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Philomena M. Bluyssen

TNO-Building and Construction Research,
Department of Indoor Environment,
Building Physics and Systems, Delft,
The Netherlands

Indoor Air Quality Management

A State of the Art Review and Identification of Research Needs

Key Words
Indoor air quality management
State of the art
European activities
Research needs

Abstract
A workshop on indoor air quality management (IAQM) was held by the Commission of European Communities (DG XII) in Lausanne on May 27–28, 1991, to determine the state of the art of the current knowledge concerning IAQM, the missing know-how and possible research areas. Twenty-six IAQ experts participated, and each expert presented a state of the art and future research needs on one of the following topics: sick building syndrome, IAQ measurement, IAQ and energy, sources and source control, ventilation, ventilation systems, and European activities and regulations. This paper presents a summary of the outcome of this workshop.

Introduction

During the past 20 years, indoor air quality (IAQ) has received growing attention. Many complaints with respect to IAQ occur, and the causes of these complaints are often not found, in spite of thorough investigations. This phenomenon as well as its outcome is often called sick building syndrome (SBS). In Europe, the IAQ issue had already emerged in the late 1960s, first in the northern countries, in particular in Denmark and Sweden, whereas in most Mediterranean countries it has been perceived only rather recently.

The problem of the quality of the indoor environment has been addressed from several different perspectives. Air quality guidelines seem to suggest that a clear separation exists between occupational health (or hygiene) and comfort. However, some standards imply that a lower level of a contaminant, which is not necessarily harmful to health, may have some consequences for comfort.

Buildings are constructed to provide protection for people and their belongings against the outdoor climate, illegal entry and destruction, to ensure that adequate functional requirements are met for indoor activities, and to constitute a valuable asset in economical, social as well as psychological terms. Thus requirements set by demands for health, comfort and hygiene are important. However, essential knowledge is still lacking for successful IAQ management (IAQM).

A workshop on IAQM was held by the Commission of European Communities (DG XII) in Lausanne on May 27–28, 1991 [1], to determine the state of the art of the current knowledge concerning IAQM, the missing know-how and potential research areas. The 26 experts who contributed to this review on IAQM are, in alphabetic order: S. Becirspahic (France); J. Bekker, J. Bergs (The Netherlands); D. Bienfait (France); P.M. Bluyssen (The Netherlands); C. Boffa, R. Borchiellini (Italy); G.W. Brundrett, P.S. Burge (UK); W. de Gids (The Netherlands); E. de Oliveira Fernandes (Portugal); P.O. Fanger (Denmark); G.V. Fracastoro, M. Girard, H. Knoeppel (Italy); S. Leskinen (Finland); M.W. Liddament (UK); T.L. Lindvall (Sweden); P. MacDonald (UK); A.T.U. Norlen (Sweden); W. Raatschen (FRG); M. Rolloos (The Netherlands); C.-A. Roulet (Switzerland); B. Seifert (FRG); O. Seppänen (Finland), and O. Valbjørn (Denmark). The workshop was organized by T.C. Steemers and P. Wouters (Belgium) and hosted by the Swiss Federal Office of Energy. More detailed information on the

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Philomena M. Bluyssen
TNO-Building and Construction Research
Department of Indoor Environment
Building Physics and Systems, PO Box 29
NL-2600 AA Delft (The Netherlands)

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presentations given in this workshop has been published elsewhere [1, 2]. The following review reports the outcome of the workshop.

Current State of the Art

Sick Building Syndrome

Sick building syndrome (SBS) comprises a group of symptoms that are common in the general population, but which are more prevalent in some buildings than others. Principal symptoms are lethargy, headache, blocked or runny nose, dry or sore eyes, dry throat and sometimes dry skin and asthma.

A sick building is commonly characterized by a higher prevalence of just the same symptoms as are reported in a non-sick building. It is seldom possible to attribute the symptoms to the influence of a single factor, like formaldehyde or dust. More than 1 factor might result in the same symptom, e.g. both heat radiation and formaldehyde can cause dryness of the eyes. From the investigational point of view, use can be made of the fairly reasonable hypothesis that several factors, each unlikely to cause any symptoms alone, can do so when they occur together. It is accepted that SBS is a multifactorial problem, and research has shown that many of the single factors that are associated with the symptoms can be related to occupancy in buildings. A more profound knowledge of the underlying mechanisms of SBS and the strength of the effects are still key issues. Many of the so-called causes may merely be indicators of others.

