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Environmental Protection
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NATO: Committee on the
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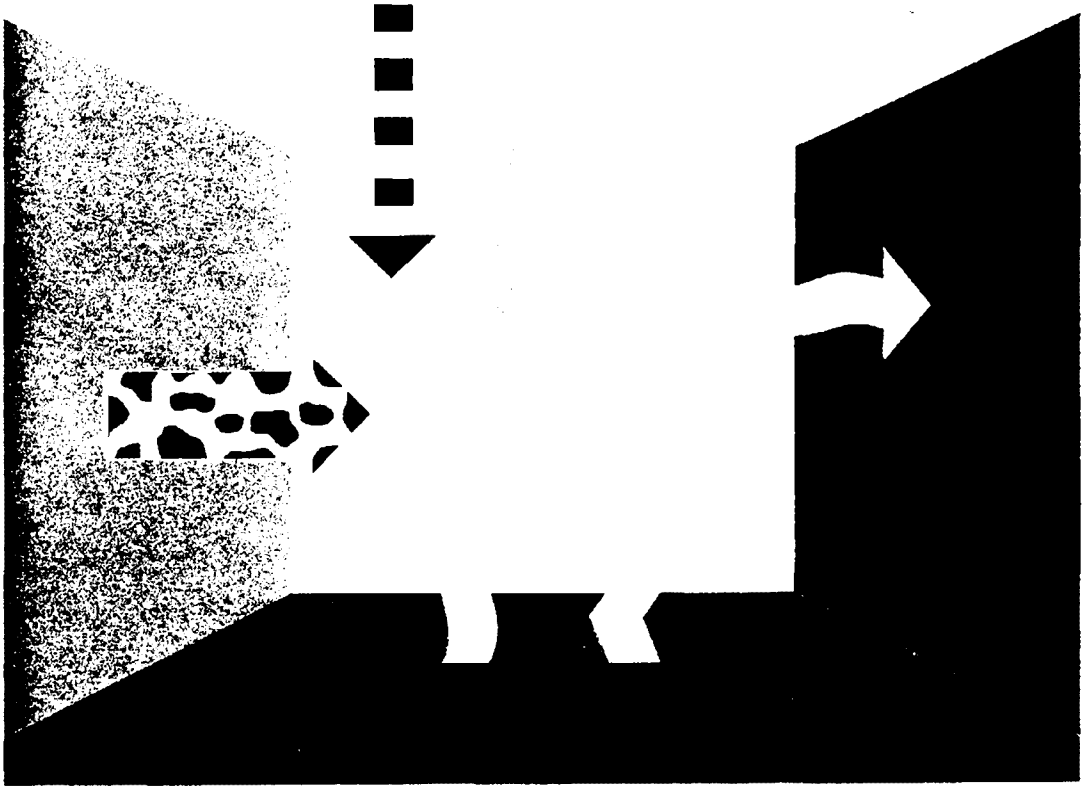
Pilot Study On Indoor Air Quality

Managing Indoor Air Quality Risks



Report on a Meeting Held in St. Michaels, Maryland
October 25--27, 1989

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Abstract: Contents: Quantifying Future Trends Of Indoor Air Quality As A Basis For Government Policy Plans; Assessing Indoor Air Quality Risks of Pesticides; Formaldehyde Emission Standards In The Federal Republic of Germany; Orientations and Actions of the European Community in the Assessment and Prevention of Indoor Air Pollution; EPA and Indoor Air Quality; The Non-Regulatory Approach to Reducing Risks from Radon Exposure; U.S. Consumer Product Safety Commission; A Builders Guide to Healthy Homes; WHO Air Quality Guidelines for Europe; The Approach to Control Indoor Air Quality in Italy; Guidelines - Ventilation Classes; Energy Consequences of Upgrading Indoor Air Quality; Canada's Guidelines for Residential Indoor Air Quality: Rationale and Scope; Canadian Ventilation and Venting Standards; Indoor Air Quality Building Surveys Case Studies; Design of Indoor Air Quality Studies; Summary Findings of Inter-Ministerial Committee On Indoor Air Quality (Ontario); The Quebec Approach; Employee Survey EPA Headquarters; Pollution in Closed Spaces and Its Consequences in Conservation of Works of Art; How Norwegian Health Authorities Will Handle Indoor Air Quality Problems.

NATO/CCMS WORKSHOP

Pilot Study
on Indoor Air Quality

Managing Indoor Air Quality Risks

Report on a meeting held in St. Michaels, Maryland
October 25 - 27, 1989

This report has been assembled and edited by the
U.S. Environmental Protection Agency

DISCLAIMER

The opinions expressed in these workshop papers are those of the individual authors unless specifically indicated otherwise. These papers do not represent the official position of the North Atlantic Treaty Organization, the Committee on the Challenges of Modern Society, or the U.S. Environmental Protection Agency.

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Foreword and Acknowledgments

Professor Marco Maroni, Director of the Pilot Study

The North Atlantic Treaty Organization (NATO) formally established the Committee on the Challenges of Modern Society (CCMS) on November 6, 1969. CCMS' goal was to attack practical problems already under study at the national level and, by combining the expertise and technology available in member countries, to arrive fairly rapidly at valid conclusions and to make recommendations for actions to benefit all member countries. The interchange of practical applications and of technological and scientific information are of special importance.

In 1988, Italy proposed to the NATO/CCMS a pilot study on indoor air quality. The United States agreed to participate as co-chair. There are a number of policy and research objectives of the pilot study:

- The policy objectives are to identify agencies, institutions, and individuals responsible for establishing policy and regulations; and to examine policy strategies and propose a range of policy options that could be adopted by NATO nations.

- The research objectives are to identify current research efforts and develop a registry of contacts; to characterize indoor air quality problems in NATO countries; to identify problems which pose high risks to human health and materials; and to identify, study, and recommend mitigation or control methods.

The first plenary meeting for the pilot study was held in Erice, Italy in February 1989; a tentative schedule of five subsequent workshops was agreed upon:

- *Risk Management*, USA, October 1989;
- *Energy and Building Sciences*, Canada, August 1990;
- *Risk Assessment and Case Studies*, Federal Republic of Germany, February 1991;
- *Epidemiological and Clinical Assessment of Indoor-Related Health Effects*, United Kingdom, 1991; and
- *Diagnostic Principles and Methods*, USA, 1991.

The pilot study will conclude with a final report to the CCMS in the summer of 1992.

The US Environmental Protection Agency (EPA) organized the second meeting, which focused on "Managing Indoor Air Quality Risks." The workshop, held October 25-27, 1989, in St. Michaels, Maryland, explored programs and policies designed to resolve indoor air quality problems in participating countries. Forty participants, representing seven countries shared information about

regulatory and non-regulatory approaches to controlling indoor air quality. This volume, the second report of the pilot study, contains the papers that were presented at the workshop.

Special thanks and appreciation is extended to the workshop participants whose knowledge, cooperation, and enthusiasm were critical to the successful planning and conduct of the workshop activities. Thanks is also expressed to the staff of EPA's Indoor Air Division, and to ICF Incorporated, who assisted EPA in providing the logistical support for the workshop and in preparing and publishing these proceedings.

NATO/CCMS Pilot Study on Indoor Air Quality[1]
Managing Indoor Air Quality Risks

St. Michaels, Maryland
October 25 - 27, 1989

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Section I

Developing Information for Risk Management Decision Making

Quantifying Future Trends Of Indoor Air Quality As A Basis For Government Policy Plans

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Summary

The home is an important micro-environment for human exposure to air contaminants. As a basis for policy development, Dutch indoor air quality for the coming decades has been assessed for "current efforts" and "maximum mitigation" scenarios to show the range of achievable quality. Air quality is quantified in terms of the percentage of Dutch homes exceeding pollution levels that correspond to the "maximum allowable risk." The highest frequencies were obtained for nitrogen dioxide (90 percent), radon (70 - 90 percent), particulate matter and environmental tobacco smoke-related components (60 - 65 percent), and dampness (15 percent) -- used as an indicator for biological contamination.

The current percentage of homes that do not exceed any of these levels is negligible. In the "current efforts" scenario, this percentage increases, to a maximum of five percent by the year 2010, whereas the percentage reaches 40 percent in the year 2010 in the "maximum mitigation" scenario.

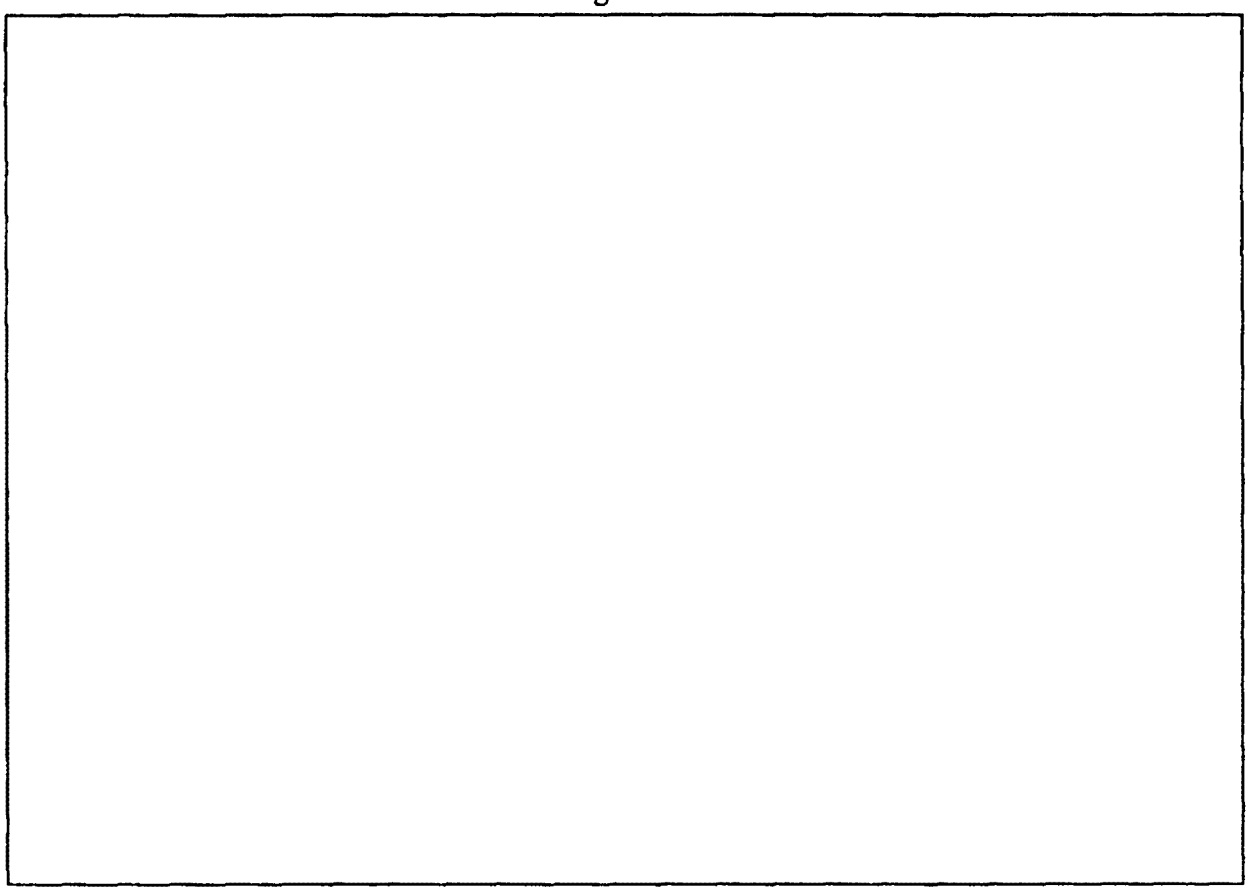
Introduction

Several aspects of the indoor environment, such as daylight access, ventilation, noise, and pest control, traditionally have been the province of government. Since the early 1980s, indoor air quality (IAQ) has received increased governmental attention. In the framework of the Netherlands' National Policy Plan for the Environment, an investigation has been conducted to quantify the present and future IAQ characteristics in terms of the percentage of Dutch housing stock that exceeds health-related air quality limits. Two scenarios were used: "current efforts" and "maximum mitigation." The results of the two scenarios indicate the range of obtainable IAQ in the future.

Health Related Limit Values

In The Netherlands, an important principle of risk management is that man-made pollution levels should remain below the level of "maximum allowable risk." Because of the lack of knowledge concerning the effects of a mixture of pollutants, the principle is applied to each of the agents separately. By definition, the maximum allowable pollution limit corresponds to the human "no-effect-level" for non-carcinogens, and to an annual individual cancer risk of 10^{-6} for carcinogens. Pollutants were screened according to the criteria given in Figure 1.

Figure 1



Thirteen compounds, all of physical-chemical nature, passed the criteria. A fourteenth IAQ indicator, dampness, was introduced to cover the potential exposure to high levels of biological agents, such as housedust mites and mold allergens (Table 1).

Modeling and Estimation

For pollutants emanating from indoor sources, the percentage of homes exceeding the air quality limit was estimated using the presence of sources in the Dutch housing stock (broken down into three categories: existing homes, renovated homes, and new homes), and the probability of passing the air quality limit if one or more sources were present in a home (Figure 1).

