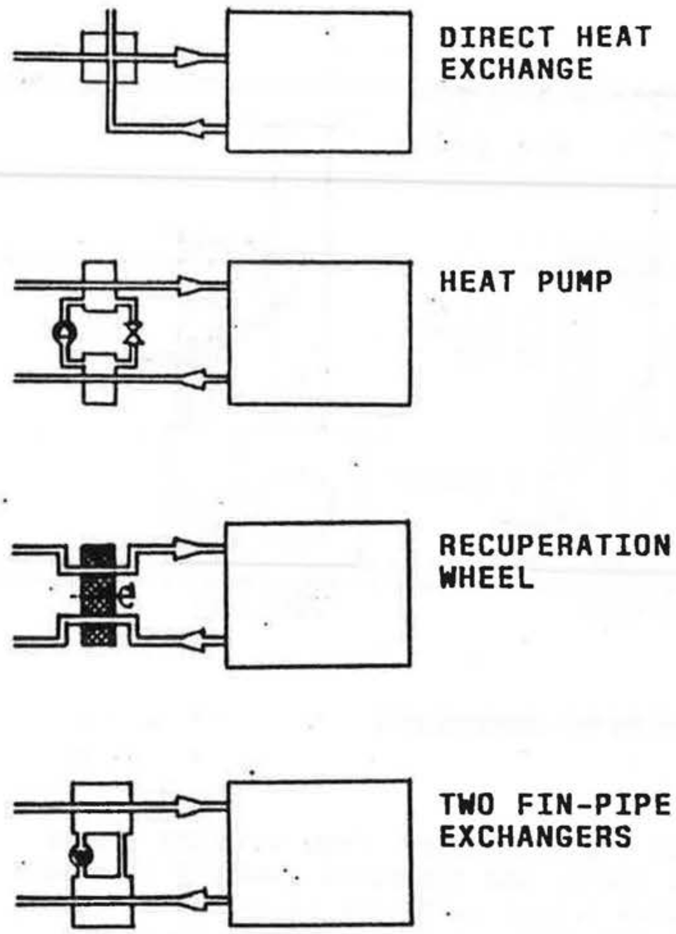

Fig.4. Systems for heat recovery

The surfaces of the wheel itself are in intermittent contact with clean and polluted air; there could be an adsorption effect. If the wheel also recovers the latent load (humidity), the material of the wheel is of a porous nature. The risk of exchange of gaseous pollutants or odours is extended.

6. THE BUILDING PROCESS AND ITS SOCIETAL FACTORS

The realisation of a building with its installations and other equipment is an extremely complicated **process**. It is much more than the addition of technical specifications. The process assumes the cooperation of concerns and other business units and finally the cooperation of **people.**

The main parties in the building process are the **principal** (the employer, the owner, the investor), the **architect**, the **consultants**, the **contractors**, the **commissioner** and the ultimate **user. There is also a maintenance** responsability with the owner and/or the user.

All these parties have their responsabilities- and their authority. The ultimate power, in our society, is reserved to the money. The parties involved all try to keep their position in the market, work for their reward and satisfy the given specifications, within their responsability and their span of power.

It is obvious that this process and its management is far from perfect. The technical knowledge often plays a minor role between authority and money. **In a majority of cases the results of the project do not satisfy the given demands, and the total costs exceed the originally given budget.** If we really don't look for the basic reasons of these failures, we will never fulfill the given (technical) requirements, and will not properly use the collected technical knowledge.

If we accept the ultimate power of the money, which is under control of the principal, the principal must, in his turn, accept his ultimate responsability for the project. The full delegation of this responsability must be impossible.

In our current practice, the ultimate goal of the project (a good building) will be **translated** in split responsabilities for different disciplines. Based on these responsabilities, the tasks are specified, and referred to cost levels. What has to be changed, is that all parties involved must not restrict themselves only to their specific task but must overlook the total aim of the project.

Standards and rules, and **contracts** too, are useful in the prevention of mistakes, but they can not replace the real responsability of parties in a project. The satisfaction of rules do not garantee the perfect result. The recent development of the "performance specification" in contracting will not give the definite solution: it only moves the final responsability to the last party in the process, the contractor.

If, for instance, an important cost reduction in the project comes in the discussion, all parties must have the possibility to report the (negative) consequences of that measure (in their discipline) without being rejected. And, in his turn, the principal must **ask** for these consequences and take **his** responsability. The indicated procedure will only be possible if the work is done in the organisation of an **open team** in which all information is freely exchanged. The principal again has the task organize this open team, in which a thorough base of mutual **confidence** must be established.

In the field of quality control, an effective **commissioning** of the project is essential. All parties involved will be convinced about their quality level, but it won't work if parties must check their own work. This statement definitely applies too for the consultant. The commissioner must be absolutely independent, and only have a direct reponsability to the principal.

In many cases, the **architect** plays a dominant role. The principle must convince him to **play a serving role**, as the other **parties do**. It must not be the artistic creation in first order to demonstrate, but to serve **human** requirements and measures.

The **consultant** can only be effective if he can stay really independent, specially independent from the architect. The **principle** will have to provide protection for the consultant in this relation.

Also the **contractor** needs protection. Normally his interest depends on the **answer** to the demands of the consultant or the architect, while he uses to have the final responsibility for the performance and costs of the installation.

Again, only the **open project team** provides the possibility for this approach.

7. PROPOSITIONS. PROPOSALS FOR FUTURE RESEARCH

(the following items are referred to in the text as ((1)),((2)), etc.)

The following items, derived from the present contribution, are proposed for dicussion in an E.C. Programme for future research in Healthy Building Development, specially directed to Indoor Air Quality. The proposals will focus mainly on **installations**.

((1)). Control of natural ventilation with an open window.

((2)). Which type of fine filter do we need to <u>avoid</u> pollution of the installation, specially the duct work?

((3)). Is control of air humidity a necessity, supposed the indoor air is <u>clean</u> enough?

((4)). Pollution effects from materials used in airconditioning equipment.

((5)). Pollution risks of a heat recovery wheel, specially if made for latent heat recovery (humidity).

((6)). Health risk of humidifier sections, specially if operated with fluid water.

((7)). Design procedures for installations, looking at the facilities/possibilities for maintenance.

((8)). Design specifications for installations when windows can be opened. Influence of pressurization of the building by wind force.

(9). Air recirculation should be forbidden in office buildings. Which alternatives do we have for energy conservation. What will be the cost level of this avoidance?

(10). Displacement ventilation is a hopeful development. But there is still a severe lack of knowledge as design aids. A thorough laboratory research is a necessity to be succesful in the application, and give the system a chance.

(11). A laboratory research should be made to find out the restrictions for the use of "cold ceilings" as an additional equipment with displacement ventilation. Capacity specifications and consequences for comfort. The combination with displacement ventilation; possible problems with velocity- and temperature distribution.

(12). The model for the operation of an "open project team" should be thouroughly developed. This societal problem should not (only) be treated by engineers or technical scientists.

6. REFERENCES

[1] Boerstra, A.C., **Zin en onzin van gesloten gevels en volledige luchtbehandeling in kantoorgebouwen.** RBB Arbo-adviesbureau O&O, AG 91/016, 1991.

[2] Davidowicz, N., Thomas Lindvall, Jan Sundell, **The Healthy Building. Summary report from a Nordic seminar held in March 1987.** Swedish Council for Building Research, Stockholm, 1988.

[3] Elixmann, J.H., **Filter einer lufttechnischen Anlage als Ökosystem und als Verbreiter von Pilzallergenen.** Dustri-Verlag Dr. Karl Feistle, München-Deisenhofen.

[4] Lindvall, T., O. Valbjorn, **Sick Building Syndrome, 1st Edition.** REHVA course, Amersfoort, 1986.

[5] Rolloos, M., R.W. Lanting, **Gezonde Klimaatinstallaties**, Klimaatbeheersing 18 (1989) nr 12, **p.418-429.**

[6] Rolloos, M., **Luchtkwaliteit en luchtkwaliteitsbeheersing, consequenties voor het vakgebied van de TVVL.** Rapport TVVL WG-17 'Luchtkwaliteit', 1988.

[7] Schalkoort, T.A.J., **Studierapport ontwikkeling en behoud van 'gezonde'kantoorgebouwen.** Ministerie van Sociale Zaken en Werkgelegenheid, Directoraat-Generaal van de Arbeid, Directie Gezondheid, 1991. (concept)

[8] Vroon, P.A., **Psychologische aspecten van ziekmakende gebouwen.** ISOR, Utrecht, 1990.