Naturally ventilated buildings seem to have less symptomatic workers than air-conditioned ones. Women are more susceptible than men, and the public sector workforce experiences more problems than that of the private sector [3]. Besides the difference between the frequency of symptoms in men and women, working conditions can also have an influence. For example, people in leading positions generally complain 3 times less than people in other groups. Stress and psychological conditions are associated with the named symptoms, either directly (as with tiredness) or by an increase in sensitivity towards physical and chemical exposure [4]. In some cases, it is still an unanswered question as to which of the two groups of factors, psychological or physical, is the determining element or whether they at all interfere.

The symptoms arising from building occupancy are considered primarily to depend on the quality of the air and the hygro-thermal climate and, to a lesser degree, on sound levels and lighting conditions, plus a range of individual and job-related factors. Draught and high and low temperatures appear frequently in connection with unspecified complaints. A high temperature causes higher emission rates and increases microbiological activity, and low temperature level reduces the frequency of symptoms but increases draught sensation. Microbiological growth (e.g. in connection with water damage, humidity absorbed by dirty carpets from water used during cleaning or growth in humidifiers) is probably an essential cause of the increased occurrence of symptoms.

The relation between hypersensitivity and air quality is one of the major contemporary problems encountered in buildings. Hypersensitivity is an umbrella term used to describe conditions in which the sensitivity of organs in the body to different substances is increased pathologically. This increased sensitivity is due to either immunological (allergy) or non-immunological (non-allergic hypersensitivity) mechanisms. With allergy, the reaction is caused by special antibodies or by the blood cells after contact with a foreign substance (an antigen), e.g. pollen, animal hair or dander, dust mites, airborne mould spores: 15% of the population suffers from allergies. Non-allergic hypersensitivity can be defined as an increased tissue reaction to such things as smoke, dust, chemicals, odours, cold and moisture. The biological mechanisms are largely unknown.

Asthma is a temporary condition characterized by breathing difficulty caused by contraction of the bronchial smooth muscle. 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 some drugs, physical exertion and psychological stress. The incidence of asthma is 3–4% in children below school age and about 2–3% among adults [5]. The incidence of asthma and hay fever have increased in North Sweden, possibly due to differences in the built environment [5].

Environmental pollution (e.g. organic solvents and carbon monoxide) can influence the nervous system. It is deemed that neurotoxicity may be a neglected non-cancer risk, since few chemicals have been adequately evaluated for neurotoxicity.

In a review of IAQ problems, a brief analysis of more than 90 technical papers revealed many suggestions regarding the causes of such problems. These can be categorized into the following three broad themes: ventilation system performance, contaminants and other parameters.

Since a wide range of problems are associated with unhealthy buildings, it is unlikely that a single common cause exists.

IAQ Measurement

The quality of indoor air has been determined with different techniques, which can be divided into three main categories: (1) techniques that concentrate on the human beings (questionnaires, medical examination, biological monitoring, response of visitors); (2) techniques considering the contents and/or characteristics (temperature, velocity, humidity) of the air, and (3) a combination of these two categories (epidemiological and clinical studies). Besides studies in these categories other means of IAQ measurement have been used. The prevalence of symptoms and the acceptability of the indoor air can give an indication of air quality, as can measurable contaminants in body fluids or the prevalence of exposure to specific sources. There is no objective test available for measuring lethargy, headache and dry throat, but objective measurements have been used to validate dry eyes, blocked nose and asthma symptoms. Techniques that measure contaminants in the indoor air are numerous, since the number of air pollutants is numerous. Many things can go wrong when sampling, identifying and quantifying these pollutants. This makes the reproducibility and credibility of the results questionable. When it comes to identifying specific pollutants which have carcinogenic or other serious health effects, measurement techniques which are concerned with the contents of the air are, however, necessary. Limits of exposure have not been determined for all pollutants causing health effects; indeed, it is unlikely that all pollutants causing health effects have been identified yet. Traditional methods of pollution measurement often lack evnrinonmental health relevance. In addition to measuring pollutants in the air, combined with forecasting individual exposures from activity patterns, more can be gained from the measurement of their uptake into biological tissues and fluids.