Most of the abundant outdoor pollutants originate from motorized traffic. Concentrations of pollutants at the house front on busy streets were computed using the traffic model CAR [5]. The corresponding indoor concentration depends on the penetration/decay factor, e.g., 1.0 for inert gases, 0.4 for particulates. The occupancy factor is assumed to be constant. More details are provided in References 6 and 7.

Table 1
Selected IAQ Indicators and
Their Maximum Allowable Concentration

IAQ Indicator	Conc./Av. Time	Reference
Radon	1 Bq/m^{3}EER; year	1
Asbestos	4000 - 40,000 F/m^3; year	2
Particulate matter	40 μg/m^3; year	2
	140 μg/m^3; 24 hours	2
Cadmium	10-20 ng/m^3; year	1
Benz(a)pyrene	1 ng/m^3; year	1
Benzene	12 μg/m^3; year	2
Lead	0.5 μg/m^3; year	3
Nitrogen dioxide	300 μg/m^3; 1 hour	3
Carbon monoxide	40 mg/m^3; 1 hour	3
	10 mg/m^3; 8 hours	3
Sulfur dioxide	150 - 200 μg/m^3; 1 hour	1
	100 - 120 μg/m^3; 8 hours	1
Formaldehyde	120 μg/m^3; 1 hour	4
Dichloromethane	1.7 mg/m^3; 24 hours	2
Housedust mites and mold allergens	indirect: "dampness"	

Present and Future IAQ

Nitrogen Dioxide

The most abundant indoor source of nitrogen dioxide is unvented water heaters (geisers). Hourly averages as high as 2,000 $\mu g/m^3$ have been monitored in Dutch kitchens [8]. This value is likely to occur in approximately 23 percent of Dutch homes.

Marginal exceedance of the nitrogen dioxide limit will occur in homes in which gas-ranges are used (approximately 90 percent of Dutch homes). Other sources are not widely used (unvented kerosene heaters) or will not cause significant increases of nitrogen dioxide levels to occur (motorized traffic). Unvented geisers are rarely installed in new homes. Furthermore, there is a trend to combine space heating and water heating in a single vented heater. Improving burner technology will reduce nitrogen dioxide pollution, but will not prevent levels in excess of the air quality limit. Further reduction of the percentage of homes with severe exceedance will only be possible if the indoor sources are eliminated. The severe exceedances of the nitrogen dioxide limit is likely to decrease from 23 percent in 1985 to nine percent in 2010.

In the "maximum mitigation" scenario, it is assumed that new unvented geisers will not be permitted in the new housing stock and that an existing unvented geiser will not be permitted when moving into an existing home. These additional measures result in negligible exceedances after 2003.

Gas-fired cooking-ranges will gradually be replaced by electric cooking-ranges and microwave ovens. However, approximately 65 percent of the homes will still be equipped with gas-fired cooking ranges in 2010. Application of low-NO_x burners in gas-ranges will prevent exceedance of the air quality limit. A mitigation scenario similar to the unvented geiser eliminates exceedances in 2006.

Radon

There are three main sources of radon exposure:

- radon emitted by building materials;
- outdoor radon emitted from the soil; and
- outdoor radon emitted from the soil that leaks indoors through crawl spaces.

The average radon daughter concentration in Dutch homes is 12 Becquerel equilibrium equivalent radon per cubic meter (Bq/m^3EER). The average outdoor concentration is 2.0 Bq/m^3EER.

In practice, radon from conventional building materials and exposure to outdoor radon cannot be avoided, and therefore is not part of risk management. However, radon penetration via the crawl space is avoidable by technical means. Only this kind of indoor radon contamination is considered. This radon contamination contributes to approximately 60 percent of all radon indoors.

The percentage of homes passing the air quality limit is 70 - 90 percent. Although new homes will have much lower air transfer from the crawl space, their beneficial effect on the total percentage will be counterbalanced by the demolition of leaky old homes. An additional reduction of the transfer rate will bring the percentage down to approximately 50 percent in 2010.

Particulate Matter

The dominant source of particulate matter is smoking. Every home-smoked cigarette raises the daily average concentration of particulate matter by 2 - 5 $\mu g/m^3$ [8]. The average daily consumption of 8 - 10 home-smoked cigarettes per smoker is high enough to raise the annual average above the 40 $\mu g/m^3$ air quality limit. Without smoking in the home, exceedance of this limit is improbable. Approximately 60 percent of Dutch homes have one or more occupants that smoke. The number of smokers is decreasing by two percent per year. If this reduction rate continues, approximately 39 percent of the population will smoke in 2010.

The Netherlands has endorsed WHO's target of a 20 percent population of smokers by 1995. To achieve this target, an annual reduction of smokers by six percent is necessary. Continuation of such a "discouragement policy" after 1995 will lead to 15 percent total smokers by 2010.

Tobacco smoke contains thousands of constituents. As with particulate matter, the impact of smoking on the air quality limit exceedance will influence levels of benz(a)pyrene and, possibly cadmium.

Dampness

Currently, 15 percent of the Dutch housing stock consists of damp homes. Present regulations on construction and ventilation may reduce this percentage to ten percent damp new homes and 12 percent damp renovated homes. The impact on the total percentage of damp homes is small: 15 percent reduction in 1985 and 13 percent reduction in 2010. There is a general opinion among experts that by implementing stricter measures, the percentage of new and renovated damp homes will not fall below five percent and ten percent, respectively. These measures imply stricter regulations on insulation, ventilation, and moisture penetration, in combination with information programs for users and producers. If these measures are implemented, the corresponding percentage of homes in exceedance of the air quality limit will fall to eight percent in 2010.

Miscellaneous

Lead, benzene, benz(a)pyrene, and carbon monoxide from motorized traffic contribute to the air quality limit indoors exceedance. The increasing use of unleaded gasoline resulted in negligible exceedance of the lead limit in 1987. Furthermore, the introduction of the catalyst will eliminate exceedance for other pollutants by the year 2000.

However, evaporation of gasoline remains an important source of indoor benzene. Additional reduction of car exhaust will be governed by acid deposition and outdoor pollution objectives. Reductions in car exhaust will speed up improvement of IAQ marginally.

As with nitrogen dioxide, unvented geisers are the most important source of carbon monoxide. About 20 percent of these appliances can cause levels of carbon monoxide beyond an hourly mean of 40 $\mu g/m^3$. Results of the scenario studies for carbon monoxide are comparable to those of nitrogen dioxide.

Dichloromethane, when used as a paint stripper, exceeds the air quality limit in one to five percent of the homes. Heat guns are expected to replace paint strippers in the coming decade. Dichloromethane in hairspray may lead to exceedance of the air quality limit, but only for the users. Dichloromethane exceedance is not considered an IAQ problem.

A number of pollutants have a negligible percentage of homes in exceedance: sulfur dioxide, ozone, cadmium, asbestos, and formaldehyde. However, the numerous indoor sources and the lack of representative data do not allow a quantitative assessment.

In summary, the percentage of exceedance due to all of these components adds up to about 15 percent in 1985 and four percent in 2010. Extra mitigation causes a 50 percent reduction by 2010.

Conclusion

Pollution caused by several sources isn excess of the maximum allowable limit in a substantial percentage of the Dutch housing stock. Presently, maximum levels for nitrogen dioxide are exceeded in 90 percent of Dutch homes. Maximum radon levels are exceeded in 70 - 90 percent of Dutch homes; particulate matter levels are exceeded in 60 - 65 percent of Dutch homes; and allergens levels are exceeded in 15 percent of Dutch homes.

In the coming decades, there will be a positive trend toward reductions in indoor air pollution. However, the percentage of "healthy homes" will be small (five percent). A level of approximately 40 percent will be achievable only if maximum mitigation measures are taken now.

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Section II

Controlling Sources - The Regulatory Approach

Assessing Indoor Air Quality Risks of Pesticides

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Introduction

EPA regulates pesticides under the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA). When making decisions involving the regulation of pesticides, FIFRA directs the Agency to weigh the beneficial aspects of a pesticide use versus the risks associated with such a use. This process is known as risk management. This outline will deal with the key aspects of the process of exposure and risk assessment.

EPA regulates the use of pesticides through its Office of Pesticide Programs (OPP). Within OPP, the human exposure and risks associated with pesticides are evaluated by the Health Effects Division (HED). The following presentation will focus on five topics:

1. Health Effects Division organization;
2. Toxicology data requirements;
3. Data requirements for Residential Post-Application Exposure Monitoring (proposed);
4. Criteria for requiring exposure data; and
5. Future development.

Health Effects Division (HED)

The Health Effects Division is composed of five branches:

1. Science Analysis and Coordination (SACB)
2. Toxicology - Insecticide, Rodenticide Support (TB-IRS)
3. Toxicology - Herbicide, Fungicide, Antimicrobial Support (TB-HFAS)
4. Dietary Exposure (DEB)
5. Non-Dietary Exposure (NDEB)

Non-Dietary Exposure Branch (NDEB)

Function: Assess human non-dietary exposure to pesticides resulting from:

- Direct handling, such as mixing/loading and applying pesticides;
- Agricultural reentry and other occupational post-application contact, such as harvesting and pruning; and
- Residential post-application contact resulting from indoor and lawn treatment.

Methodology:

- Determination of unit exposure (i.e., exposure per amount of material handled, per time period, or per exposure incident).
- Integration of unit exposure determination with information regarding the specific use of the pesticide to yield a comprehensive exposure assessment.
- If exposure and risk are unacceptable, determination of the value of various risk reduction measures, such as protective clothing, engineering controls, limiting application rates, limiting the acreage treated in a single day, watering-in lawn pesticides, etc.

The Other Branches of the Health Effects Division

Toxicology and Coordination Branches/HED

Function:

- Conduct hazard assessment and analyze dose-response relationship; and
- Integrate hazard and exposure assessments to yield a risk assessment.

Biological Analysis Branch/BEAD

Function:

- Develop quantitative use assessment to answer questions related to amount of material handled, duration of exposure, and number of treatments per use site per day/season/year;
- Types of mixing/loading and application equipment utilized; and
- Range and distribution of use sites.

Toxicology Data Requirements (40 CFR 158.340)

Type and amount of data below required depends on the use pattern of the pesticide.

- Acute toxicity (oral, dermal, inhalation, eye irritation, dermal irritation and sensitization);
- Sub-chronic toxicity (oral, dermal, inhalation including neurotoxicity testing);
- Mutagenicity;
- Developmental toxicity and reproductive toxicity;
- Chronic toxicity, including carcinogenicity, neurotoxicity, and immunotoxicity; and
- Other, including metabolism and dermal penetration.

Residential Post-Application Exposure Monitoring Data Requirements (proposed)

A. Types of data required:

- Foliar residue dissipation;
- Soil residue dissipation;
- Indoor surface residue dissipation;
- Passive dosimetry / dermal exposure; and
- Passive dosimetry / respiratory exposure (note: includes personal or fixed-site studies in which the dissipation of ambient air levels over time is monitored.

B. The following should be considered when developing a post-application exposure monitoring study protocol:

- Data bridging foliar, soil, or indoor surface residue data to potential dermal and oral exposure for children and adults;

- Ambient air level dissipation data extrapolated to respiratory exposure by considering the effect of age, sex, and activity patterns variation on respiration rates;

- Each use site / formulation type combination; and

- Studies reflecting maximum application rates, maximum number of treatments, minimum intervals between re-treatment, and a variety of use sites (e.g., for home lawn studies, consider various grass varieties and geographical locations; for indoor studies, consider various housing or construction types and ventilation rates).

Criteria for Requiring Residential Post-Application Exposure Monitoring Data

Data will be required if the following toxicity criteria are met:

- The acute dermal toxicity of the technical grade of the active ingredient (TGAI) is less than 2000 mg/kg (i.e., Toxicity Categories I and II listed in 40 CFR 162.10).
- The acute inhalation toxicity of the TGAI is less than two mg/liter and the TGAI has a vapor pressure greater than 10^{-4} mm Hg at 25°C if used indoors or 10^{-3} at 25°C if used outdoors.
- The TGAI is found to cause developmental toxicity.
- The potential for other adverse health effects exist, including carcinogenicity, neurotoxicity, reproductive effects, immunotoxicity, and others for which the Agency requires toxicity testing.
- Epidemiological/poisoning incident data indicate that adverse health effects are resulting from post-application exposure.

Residential Exposure Assessment - Future Developments

- Consumer pesticide use survey;
- Cooperative efforts by various EPA offices (Office of Pesticides and Toxic Substances and Office of Research and Development) to fund research on developing a methodology to assess residential post-application exposure to lawn pesticides and indoor use pesticides; and
- Non-Occupational Pesticide Exposure Study (NOPES) - Results will be released shortly of a retrospective multi-season monitoring study conducted in Jacksonville, Florida and Springfield/Chicopee, Massachusetts.

Formaldehyde Emission Standards In The Federal Republic of Germany

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The Initial Events

In 1975, students and teachers of several newly built air-conditioned schools in Cologne, Federal Republic of Germany, complained about headaches, and eye and throat irritations. It quickly became clear that these complaints were caused by high concentrations of formaldehyde in the air of the classrooms. The high formaldehyde levels were mainly traced to special urea-formaldehyde particleboards glued to the ceiling for noise reduction purposes and, to a lesser extent, to particleboard-based furniture.

Table 1 shows some of the results that were obtained when the air of the respective rooms was analyzed [1]. The very high levels of formaldehyde were attributed to inadequate ventilation. This result could be proven by taking measurements in an otherwise similar, but well-ventilated school building, in which formaldehyde levels about ten times lower were observed.