IAQ ORIENTED BUILDING PERFORMANCE SPECIFICATION
A METHODOLOGICAL APPROACH

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ABSTRACT. The problem of setting standards and regulations in the field of Indoor Air Quality is discussed in a general methodological approach. In the first part of this paper, the representation of the real phenomenon with a model is analysed; it is showed that the dynamic behaviour of the energy and mass transportation in a building can be well represented by a set of interacting generalised networks, characterised by nodes and branches. The relation between the level of each quantity in the nodes of the network and the fluxes in the branches can be a general conservation equation. It is also shown how any standardization or regulation action can be related to the examination of behaviour in nodes and branches. In the second part a brief review of the international activities in the field of the air quality standards is made. It is outlined that these standards are mainly devoted to the Outdoor Air Quality. Finally some suggestions to set the European standards are exposed.

1 INTRODUCTION

It is possible to define a building as a very complex machine that maintains, preserves, stores, moves in the space and sometimes transforms, many different kinds of matter, energy and information: e.g. people, thermal, radiant and electrical energy and many other types of solid, liquid and gaseous substances.

The "internal volume" is here defined as the air space inside the building and divided from exterior by the building envelope. If a building is considered as a factory, its main purpose is to produce a set of physical conditions in order to maintain the internal volume the **Indoor Quality** reasonably constant in time in a range of acceptability.

The building machine complexity is mainly due to the physical behaviour and to the real difficulty to establish mathematical relationships that can always be solved with an acceptable degree of accuracy of the results.

Let us try to explain a methodological approach that can be utilized to establish general rules to classify and identify building characteristics from the point of IAQ.

The control, the management and the forecast of the physical behaviour of this complex system, as for all real systems, require to establish an organic set of mathematical relationships, called **model**, according to the scheme explained in figure 1 (Calì 1990).

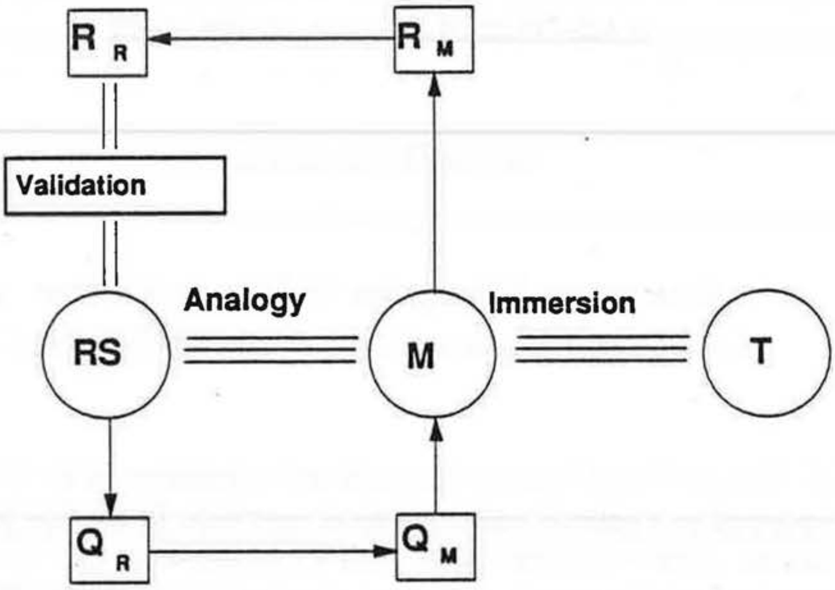

Figure 1 - The schematic representation of the real phenomenon with a model

In this figure RS is the real "problematic" situation that is under study; it is assumed that RS sets the questions Q_R. The development of the study is made constructing a model M of the reality, with a procedure called "analogy"; in our case we have a mathematical analogy. Any question Q_R posed by RS is therefore translated into a question Q_M posed to the model M; the model answer R_M (e.g. numerical results) is then converted into an answer R_R to Q_R . The model must be embedded in the physical theories of the studied phenomena. Finally, the loop is closed by a validation procedure that must refer to experimental results.

As examples of real situations RS related to the IAQ problem we can cite comfort, health protection, safety, all related to the social and regional habits.

A model that gives a complete and acceptable representation of the complicate systems that compose a building can be built as a set of generalized networks.

The term **network** refers to an abstract but wide concept that is a powerful tool of analysis; it applies to many fields of science, whenever it is necessary to study phenomena where relations and communications between entities or objects of whichever nature are established.

A network is a topological object constituted by a set of elements divided in two subsets, the nodes and the branches that establish relations between nodes. The linking to reality is made associating physical or logical variables to nodes and branches. With this kind of representation it is possible to analyse the phenomena emphasizing only the characteristics that are useful for the current study, and omitting those which are negligible.

In the case we are discussing, the nodes can represent the volumes into which the building is divided (rooms, apartments, ..) while the branches are all the building elements that permit relations between nodes, as external and internal walls, openings, HVAC plants, etc...

Physical quantities related to nodes and branches are:

- thermodynamic status of the indoor gas mixture in term of temperatures, pressures, molar concentrations of all gases;
- chemical composition, mass concentration and size distribution of solid particles diluted in the indoor gas mixture;
- statistical distribution of people presence;
- ...

Knowledge of the amount of each quantity and of its time variation in each node it is important, while in all branches it is necessary to know the fluxes of the related quantities. An examples is temperature at the nodes and heat flows along the branches.

2 MANAGEMENT AND CONTROL OF BUILDING PERFORMANCES

In this scenario the words **MANAGEMENT** and **CONTROL** of **BUILDING PERFORMANCE** must be clarified specifying:

a) The reasons that move an international group to invoke and actuate these actions.
b) The purposes that will be reasonably pursued.
c) The fields of application of this kind of actions.
d) The tools that will be utilized.

These items will be briefly evaluated and analysed in the following paragraphs.

2.1 Reasons and Purposes of International Actions on IAQ

In the last three decades the attention on the air quality has been posed essentially on the pollution in the atmosphere and on the workplace.

A meaningful examples of this work is the activity of Technical Committee TC 146 of ISO (International Standard Organisation) "Air Quality". The task of this group, as reported by Aronds (1990), was divided into four Subcommittees:

SC1 - Emissions from stationary sources
SC2 - Workplace atmosphere
SC3 - Ambient atmosphere
SC4 - General aspects

Up to now many documents and standards have been produced that partially cover similar documents in a few industrial countries, as Germany, France, United Kingdom, USA, The Netherlands. At this moment the same field of interest is covered by the Technical Committee TC 127 of CEN, the European Community Standard Organisation.

Without discussing in detail the content of the large activity of these national and international organisations, we can stress that the only field of interest is the status of the external air, due to the great problems that were posed in the 60's in many cities in the world.

Up to now the status of scientific and technical knowledge has focused the attention also on the problems that arise on the other side of the wall, i.e. in the internal space. Many international Conferences and Meetings since the early 80's have deeply discussed the critical problems related to the internal air quality status. But, apart from some local regulations (see Freund, 1987), only one Standard has been set to give rules in this field, i.e., the ASHRAE 62-1989 (1989).

At this stage, after a period of about ten years of attention, studies, discussions on this argument, it is necessary to go to the second step: standardization. As pointed out by Aronds (1990), there are many reasons to standardize procedures, methods and knowledge on some field: "to improve the quality of measuring results to make them comparable and reliable" and "to prevent extra costs for the application of different methods for the same purposes".

In this meeting many meaningful reasons to state a set of standards in the field of IAQ are exposed. We should try to identify, within a unified approach, the fields and the arguments that can constitute the object of an international standard on IAQ.

Two requirements must be satisfied for starting a standardization work:

- the scientific and technical knowledge should be well established.
- the related fields in the technical community should be well identified.

These arguments are well summarized in the statements of the ISO Guide 26-1981 (1981) on the 'Justification of proposals for the establishment of standards'; in this paper it is stressed that a proposal for a new standard "should include the following elements":

- Title
- Scope
- Purpose and justification
- Programme of work
- Relevant documents
- Cooperation and liaison

2.2 Fields of Application and Tools

In order of priority, these are the aims that regulations on IAQ can pursue:

A. Safeguard of the health of the people living and working indoors.
B. Protection against accidents (mainly, fire risk and smoke diffusion)
C. Comfort level protection.

All this aspects refer to a particular point of view of the same object, the "building system", with many interactions on overall behaviour and element performances.

A suggestion for a systematic approach to the identification of points that can be susceptible of standardization and/or regulation can be the representation of the whole system with a model of interacting networks.

Building behaviours in which we are interested, that correspond to space movement of energy and/or matter, can be represented as a set of networks, each one devoted to the transport of a particular quantity. Figure 2 is a schematic diagram of this approach.

The functioning of a network is described writing down a conservation law in each node and the transport equations for each branch or for a path along a specified subset of branches.