Epidemiological studies investigate the incidence of disease in a population and its relation to environmental factors. Clinical studies generally establish acceptable levels of human exposure to air pollutants. Other means of measuring or determining IAQ are: indicators of latent sources (fleece factor, shelf factor, olf load), general indicators of IAQ (CO_2 or water vapour levels), visual inspection of the building with a checklist, and theoretically proposed IAQ indicators or models [total volatile organic compounds (TVOC) indicator, pattern of chemicals].

Ventilation performance can be measured with the use of low concentrations of tracer gases, which can be used in combination with a suitable analyzer to mark air or to simulate a contaminant and follow its distribution. Most of the instruments and techniques for tracer-gas measurement have been developed for research use. A useful recent development is the passive tracer technique using perfluorcarbon tracers, which can be applied in the field on a large scale, i.e. for thousands of measurements. This technique uses a sample containing an adsorbent, trapping the tracer diluted in the air around the sampler. After a given period of time, this sampler will have accumulated tracer, which can then be analysed and quantified in the laboratory using gas chromatography.

Until now, only a few buildings or dwellings have been examined for their ventilation performance, and most of these were located in Nordic countries. No statistically significant information is available on a European level. Comfort has so far been mostly looked upon as a quasi-steady-state issue. There is a lack of information concerning comfort under transient conditions. Measurement of the 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. Quantification and identification of each of the hundreds of compounds present in indoor air is impossible with the currently available instruments. A threshold limit (odour and/or irritation) is not available for each of the identified compounds. With respect to effects of mixtures of pollutants, little or no knowledge is available.

A few years ago, two new units for air quality were introduced. The sensory unit for source strength is 1 olf, defined as the air pollution from 1 standard person [6]. Perceived air quality is measured in decipol, 1 decipol being the air quality in a space with a pollution source of 1 olf ventilated with 10 l/s of clean air. There is a direct relation between decipol and the percentage of dissatisfied persons.

The latest method developed to measure IAQ is based on the evaluations made by independent visitors. Here, the human nose serves as the instrument to quantify IAQ. The panel of subjects who are to evaluate the air quality with respect to its acceptability, or directly in decipol units, do this immediately after they enter the building or space. When the ventilation rate of the evaluated building or space is determined together with the evaluation of the perceived air qulaity, an indication of the total olf load of that building (in olf/square metre) can be established. A method has been developed to train a panel of selected persons to evaluate perceived air qulaity directly in decipol, using 2-propanone as the reference gas [7]. This method needs to be further developed and standardized. This comfort measurement does not indicate the effect of long-term exposure. Source strength of single materials (in olf) are not known yet, which makes prediction of the air quality based on the used materials (olf load) alone impossible. A standard method to obtain the source strength of materials and components of and in a building is lacking.

IAQ and Energy

The achievement of health and comfort in the indoor environment combined with energy efficiency requires both minimization of human exposure to indoor air pollution, i.e. via source control and a well-functioning and energy-efficient heating, ventilating or air-conditioning system. The technology available in the 1960s, along with the economic expansion and a general increase in income, stimulated the development of new forms of building constructions, and new heating as well as new ventilation systems. Due to low energy prices, maintainng high ventilation rates was no real problem. The sharp increase in energy prices due to the energy crises in the 1970s significantly changed the situation. Research activities in the period of 1975–1985 were primarily focused on strategies to reduce energy consumption. A reduction in energy consumption was achieved by reducing the energy needs for heating and cooling. This was accomplished by using well-insulated and well-sealed envelopes which reduced the ventilation rates. The variation of recommended ventilation rates closely followed the changes in energy prices. Environmental issues became more and more important towards the end of the 1980s. Health issues and increased concern related to the quality of the indoor environment received much attention from the public and the media.