The Setting of a Guideline Value

Because complaints similar to those observed in Cologne were reported from other parts of the country, the Federal Health Office, in 1977, convened an ad-hoc commission of experts to discuss setting a limit value for formaldehyde in indoor air. In those days, not much information was available on potential adverse health effects of formaldehyde at levels below 1.0 ppm.

Based on toxicological knowledge and the scientific literature, the commission proposed a guideline value of 0.1 ppm [2]. It is noteworthy that this value was only given with one significant digit, which implies that it could not be considered as an exact limit below which any effect would be excluded. When publishing the 0.1 ppm value, the commission did not determine the conditions under which measurement would have to be carried out to determine the formaldehyde level in indoor air. In addition, the value was not linked to a time interval.

Over the years, the 0.1 ppm value has been adopted by many other European countries. The World Health Organization, in the recently published "Air Quality Guidelines for Europe," proposed a value of 100 $\mu g/m^3$ as a 30 min average [3].

The Consequence of the Guideline Value

The guideline value was used to develop the formaldehyde emission standards for particleboard because urea-formaldehyde-glued particleboard is one of the basic materials in the construction of pre-fabricated houses. In 1980, a guideline was issued by the Committee on Harmonized Technical Prescriptions for Construction [4]. In this guideline, particleboard was classified into three categories, according to its formaldehyde emission (see Table 2). The Institute for Building Technology, an institution created by the Federal States (Länder), which have the responsibility for building codes in the Federal Republic of Germany, recommended applying the guideline to the Länder.

Although the equilibrium concentration in a large test chamber, as determined under the conditions given in Table 3, was defined to be the reference, a more simple, derived test method, namely the "perforator" method, was developed to permit a more practicable and rapid classification. According to the perforator method, the sample of particleboard is cut into small pieces and extracted with toluene. The formaldehyde content of the water used for re-extraction is then determined by iodimetric titration. The full procedure is explained in the German standard DIN EN 120 [5], the text of which is identical to the respective European standard, adopted in 1982.

In addition, another derived method was developed which is the so-called "gas analysis" method [6]. In this method, specified in German standard DIN 52368, a small piece of particleboard (400 mm x 50 mm) is placed in a special oven at 60°C. Air with a relative humidity of two ± one percent is drawn through the oven at about one liter/min and collected in bubblers filled with water. The formaldehyde content of the water is determined photometrically using the acetylacetone method. There is a linear correlation between the perforator and the gas analysis method [7].

According to the ETB guideline [4], only class E1 particleboard can be used for construction purposes, but E2 and E3 quality particleboard can be used if it has been given an appropriate coating to lower the formaldehyde emission to the E1 level. However, since some of the adhesives used to fix veneers contain large amounts of formaldehyde, the coating process does not result in lower formaldehyde emissions in all cases [7].

In 1985, a guideline was also issued to control formaldehyde emission from urea-formaldehyde foam insulation (UFFI) [8]. In this guideline, three classes of UFFI were defined, as well as the conditions under which the respective foam quality could be used. To guarantee a formaldehyde concentration of or below 0.1 ppm in the air of the adjacent room, materials used to separate the respective foam from the atmosphere of the room were prescribed. The guideline provided detailed conditions under which the formaldehyde off-gassing of the foam had to be determined. However, it should be

mentioned that the actual practical importance of this guideline is low because UFFI is no longer widely used in the Federal Republic of Germany.

The Shortcomings of Regulation

The classification of particleboard proved to be very useful as a tool for lowering formaldehyde concentrations in indoor air. However, the shortcomings of the regulation soon became apparent: because only the use of particleboard for construction had been regulated, low quality particleboard (increasingly used in the manufacturing of furniture -- especially imported furniture) was not subject to any regulation. Thus, despite the use of E1 quality particleboard in construction, indoor air formaldehyde levels did not decrease as much as had been expected.

Another critical aspect was that the guideline was misinterpreted. When the 0.1 ppm value was issued in 1977, it was meant as a guideline value. However, over the years, many people, including judges, considered it to be a standard with resulting legal implications. This interpretation did not take into account that the guideline had not provided detailed prescriptions of all the conditions under which the formaldehyde concentration in the air of a room would have had to be measured (e.g., temperature, relative humidity, ventilation status, and sampling period).

Furthermore, it appeared that the correlation between the reference method (test chamber) and the widely used perforator method was not satisfactory for low formaldehyde contents. This result was due to two effects: on the one hand, for E1 particleboard, the results were very close to the detection limit, and on the other hand, the iodimetric titration, by nature, is not specific for formaldehyde.

The Recent Approach

In October 1986, the Ordinance on Hazardous Substances [9] came into force under the Chemicals Act [10]. In this ordinance, a number of paragraphs also addressed the question of formaldehyde. Among other things, the following prescriptions, effective as of January 1, 1988, were made in §9 with the goal of regulating all wood-based materials, regardless of their use:

- Wood-based products (particleboard, coated particleboard, blockboard, veneer plywood, fiberboard) must not be circulated if they lead to an equilibrium concentration of formaldehyde of more than 0.1 ppm. The equilibrium concentration is to be determined in a large test chamber using a test method which corresponds to the scientific and technical state-of-the-art. The Federal Health Office will publish such a test method in agreement with the Federal Institute for Materials Research and Testing, following an expert hearing.

- Furniture must not be circulated if it contains wood-based products which do not meet these requirements.

One of the critical points left open in the ordinance was the publication of an appropriate test method, since measured formaldehyde levels are critically dependent on a number of parameters, (e.g., temperature and relative humidity). As an example, the nomogram shown in Figure 1 establishes the link between the formaldehyde concentration and both temperature and relative humidity [11].

As it is difficult to set values for these parameters that would be valid for any public or private space, long and intensive discussions among experts, industry, consumer associations, and the general public preceded the publication of the test method as requested in the ordinance.

The parameters that were given most attention in these discussions were relative humidity, the loading factor, and air velocity:

- Relative humidity could certainly exceed 45 percent under certain circumstances, especially in the summer.

- A loading factor of 1.0 was believed by many experts, including those of the Federal Health Office, to be too low for a number of situations encountered in practice.

- The air velocity in the test chamber also has a pronounced influence on the formaldehyde level (see Table 2). Indeed, an air velocity of 0.3 m/sec had been chosen in a large number of test chamber experiments because of a much better reproducibility of the results. However, as Figure 2 shows, the concentrations obtained under these conditions were higher by about 15 percent than those that would have been measured in the field where much smaller air velocities (< 0.1 m/sec) prevail.

Finally, the conditions given in Table 4 were proposed [12]. Air velocity in the test chamber of 0.3 m/sec was used in order to get more reproducible results. The fact that the concentration measured in the chamber could be 15 percent too high was accepted as a kind of safety margin for cases in which relative humidity and/or loading factors were higher than those given in Table 4.

To account for the differences in coated and uncoated particleboard, the way of preparing the test specimen was prescribed in detail, taking into account the ratio of cut-to-total areas. The new proposal also permits testing of pre-formed pieces made of wood-based products, such as medium-density fiberboard.

The Trend in Formaldehyde Concentrations

In the Federal Republic of Germany, many formaldehyde measurements have been carried out since 1977 when the guideline value of 0.1 ppm was introduced. However, many of these measurements have been made by local institutions and the data have usually not been compiled and published. The Institute for Water, Soil and Air Hygiene

of the Federal Health Office, between 1984 and 1986, ran three programs to analyze formaldehyde in a larger number of indoor environments.

In Program I and Program II, measurements were made following complaints of home dwellers; randomly chosen homes were included in Program III. The homes visited in Program I were located in Berlin; the homes in Program II were located in the remainder of the Federal Republic of Germany. Program III included homes in any part of the country with a response rate of 89 percent. In all three programs, formaldehyde was determined using passive samplers exposed as duplicates over 48 hours. Table 5 gives an overview of the sampling. Table 6 summarizes the results of the three programs.

The guideline value of 0.12 mg/m^3 (0.1 ppm) was generally met, with averages close to 0.06 mg (0.05 ppm). In the complaint cases (Programs I and II), the number of homes exhibiting a concentration level higher than 0.1 ppm was approximately ten percent, whereas in the random study (Program III), the rate of exceedance was only two percent. In all programs, the 50th percentile was lower than 50 μg/m^3.

Since the passive samplers were exposed over 48-hour periods, the results in Table 6 are 48-hour averages. Thus, short-term sampling in the same homes, e.g. over 30-minute periods, may have led to higher concentrations than those reported here. It should also be mentioned that results obtained by a passive sampling procedure are generally less reproducible than those of active sampling procedures. For the samplers used in the studies described above, the relative standard deviation under field conditions as calculated from the duplicates was approximately 20 to 30 percent at concentration levels between 50 and 100 μg/m^3.

Although the official regulatory abatement strategies have been effective in reducing formaldehyde concentrations in indoor air, further reductions are possible by additional control measures. As an example, the local authorities in Nürnberg, FRG, undertook to achieve formaldehyde levels of less than 0.075 ppm in 320 rooms of more than 100 pre-schools [13]. Table 7 shows the distribution before and after the four-year abatement program which cost about 1.1 million Deutsche Marks (with about 25 percent spent on chemical analysis).

One effective control measure was the sealing of all uncoated particleboard edges in the rooms. In addition, the substantial contributions from cleansing and disinfecting agents, tobacco smoking, processed cork, and various hobby products was reduced by more careful selection of products and better education.

The Future

Particleboard is but one, although major, source of formaldehyde in indoor air. In addition, formaldehyde emissions may result from other products, such as textiles, carpeting, wallpapers, lacquers, and varnishes. Until now, the contribution of these products to the final formaldehyde concentration has not been considered in the

regulatory processes. Although much progress has been made in the Ordinance on Hazardous Substances [9] by extending regulation to wood-based products of all kind, the inclusion of more formaldehyde emitting materials still needs to be reached to guarantee a 0.1 ppm level under all circumstances. However, even after achieving this level, the final goal should be to bring the formaldehyde concentration in indoor air down to levels below 0.1 ppm. The example of the city of Nürnberg shows that this goal can be reached even without further regulation.

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TABLE 1

FORMALDEHYDE CONCENTRATIONS IN 4 COLOGNE SCHOOLS AS MEASURED DURING THE SUMMER HOLIDAYS (1976)

		Formaldehyde concentration (ppm)			
		School 1	School 2	School 3	School 4
Room	1	0.53	0.97	0.63	0.97
	2	0.37	0.47	0.52	0.64
	3	0.31	0.56	0.46	1.2
	4	0.40	0.48	0.40	1.4
	5	0.38	0.31	0.37	1.1
	6	0.51	0.63	0.42	1.3
	7	0.61	0.58	0.50	1.9
	8	0.43	0.73	0.35	1.6

TABLE 2

CLASSIFICATION OF PARTICLEBOARD ACCORDING TO ITS FORMALDEHYDE EMISSION

Class	Equilibrium concentration in a 40 m^3 test chamber	"Perforator value" (mg HCHO/100 g dry material)
E 1	≤ 0.1 ppm	≤ 10
E 2	> 0.1 - 1.0 ppm	> 10 - 30
E 3	> 1.0 - 2.3 ppm	> 30 - 60

TABLE 3

CONDITIONS FOR THE REFERENCE METHOD TO TEST PARTICLEBOARD FOR FORMALDEHYDE EMISSIONS (1980)

Size of test chamber	40 m^3
Temperature	23 ± 1 °C
Relative humidity	45 ± 3%
Loading	1 m^2/m^3
Air exchange	1 ACH

TABLE 4

CONDITIONS FOR THE REFERENCE METHOD TO TEST PARTICLEBOARD FOR FORMALDEHYDE EMISSIONS (1989)

Size of test chamber	≥ 12 m^3
Temperature	23 ± 1 °C
Relative humidity	45 ± 5%
Air exchange	1 ± 0.1 ACH
Air velocity	0.3 ± 0.1 m/s
Loading	1 m^2/m^3

TABLE 5

OVERVIEW OF MEASURING PROGRAMMES

	I	II	III
Distributed samplers	188	1,388	740
Lost samplers	-	8	80
Unused samplers	-	2	-
Samplers as duplicates	154	1,158	656
Samplers as "singles"	34	147	4