For a generic quantity, Y, the conservation law assumes the form:

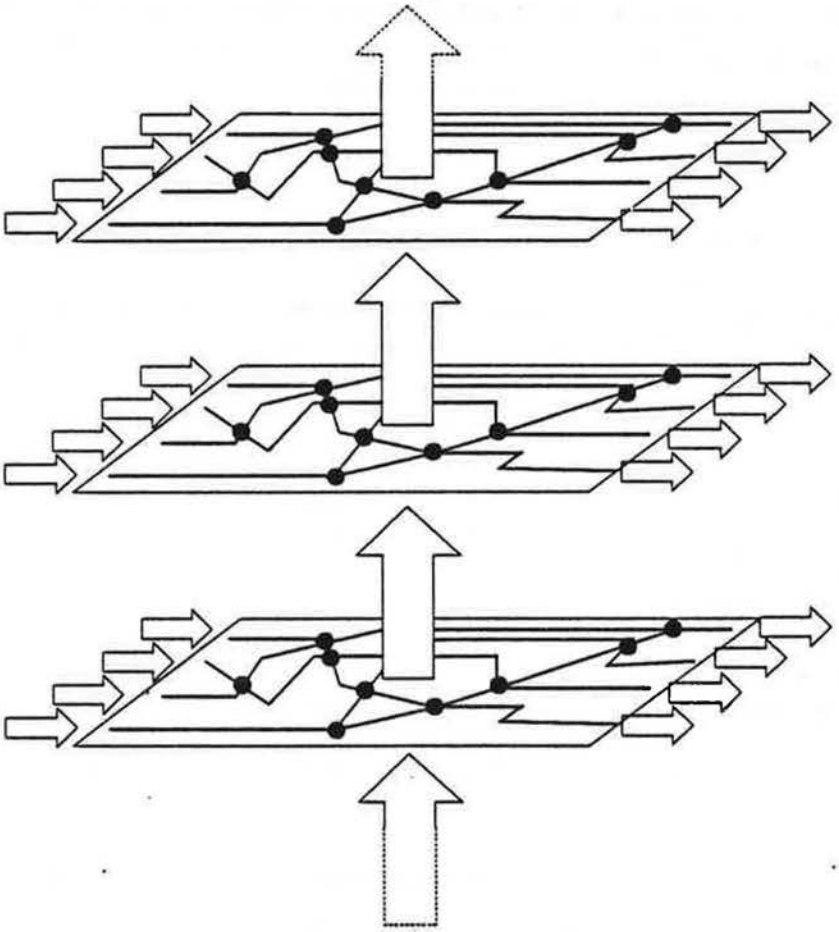

Figure 2 - Scheme of the interacting networks

$$\frac{dY}{dt} = \Phi_Y + P_Y$$

where t is the time, Φ the flow across the boundaries of the volume associated to the node and P the production of Y in the node (due for example to release of contaminants to the indoor air) or due to a boundary effect.

The table I below, shows some examples of physical quantities related to network elements.

In the context of this scheme, the words **Management** and **Control** mean:

- capability of identifying and measuring the level of Y's in each node;
- capability of identifying and measuring the fluxes Φ_Y in each branch;

while the word **Standardization** refers to:

- establishment of measurement procedures of the Y levels;
- establishment of measurement procedures of the fluxes through the boundaries;
- establishment of measurement procedures of the performances of the elements that define the boundaries;

Table I - Examples of the physical quantities related to networks			
Conservation Law	Y	Φ_Y	P_Y
energy	internal energy	heat	heat released by: people equipments flames ......
mass	mass of: air or tracers or contaminants or pollutants	mass flow rate: air contaminants	emission from: people furniture building materials ....
momentum along a path	-	momentum of the mass of gas and solid mixtures	shaft work friction wind energy stack effect
....	.....	.....	.....

- definition of criteria for establishing ranges of acceptability (for example Predicted Mean Vote in comfort analysis) or of Threshold Level Value of each Y in the nodes in relation to the the objectives A., B., C.;
- definition of operating procedures for controlling the behaviour to maintain the internal status in prescribed limits
- definition of operating procedures to reduce the risks connected to accidents (fire in some part of building and diffusion of combustion products);

3 CONCLUSION

As a conclusion we can submit some suggestion to set the problem of European Standard on IAQ.

1. In many phases of the kind of Standard we are discussing, it will be necessary to set up measurement techniques on gas flows, on components of gas mixtures, on solid particles transported by air and on thermodynamics properties of these substances. The work made in the field of Outdoor Air Quality can be utilized. Up to now there are very comprehensive standards and draft standards also at the level of ISO TC 146 and of CEN TC 127. These documents can be also utilised to characterize the external air that is one of the causes of pollution and indoor contamination.

2. We think that the problem of safety against fire risks and combustion product diffusion, is strictly related to the problem of IAQ; many standards can cover overlapping fields, mainly in measurement techniques and in procedures to calculate the diffusion of gases among the different zones into which the building is divided.
3. The new works should be primarily concentrated on the health and safety problems and on materials behaviour. The first two items should cover together both quantitative and statistical methods of analysis (e.g. gas concentration measurements or "olf" method).
4. The problem of the building material behaviour is essentially related to gas and energy "permeability", to fire resistance and to the release of dangerous, unhealthy or noisy substances in the internal air. There is a strict relation between this technical problem and productivity and economics problems due to the presence on a large market of many companies, this situation could move the solution far from the technical world. Therefore this item will be the most difficult to bind in standards and regulations. For this reason, as the experience in some national and international standardisation groups shows, adoption of the standards by the national community will take more time than usual.

We hope that, due to the strict relation with health problems, the mean time that is necessary from the conceiving of an international standard to the final adoption in all the countries participating that, according to Aronds (1990) is of about eleven years, can be dramatically shortened.

4 REFERENCES

Aronds C.A., 1990. 'International Efforts for Standardisation of Measuring Methods in Air Pollution Control - Requirements and Aims', *Proceedings of the Conference of VDI-Kommissione Reinhaltung der Luft on "Aktuelle Aufgaben der Meßtechnik in der Luftreinhalung", Heidelberg, pp.3-10.*

Dunmore J., 1987. 'Indoor air quality: Acceptable standards and building design', *Clean Air*, vol. **17**, n.2, pp.87-89.

ASHRAE, 1985. *Handbook of Fundamentals*, Atlanta, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE, 1989. ASHRAE/IES Standard 90.1-1989 *Energy Efficient Design of New Buildings except New Low-rise Residential Buildings*, Atlanta, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE, 1989. ASHRAE Standard 62-1989 *Ventilation for Acceptable Indoor Air Quality*, Atlanta, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Calì M., Borchiellini R., 1990. 'I problemi del calcolo delle reti per il trasporto e la distribuzione di fluidi', in *Atti del 3o Convegno ATIG Gas 2000*, Genova 26-28 novembre.

Fanger P.O. 1990. 'Comfort Criteria related to Ventilation of Spaces', *Proc of ROOM-VENT '90*, Opening Lecture B..

Freund A., 1987. 'Development of a New Jersey IAQ Standard', *Practical Control of IndoorAir Problems, Proc. Of the ASHRAE Conference IAQ 87*, pp. 3-13, May 18-20, Arlington, Virginia.

Grefen K., 1990. 'Standard Settings Procedures for clean Air in the FRG in view of the European single Market', *Communication to ISO Meeting.*

ISO, 1981. ISO Guide 26-1981 (E), *Justification of proposals for the establishment of standards*, International Standard Organisation.

Stolwijk J.A.J., 1987. 'The "Sick" Building Syndrome', *Practical Control of IndoorAir Problems, Proc. Of the ASHRAE Conference IAQ 87*, pp. 3-13, May 18-20, Arlington, Virginia.

Teichman K.Y., Woods J.E., 1987. 'Ventilation and Indoor Air Quality: Regulations, Codes, and voluntary Consensus Standards', *Practical Control of IndoorAir Problems, Proc. Of the ASHRAE Conference IAQ 87*, pp. 3-13, May 18-20, Arlington, Virginia.

BUILDING PERFORMANCE SPECIFICATIONS

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INTRODUCTION

Most people spent a great deal of their time (and life) in an indoor environment, residential and/or occupational. In their environment more and more skylines are changing by towering high-rise buildings, creating windy streets and blocking the sun. Many of them tall and thin or low and wide, mirrored in silver or bronze. The buildings we see, live and work in are an important part of our total environment. However we tend to take them for granted, they are just there. We tend to take whatever we get. While fighting for the quality of our natural environment in protecting trees, the quality of water, wildlife etc., we rarely act on buildings.
The quality of the buildings we occupy however is just as important as the quality of the natural environment. But when we look at modern (most office-) buildings it seems that they are made for the outside and not for people to live in: most building interiors are not as glamorous and colorfull as the outside.
As we know from several building investigations (1) some 20-30 % of the existing building stock may be characterized as problem buildings. Many people are likely to be exposed to either a sick home or a sick commercial building (30-70 % in the U.S.). Consequences are health effects (2), high sickness absence rates (3), low worker moral and reduced employee performance and organizational productivity (4,5). So it is a social responsibility and certainly a responsibility of all building professionals (not only the architect) to ensure that standards of quality are maintained in the buildings we use and live in. Regulations and guidlines for the indoor air quality are a contribution to that.