The challenge in the near future is to aim simultaneously at a low-energy consumption and a comfortable and healthy indoor environment.

Sources and Source Control

To be able to properly characterize the indoor environment, it is important to understand the sources of indoor air pollutants. These sources can be placed in the following categories: outdoor environment (air, soil and water), people and their activities (the human factor, energy production, smoking, office equipment and chemicals), materials (building materials, furnishings) and Heating, Ventilation and Air Conditioning (HVAC) systems.

The identification of pollution sources is difficult due to dynamic processes like adsorption and desorption. The concentration of indoor air pollutants may vary widely as a function of both time and space, and the sampling strategy used to determine the pollutant level has a marked influence on the result. Short-term peak concentrations of inorganic components and suspended particulate matter may exceed the average concentration by a factor of 5–10 or even more. This is of 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.

Most research work on organic compounds in the past has been focused on non-polar VOC. Most organic chemicals with higher boiling points, e.g. semi-VOC (SVOC) which are generally bound to dust particles, have not until now been sufficiently studied. The large variety of VOC makes it difficult to deal with each of them individually.

Of the remedial actions such as dilution by ventilation, reduction by air cleaning, and prevention of emissions by product amelioration, the latter should always be given preference. Source control reflects the general philosophy of environmental protection: preventing rather then curing.

Selecting a 'safe' product or material is not an easy task. There is little information on product composition, since manufacturers are generally not obliged to provide such information. Even if that information were available, a rule would still have to be developed to evaluate this information, e.g. in the form of an index, derived from the toxicological and comfort-related properties of the product/material, which would permit ranking.

An essential role of the design process is to create the conditions to prevent the release of the contaminant at source before addressing the cleaning (by filtration) and dilution (by ventilation) strategies. The most obvious way of reducing the ventilation requirement is to control the indoor pollution sources. The required ventilation rate is proportional to the pollution load. The question is how high is the pollution load in buildings?

When pollution sources show an approximately constant emission rate, an ordinary ventilation system may realize acceptable IAQ. When the emission rate is highly variable, the installation of a demand-controlled ventilation (DCV) system should be considered.

Ventilation

In many buildings with known problems, unsatisfactory ventilation is suspected or shown to be a contributor. However, the measurement of air change rates is not a common feature of air quality investigations. Without readily available and basic information on the air change rates in buildings, ventilation recommendations to improve building air quality are hard to make.

The variety of ventilation systems is extremely wide, and no single approach can be expected to meet the requirements of all applications. Ventilation systems can be divided into 'dilution' 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 these 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, for example, occupant activities, temperature fluctuations and door opening. Where air is conditioned, or air-heating is used, high recirculation rates and mixing ventilation systems may be necessary. The driving force for ventilation may be either natural or mechanical.

The building must be constructed to suit the ventilation system. Building airtightness is inevitably a vital part of the design strategy, e.g. mechanically balanced supply/extraction systems demand very airtight building shells for correct operation, while natural ventilation systems need user-controllable perimeter openings to ensure provision for adequate airflow under all operating conditions (no constant air supply can be expected). The concern for energy on one hand and the renewed interest for air quality on the other have given rise to a variety of applications of ventilation systems which are controlled by IAQ levels. These kinds of systems have been termed DCV systems by the International Energy Agency (IEA), which promoted a working group (Annex XVIII) under this heading [8]. DCV is a system which would be able to maintain always acceptable IAQ levels at the lowest possible energy costs. According to the definition provided by the IEA Annex XVIII, a DCV system may be defined as a 'ventilation system in which the airflow rate is governed by airborne contaminants'. One of the pollutants in the building, the driving (or dominant) contaminant, is chosen to drive a DCV system, which will provide on average the highest ventilation rates. The driving contaminant should have an emission rate which is high enough to ensure the required additional ventilation on top of that provided by natural infiltration. The driving contaminant should also be strongly variable in time and unpredictable as to time and location of the source. Building-related factors which are relevant for the adoption of a DCV system are the airtightness of the envelope of the building (the tighter, the better), building use and designation, and emission and absorption of pollutants by building materials. 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). Available DCV systems are those which use water vapour, CO_2 or mixed gases (volatile compounds) as an indicator to control air quality, odours, tobacco smoke and humidity.