TABLE 6

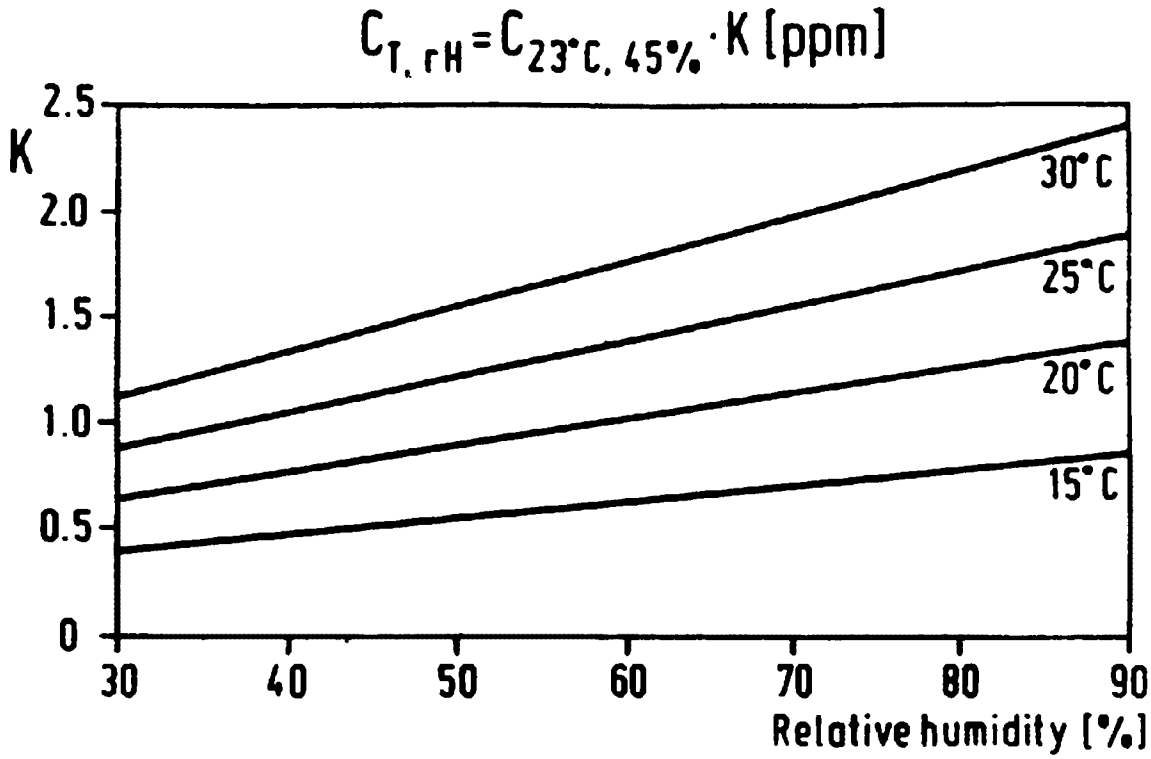
RESULTS OF MEASURING PROGRAMMES I - III (/$\mu g/m^3$)

Parameter	I	II	III
Arithmetic mean	60	63	56
Standard deviation	±43	±68	±28
Minimum	ND	ND	ND
Maximum	229	1,240	279
Values exceeding 0.12 mg/m^3 (%)	8	8	8

TABLE 7

DISTRIBUTION OF FORMALDEHYDE CONCENTRATIONS IN 320 PRESCHOOL ROOMS BEFORE AND AFTER CONTROL

Formaldehyde concentration (ppm)	Before control	After control
<0,04	19	30
0.04 - 0.075	44	65
0.075 - 0.1	18	4.6
0.1 - 0.15	15	0.4
0.15	4	-


$C_{T,rH} = C_{23°C,45\%} \cdot K$ [ppm]
K
2.5
2.0
1.5
1.0
0.5
0
30°C
25°C
20°C
15°C
30
40
50
60
70
80
90
Relative humidity [%]

Orientations and Actions of the European Community in the Assessment and Prevention of Indoor Air Pollution

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Introduction

While various services of the Commission of the European Communities have developed some interest in certain aspects of IAQ, or will develop such interest, no comprehensive policy and action is being developed in this area. Research activities of the Commission have been developed since 1981 by Directorate-General XII (Science, Research and Development) through its Joint Research Center (Ispra). Various Commission services are actually or potentially involved in some IAQ policy and regulatory acts:

- The Directorate-General XI (Environment, Nuclear Safety and Civil Protection) is in charge of "defining and implementing preventive measures against indoor pollution from a growing number of substances";
- The Directorate-General III (Internal Market and Industrial Affairs) is in charge of regulating hygienic properties of building materials;
- The Directorate-General V (Employment and Social Affairs) is in charge of community legislation on smoking prevention; and
- The Consumer Protection Service is preparing its first action program which may consider the impact of consumer products on indoor air quality.

The various activities and tasks of these Commissions are described in the rest of this paper.

Research Activities

As explicitly stated in the fourth "Policy and Action Program on the Environment (1987-1992)" of the European Community, approved by the Council of Ministers on October 19, 1987, scientific research is an essential preparatory activity for almost any political action in the field of environmental protection. Moreover, under the title "actions in specific sectors, atmospheric pollution," the program specifies that a major objective of an overall longer-term strategy to reduce air pollution is "to identify the atmospheric pollutants (outdoor and indoor) of greatest concern from the standpoint of the protection of human health."

Research supporting the environmental policy of the Community may be carried out within three different frameworks:

- In-house or "direct" research performed within the framework of multi-annual specific research programs of the Joint Research Center or, on request, of other Commission services;

- Contract or shared-cost research performed in the Member Countries and co-financed by the Commission within the framework of multi-annual research action programs; and

- Concerted actions which implement a cooperation at the community level among national research institutions in specific research areas are also defined in the multi-annual research action program. The financial contribution of the Commission to concerted actions usually covers only expenses for a secretariat and for the organization of meetings.

European non-member countries may participate in the research action program (shared cost research and concerted actions) via an agreement with the Community. Member countries also have the option of participating in selected concerted actions in the COST ("Cooperation Europeenne dans le Domaine de la Recherche Scientifique et Technique") framework. COST is a cooperation agreement between all European OECD Countries and the European Community. Community concerted actions become Category A COST projects as soon as a COST country which is not an EC member state begins to participate in it (Category B COST projects are those projects developed and decided upon within the COST framework and which may or may not be included in the Commission's research action program).

For the time being, IAQ research has been implemented at the community level as in-house research and as a concerted action. Both are briefly described below.

JRC Research

Studies on indoor air pollution by organic chemicals started at the Ispra Establishment of the Joint Research Center (JRC) in 1981, with the goal of gaining knowledge on the actual concentrations of these compounds in indoor spaces and of developing analytical methods adequate for such investigations. This research action is continuing and is now part of the activity of the JRC's Institute for the Environment. Presently, it mainly addresses the emission of volatile organic compounds (VOCs) from building furnishing materials and from household products.

The following studies have been performed (relating information may be found in the publications listed in the Appendix):

- ***Field Studies:*** contribution of micro-environments to 24-hour exposure of a pupil to VOCs (March 1981); analysis of aldehydes and other VOCs present in different indoor spaces (15 homes, indoors and outdoors, in 1983-84); pentachlorophenol in homes and in a tannery (1985); semi-volatile and particulate organic matter in a home sample (1985); and aldehydes and other VOCs in the buildings of the European Parliament (1986-88).

- ***Emission Studies:*** headspace and chamber measurements of aldehydes and VOCs emitted from building/furnishing materials and household products (since 1985); aldehydes and ketones in mainstream (active) and sidestream (passive) cigarette smoke (1987).

- ***Methods Development:*** development and testing of analytical and characterization methods, including the organization of and participation in inter-laboratory comparisons (determination of aldehydes and ketones, diffusion or passive sampling of VOCs, characterization of VOC emissions).

- ***Biological Effects:*** bioassays for mutagenicity on bacteria and mice to determine the genotoxicity of pollutants relevant in indoor air; *in vitro* and *in vivo* measurements in mice to investigate embryotoxic effects of methylglyoxal and acetaldehyde.

COST Project 613: "Indoor Air Quality and Its Impact on Man"

The most important activity in the IAQ field at the community level is the concerted action "Indoor Air Quality and Its Impact on Man," which is part of the Community multi-annual research program for the protection of the environment (1986-1990) and was approved in June 1986. The Committee met for the first time in March 1987. The concerted action became COST project 613/1 through the association of Sweden and Switzerland; Norway and Finland will soon join the concerted action. The Institute for the Environment of the Joint Research Center acts as leader of the project.

The scope of COST Project 613/1 is to determine the human health and comfort effects caused by air pollution in non-industrial, indoor environments (homes, schools, offices, etc.). COST Project 613/1 has five objectives:

- Identification and characterization of pollutants and sources;
- Assessment of population exposure;
- Assessment of health effects;
- Development and validation of reference methods;
- Collation, synthesis, and dissemination of data;

Cooperation is implemented through a committee composed of members of all participating countries, the Secretariat and through working groups (WGs). For the time being, six WGs have been established:

- ***WG 1:*** preparation of a practical guide to "sick building syndrome" investigations (task achieved);
- ***WG 2:*** preparation of the guide, "Sampling Strategy in Indoor Air Chemical Analysis";
- ***WG 3:*** preparation of a guideline for the determination of steady state concentrations of formaldehyde in test chambers due to emissions from wood-based materials (task achieved);
- ***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 pollution; and
- ***WG 6:*** preparation of a guideline on ventilation requirements.

In an attempt to overcome the increasing difficulty of having to hand over the essential information in a concise form, the Committee, through the Secretariat and the Working Groups, issues summary reports on single pollutants of high priority and on other topics. Five publications have been issued:

- ***Report No. 1:*** Radon in Indoor Air
- ***Report No. 2:*** Formaldehyde Emission from Wood-Based Materials: Guideline for the Determination of Steady State Concentrations in Test Chambers

- *Report No. 3:* Indoor Pollution by NO_2 in European Countries
- *Report No. 4:* "Sick Building Syndrome" - a Practical Guide
- *Report No. 5:* Project Inventory

Policy and Regulatory Activities

Before presenting the actual and potential policy and regulatory activities, it is worthwhile to recall the institutional framework for the implementation of Community policies and its terminology. Community policy is broken down into sectorial policies which usually are associated with one of the Directorates-General or Commission Services assisting the Commission in its task. The Commission defines its policy objectives in sectorial multi-annual Policy and Action Programs approved by the Council of Ministers.

The regulatory process in the Community starts with a proposal of the Commission to the Council of Ministers, which is the organization with decision-making authority -- the European Parliament only has an advisory role, with limited budgetary power. There are three types of legal acts with binding force at the Community level: regulations, decisions, and directives. Directives are mainly used in the environmental field and define a result to be achieved, but leave to the Member States the choice of forms and methods. The Commission also has the task of implementing the approved rules, and verifying their implementation by the Member States. Besides the three types of acts mentioned above, the Commission may propose (and the Commission and Council may approve) recommendations and resolutions which do not have binding force, but are only a commitment in principle. The Commission and Council may, however, exert a remarkable pressure on national governments and social forces.

Several sectorial policies of the Commission and, hence, the activity of several Directorates-General or Commission Services, actually or potentially touch aspects of the IAQ issue. Directorate-General XI (Environment, Nuclear Safety and Civil Protection) is responsible for the environmental and radiation protection policy of the Commission. Its fourth "Policy and Action Program on the Environment (1987-1992)," approved by the Council of Ministers on October 19, 1987, includes as one of the major objectives "an overall longer-term strategy to reduce air pollution, and "to define and implement preventive measures against indoor pollution from a growing number of substances."

The presence of radon in indoor air is one of the major causes of concern for those working to protect human health from indoor pollutants. In 1989, a "recommendation of the Commission on the protection of the public against indoor exposure to radon" was drafted and is now under discussion. The recommendation introduces "a reference level for consideration of remedial action" (not to be used for the purpose of legal regulation) for existing housing and a "design level" for future housing. The levels, in terms of effective dose equivalent, are 20 Sv/year for existing homes and ten Sv/year for future homes. In terms of radon gas concentration, the levels are 400 Bq/m^3 for existing homes and 200 Bq/m^3 for future homes.

As a further preventive measure, an information booklet is under preparation for the general population on the potential hazards of indoor air pollution and possible methods to avoid or reduce it. The Directorate-General III (Internal Market and Industrial Affairs) has prepared the important directive 89/106 "on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products," approved by the Council on December 21, 1988. This directive, issued in order to guarantee the free movement of goods, sets out a framework for regulations concerning construction products. The directive requires that such products "must be suitable for construction works which (as a whole and in their separate parts) . . . satisfy the . . . essential requirements."

One of these requirements concerns "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 neighbors, 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; or the emission of dangerous radiation.

Limiting the emission of formaldehyde from wood-based materials is presently under consideration as a first case to safeguard the above mentioned essential requirement. For this scope, CEN (Commitee Europeen de Normalisation), the organization 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 a Working Group of COST Project 613.

A directive regarding asbestos has been issued by the Commission (87/217/CEE, in force since March 19, 1987). Although it makes no explicit reference to indoor air pollution, the directive has an indirect impact on indoor air quality. The directive introduces measures to prevent and reduce air and other environmental pollution by asbestos, and specifies rules to be observed during removal of asbestos containing materials from buildings.

The Directorate-General V (Employment and Social Affairs) is in charge of Community legislation on smoking prevention which is being recognized as the most important issue of indoor air pollution. In the framework of the program, "Europe against Cancer," the Council of Health Ministers adopted on May 16, 1989 a resolution banning smoking in public places, except in clearly defined areas reserved for smokers. A directive in a very advanced stage of preparation (approval is expected in the Council meeting of November 13, 1989) concerns the labeling of tobacco products with warning messages ("seriously damages health," "causes cancer," etc.). Two directives are in the discussion phase: one concerns the maximum tar yield of cigarettes, the other concerns the limitation of advertising by press and posters.

The Consumer Protection Service is preparing its first action program. The impact of consumer products on indoor air quality is presently under consideration as a subject of the program.

It is interesting to observe that all presently taken or prepared actions follow the approach of reducing exposure to indoor pollutants through the reduction or appropriate manipulation of the source. This approach, along with appropriate information on the population and on selected professional categories, appears the only realistic way of reducing exposure of the population to pollutants in indoor air.