REGULATIONS

The development of each and every new policy area knows a certain amount of phases (policy cycle). The first phase consists of the observation and inventarisation of problems (effect on health, kind and bulk of problems). The second phase is marked by research in mechanisms, cause and consequence relations: parameter studies. In the third phase dosis-effect relations of the different relevant aspects in the problem area are being pinned down. In the fourth phase all aspects are weighted, translation into regulations takes place (laws, norms, guidelines). The last phase sees an evaluation of regulations and feedback from practical experience. Regulatory measures take an essential and central place and formulate the translation of science into the building practise. Implementation of knowlegde. This policy cycle is also relevant to the sick building problems. In actual fact this policy-cycle is risk assessement (hazard indentification, dose-response assessement, exposure assessement, risk characterization) followed by risk management, political decission (regulations) and evaluation of regulations.

Occurance of health problems related to buildings stem from the seventies. In the eighties several large scale investigations into the subject have been executed (a.o.1 and 6) indicating the kind and seize of the problem area. Then (as well as now) a lot of research into health effects, cause-consequences mechanism and dosis-effect relations has been executed. Taken the proceedings of past Indoor-Air conferences one can conclude that until the mid-eighties efforts largely concentrated on the first three phases. In previous years attempts were made to move some aspects of the complex matter into phase four. Gradually more attention is given at international conferences to the necessity of and possibilities of policy making and regulations.

In Berlin (1987) Ken Sexton (EPA) concludes that up until that moment research efforts have focused on the relevant scientific and technical questions. Consequently, relatively little attention has been paid to identifying and resolving the key policy questions (7). Key words: risk assessment, risk management as an essential part in societies efforts to attain healthy and comfortable indoor environments (also 8). For the first time the necessity to translate available knowledge to suit the practical needs of the architects comes to the fore ground.
The main object of the CIB Conference Healthy Buildings '88 (Stockholm) was to give recommendations to architects, consultants and real-estate owners. Several lectures look into the matter of translation (the importance, possibilities and limitation) into the practise of building (a.o. 10, 11 and 12). Ferahian (12) concludes 'All findings about indoor air quality are of little use to the avarage citizen, if they are not applied and translated into rules incorporated in our building codes for design, construction and, last but certainly not least, maintenance of our buildings'. Key words: healthy building design, regulation, standards, codes, quality assurance, policy and regulatory science. Certain lectures stress the point that more is necessary than just regulations to ensure healthy buildings, cooperation with the world of construction and implementation in the building proces by quality assurances.
During Indoor Air '90 in Toronto several lectures were held which dealt with the (possible) development of policy and regulation (a.o.Seifert, Dionne, Rajhans, Stolwijk, Berglund, Fanger). Attention was given as well to the (necessity) development in research: programs of EPA (Berry), WHO (Suess), NATO (Marconi).
It must be apparent that to ensure a healthy indoor-climate, regulations are necessary but an insufficient condition.

The need for regulations

Before we speak about building requirements, we have to consider the possibilities for regulations. Because the demands are intended to be incorporated into the regulations. Regulations are more than a collection of loose demands and recommendations. These days regulations are part of a much encompassing (building) quality policy. Regulations regarding construction are moving along, strongly influenced by Europe '92. Building products have to meet Essential Requirements (Council directive on the approximation of law, regulations and administrative provisions of Member States relating to construction products). One of the essential demands which is very important in this context is "hygiene, health and the environment". This will be elaborated by a Technical Committee TC3) into a foundation document. Harmonised European standards will eventually form the ground for an EC-mark.

Demands regarding policy regulations:
- requirements should be unambiguous, measurable (simple) and controllable (refering to CEN standards)
- there has to be a relationship between the prescription and the intended effect (here: prevention or reduction of health effects)
- requirements should not be a barrier for innovation (non-material bound specifications).

In connection with past developments it is important to demand performance specifications of relevant features and characteristics of buildings or building parts.

Form of regulations

Regulations can be devided into:
- legislation: bans, standards (IAQ, emission, ventilation)
- standards: IAQ, emission, ventilation
- guidelines: operation and maintenance, building- and HVAC-design.

Guidelines and standards (unless they are mentioned in a building code or other legislation) do not have the force of law; compliance with them is voluntary. Their principal value is that development is not as cumbersom as legislation procedures.
Dionne (14) does mention in the regulatory approach: prohibitive bans (of products), emission standards (applied to sources), air quality standards (intervention guide for labor inspectors), application standards and warnings (manufacturers' responsability in case of hazardous product). He concludes that providing and maintaining healthy air quality is more than just scientific information alone.

To people who need to make practical decisions it is of little value. In the non regulatory approach he mentions: health guidelines, ventilation guidelines and public information/education.
Rajhans adds to this (15) the possibility of a release of operation and maintenance guides for all buildings, for most IAQ problems arise not because a building has a below capacity ventilation system, but because this system is not properly maintained.
Finally Seifert concludes (16) that, although setting air quality standards has been instrumental in reducing the pollution of outdoor air, guideline values, rather than standards, should be developed for indoor air: one value should be an action level, one level would define a target concentration.

Goal of regulations

The goal of regulations (functionally described) is the prevention or reduction of health symptoms to an acceptable level in buildings. Or positively formulated: to assure an indoor environment that respect health, comfort, well being and productivity with acceptable social costs. That's why it is important to stop and consider the source (mechanisms) of health symptoms in buildings; fig 1 shows a simple model.
It is known that the development of symptoms are not solely dependent on the building and building environment factors (fysical, chemical and biological factors) and the usage (management and maintenance) of the building but also psycho social and other factors (the work experience and personality). The first two do determine the physical environment in buildings. This physical environment lents itselfs for building regulation. The following story points to these factors.

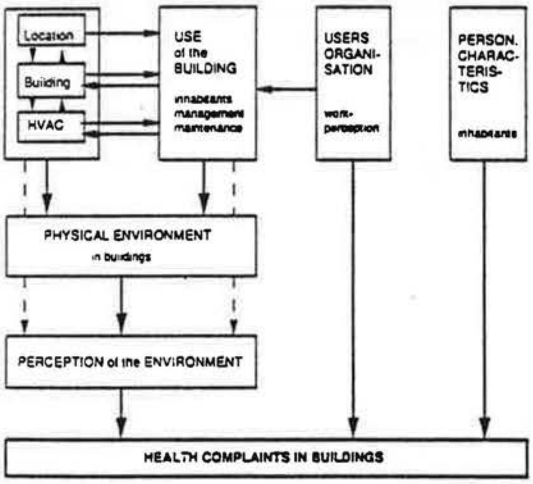


Fig. 1: Simple model for health complaints in buildings.

The figure shows that a different category of buildings needs different demands (probably different strategies) for a good IAQ (schools, hospitals, offices, residential dwellings etc.)

BUILDING PERFORMANCE SPECIFICATIONS

It's a known phenomenon that there are buildings which comply with every known demand and still remain problem buildings. One of the reasons for this could be that the set of requirements is incomplete or worse that demands are made on non-relevant aspects, which seem to suggest a certain quality (like detergent advertisements). Its of the utmost importance to pinpoint all relevant building factors before specifing requirements. When regulations are implemented one has to separate building factors (design demands) and user-factors (user demands). In the following, especially building factors will be dicussed .

Relevant factors

To determine systematically all the relevant health-related building factors two methods can be used (generally not specifically IAQ).

- On the basis of expert opinions (building factor)
  - Yes/no relevant (Delphi-method)
  - calculation of risk factor per aspect
- On the basis of judgement of occupants (Post Occupancy Evaluation)
  - assessement of (Building in Use)dimensions of Environmental Quality
  - data analysis of building investigations: relative risks out of building and symptoms correlations.

Expert opinions

The first rough way to determine relevant quality factors is to give experts a list of all known building quality factors. They are requested to translate relevant health factors (including comfort and well-being) on humans in buildings on a scale of 1 (utmost important) to 5 (not important). In Holland in 1989 this research took place by GBA among the Dutch participants of the Healthy Building congress in Stockholm (16 respondants). In this investigation an adapted list of quality factors for buildings was used, which the GBA uses for cost-quality policy (see appendix 1). The quality factors are subdivided into spacial visible aspects, functional and technical factors. It appeared that spacial visible factors got the lowest-score. Of the functional aspects the floorspace per person gets a reasonable score. A reasonable score is also given tot part of the technical aspects (outdoor air quality, used materials, noise and vibration, natural light and humidity). A very high score was preserved for thermal comfort, lighting and the quality of indoor air.
It won't surprise anyone that in a similar investigation held among architects, spacial visible aspects got a higher score, principally the use of colour and spacial perception.