Experience with DCV is still very limited. As this technology is rather new, many items should need further research, both in the field and in the laboratory. It is not clear which would be the best factor or variable to monitor in order to keep an agreeable IAQ. CO_2 is often considered to be the best indicator of bioeffluent, but this may no longer be valid when smoking is allowed. Sensors are a keypoint for the good performance of DCV. Low cross-sensitivity, good stability, and immunity to climatic, mechanical and electromagnetic interference should be considered. Another important consideration is the positioning of the sensors.

In dwellings, it is generally not the ventilation rate which determines the concentrations of pollutants, but the outside air infiltration rate and the transport of pollutants from other rooms, together with the use of the ventilation provisions by the inhabitants. Positions of internal doors play an important role, but there is very little information available on the use of doors. There is also a lack of knowledge in the understanding of flow through large openings; information about airflow and contaminant transport from floors and leakage from crawl spaces into wall cavities is almost completely lacking.

Ventilation Systems

Little has been done to analyse the IAQ problem of ventilation systems, to identify potential sources of pollution and to eliminate them [9]. Guidelines of hygiene requirements are almost totally lacking. Filters, heat exchangers, humidifiers and mixing sections have the potential for affecting IAQ in both positive and negative ways. Air filters are specified and selected to protect heat exchangers and fans, where they are expected to remove fibres and large dirt particles from incoming air. Filters of higher grades can remove pollens and other allergens that may be present in the air, including bacteria and even viruses, and they can take out irritants, such as tobacco smoke. Carbon filters will remove contaminants such as odours, chemicals and solvents given off by the building fabric, furnishings and internal equipment. For economic reasons, the very positive benefits that good air filtration contributes towards IAQ are often ignored.

Systems consist of various parts, of which some can be potential sources of indoor contaminants. Some examples are: heating coils, dirt build-up on the surfaces can cause odours; cooling coils, finned surfaces and drain trays can become covered with bacterial slime; and heat recovery units, air leakage can occur between exhaust and supply airstreams. Humidifier fever is a respiratory illness caused by inhaling water droplets contaminated with 'organisms'. Spray humidifiers and spinning-disc humidifiers introduce a spray of droplets into the airstream, therefore there is a risk of infection. Steam injection humidifiers are the safest.

Mixing sections should control the relative amounts of outdoor air and recirculated air, ensure that the two airstreams are thoroughly mixed so that stratification does not occur, and they should provide an even velocity profile downstream across the duct section. Mixing sections do not always meet these objectives in a satisfactory manner.

European Activities

The most important common activity in the field of IAQ in the European Community so far is the concerted action 'Indoor Air Quality and Its Impact on Man', which is part of the Community Multi-Annual Research Programmes for the Protection of the Environment 1986–1990 and 1989–1992. Ten communities (Belgium, Denmark, France, the FRG, Greece, Ireland, Italy, The Netherlands, Portugal and the UK) and the Commission are actively participating. Sweden and Switzerland are associated as well, and Norway and Finland are about to join. The ultimate goal is: to help answer the question of which consequences for human health and comfort derive from air pollution and, especially, inadequate air quality in non-industrial indoor environments. The main objectives are to promote the identification and characterization of pollutants and sources; the assessment of population exposure and of health effects, and investigations of IAQ complaints in office buildings. No proper research funds are available. So far, 10 working groups have been set up.

Other Commission services which have an interest in some aspects of IAQ are:

(a) The Directive 89/106/CEE on construction products – defines 'essential requirements', among which one concerns 'hygiene, health and environment'.

(b) The Directive 87/217/CEE – introduces measures to prevent and reduce asbestos-related air pollution.

(c) The DG V Employment, Industrial Relations and Social Affairs – in charge of actions against smoking.

(d) The DG XI: Environment Nuclear Safety and Civil Protection, 4th policy and action programme on the environment (1987–1992) – sets requirements 'to define and implement preventive measures against indoor pollution by a growing number of substances'.

(e) The 'Consumer Policy Service' – interested in emissions from consumer products.