The European Parliament, in October 1988, adopted a resolution on air quality in buildings, in which, considering that "more attention should be devoted in Community environmental policy to the problem of the quality of air in indoor environments, reiterates the request already made with regard to bans on smoking . . . considers . . . that the Commission should promote further in depth research into the possible causes and effects of air pollution inside buildings on human health." Moreover, the resolution invites the Commission to prepare a directive on the subject, which should include:

- A list of substances whose use in construction works and in cleaning should be regulated or prohibited;
- Quality standards to be applied to air in indoor environments;
- Rules governing the planning, building, management and maintenance of air conditioning and ventilation systems; and
- Minimum rules for the maintenance of buildings open to the public, in order to ensure the highest standard of hygiene and cleanliness."

Appendix A
Publications by the Environment Institute of the JRC - Ispra on Indoor Air Quality

M. De Bortoli, H. Knoppel, L. Molhave, B. Seifert, D. Ullrich: "Inter-laboratory Comparison of Passive Samplers for Organic Vapors with Respect to their Applicability to Indoor Air Pollution Monitoring: a Pilot Study." Commission of the European Communities, Report EUR 9450, Brussels-Luxembourg 1984.

M. De Bortoli, H. Knoppel, E. Pecchio, A. Peil, L. Rogora, H. Schauenburg, H. Schlitt, and H. Vissers: "Measurements of Indoor Air Quality and Comparison with Ambient Air: A Study of 15 Homes in Northern Italy'. Commission of the European Communities, Report EUR 9656, Brussels, Luxemburg 1985.

M. De Bortoli, L. Molhave, M.A. Thorsen, D. Ullrich: 'European Inter-laboratory Comparison of Passive Samplers for Organic Vapor Monitoring in Indoor Air," Commission of the European Communities, Report EUR 10487 EN, Brussels-Luxemburg 1986.

M. De Bortoli, H. Knoppel, E. Pecchio, A. Peil, L. Rogora, H. Schauenburg, H. Schlitt , and H. Vissers: 'Concentrations of Selected Organic Pollutants in Indoor and Outdoor Air in Northern Italy." Environ. Int., 12 (1986) 343 - 350.

S. Mahajan, G. Pellegrini, M. Shea, R. Colombo, and M. De Bortoli: "Comparison between Measured and Model (LBL and BRE) Predicted Infiltration Rates for a Passive Solar Test Cell"- Int. J. Solar Energy, 4 (1986) 109 - 120.

H. Knoppel: "Sampling and Analysis: Chamber and Field Studies"; Chairman's Summary, Session V, Symposium on Characterization of Contaminant Emissions from Indoor Sources. Atmospheric Environment, 21 (1987) 439 - 442.

M. Maroni, H. Knoppel, H. Schlitt and S. Righetti: "Occupational and Environmental Exposure to Pentachlorophenol." Commission of the European Communities Report EUR 10795 EN, Brussels, Luxemburg 1987.

L. Clerici: "Acetaldehyde activation of poly(AD-ribose)polymerase in hepatocytes of mice treated in vivo." In Mutation Research, 227(1989) 47-51.

H. Schlitt and H. Knoppel: "Carbonyl compounds in mainstream and environmental cigarette smoke." In "Present and future of indoor air quality," C.J- Bieva, Y. Courtois and M. Govaerts Eds, Excerpta Medica, Amsterdam 1989, 197-206.

H. Knoppel and H. Schauenburg: "Screening of Household Products for the Emission of Volatile Organic Compounds." Presented at 'Indoor Air 1987', Berlin 17 - 21 August 1987, Environment International 15(1989) in press.

M. Oehme and H. Knoppel: "Analysis of Low Volatile and Particulate Bound Organic Indoor Pollutants: Assessment of a Sensitive Method and First Results," ibid.

M. De Bortoli, H. Knoppel, E. Pecchio, and H. Vissers: "Performance of a Thermally Desorbable Diffusion Sampler for Personal and Indoor Air Monitoring," ibid.

A. Colombo, M. De Bortoli, E. Pecchio, H. Schauenburg, H. Schlitt and H. Vissers: "Chamber testing of organic emission from building and furnishing materials," The Science of the Total Environment, in press.

H. Knoppel and M. De Bortoli, "Experiences with indoor measurements of organic compounds," presented at the Indoor Air Quality International Symposium of the American Industrial Hygiene Conference, 21-26 May 1989, St. Louis, USA.

EUROPEAN COMMUNITIES SERVICES

INVOLVED IN POLICY AND REGULATORY ASPECTS

OF INDOOR AIR QUALITY

Directorate - General XI: Environment, Nuclear Safety and Civil Protection

Definition and Implementation of preventive measures against Indoor pollution from a growing number of substances

Directorate - General III: Internal Market and Industrial Affairs

Regulation of hygienic properties of building materials

Directorate - General V: Employment and Social Affairs

Legislation on smoking prevention

Consumer Protection Service

Preparation of an action program considering the impact of consumer products on indoor air quality

RESEARCH ACTIVITIES SUPPORTING EC ENVIRONMENTAL POLICY

In-house or "Direct" Research

- Joint Research Centre, Ispra
- Other Commission Services

Contract or Shared-cost Research

- Carried out by Member Countries with financial support of EC Commission

  (Multi-annual Research Action programmes)

Concerted Actions

- Cooperation of member States without financial support of research costs

  (Other European OECD countries may participate)

COST

- **Cost projects facilitate work that goes beyond the resources of individual partners.**
- **The majority of COST projects operate without any joint funding.**
- **Most COST projects are designed to promote basic applied scientific and technical research in the following areas:**

1. Informatics
2. Telecommunications
3. Transport
4. Oceanography
5. Metallurgy and Materials Science
6. Environmental Protection
7. Meteorology
8. Agriculture
9. Food Technology
10. Social Technology
11. Medical Research

COST STRUCTURES

- **Committee of Senior Officials (CSO)**
  (Permanent body of representatives of 19 States and EC)
- **Committees to prepare COST projects**
  - Working Party on Legal, Administrative and Technical Questions (Representatives of all interested parties)
  - Ad hoc Working Parties for Special Topics
    (Delegates from States with particular interest and EC)
- **Committee for the implementation of COST projects**
  - Concertation Committees
  - Management Committees
- **COST Secretariat**

COST 613

Indoor Air Quality and its Impact on Man

Category A Type cooperation:

- The subject is part of the Community program
- The secretariat is provided by the EC Commission
- Non-Community COST states contribute the extra cost for their participation

History:

- Ad hoc working party since 1982
- Concerted Action started in 1987

Actual Situation:

As Switzerland and Sweden have joined in, the Concerted Action is now a COST-Community action, directed by a Community-COST Concertation Committee (CCCC)

COST 613
Indoor Air Quality and its Impact on Man

ACTIVITIES

The COST project has the aim of promoting the scientific cooperation and the exchange of knowledge in the following fields:

- Identification and characterisation of indoor pollutants and sources
- Assessment of exposure and health effects
- Development and validation of methodologies

The program is implemented through the following activities:

- Establishment of working group
- Publication of reports on issues of major concern
- Organization of scientific symposia and workshops
- Liaison with other international organizations (WHO, NATO/CCMS)

COST 613
Indoor Air Quality and its Impact on Man

EXISTING WORKING GROUPS

- Strategies for indoor measurements (final draft)
- "Sick Building Syndrome" - A practical guide (final draft)
- Biological effects in man related to indoor air pollution (preliminary draft)
- Determination of formaldehyde emissions in test chambers (interlaboratory test)
- Determination of biological pollutants (work started)
- Guideline on ventilation requirements (work started)

Section III

Controlling IAQ - The Non-Regulatory Approach

EPA and Indoor Air Quality

Robert Axelrad
Director, Indoor Air Division
US Environmental Protection Agency

Introduction

In 1970, when the Clean Air Act was passed to address the problems of urbanization, industrial development, and the increasing use of automobiles, the Act was interpreted as applying only to the air external to structures. As a result, most Federal programs concerned with reducing exposure in enclosed spaces (for example, residences, public or commercial buildings, or transportation vehicles) have singled out only a handful of individual pollutants for action or control under various Federal statutes. To date, no comprehensive legislation to address many of the issues raised by indoor air pollution has been enacted.

In the early 1970s, formaldehyde was identified by the Consumer Product Safety Commission (CPSC) as the source of acute irritant reactions and a cancer hazard in individuals whose homes were insulated with urea-formaldehyde foam insulation (UFFI) or constructed of large amounts of particleboard and/or plywood. Programs to address another major indoor air pollutant -- asbestos -- have been in operation for some time and two major laws have been enacted by Congress to provide (1) loans and grants to schools with severe asbestos hazards and financial need, and (2) a regulatory framework for asbestos control in schools. In the late 1970s and early 1980s, concern over naturally occurring radon began to rise and in 1984, when extremely high levels of radon were found in homes in the Reading Prong geological formation in Pennsylvania, New Jersey, and New York, radon became a major indoor air pollution program.

In the early 1980s, however, EPA's research program, using the total exposure assessment methodology, began to demonstrate that for many people, indoor exposures to pollutants were significantly greater than exposures from outdoor, or ambient, sources. In addition, studies of a selected number of pollutants in ten buildings demonstrated that for many pollutants, indoor levels were often higher than outdoor levels. Coupled with the extremely high percentage of time spent indoors (approximately 90 percent for most people), concern began to grow that indoor air pollution may pose higher risks to the population than previously thought.

In 1984, Congress began appropriating approximately $2 million a year for EPA to conduct indoor air research. However, considerable debate and uncertainty continued among the various Federal agencies over the appropriate government role in the indoor air arena.

In 1986, following years of increasing concern over the potential risks to human health from pollutants in indoor environments, Congress enacted Title IV of the Superfund Amendments and Reauthorization Act (SARA) to establish an effective research effort aimed at characterizing the extent of the indoor air pollution problem and to begin to take steps to enhance the quality of the indoor air. Title IV (the Radon Gas and Indoor Air Quality Research Act) gave EPA clear authority for the first time to begin to address IAQ problems on a more comprehensive basis. Title IV directs EPA to:

- Conduct research on all facets of the IAQ issue;
- Disseminate information on IAQ problems and solutions;
- Establish two advisory committees to assist EPA in carrying out the mandate of Title IV; and
- Submit two reports to Congress describing, in the first report, EPA's plans for implementing Title IV, and, in the second report, the activities carried out under Title TV and whatever recommendations the Agency deems appropriate.

In June 1987, EPA submitted to Congress the EPA Indoor Air Quality Implementation Plan, describing the Agency's plans for fulfilling the mandate of SARA Title IV. In the report, EPA described two overall goals in addressing IAQ problems: to adequately characterize and understand the risks to human health which pollutants pose in indoor environments, and to reduce these risks by reducing exposure to indoor pollutants. The Agency said that it would pursue the two goals through the implementation of three policy objectives:

1. The Agency will conduct research and analyses to further refine its assessment of the nature and magnitude of the health and welfare problems posed by individual air pollutants as well as by pollutant mixtures indoors.

2. The Agency will identify and assess the full range of mitigation strategies available to address high priority indoor air problems.

3. For identified high risk, high priority problems, the Agency will adopt and execute appropriate mitigation strategies. These strategies may involve one or more of the following:

   - Issuing regulations under existing regulatory authorities (e.g. Toxic Substances Control Act (TSCA), FIFRA, or the Safe Drinking Water Act);

   - Building state, local government, and private sector capability to address IAQ problems through non-regulatory programs of information dissemination, technical assistance, guidance, and training;

- Referring problems to other Federal agencies with appropriate statutory authority (e.g. CPSC and the Department of Housing and Urban Development); and

- Requesting separate indoor air regulatory authority from Congress if deemed necessary.

In 1988 and in 1989, legislation was introduced in both houses of Congress that would dramatically expand the Federal government's role in carrying out research and providing technical assistance and information dissemination programs on indoor air quality.

How Indoor Air is Organized at EPA

Many different EPA offices have played and will continue to play significant roles as EPA continues to develop an effective response to indoor air issues. In part due to varying statutory mandates and separate development tracks, EPA's various indoor air activities continue to be decentralized. Major indoor air related activities occur in four separate Assistant Administratorships. Radon policy is developed and carried out by the Office of Radiation Programs in the Office of Air and Radiation. Research activities are conducted by a number of laboratories within EPA's Office of Research and Development. Asbestos regulatory and grant assistance programs are administered by the Assistant Administrator for Pesticides and Toxic Substances, as are regulatory activities related to indoor exposures to pesticides and other chemicals. The Office of Drinking Water has responsibility for indoor air pollution sources originating with the water supply.

In early 1986, the Office of Air and Radiation established a small, three-person IAQ staff to begin to identify and fill the gaps in the Agency's response to human exposures to air pollutants indoors and to provide policy direction in the implementation of SARA Title IV. Since 1986, additional staff and financial resources have been allocated to indoor air issues and in September 1988, the indoor air staff was elevated to division status as part of an office-wide reorganization. The Indoor Air Division is currently comprised of 11 full-time employees, with an extramural contract budget of $1.37 million. The Division's functions include the following:

- Evaluate various policy options and develop a national IAQ policy and program;

- Assist in setting the research agenda to ensure that the research that is conducted is policy-relevant;

- Coordinate the IAQ activities of the various EPA program offices and stay abreast of other Federal, state, and local agencies, as well as private sector activities addressing various facets of the IAQ problem; and

- Develop and disseminate information to the general public, building owners and managers, architects, health care professionals, state and local

government agencies, industry, the public interest community, and other interested groups.