The second method is based on the same list, but more specified and extensive, accentuating a healthy building quality. An example of the extended list is given in appendex 2. The opinion of the expert will be more or less guided to calculate the risk factor per aspect in terms of chance x consequences. We will use the following equation:

$$\text{Risk} = [\, P * C * I \,] * E/10$$

Risk = health risk of observed aspects [1-100]
P = prevalence in buildings (exposure of population) [1-5]
C = characteristic of exposure of the aspect [1-5]
I = measure of individual influence [1-4]
E = health effect [1-10C], in which C is raised cancer risk or death risk.

This project has been executed just as a pilot project with 4 experts. The method, which in its larger structure is the same as allready in use in Holland on several chemical agentia in residential dwellings, when adapted, it can be used for this air as well.

Post Occupancy Evaluation

A different approach is, instead of using the experts opinions, to use the perception of the occupants. In 19 office buildings research has been carried out about environmantal quality (17) with the help of a questionnaire. Each questionnaire contained a number of rating scales from 1 (bad or uncomfortable) to 5 (good or comfortable). The rating scales were submitted to a factor analysis. Ten factors emerged consistently, using a variety of different factor-analysis procedures. These factors are: privacy, indoor air quality, thermal comfort (warm), thermal comfort (cold), spatial comfort (furnishing), dust, spatial comfort (fittings), individual control, external noise and lighting.
These factors (dimensions) represent sets of environmental ratings, wich can be averaged to produce a score for each dimension. These scores are indicative of how people judge environmental quality (and do take psychological factors in consideration). They do not necessary correspond to instrument measurements of human comfort.

Remaining aspects (questions) after factor analyses are:

For the dimension *Air Quality*:
- Air Freshness (stale air - fresh air)
- Odours (unpleasent - not noticeable)
- Nuisance unpleasant odours (often - never)

For the *Thermal Comfort (warm)* these are:
- Heat nuisance (often - never)
- Summer temperature (uncomfortable - comfortable)
- Temperature-shifts (often - never)

For *Thermal Comfort (cold)* these are:
- Affected by cold (often - never)
- Cold feet (often - never)
- Winter temperature (uncomfortable - comfortable)
- Draughts (often - never)

For *Dust*:
- Dust (dusty - free from dust)
- Cleaning (discontent - content)
- Rel. humidity (too dry - good).

Although this method is very interesting when determing the environmental quality (fig. 2 gives an example), these scores do not lend themselves for regulations in terms of building performance specifications. For these one needs to find the correlation between these aspects and building and installation characteristics. These analysis are being carried out at the moment.

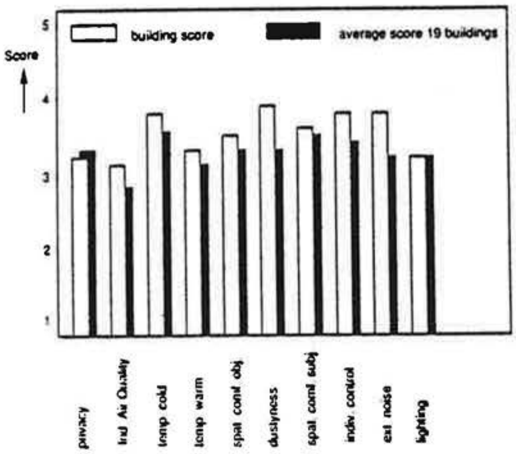


Fig. 2: Example of a building score with the Healthy Building Quality Method.

Research in 61 Dutch office buildings (18) shows groupings of complaints related to building features, translated into a relative risk. On the bases of these its aparent that the following aspects (no individual characteristics like gender) are relevant: the possibility to manually change the temperature, treatment of occupants complaints, the work experience, mechanical ventilation, recirculation, air humidification, number of persons per room and working with screens. It boils down to the following installation characteristics.

- installation types:
  - natural versus mechanical ventilation
  - existence of himidifiers
  - existence of recirculation
- manually/individually controled temperature.

IAQ-factors

The following aspects for Indoor Air Quality are destilled from previously mentioned research.

Air Quality
- freshness
- odours
- pollutions (chemical, biological, dust)
- individual control of ventilation
- dust
- cleaning

Thermal Comfort
- temperature (warm, cold)
- temperature shifts
- draughts
- humidity
- individual control of temperature, sunshades

Type of HVAC system
- natural versus mechanical ventilation
- existence of humidifiers
- existence of recirculation.

One can translate these to the following building/installation characteristics:

Functional Quality
- amount of person per workplace

Architectural Quality
- used materials (emission, sources of dust, growth of fungae, odour)
- ways of construction and application of detail (damp, growth of fungae)

Urban Planning Quality
- Outdoor air quality

Building Fysical Quality
- thermal comfort

Technical HVAC Quality
- amounts of ventilated air
- manual control of temperature, ventilation, sunshades (lighting)
- amount of recirculation
- nature of air humidity systems.

Next to these the following users aspects are relevant:
- emissions caused by used appliances
- cleaning (dust)
- amount of persons per m2
- treatment of complaints
- enjoyment of work.

STATE OF THE ART

This chapter will deal with previously mentioned relevant aspects. The state of the art of every aspect is mentioned and elaborated.

Amount of persons per workspace

The amount of space per person is, provided enough ventilation per person is present, not very relevant for the IAQ, although it is important for privacy and spatial comfort. National standards appear in several countries (a.o. Holland, France). In the context of individually controled ventilation, temperature, light and sunshades, the amount of persons per jobspot is important. It's known from practical experience that many persons per workspace give rise to comfort complaints. What some consider fresh air, others feel as draught. A comfortable temperature for the one, is chilly to another. Landscape-offices are notorious for this, it will be better to avoid them. Standards or guidelins in this area are yet unknown.

Use of materials

Materials used for construction, finishing and installation of a building can be responsible for emissions of toxic or dangerous gases and particles (formaldehyde, VOC's, fibres etc.), dangerous radiation (radon), odours, pollution of water and presence of damp on surfaces. For many substances advers health effects are known and guideline values are available and published (ex.: 19, 20). Some different (regulatory or non regulatory) strategies are previously brought to the foreground.
With regard to emissions two ways to approach the problem are possible for building regulations.

- Prohibitive bans
  This tactic can be applied to products that may cause significant indoor air contamination and health risk (ex.: asbestos, PCP). Most governments are very careful with bans while one has to proof the detrimental effect and there has to be an acceptable substitutional product.
- Emission standards
  Contaminants can be controled by appling emission standards to sources in a source category irrespective of existing air quality. One can start from a acceptable indoor concentration level and calculate the emission rate, assuming the average conditions under which the product is used in practice. Although the necessary work has been done, like guidelines for test chamber measurements (21) and the Council Directive on construction products (22), much work remains to be done to establish harmonised standards for products (16).

Standards and guideline values for indoor air quality are unsuitable instruments for building regulations but are important and usable for problem solving in existing buildings. They can be used as an instrument by the labor inspection. A very promising new approach for IAQ (i.c. future ventilation standard) is presented by Fanger, in which all pollution sources are acknowledged, so too of building materials and installation. Emissions outof building materials can become a major design tool and probably can be considered in the near future for conversion into regulations.

It is known that dust as a reservoir of microbic pollution, can lead to complaints (mucosal and general symptoms). Correlated parameters are a.o. amount of floor dust, fleece-index, shelf-index and floor-covering (24). For the time being there is no substantiated performance requirement.

Various studies have demonstrated health effects on inhalation when exposure to *fungi* in indoor air was present. Depending on factors such as the degree of humidity, temperature, the presence of oxygen, pH, nutrients etc., a microbial flora can grow in/on building materials (chipboard, mineral wool etc.). Some building materials may already from the production line be contaminated with micro-organisms (corck sheeting).
Regarding the dependancy of humidity (ventilation) and temperature and the probability of organisms to become airborne it seems that regulation concerning material application is not obvious. An investigation into the presence of micro-organisms in building materials and constructions (25) in both healthy and sick buildings, did not show any correlation of airborn microorganisms and the presence of microorganisms in/on building constructions.
Recommendations which are independent of used materials should be included into guidelines (sealing in tight constructions).

Construction design and details

The relation of the ways of construction and application of detail with IAQ lays in the possible occurence of (internal) condensation. This creates favorable conditions for the development of fungi. Internationally as well as nationally a lot of research is carried out in de context of IEA Annex XIV (26). In several countries the results are already incorporated into the building codes.