(f) The DG XII: 'Science, Research and Development' and the 'Joint Research Centre' (JRC) – both promote research in the field of IAQ.

In Finland, multidisciplinary research takes place at the Helsinki University of Technology. A large epidemiological study in the Pasila Office Centre comprising 2,150 workers has just been reported [10].

In Sweden, 5,000 houses were randomly selected within 60 (out of 284) municipalities, and the residents were asked to complete a postal questionnaire. Subsamples consisted of 1,200 and 200 houses. 1,200 houses will be inspected onsite and measured in the winter of 1991/1992 and 200 houses will be studied by making complementary measurements in the same period. The survey is an attempt to obtain quantitative data about IAQ.

Regulations

Regulations can be divided into legislation, standards and guidelines. Standards and guidelines do not have the force of law; compliance with them is voluntary. The goal of regulations is the prevention of health symptoms in buildings or their reduction to an acceptable level.

Some buildings comply with every known demand and still remain problem buildings. Incomplete requirements and/or non-relevant demands could be responsible for this phenomenon. All relevant building factors should be pin-pointed before requirements are specified. When regulations are implemented, one has to separate building factors (design demands) and user factors (user demands). Certain aspects of IAQ can be included (or have already been included) into building regulations in the form of building performance specifications, e.g. a ban of certain products or demands imposed upon the way of construction in connection with condensation, thermal comfort or ventilation quantities. Other aspects lend themselves in a lesser degree but can be incorporated into guidelines, as, for example, IAQ standards, use of materials involving growth of microbial flora, individual controllability or amount of recirculation air. Furthermore, recommendations for outdoor air, used as intake air, are lacking.

A number of workshops and meetings (US DOE and APR, US EPA, IEA, NATO/CAMS, ENBRI/CES, CEC COST 613) on healthy and energy-efficient buildings have been held. In nearly all of the workshops, the development of guidelines and/or standards is recommended as an essential tool to promote the achievement of high IAQ: e.g. harmonized standards (on an international level) on emission testing; and guidelines on pollutant concentrations in indoor air, ventilation, emission from materials, methods for IAQ assessment and control, the commissioning process of a building and installations, and quality assurance and product responsibility for buildings and installations.

Conclusions of the Workshop

Sick Building Syndrome

(1) SBS is a multifactorial cause-effect problem. A key issue is the knowledge of the mechanisms behind it and the strength of the effects. Mechanisms for the symptoms have not yet been defined.

(2) A question still exists over which of the two groups of factors, psychological or physical, is the determining element or whether they at all interfere.

(3) The relation between hypersensitivity and air quality is one of the major contemporary problems encountered in buildings. However, biological mechanisms of non-allergic hypersensitivity reactions are largely unknown.

(4) Few chemicals have been evaluated adequately for neurotoxicity.

IAQ Measurement

(5) No absolute tests for lethargy, headache and dry throat are available.

(6) No statistically significant information on ventilation performance in buildings is available.

(7) The reproducibility and credibility of indoor air pollutant identification, quantification and sampling are often questionable.

(8) Limits of exposure for all pollutants causing health effects have not been determined. Perhaps not even all pollutants causing health effects have even been identified.

(9) More information can be gained from measurement of pollutant concentrations in biological tissue and fluids.

(10) Quantification and identification of each of the hundreds of compounds present in indoor air is impossible with the instruments developed so far. On the effects of mixed pollutants, little or no knowledge is available.

(11) A standard method is lacking to obtain the strength of a pollution source in olf units.

(12) A method to train persons to evaluate perceived air quality in decipol units has been developed, but needs further development and standardization.

(13) The olf loads of complete buildings (olf units/square metre) have been determined in Denmark.

(14) There is a lack of information concerning comfort under transient conditions.

(15) Biological indicators for environmental health monitoring are needed.

(16) Research is required to develop measurement methods of neurotoxicity, and to clarify the size of the problem in different populations and the responsible mechanisms in the nervous system.

IAQ and Energy

(17) The IAQ issue and energy use are closely linked.

(18) The challenge in the near future is to simultaneously aim at low energy consumption and a comfortable and healthy indoor environment.

(19) The definition of limits and prospects for energy-efficient yet healthy buildings is needed.