Indoor Air Program Elements

Over time, the indoor air program will address all of the factors affecting air quality in all indoor environments. The program is currently comprised of five major elements:

- ***Policy Development*** -- Studies and analyses to characterize the nature and extent of IAQ problems and lead to the integration of information into clear cut policy options;

- ***Buildings Program*** -- The development of building-related information and implementation programs for key building management audiences to encourage prevention, diagnosis, and mitigation of IAQ problems;

- ***Pollutant/Source Program*** -- Activities to identify and characterize specific indoor air pollution sources and pollutants, and to devise strategies for their control;

- ***Intergovernmental Programs*** -- Activities designed to ensure that indoor air activities are coordinated at all levels of government and that specific program components are designed to enhance the capabilities of other Federal agencies and state and local governments; and

- ***Public Information Program*** -- Activities to communicate information on indoor air pollution risks and remedies to the public.

Policy Development

Report to Congress

Among other requirements, EPA was specifically required under Section 403(e) of Superfund to submit a Report to Congress describing the activities carried out under SARA Title IV and make recommendations as appropriate. In August 1989, the Agency submitted its Report to Congress on Indoor Air Quality and concluded: "sufficient evidence exists to conclude that indoor air pollution represents a major portion of the public's exposure to air pollution and may pose serious acute and chronic health risks. This evidence warrants an expanded effort to characterize and mitigate this exposure." There are three volumes of the report:

- Volume I -- Federal Programs Addressing Indoor Air Quality

- Volume II -- Assessment and Control of Indoor Air Pollution

- Volume III -- Indoor Air Pollution Research Needs Statement

The report reached a number of conclusions and made several recommendations. However, the report also indicated that indoor air research and policy programs have not yet sufficiently characterized IAQ problems and solutions to be able to determine whether additional regulatory approaches to IAQ problems are needed. Nevertheless, EPA made a number of recommendations intended to develop the necessary information to make such determinations:

1. **Research to better characterize exposure and health effects of chemical contaminants and pollutant mixtures commonly found indoors should be significantly expanded.**

   Although EPA is beginning to devote greater attention to characterizing non-cancer health effects from various exposure routes, information on exposure in homes and buildings is limited to a very few pollutants and groups of pollutants. In addition, virtually nothing is known about cancer and non-cancer health effects caused by low-level respiratory exposures to multiple chemical contaminants. An expanded research program in this field is needed to help characterize causes of and solutions to the "sick building syndrome" and to investigate emerging health issues, such as multiple chemical sensitivity.

2. **A research program to characterize and develop mitigation strategies for biological contaminants in indoor air should be developed.**

   EPA's historical experience in addressing environmental hazards has predominantly focused on chemical contaminants. However, biological contaminants in indoor air are predominantly responsible for known building-related illnesses, which include Legionnaires disease and hypersensitivity pneumonitis, and have been increasingly associated with poor hygienic and maintenance practices in buildings. While both the National Institute for Occupational Safety and Health (NIOSH) and the CPSC have active research underway, the lack of EPA participation limits the scope and magnitude of the effort.

3. **Research to identify and characterize significant indoor air pollution sources and to evaluate appropriate mitigation strategies should be significantly expanded.**

   Source control is the most effective control option when major sources can be identified and characterized, and it may be the only viable option in some situations. However, significant resources must be devoted to identifying and characterizing sources to enable EPA and other Federal agencies to take appropriate control actions under existing authorities or to advise the public of the health risks from specific sources as well as actions the public can take to reduce risk. Furthermore, research into innovative control technologies and evaluation of technologies developed by the private sector, including air cleaning technologies, should be significantly enhanced.

4. **A program is needed to develop and promote, in conjunction with appropriate private sector organizations, guidelines covering ventilation, as well as other building**

design, operation, and maintenance practices for ensuring that IAQ is protective of public health.

An effective national program to control indoor air pollution will require the application of generic strategies involving provisions for adequate ventilation, and provisions to avoid problems through proper building design, operation, and maintenance. This approach, combined with programs targeted to specific individual high risk sources and pollutants would provide a comprehensive, but feasible and cost-effective control strategy. In our view, a pollutant-by-pollutant approach encompassing target levels for individual pollutants would not resolve the bulk of IAQ problems.

5. **A program of technical assistance, and information dissemination, similar in scope to the Agency's radon program, is needed to inform the public about risks and mitigation strategies, and to assist state and local governments and the private sector in solving IAQ problems. Such a program should include an IAQ clearinghouse.**

While EPA has joined the ongoing Federal and private sector efforts to disseminate information on indoor air quality, as our experience with radon has demonstrated, a program is needed that can keep pace with the needs of state and local governments, architects, building owners and managers, researchers, the medical and health communities, building occupants, and others who are seeking reliable technical and non-technical information. A program to transfer knowledge and develop capabilities in the public and private sectors would include a variety of technical assistance and information dissemination activities comparable to those developed to address the radon problem. An indoor air information clearinghouse is needed to enhance coordination and access to such information.

6. **The Federal government should undertake an effort to characterize the nature and pervasiveness of the health impacts associated with IAQ problems in commercial and public buildings, schools, health care facilities, and residences, and develop and promote recommended guidelines for diagnosing and controlling such problems.**

The available literature suggests that IAQ problems are pervasive in a wide spectrum of buildings, but the prevalence of such problems, the nature of their sources, and the amount of human exposure attributable to these sources are virtually unknown. However, an increasing number of complaints are being registered to government agencies, and a growing number of private sector firms are attempting to respond to a rapidly emerging market for diagnostic and mitigation services. A major study is needed to determine the scope and character of such problems, and to develop recommendations to guide and control the quality of diagnostic and mitigation services in the private sector.

Pending Legislation

Two bills, S. 657 and H.R. 1530, were introduced during the 1st Session of the 101st Congress which, if enacted, would expand Federal IAQ programs. Initially identical in language, at this writing the Senate version has been substantially modified to correct a number of problems with the bill identified by a variety of individuals and organizations. It is anticipated that many, if not all, of the changes in the Senate version may also be adopted in the House version. At this time, the key provisions of the Senate bill include:

- No new regulatory authority;
- Authorizations of $48.5 million per year for five years;
- Expansion of indoor air research and requirements for special studies on exposure assessment and characterization of IAQ problems in schools and child care facilities;
- Development and promotion of building technology management practices, including a new emphasis on ventilation needs;
- Development of a list of contaminants "...which are known to occur (or which are expected to occur) in indoor air at levels which may reasonably be expected to have an adverse impact on human health." The initial list must include 11 specific pollutants for which EPA must develop health advisories within three years: benzene, biological contaminants, carbon monoxide, environmental tobacco smoke, formaldehyde, lead, methylene chloride, nitrogen oxide, particulate matter, polycyclic aromatic hydrocarbons (PAHs), and radon.
- Preparation of a National Response Plan, integrating actions to be taken by the Federal government under its various statutory authorities to address IAQ risks;
- A Federal Building Response Plan and Demonstration Program;
- A major state grant program to provide assistance to states for IAQ assessment and mitigation programs;
- A national IAQ information clearinghouse; and
- Expanded roles for a number of other Federal agencies, including NIOSH and the Occupational Safety and Health Administration (OSHA).

Other Policy Development Activities

In Fiscal Year 1990, the indoor air program will pursue a number of other policy development initiatives, including:

- Initiation of a process to establish a consensus-based system for credentialing private sector IAQ diagnostic and mitigation firms;
- Initiation of an assessment of multiple chemical sensitivity issues to determine what is currently known, and what research needs to be done to address indoor air issues relevant to sensitive individuals and populations (this assessment will be used to develop a long-range research and analysis agenda); and
- A training needs analysis to aid in the development of a comprehensive, long-range IAQ training plan.

Buildings Program

Development of targeted guidance programs, information dissemination, and training tailored to building owners and managers, design engineers, and architects and covering public and commercial buildings, schools, and residential structures is a high priority. A number of guidance documents are in development:

- Information to be used by architects, developers, and engineers in the design and construction of new buildings, including a technical manual on preventing problems in commercial structures as well as a new home construction guide geared specifically to builders;
- Information for building owners and managers designed to be used in an assessment program to identify and correct potential problems in existing buildings before complaints begin; and
- Information for building owners and managers on how to manage an existing building-related IAQ problem, including components on conducting a building investigation, employee relations, use of contractors, and mitigation techniques.

Another high priority need is for the development of baseline data on the scope of the indoor air problem nationwide and of appropriate guidelines for conducting building investigations. An effort to develop such guidelines and protocols is expected to get underway in 1990.

Pollutant/Source Program

Initially, the pollutant/source program focused on the risks associated with environmental tobacco smoke (ETS), a known carcinogen and the largest source of

particles and mutagens indoors where smoking is permitted. This past year, the Indoor Air Division wrote and distributed a fact sheet on environmental tobacco smoke, describing the current state of knowledge about health effects and mitigation. A number of other significant projects are underway:

- Preparation, in cooperation with EPA's Office of Research and Development (ORD), of a lung cancer and respiratory disease risk assessment of environmental tobacco smoke;

- Development, in cooperation with the Department of Health and Human Services (DHHS), of a policy-makers' guide to mitigation of ETS exposure; and

- Publication of a compendium of technical information on the environmental tobacco smoke issue.

The indoor air program is actively involved in a number of Agency working groups that focus on other indoor pollutants for which primary responsibility is located elsewhere in the Agency, including radon, asbestos, formaldehyde, chlorinated solvents, and pesticides.

Intergovernmental Program

Federal Coordination

A number of Federal agencies are involved in IAQ issues and participate with EPA on the interagency Committee on Indoor Air Quality (CIAQ). As one of four co-chairs of the CIAQ, EPA provides staff and funding support for the CIAQ and prepares a yearly compendium of Current Federal Indoor Air Quality Activities.

The Consumer Product Safety Act and the Federal Hazardous Substance Act provide the CPSC with regulatory authority over consumer products that may contribute to indoor air pollution. Since many of the sources of indoor air pollution are consumer products (e.g. household chemicals), CPSC plays a significant role in addressing indoor air pollution.

The Department of Energy (DOE) has played a major role in IAQ since the 1970s. The two primary DOE policy goals concerning indoor air quality are: 1) eliminating potential hazards to the public and the environment from radioactive contamination remaining at facilities and sites previously used in the nation's atomic energy programs; and 2) developing information to ensure the maintenance of healthful indoor environments with continuing use of energy conservation measures in buildings. DOE's IAQ interests are focused on research and development, the DOE Remedial Action Program, health risk assessment, and participation in the CIAQ. A significant portion of DOE's efforts in indoor air are related to radon exposure and health effects research.

The Department of Health and Human Services is a major contributor to the identification and resolution of IAQ problems through several of its organizational components. The National Institute for Occupational Safety and Health serves as the DHHS co-chair of the CIAQ and is the primary agency of the Federal government with extensive experience in conducting building investigations. Since 1971, NIOSH has conducted approximately 550 IAQ investigations under its Health Hazard Evaluation Program.

The Occupational Safety and Health Administration is charged under the Occupational Safety and Health Act with protecting the health of workers in the workplace. Recent interest in IAQ in non-industrial settings has prompted OSHA to begin development of guidance for its inspectors on identifying non-industrial IAQ problems.

The General Services Administration is involved in a variety of IAQ activities related to its responsibilities to manage a significant portion of Federal buildings.

State and Local Governments

EPA recognizes state and local governments as the cornerstone of a long range strategy to control IAQ problems. Many state and local governments currently address IAQ concerns through restrictions on smoking in public places, ventilation requirements in building codes, asbestos inspection and abatement programs, pollutant concentration and emission standards, problem building evaluations, and research and public information dissemination activities.

However, most states currently do not have a comprehensive strategy for addressing indoor air problems. A fundamental component of EPA's long range strategy is to provide technical assistance to states to implement comprehensive indoor air programs. Technical assistance will be provided on substantive levels through the provision of training and technology transfer as well as assisting states in organizing effective indoor air programs.

Development of model state programs during the next two to three years is a high priority. A limited number of state pilot grants for IAQ assessment activities will be made available during this period. Ultimately, the availability of grant assistance for the development of state IAQ assessment and response programs will be essential in the development of a strong and independently funded set of state programs necessary to limit the long-term Federal role in indoor air quality.

International

Internationally, EPA is involved as co-chair of a three year international pilot study on IAQ under the auspices of NATO's Committee on the Challenges of Modern Society (NATO/CCMS). Proposed and led by Italy, the outputs from this study will include a series of proceedings from the bi-annual meetings, an inventory of risk management activities in the NATO countries and integration of US research activities into the European Communities' existing database on IAQ research.

Public Information Program

As a predominantly non-regulatory program, developing and disseminating both technical and non-technical information is the fundamental core of the program. In addition to providing guidance of a technical nature to audiences such as building owners and managers, state and local governments, physicians and other health care providers, there is a need to communicate with the general public about IAQ risks and risk reduction strategies.

In 1988, the program published and disseminated "The Inside Story -- A Guide to Indoor Air Quality," which was produced jointly with the Consumer Product Safety Commission. Through the Public Health Foundation, a Directory of State Indoor Air Contacts has also been developed and distributed. In addition, EPA has published a series of fact sheets on various IAQ topics (e.g., "Environmental Tobacco Smoke" and "Ventilation and Air Quality in Offices").