Outdoor Air Quality

It is obvious that a good indoor air quality starts with a good outdoor air quality. In many countries there are ambient air quality standards which limit the emission of pollutants into outdoor air.
Research into this area, from the viewpoint of indoor climate, is usually restricted to the influences of temperature, humidity and wind. In several research projects the indoor as well as the outdoor concentrations of suspended particles and VOC's are measured, concluding that the majority of the VOC's have infiltrated from outdoors. In (28) some guidelines concentrations are given for some outdoor pollutants (good air) and supply air quality (half of the contaminant concentration indoors). Also in (19) guideline values for certain substances in the outdoor air are given.
Since polutants in the building will be added to the outdoor air, it seems relevant that building regulations make demands on the quality of supply air, inclusive the effect of filters (comparable with the regulations with regard to noise (maximum noise level outdoors, sound insulation, acceptable noise level indoors).

Thermal comfort

Requirements to the thermal environment, i.e. air temperature, thermal radiation, air velocity, humidity, are specified in the international standard ISO 7730 (29). It is possible at the design stage to predict the thermal parameters. There is, however, a need for better methods to predict the air temperatures and air velocity in a room (30).

Ventilation

There are several national standards for ventialtion, the most well known are the ASRAE standard 62-1989 and the German DIN 1946. For the state of the art with regard to ventilation one is refered to "The new principles for a future ventilation standard" by Fanger (23).
A minimum of fresh air (35 m3/h p.p.) can be incorporated in building codes or occupational regulations.
For the building codes it might be necessary to make this demand independent of number of occupants, because in practise this is determined by the the use of the building. While translating one can use the standard with regard to the minimal space per occupant (8 m2) in offices or an average occupancy per room for dwellings.

Individually controled temperature, ventilation, sunshades, lighting

It is apparent from research that individual controle of temperature, ventilation and sunshades are important aspects in relation with the development of complaints. Is it difficult to express this aspect into a performance specification, it does not lend itself for building regulation (building code). It can be included in guidelines and standards in the form of a functional discription: (aspect) must be individually controlable. The amount of occupants per workspace can be a problem.

Type of installation

A lot of research shows (a.o. 2,31) that the amount of complaints increase as more air treatment technics are applied. Buildings with natural ventilation have the lowest complaints percentage, buildings with airconditioning the highest.
Explanations up till now have been largely hypothetical although suspicions are raised by microbic pollutions in ventilation and AC systems.
The given facts are useless for incorporation into regulations, but suitable for guidelines.

Amount of recirculation
Recirculation of indoor air is often used as an energy saving measure. Pollutants will be spread through out the whole building. Filters can not remove all pollutants (tabacco smoke, VOC's, biological contaminants). Correlation between (the amount of) recirculation and certain health symptoms are not unambiguous. Calculations show that whith 50% recirculation twice as many concentrations occur as without. When 30% recirculation the factor is 1.5. One is advised either to stop recirculation or restrict to 30%. In any case the amount of fresh outdoor air of 35 m3/h p.p. must be guaranteed. Prohibition of recirculation seems premature.

Nature of air humidity installation
When air humidity installations are present spraying results in more complaints than steaming (18). Here also only hypothetical explanations are given. The accessibility of this aspect into regulations is limited.
There are some recommendations for maximal allowed micro biological pollutants (water, air) during the usage of the installations.

CONCLUSIONS

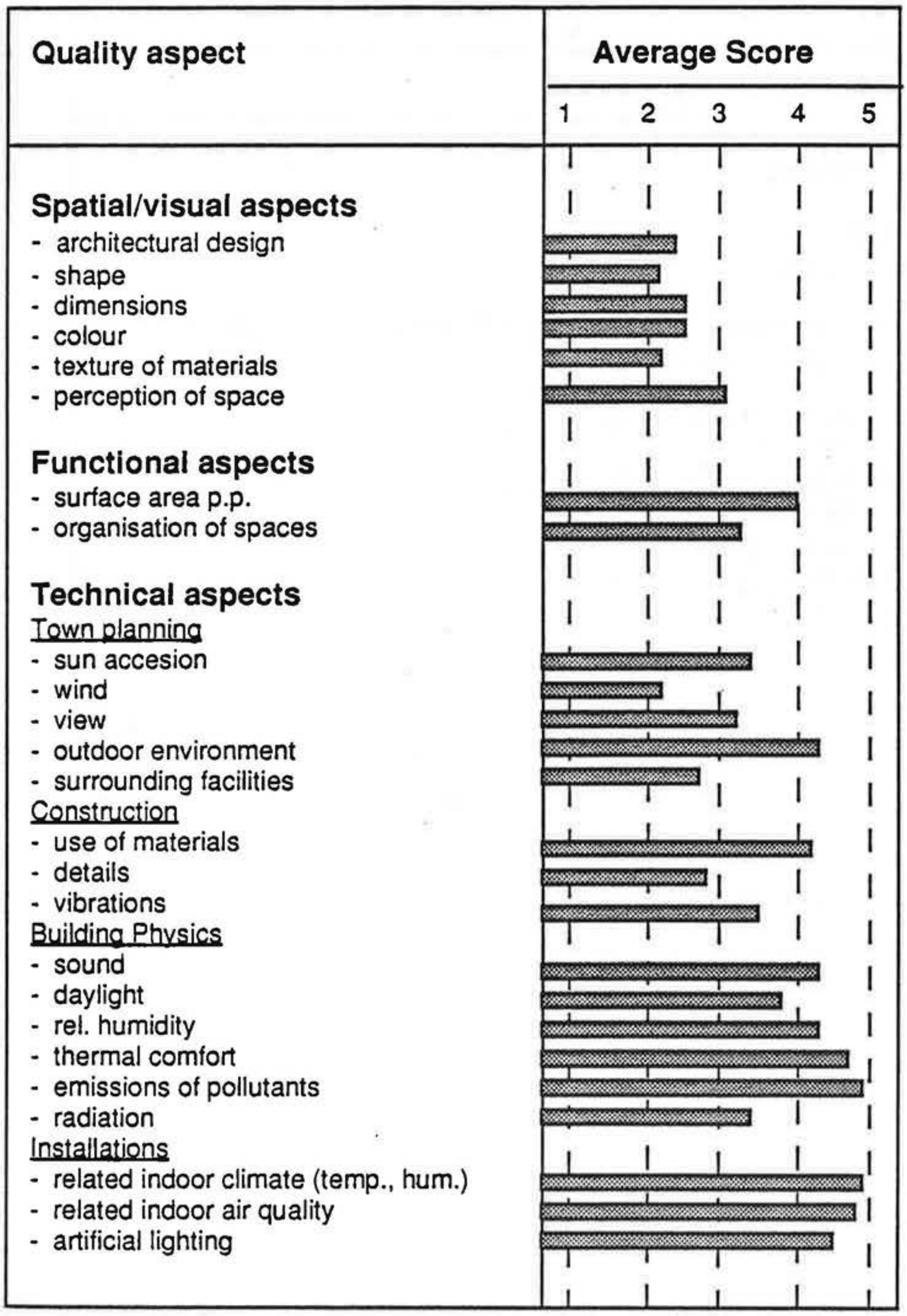
From the previous we can conclude that certain aspects of IAQ at this moment can be included (or have already been included) into building regulations in the shape of building performance specifications: ban of certain products, demands imposed upon the way of construction in connection with condensation, thermal comfort, ventilation quantities. Other aspects lend themselves in a lesser degree, but can be incorporated into guide lines: IAQ standards, use of materials involving growth of microbial flora, individual controlability, amount of recirculation.
Several aspects need further research. For building regulations: absent emission standards, relation between building features and dust in connection with microbial pollution, quality of suplpy air, amount of recirculation. For guidelines: olf catalogue of building materials, individually controlled systems and amount of persons per workspace.
Lastly it's stressed that we cannot achieve anything with only scientifically justified standards and regulations. Implementation into the building proces is vital. Perhaps more can be achieved now with implementation of existing knowledge into the building proces than to remain in search of even more refined rules (concerning new buildings). This applies to a lesser degree to the amelioration of the existing building stock.