Sources and Source Control

(20) Effects of prolonged pollution exposure are not completely known.

(21) Identification of pollution sources is difficult due to dynamic processes like adsorption and desorption.

(22) Most organic chemicals with high boiling points, e.g. SVOC which are generally bound to dust particles, have not until now been sufficiently studied.

(23) There is little information on product composition since manufacturers are generally not obliged to provide such information. Evaluation of this information is the next step to be taken.

(24) The olf load of a building can help to determine the source control strategy.

(25) Indoor pollutant levels are strongly influenced by factors such as the deposition of pollutants, absorption, adsorption, desorption and condensation.

Ventilation

(26) Present ventilation guidance is insufficient.

(27) Knowledge of air change rates is required to recommend ventilation rates which improve building air quality.

(28) There is a lack of knowledge on flows through large openings. Information on airflow and contaminant transport from floors and leakage from crawl spaces into wall cavities is almost completely lacking.

(29) Very little information can be found on the effect of the use of doors on the ventilation rates of buildings.

(30) Experience with DCV systems is still very limited. IAQ sensors are a key point for the good performance of a DCV system.

(31) Studies in the areas of Europe where air conditioning is used is a necessity. Most studies have taken place in the more temperate regions of Europe.

Ventilation Systems

(32) Little has been done to analyse the IAQ problem stemming from ventilation systems, to identify potential sources and to eliminate them. Guidelines of hygiene requirements are almost totally lacking.

(33) Our knowledge of the sanitation of ventilation systems is very limited.

European Activities

(34) The concerted action 'Indoor Air Quality and Its Impact on Man' is so far the most important activity in the field of IAQ in the European Community.

(35) In Sweden, a large epidemiological study has been started and hopes are that it will contribute to the IAQ data base.

Regulations

(36) It is of utmost importance to pin-point all relevant building factors before specifying requirements.

(37) Recommendations for outdoor air, used as intake air, are lacking.

(38) Development of guidelines and/or standards is recommended as an essential tool to promote the achievement of high IAQ: e.g. international standards on emission testing; and guidelines on indoor pollutant concentrations, ventilation, material emission, methods for IAQ assessment and control, the commissioning process of building and installations, and quality assurance and product responsibility.

(39) Criteria for source control, outdoor air rates and air treatment are needed.

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

General Research Needs

Sick Building Syndrome

(1) Further assessment and surveys of symptoms are required in a wider range of buildings, according to a common test procedure. Attention should be given to mechanisms such as allergies and irritation, sensory and health exposure effects of pollutants, physical factors, psychosocial factors, transient conditions and activity patterns of occupants.

(2) Human exposure studies in environmental chambers.

IAQ Measurement

(3) Assessment of ventilation rates in the existing building stock (with the use of passive-tracer techniques).

(4) Development of a method to determine the source strength of pollution sources (chemically and sensory).

(5) Development of an IAQ sensor based on human response.

(6) Development of the existing standardized method to train people to evaluate perceived air quality (in decipol).

IAQ and Energy

(7) Evaluation of the energy consequences of meeting ventilation requirements.

(8) The development of quality categories (classes or levels) for comfort, IAQ and energy conservation measures linked with acceptable indoor climates and air quality in buildings.

Sources and Source Control

(9) Identification and quantification of pollution sources in buildings (chemically and sensory).

(10) Behaviour of sources and sinks with respect to mechanisms such as absorption, adsorption, desorption, physical factors and time.

Ventilation

(11) Quantification of ventilation rates in relation to occupant needs, the need for a safe 'background' level, occupant activities and emissions of building materials, ventilation components, furnishings and fabrics.

(12) Evaluation of ventilation performance in relation to occupant behaviour, climatic conditions, internal airflow pattern and type of ventilation system (European testhouse).

Ventilation Systems

(13) Performance studies of ventilation systems, including filtering of the outdoor air and maintenance requirements, in the field as well as in laboratory set-ups.

European Activities

(14) European studies with respect to symptom assessment, ventilation performance, source identification and IAQ measurement.

Regulations

(15) A study to define acceptable indoor air quality standards.

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