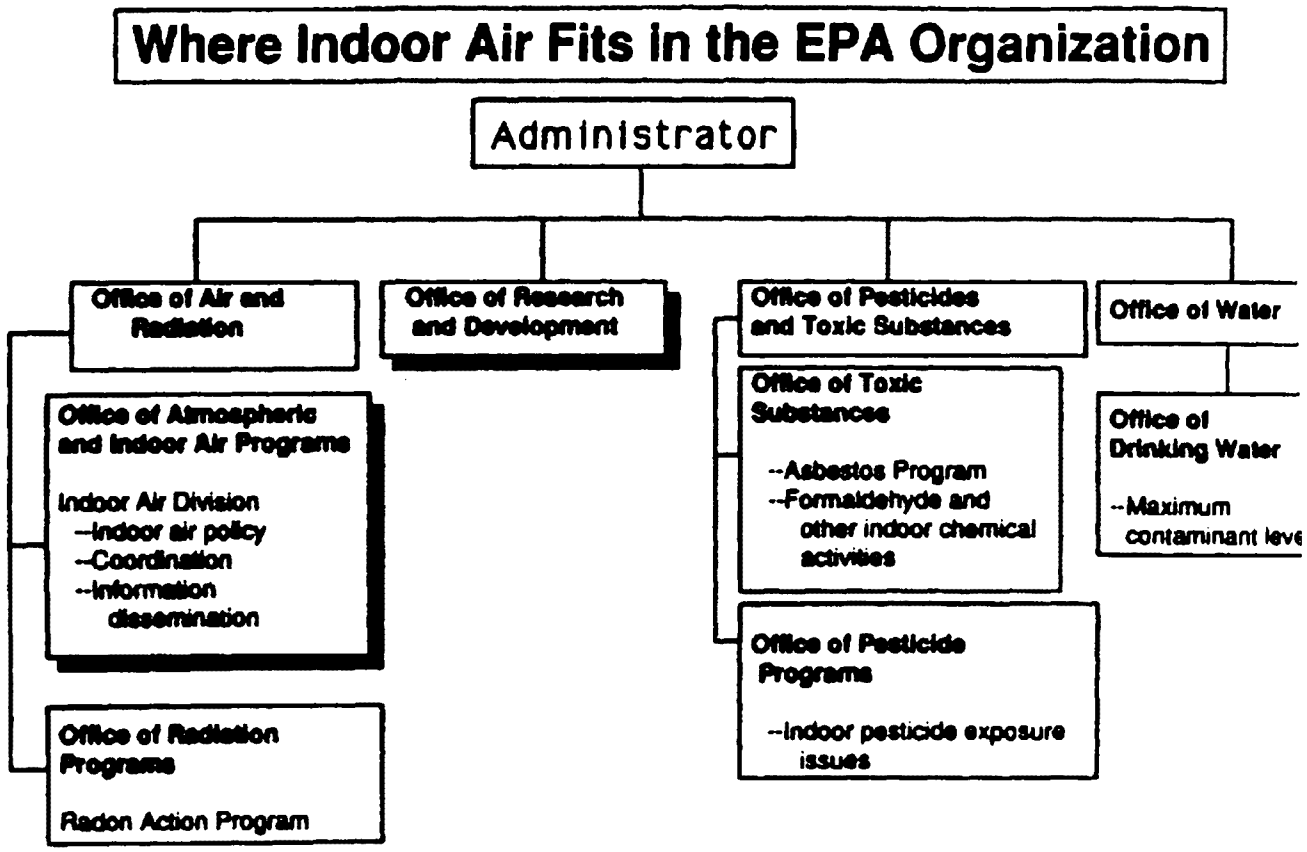
The indoor air program is continuing to develop public information materials on a variety of topics. A recently published report of a survey of private sector IAQ diagnostic and mitigation firms contains listings of more than 1,200 firms which responded to the survey and which can be used as a directory to assist the public in obtaining IAQ services.

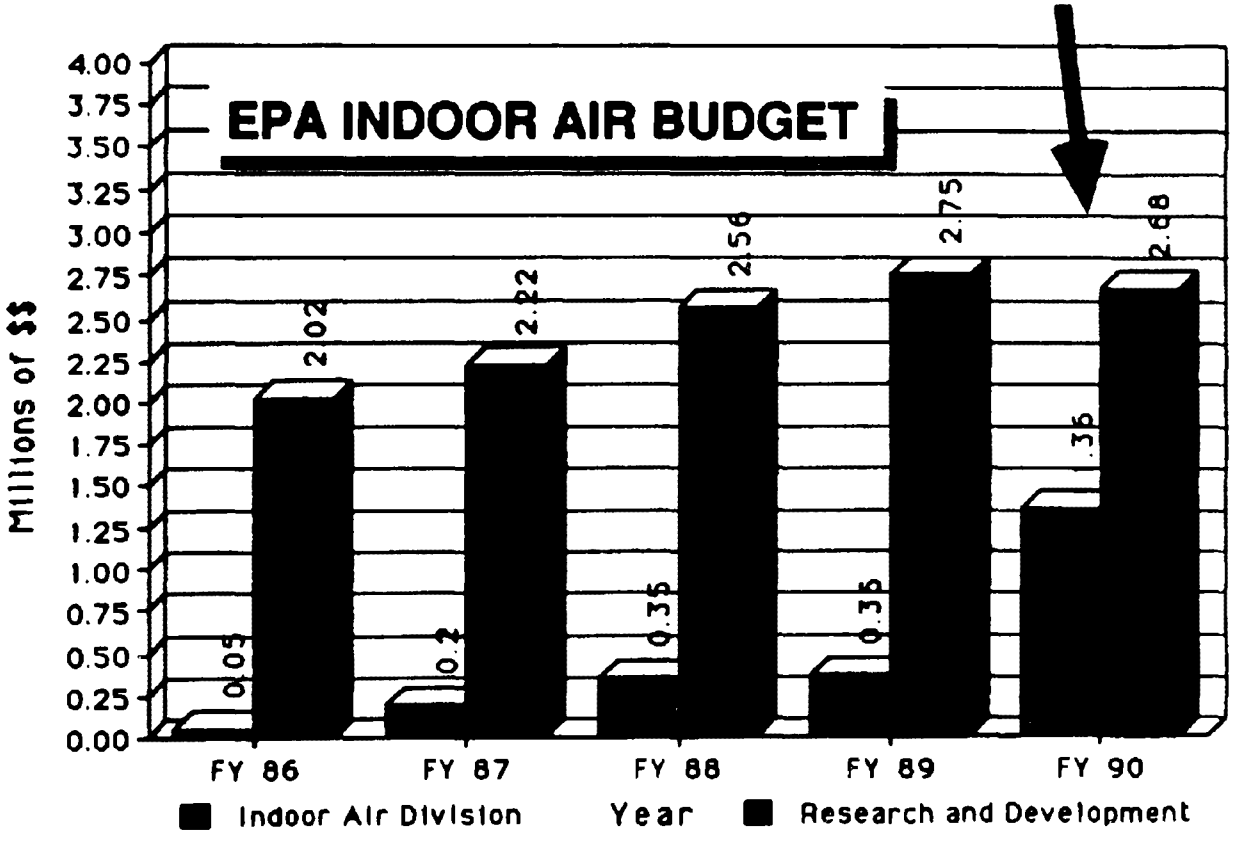
Projects currently underway include:

- Planning for an IAQ information clearinghouse, the objective of which is to serve as a repository for technical and non-technical information on IAQ issues which will be accessible to the scientific community, all levels of government, private sector groups, and the public;
- Production of a videotape version of "The Inside Story -- A Guide to Indoor Air Quality; and
- Publication of a summary of available information on residential air cleaning devices.

Summary

Although IAQ has not been the focus of major legislative and agency initiatives until recently, a significant body of scientific evidence indicates that indoor air pollution poses considerable risks to public health. Currently decentralized in its organization, EPA is developing an effective program to develop and disseminate information on a broad range of indoor air issues and to begin to study and analyze some of the most difficult long term policy questions. An expanded public and private sector effort to characterize IAQ problems and to evaluate, recommend, and implement risk management strategies is needed.


Where Indoor Air Fits in the EPA Organization
Administrator
Office of Air and Radiation
Office of Research and Development
Office of Pesticides and Toxic Substances
Office of Water
Office of Atmospheric and Indoor Air Programs
Indoor Air Division
--Indoor air policy
--Coordination
--Information dissemination
Office of Toxic Substances
--Asbestos Program
--Formaldehyde and other indoor chemical activities
Office of Drinking Water
--Maximum contaminant leve
Office of Radiation Programs
Radon Action Program
Office of Pesticide Programs
--Indoor pesticide exposure issues


EPA INDOOR AIR BUDGET
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Indoor Air Division
Research and Development

The Non-Regulatory Approach to Reducing Risks from Radon Exposure

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Radon is believed to be the second leading cause of lung cancer in the United States, causing an estimated 20,000 deaths each year. USEPA's senior scientists have ranked radon as the top environmental health problem facing the nation. Many leading health and scientific organizations, including the U.S. National Academy of Sciences and the U.S. Public Health Service, share this perspective. Estimates of the health risk from radon exposure are based on strong human and animal data, including studies of thousands of underground miners. At this time, the United States government has undertaken an entirely non-regulatory approach to reducing radon risk to the population.

Although radon has been regulated in underground mines in the U.S. since the 1950's, residential radon exposure was not believed to be a problem. In the late 1960's, several houses in Grand Junction, Colorado were discovered to have highly elevated radon levels because of the materials used in their construction. The foundations had been made with mill tailings from a nearby uranium mine. At about the same time, several houses with elevated radon levels were discovered in Florida. The source was traced back to reclaimed phosphate lands, again a "man-made" source. Even after these discoveries, elevated indoor radon was believed to be a purely "man-made" phenomenon.

This belief changed radically in 1985, when a nuclear power plant worker named Stanley Watras began triggering the plant's radiation safety alarms on his way home from work each day. The plant managers were puzzled since Mr. Watras' job did not bring him into contact with any radioactive material. They decided to pass him through the radiation detectors on his way in to work. He again triggered the alarms. After further investigation by the State of Pennsylvania, it was determined that the worker's radiation exposure source was in his home. The source was narrowed to radon gas, exposing the worker and his family to over 10 working levels.

News of this discovery set off a local panic in areas near the "Reading Prong", as the large geological formation where Watras' house is located is known. Several Federal agencies, State governments, universities and private organizations became curious as to whether elevated radon levels were isolated to this part of the country. As EPA worked with other States, EPA's concerns about the scope and severity of the problem were confirmed. Data collected through radon surveys, conducted jointly by EPA and 25 States to date, have shown that radon is a widespread national health problem, affecting millions of homes nationwide.

Elevated radon levels have been found in every State tested thus far. We estimate that about eight million or 10 percent of the nation's homes could have annual average radon concentrations above EPA's current action guideline of 4 pCi/L.

Based on this information, the U.S. government has recommended that all homes below the third floor of a building be tested for radon, and elevated levels lowered. At the time this recommendation was made, citizens were directed to follow our previously established guideline or "action level" of 4 pCi/l. Selection of 4 pCi/l, in 1986, was not a risk-based decision, but rather a decision based on the ability of the current radon reduction technology. At that time, radon mitigation technology was still fairly new, and the best available technology could only guarantee results down to 4 pCi/l. In spite of pressure to be consistent with acceptable risk levels in other EPA programs, we did not feel that it was appropriate to establish a more protective action level at that time.

EPA's Radon Action Program

The U.S. EPA established its Radon Action Program in 1985 as a non-regulatory program. A small program was established to undertake a variety of activities designed to assess the extent of radon risk nationwide, and develop reliable techniques to measure radon and mitigate elevated levels.

EPA believes that radon risk reduction is best achieved by a concerted effort of Federal and State expertise and resources. As with many government programs in the U.S., particularly environmental programs, national level programs are frequently designed to support State efforts. The USEPA felt this approach would be the most appropriate for radon risk reduction as well. Different States have drastically different radon characteristics and needs, and it was believed that the State governments were in the best position to act appropriately for their citizens. The current USEPA radon program still works within this framework.

Two important pieces of legislation have charted our course and greatly expanded our involvement in reducing radon risk. First, the Radon Gas and Indoor Air Quality Research Act of 1986 (Title IV of the Superfund Amendments and Reauthorization Act of 1986, P.L. 99-499) confirmed EPA's direction in surveying, research and technology. And then, in October 1988, the Indoor Radon Abatement Act (P.L. 100-551) directed EPA to undertake a broad range of activities to achieve the National goal of making indoor air as free from radon as outdoor air.

The goal of our program was and continues to be to reduce the public health risks of radon by 1) forming partnerships with the States and other Federal Agencies, 2) by informing and educating the public, and 3) by developing the technical capabilities of the States and private sector.

State Partnerships

Our initial success in this program is due in large part to the strong partnerships we developed with the States where radon was first identified as a problem. Early in the program we recognized that reducing radon risk would require the efforts of Federal and State government. The basis for this approach is that certain types of activities, such as research and technical studies, are best done by the Federal government. Other activities, such as providing day to day advice to the public and detailed analyses of local situations are best handled by State and local agencies because of their proximity to the problem. In addition, we have found that State governments play the key role in motivating the public to act.

EPA has traditionally provided a broad range of technical assistance to States. This includes assistance in assessing radon potential in the State, designing effective radon programs including public information strategies, and providing the technical training and assistance needed by State officials and the fledgling radon industry to meet the needs of the public.

We have continued to strengthen our partnerships with States in a number of ways.