REFERENCES

1. Woods J.E. (1990) Continuous accountability: a means to assure acceptable indoor environmental quality. Proc. 5th Intern. Conf. on Indoor Air Quality and Climate Vol. 5, 85-94
2. Burge S., Hedge A., Wilson S., Bass J., Robertson A. (1987) Sick Building Syndrome: a study of 4373 office workers. Ann. Occup. Hyg., Vol. 31, no. 4A, 493-504
3. Preller L, Zweers T (1990) Sick leave due to work-related health complaints among office workers in the Netherlands. Proc. 5th Intern. Conf. on Indoor Air Quality and Climate, Vol. 1, 227-230
4. Raw G., Roys M. (1990) Further findings from the office environment survey: productivity. Proc. 5th Intern. Conf. on Indoor Air Quality and Climate, Vol. 1, 231-236
5. Vischer J.C. (1989) Environmental Quality in Offices, 19-24, Van Nostrand Reinhold, New York
6. Harrison J., Pickering A.C., Finnegan M.J., Austwick P.K.C. (1987) The sick building syndrome: Further prevalence studies and investigation of possible causes. Proc. 4th Intern. Conf. on Indoor Air Quality and Climate, Vol. 2, 487-491
7. Sexton K. (1987) Public policy implications of exposure to indoor pollution. Proc. 4th Intern. Conf. on Indoor Air Quality and Climate, Vol. 4, 105-116

8. Lindvall T. (1987) Assessing the relative risk of indoor exposures and hazards, and future needs. Proc. 4th Intern. Conf. on Indoor Air Quality and Climate, Vol. 4, 117-133
9. Levin H. (1987) What architects can do to imprive indoor air quality. Proc. 4th Intern. Conf. on Indoor Air Quality and Climate, Vol. 4, 17-26
10. McNall P. (1988) Indoor air quality standards and codes in the United States. Proc. CIB Conference Healthy Buildings '88, Vol. 1, 164-168
11. Blousgaard E. (1987) Methods and prospects in building regulation as a way to healthier buildings. Proc. CIB Conference Healthy Buildings '88, Vol. 1, 199-206
12. Ferahian R.H. (1988) Building codes designed for ensuring good indoor air quality. Proc. CIB Conference Healthy Buildings '88, Vol. 3, 671-678
13. Foss I. (1988) Quality assurance in building construction. Proc. CIB Conference Healthy Buildings '88, Vol. 1, 169-179
14. Dionne J.C. (1990) Environmental regulation and guidelines in relation to health comfort and productivity objectives. Proc. 5th Intern. Conf. on Indoor Air Quality and Climate, Vol. 5, 115-119
15. Rajhans G.S. (1990) The development of IAQ policies in Ontario. Proc. 5th Intern. Conf. on Indoor Air Quality and Climate, Vol. 5, 121-126
16. Seifert B. (1990) Regulating indoor air. Proc. 5th Intern. Conf. on Indoor Air Quality and Climate, Vol. 5, 35-49
17. Van Drunen Th. (1990) Healthy Building Quality Assessement Method. Preliminary Report TNO-SCMO (in Dutch)
18. Preller L., Zweers T. a.o. (1990) Health complaints and complaints about indoor environment in office buildings. Rapport S 83, DGA Voorburg (in Dutch)
19. WHO (1987) Air Quality Guidelines for Europe. WHO Regional Publ., Europ. Series no. 23, Copenhagen
20. Health and Welfare Canada (1987) Exposure Guidelines for Residential Indoor Air Quality. Dept. of National Health and Welfare, Ottawa
21. COST 613 (1989) Formaldehyde emission from wood based materials: Guideline for the determination of steady state concentrations in test chambers. Report no. 2, Off. for Publ. on the EC, Luxembourg
22. European Communities (1989) Council Directive on the approximation of laws, regulations and administrative provisions of the member states relating to construction products. EC L 40/12
23. Fanger P.O. (1990) New principles for a future ventilation standard. Proc. 5th Intern. Conf. on Indoor Air Quality and Climate, Vol. 5, 353-363
24. Gravesen S. (1990) The role of potential immunogenic components of dust (MOD) in the Sick- Building-Syndrome. Proc. 5th Intern. Conf. on Indoor Air Quality and Climate, Vol. 1, 9-13
25. Ström G., Palmgren U., Wessén B. a.o. (1990) The Sick Building Syndrome: an effect of microbial growth in building constructions? Proc. 5th Intern. Conf. on Indoor Air Quality and Climate, Vol. 1, 173-178
26. IEA Annex XIV
27. Weschler C.J., Shields H.C. A detailed study of the effects of ventilation, filtration and outdoor air on the composition of indoor air at a telephone office building. Proc. 4th Intern. Conf. on Indoor Air Quality and Climate, Vol. 3, 142-146
28. Seppänen O., Kukkonen E. Guidelines for the design and classification of good airconditioning systems. Proc. CIB Conference Healthy Buildings '88, Vol. 3, 707-714
29. ISO 7730 (1984) Moderate thermal environments - Determination of the PMV and PPD indices and specifications of the conditions for thermal comfort. Geneva
30. Olesen B. W. Are the thermal factors critical for humans adequately considered in the design of new heating and air-conditioning systems? Proc. CIB Conference Healthy Buildings '88, Vol. 1, 83-90
31. Wilson S., Hedge A. (1987) The office environment survey- A study of building sickness. Building Use Studie Limited

APPENDIX 1: Average scores of expert opinions of quality aspects related to health complaints.



1 = not important
5 = very important

APPENDIX 2: Extended checklist of Healthy Building Quality aspects. Example: construction.

Quality aspect
Technical aspects <u>Construction</u> - Use of materials * source of dust * source of emissions (formaldehyde, asbestos, radon, benzene etc.) * source of biological material * fibres * apsorption/desorption characteristices - Details/design * source of dust (easy to clean, maintain) * cold bridges * internal condensation * air tightness * water leakages - Vibrations

Report on sessions 3, 7 and 8 of the IAQM-Workshop

Lausanne, Switzerland, May 27 and 28

Dr. Philomena M. Bluyssen
TNO-Building and Construction Research

Session 3: Sources and Contaminants
presentations: M.Girard and B.Seifert

Session 7: The IAQ-Control
presentations: P.O.Fanger, G.Fracastoro and W.Raatschen

Session 8: The IAQ-Audits
presentations: P.M.Bluyssen, A.Roulet, U.Norlen

To control IAQ means mainly to maintain always acceptable IAQ levels as defined for example by ASHRAE.
This can be done by :

. **source control:**
  - prevention of pollution sources:
    . cleaning devices
    . selection of low polluting sources
  - removing of pollution sources

and . **ventilation**

Sources of pollutants are
. outdoor environment: air, soil and water
. man and his activities: short term emissions
. materials: long term emissions

The concentration of indoor air pollutants may vary widely as function of both time and space. The sampling strategy used to determine the concentration level together with the boundary conditions will have an influence on the final results. Short-term peak concentrations may exceed average conditions.

The concentration levels have to be combined with the time spent at these levels to obtain information about exposure, which is the parameter of importance for health effect considerations (personal exposure measurements + activity patterns).

Demand Controlled Ventilation (DCV) systems are systems which should be able to maintain always acceptable IAQ-levels at the lowest possible energy costs (basic ventilation rate for pollutants originating from building + variable ventilation rate for pollutants emitted by humans and activities). An IAQ-sensor is the key point for a good performance of DCV. IAQ-sensors can only be made if IAQ is properly defined in terms of composition and perception of the human nose. There is a need for a definition of Indoor Air Quality.

Data of occuring pollutant levels and dose-response relationships are insufficient. There is a lack of knowledge of ventilation performance in buildings. Actual ventilation in buildings is not really well known.

Techniques to indicate or measure Indoor Air Quality are:
. those concentrating on the human being (questionnaires, medical examination, body fluids monitoring, response of visitors - trained or untrained).
. those considering the air (characteristics and contents)

. those considering the air and the human being (epidemiological and clinical studies)
. other methods (indicators of latent sources, general indicators, TVOC, pattern of chemicals, visual inspection, ventilation measurement techniques)

Two main procedures can be used in IAQM:
. the health procedure: air quality based on the concentration of pollutants which may have a health risk. Biomarkers is an alternative.
. the comfort procedure: perceived air quality determined by human nose and is based on the dissatisfaction/satisfaction of visitors of a building. Those visitors can be trained or untrained. Trained visitors evaluate the air quality in decipol, untrained visitors evaluate the air quality on its acceptability.

Research needs:

. Measuring techniques:
- method to determine the source strength of pollution sources chemically and sensory.
- IAQ-sensor based on the human response
- standardized method to train people to evaluate perceived air quality in decipol

. Quantitative data IAQ:
- ventilation performance
- identification/quantification pollution sources in buildings chemically & sensory
- exposure effects of pollutants: activity pattern of exposed people combined with measurement of pollutants chemically and sensory

Conclusion:

In EC-countries the following could be done:
. an epidemiological study in several EC-countries following the same procedure in each country to collect a lot of quantitative IAQ data, containing for example:
- ventilation performance measurements using a passive tracer technique
- standard questionnaire
- identification/quantification of pollution sources (sensory & chemically)
- activity patterns of exposed people
- measurement ofindoor pollutants (longterm and shortterm; sensory and chemically)
- indoor climate measurements

and/or
. several working groups could be formed, which each concentrates on a specific topic or problem, for example:
- standard method to train a panel
- method to determine the source strength of pollution (sensory & chemically)
- ventilation performance measurement

Session 2 Report: Comfort, Health and Hygiene

Session 2 focused on the medical conditions associated with sick buildings and was introduced by Dr Sherwood Burge of Birmingham Hospital, UK. and by Dr Thomas Lindvall of ... , Sweden. The principal areas of interest were the assessment of medical symptoms associated with building sickness and the identification of causes.

Conclusions drawn from this session included the need for good indoor air quality management for reasons of health, economic return and comfort. In terms of medical symptoms, sick buildings were thought to be associated with such factors as air conditioning systems, humidifiers and chillers. Also there was thought to be some link with allergens and mycotoxins. Case studies revealed that fewer symptoms associated with sick buildings were to be found in naturally ventilated buildings than in air conditioned buildings, even although parameters associated with poor ventilation or poor air quality tended to be higher. There was little or no evidence of links with the rate of ventilation or with carbon dioxide, humidity, ozone or formaldehyde concentrations. The case still had to be proven for volatile organic compounds, odour and photocopier emissions. It was argued that assessment methods used by some authorities to identify or classify symptoms of sick buildings could miss out seasonal factors, hence a standardisation of the method of assessment was urged. As a general point, concern was expressed about the use of biocides in air conditioning systems.

The recommendations of Session 2 included:

(i) the need to establish air quality and climatic requirements for healthy buildings.

(ii) the need to establish a uniform test method for assessing sick building problems.

(iii) the prioritisation and acting on major health concerns such as carcinogens and allergens to be found in buildings.

(iv) the introduction of source controls where pollutants create a problem.

(v) the need to disseminate knowledge of experience.

(vi) the need to be aware of the local environment in which a building is located.

(vii) the need for user friendly or transparent heating and ventilation systems which would perform correctly and be tolerant of user interaction. Extra capacity should be designed into ventilation systems to provide a safety margin.

Areas of future research, identified in session 2 included:

(i) further assessment and surveys of symptoms according to a common test procedure. Attention should be directed at mechanisms such as allergies and irritation as well as physical factors such as temperature and humidity. Assessments should be conducted in a wide range of buildings in order to establish building related factors.

(ii) an investigation of fungi present in indoor air. Fungal spores have been found to be more prevalent in naturally ventilated buildings, but those found in air conditioned offices have been found to be more toxic. It is therefore important to carry out a thorough investigation of fungi in buildings. The use of biocides also needs to be researched, since these are used to destroy biological contaminants yet could be harmful to occupants.

(iii) identifying air quality requirements. A study should be implemented to define acceptable indoor air quality standards. These may then be used to define ventilation needs and other necessary control measures.

Session 5 Report: The Ventilation Problem

Session 5 concentrated on identifying the role of ventilation in controlling air quality and on establishing the means to provide both energy efficient and cost effective ventilation. Contributions were presented by Martin Liddament of the International Energy Agency's Air Infiltration and Ventilation Centre, Willem de Gids of TNO, Netherlands and Dominique Bienfait of ,France.

Topics considered included quantifying the rate of ventilation needed for optimum air quality. Clearly this depends on the sources, emission rates and types of pollutants present in a building. Alternatives to ventilation such as source control must also be considered. Furthermore, the pattern of air flow and ventilation efficiency will effect the distribution and concentration of pollutants in a building. Occupant exposure to pollutants was also considered with special consideration to critical problems such as backdraughting from flues. Since retrofit represented a significant proportion of construction activities, there was thought to be a good possibility to improve ventilation as part of this renovation programme. Optimum ventilation control combined with reduced energy consumption was seen as a challenge for future research and development.

Research proposals derived from this session included:

(i) Evaluate the role of ventilation. Quantify ventilation needs in relation to:

- the need for a safe "background" level
- occupant needs
- occupant activities (eg office activities, smoking etc)
- fabric and furnishing emissions

This approach would enable the additional cost of ventilating above that required for the direct needs of occupants to be properly audited.

(ii) Evaluate the energy consequences of meeting ventilation requirements.

(iii) Assess the existing building stock for magnitude and range of ventilation rates by means of passive measurement techniques and corroborative detailed measurements.

(iv) Formulate energy and cost effective ventilation strategies according to needs, climatic conditions and building type.

(v) Improve numerical simulation techniques.

(vi) Develop and implement passive tracer techniques. Consider the establishment of European Centres for per fluoro tracer (PFT) analysis.

(vii) Establish European test houses for ventilation analysis.

(viii) Identify the magnitude of air flow through "unknown" leakage paths.

(ix) Assess occupant behaviour in relation to window opening and interaction with ventilation systems.

(x) Quantify the deposition and adsorption of pollutants on surfaces.

(xi) Undertake studies on passive (stack) ventilation systems. This should include an evaluation of the influence of external flows, pressure drops, climatic influences, condensation, heat loss, and acoustic problems.

(xii) Undertake a study of carbon monoxide poisoning incidence arising from the use of combustion appliances.

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CEC Indoor Air Quality Management Workshop

Lausanne 27-28 May 1991

Report of Sessions 1 and 9

P. Wouters

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1. INTRODUCTION

This report gives the 'rapporteurs report' on sessions 1 and 9. It is not the same as the oral presentation given at the end of the conference.

2. SESSION 1

The 2 presentations of session 1 mainly dealt with the concerted CEC action COST 613 "Indoor Air Quality and its impact on man". COST stands for "CO-opération européenne dans le domaine de la recherche Scientifique et Technique). The decision to start this action was taken in 1986 and it is till now the largest research effort by the CEC in the field of Indoor Air Quality.

The paper by Mr. Knöppel is very useful for those who want to obtain a better overview on all activities of the Commission of the European Communities related to IAQ.

It is explicitely stated in the 4th 'Policy and Action Programme on the Environment (87-92)' of the EC that scientific research is an essential preparatory activity for almost any political action in the field of environmental protection. This clearly supports the intention to start research in the field of IAQ since political actions are probably coming in the coming years. For the time being, the only recommendation by the Directorate General XI (Environment, Nuclear Safety and Civil Protection) concerns the protection of the public against indoor exposure to radon.
The financial contribution of the CEC to COST Concerted Actions covers only the expenses for a secretariat and for the organization of meetings. Such kind of support could perhaps also be considered in the framework of an IAQM programme for specific activities.

The work within the COST 613 was organized in 10 Working groups. Details on the various activities as well as an overview of the available publications can be found in the paper of Mr. Knöppel. Especially the 'Project Inventory' can be of use for the identification of research gaps and for planning new research projects.

The second speaker, Mr. Valbjorn, discussed important factors associated with SBS and building related illnesses. He recommends a stepwise method for investigating buildings with indoor climate problems.
Given the fact that many of the so-called causes for complaints are perhaps only indicators of the real causes, Mr. Valbjorn recommends to concentrate future research efforts on topics related to

this issue. Human exposure studies in environmental chambers are receiving much attention in this proposal for further research topics.

3. SESSION 9

Mr. Bekker's paper on 'Requirement on Installation Performance' situates first the issue of IAQ in the wider context of the 'Quality of the Indoor Environment'. A comparison between natural and mechanical ventilation shows advantages as well as problems with both types of ventilation (as used today). The paper of Mr. Bekker deals further with the various components of a HVAC system and also with various ventilation concepts for building (induction units, displacement ventilation, recirculation systems, ...). He finally stresses the importance of the organization of the building process. The 'power of the money" requires a very good organization. The concept of the open project team can help a lot.
At the end of his paper, a whole range of research proposals is given. They focus mainly on installations and cover control and design aspects, pollution effects, displacement ventilation and the concept of the "open team project".

The paper by Cali and Borchiellini on 'IAQ oriented performance specification : a methodological approach', discusses in a general methodological approach the problem of sending standards and regulations in the field of IAQ.
Firstly, the representation of the real phenomenon with a model is analysed. He also gives a brief review of the international activities (ISO, CEN, ASHRAE) in the field of air quality standards. Most of the existing standards are apparently devoted to outdoor air quality. The paper also gives some suggestions for further work.

The paper of Mr. Bergs deals with 'Building performance specifications". After the introduction, in which the problem is clearly situated, the various phases required to achieve (good) regulations are discussed. He then discusses various aspects of regulations : various forms of regulations, their goals and also the way of expressing requirements.
The paper gives much attention to the issue of selecting the appropriate building performance specifications. A systematical determination of all the relevant health-related building factors seems to be possible by using expert opinions or on the basis of judgement of occupants. Based on past research activities, Mr. Berghs comes to a list of relevant building/installation characteristics. All of them are briefly discussed and the link with regulation is made.
He concludes on the one hand that several aspects need further research as well as for building regulations as for guidelines. On the other hand, he correctly remarks that we cannot achieve anything with only scientifically justified standards and regulations. The implementation of the existing research knowledge into the building process is at least as important as the search of even more refined results.

An illustration of the complexity of the issue of Indoor Air Quality Management is illustrated by the different opinions of Mr. Bekker and Mr. Berghs on the recirculation concept. Mr. Bekker believes recirculation should be forbidden while Mr. Berghs states "the prohibition of recirculation in regulation seems premature".

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