State Grants

The Indoor Radon Abatement Act of 1988 gave EPA its first authority to make grants for the purpose of establishing and enhancing radon programs at the State level. 48 States, the District of Columbia, Puerto Rico, Guam and the Virgin Islands have asked for, and will receive, grant assistance. Our goal with this grant program is to develop continuing capabilities at the State level to respond to the informational and technical needs of the public.

We have designed a program which allows the States a great deal of flexibility in choosing the activities that are most appropriate for their States needs. Grant funds will be used for a wide variety of activities, including: developing State radon strategies, strengthening State technical capabilities in surveying, measurement and problem mitigation; providing support for the development of State certification programs for radon measurement and mitigation firms; and, establishing public information programs targeted at the State level to supplement Federal efforts. EPA has also made funds available to several States to develop innovative approaches to radon reduction. These projects include: a project to demonstrate cost-effective radon reduction techniques in low income housing, a pilot nationwide radon teleconference, and a project to develop radon curriculum for junior high and high school science classes.

Other State Activities

In addition to these grant-related activities, we have also undertaken a number of other activities to assist our State partners, including the development of a national radon database, design of model State radon programs, and presentation of specialized radon courses for State public and private sector audiences.

Public Information and Education

Over the past few years, the public's awareness of the problems caused by radon has increased. Our goal is to assist States in educating the public about radon risk and the need for action. EPA's approach has been to develop the highest quality informational material to distribute to the public.

These materials are designed to ensure that the public has complete and accurate information for making radon risk decisions. Studies of our materials consistently show them to be effective, informative documents. However, we now believe that the primary result of our public information efforts to date has been an increase in public awareness without a corresponding increase in appropriate and effective actions to reduce radon risks. Even with this increased radon awareness, we are concerned that only about 3% of the homes in the United States have been tested. Prior to 1988, approximately 600,000 homes had been tested for radon. Following the government recommendation in September of 1988 that most homes be tested, an estimated 1.2 million additional homes were tested. However, nearly 80 million U.S. homes still need to be tested.

In response to the severity of the national radon problem, and the evidence of limited public action, we began working to identify ways to better motivate the public to take action. As a result, we began shifting the emphasis of our public outreach materials from a purely informational tone, to a more motivational message.

We hope to expand our public information and education efforts in the future, and to find even better ways to increase public action. This challenge has led us to undertake a number of activities designed to better motivate the public to test for radon and remediate elevated levels. We are exploring ways to streamline our guidelines to make risk reduction simpler and more efficient. We have embarked on a national media campaign to motivate public action. And, we are developing strong relationships with a number of national organizations which have common interests in radon protection. I will discuss some our major activities in these areas.

Citizen's Guide

The Indoor Radon Abatement Act directs us to revise our principal radon policy document, "A Citizen's Guide to Radon." The original "Citizen's Guide" was designed as an informational document to distribute to concerned citizens through State and Federal agencies. Recognizing the mounting evidence of the severity of the radon problem, the Congress directed EPA to update and revise the guidance contained in the document.

For this revision, we are incorporating what we have learned over the past 4 years from the public, the States, and from risk communication research which clearly shows that people are more likely to take effective action to reduce their radon risks if our instructions provide clear and simple directions for action. We are currently exploring ways to streamline our testing and mitigation guidance while still ensuring a high level of technical validity and responsibility. Specifically, we are examining the use of short-term measurements (those less than 90 days) as decision making tools.

Advertising Council

We are currently working with the Advertising Council on a national advertising campaign to encourage radon testing. The goal of the campaign is to increase public awareness of radon problems and motivate public action. The campaign began in October of 1989 with television, radio, and print media advertising in 33 States. Included in this program is a nationwide telephone hotline for the public to call to receive free radon test information. The Public Service Campaign has been well received across the country. For example, most television stations in the target areas are airing the television ad.

While we are still in the initial stages of this effort, it is clear that this campaign is having an effect. The hotline is currently receiving over 2,000 calls per week. We expect this response to increase as the television, radio, and billboard advertising efforts expand.

National Organizations

We are also working with a number of national organizations to better reach the public. The American Lung Association is currently designing public information programs and media campaigns at the State and local level. For the past three years, EPA has been working with the American Medical Association (AMA) to educate health professionals about the effects of radon so that they can become community leaders in reducing radon risk. These activities include: radon seminars, designed specifically for health professionals, in 14 States; design and distribution of radon related materials for newsletters and other publications; and, a radon brochure especially designed to explain radon issues to physicians. We are also a member of a radon and real estate working group in conjunction with the National Association of Home Builders, and the National Association of Realtors to develop information and guidance for handling radon issues in real estate transactions.

Capability Development

The third major area of our program is the development of the technical capabilities of the States and the private sector. Our goal is to ensure that the public has access to reliable radon measurement and mitigation services, and that there are knowledgeable and informed State and local officials to assist them in reducing their risk.

When EPA initiated its radon program, there was only limited experience in radon measurement and mitigation. The first States to address radon problems turned to EPA for assistance in assessing the extent of the radon problem, for reliable inexpensive ways to test for radon, and techniques for reducing elevated levels.

This program area has been the cornerstone of EPA's radon program. EPA has been a leader in radon technology, including: the development and evaluation of measurement technology; research, design, testing and demonstration of radon mitigation

techniques; educating public and private sector technical personnel; and in ensuring the proficiency and reliability of private sector measurement and mitigation firms.

We are currently involved in a number of technical activities. For example, we are working with States to assess the extent of the radon problem at the State and national level. We are also continuing our research devoted to developing and demonstrating effective radon mitigation techniques. In response to the new national goal of making indoor air as free from radon as outdoor air, recent work has emphasized the development of techniques to reduce radon levels below 4 pCi/L. Other activities include developing and teaching reliable techniques for reducing elevated radon levels in existing homes and preventing radon entry into new homes and researching and demonstrating techniques for protecting school children, teachers and staff from elevated radon levels in their schools.

One of our highest priorities is the development of model standards for radon resistant new construction. We have recently completed an interim version of these standards which we expect to publish this summer. We are now working with the various building code organizations to speed adoption of these standards into State and local building codes. Adoption of these techniques is essential to ensure that millions of new homes are resistant to radon entry, and can be readily adapted to achieve even lower levels.

Proficiency Programs

EPA is now administering two proficiency programs, the Radon Measurement Proficiency (RMP) program, and the Radon Contractor Proficiency (RCP) program. The RMP is a voluntary program established in 1986, to improve State and consumer confidence in the radon testing industry. The RCP program, established in 1989, performs a similar function for the radon mitigation industry. Specifically, the programs are designed to assure homeowners that they can obtain reliable radon measurements, and receive quality mitigation services. The RMP program has focused on establishing minimum performance requirements for the industry and for test devices, and on promoting consistency and quality assurance by all measurement firms. The RCP emphasizes understanding radon behavior in structures, and tests participants knowledge of diagnostic and mitigation techniques.

Under both of these programs, we distribute performance results to State governments to respond to public inquiries about reliable testing and mitigation services. The RCP currently lists over 600 successful participants. The RMP, which has been in place since 1986, had almost 5,000 participants in 1989.

Conclusion

Some of the key points for the future of the USEPA Radon Action Program are listed below.

Although the Federal role is important, radon is not just a Federal issue. State radon programs play a vital role in determining which activities are most appropriate for each State, and for assisting the public in reducing radon risk. Our program will continue to be a non-regulatory program to support State and private sector capabilities.

Though we have raised public awareness of the radon problem, our future focus will be to assist States in translating this raised awareness into meaningful risk reduction.

We will continue our public outreach strategies attempt to reach even more Americans. We believe that large-scale risk reduction is achievable by continuing to find new and creative ways to inform and motivate the public.

We are also working on a number of activities to prevent radon exposure. We will continue to develop and promote adoption of radon resistant construction techniques. We are exploring ways to provide more radon information at the time of home sales. We are also evaluating appropriate Federal response to address radon exposure in public buildings and the workplace.

The key to our program in the future will be to empower the public to reduce radon risk. We believe that we have established an effective non-regulatory framework to give the public the tools and the confidence to take definitive action to reduce radon risk.

US Consumer Product Safety Commission**

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US Consumer Product Safety Commission

Indoor air quality is an issue that has long been of great importance to the Consumer Product Safety Commission (CPSC). In the past year, the Commission has renewed its commitment and re-energized its program in indoor air quality. This reflects to some extent the shift between administrations, and has led to increased Agency willingness to take action to ensure the safety of the indoor environment.

CPSC is an independent regulatory agency; it is not a part of the presidential cabinet, nor is it strictly part of the legislative branch, i.e. Congress. The CPSC is headed by commissioners, who are appointed by the US President but confirmed by the Senate. The CPSC, therefore, consists of a collegial body of political appointees who direct the career technical staff.

The Commission came into existence in 1973 and has been involved since the late 1970s in the regulation of products that impact indoor air quality. The Commission is best known for regulating the safety of toys. The Commission is also responsible for the labeling of hazardous products, with the exception of pesticides. Other activities include the labeling on household products. The Commission, therefore, has a broad mandate and is concerned with everything from the presence of nitrosamines in children's pacifiers to preventing children from falling into backyard swimming pools.

With such a broad mandate and a limited budget, the Commission has found it very important to rely on and work with the voluntary standards community. A majority of the Commission's activities involve, to some extent, the voluntary standards community, including the American National Standards Institute, the American Society for Testing and Materials, and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). In addition, the Commission sometimes works with other groups

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that operate outside the traditional consensus organizations but that follow similar standard making procedures. Many of the standards the commission develops will eventually go to the International Standards Organization (ISO) for consideration.

With regard to indoor air quality, the specific areas that the Commission has been working on in the past few years include combustion appliances, such as kerosene heaters, space heaters, wood stoves, and formaldehyde in compressed wood products. The Commission was required in 1981 by Congress to consider a voluntary standard whenever it is considering regulating a product. In other words, when we as a Commission came to the conclusion in 1983 that kerosene heaters presented an unreasonable risk of injury, we were required by statute to consider a voluntary standard before we could issue a mandatory standard.

This requirement has meant that the Commission defers mandatory standard setting while we work with the voluntary consensus community to see if we can develop an adequate voluntary standard. That does not mean that we say, "Go out, form a committee and do good things. Then come back to us with what you have developed." We take a very active role in this process. We attend meetings, we conduct research, and we conduct testing. For example, with kerosene heaters, we created a chamber test facility in our own laboratories for combustion appliances. We developed a test system for using this chamber, validated the system though field studies in homes, and developed what we felt was an emissions rate standard based on that chamber testing which would be adequate to protect health in the indoor air. The voluntary standard system agreed that the test system and the health effects level were adequate but argued that the research-type test system was too expensive to be practical. What was needed was a test system that could be run relatively cheaply and quickly because the voluntary standards system was going to have hundreds of heaters to test and could not employ Ph.D. chemists and engineers to run the tests. So, the Commission and the voluntary standards system started to work on a new certification test system.

The research for that new certification test system has taken the Commission three years. We think we are almost there. What we have had to do is to develop a hood testing method, where instead of having a controlled environmental chamber, there was a more open setup. This setup involved putting a hood over the top of the combustion appliance and collecting the plume gases inside of the hood. The gases had to be well-mixed to ensure that what was being measured was an accurate representation of the emissions of the appliance. This effort has taken our chemists and engineers a considerable amount of work. They are now correlating the measurements taken with the hood with those taken from the sophisticated environmental chamber. Once we get the correlation defined between the two emission test systems, we will be able to go forward with the voluntary standard based on the health effect level and emission rate. The hood system has resulted in a test that can be performed relatively cheaply and quickly, and will ensure that the home appliance would not produce levels of nitrogen dioxide and carbon monoxide that could adversely affect the health of the occupants.

The health effect levels we have chosen are scientifically justifiable. Of course, there are those that say the levels are too high, and others that say the levels are too low. We are basically looking at avoiding any occurrence of levels exceeding 0.3 ppm of nitrogen dioxide, and we believe that this level will ensure that the health effects of concern will be avoided. This level is different than most of the standard nitrogen dioxide levels because we are not dealing with averages, but rather are seeking to avoid peak exposures. Most standards are set as averages avoiding the peaks. Because this type of appliance is turned on for extended periods of time, the Commission felt that this kind of standard was best to ensure that the appliance's running cycle did not achieve a nitrogen dioxide level that could have an impact on the respiratory health of the individuals. Once this certification test method is in place and the emission rate is determined, the Commission will be able to take it though the consensus process. We are working with the Underwriters Laboratory, which in the United States is both a voluntary standards writing body (which takes its standards through the American National Standards Institute process) and a certification body. In other words, the Underwriters Laboratory will perform the test for money and allow the use of a seal on the kerosene heaters to demonstrate that the heaters have indeed met the standard.

This process is all going along reasonably well. If it doesn't work, we would have the option of issuing an advance notice of proposed rule-making and subsequently issuing a mandatory standard. We find that the difference between instituting a voluntary standard versus a mandatory standard is that if we go though the voluntary consensus process and if the industry is willing to abide by the standard, then the Commission will avoid a very expensive and messy step that is normally encountered in the United States -- litigation. In the case of litigation, we would go to court and fight over every nuance of evidence, such as whether the health study, chamber test, and hood test are adequate. This process takes a long time and is very expensive. Thus, we find that when these consensus processes can be used and when there is general agreement to an appropriate health endpoint, the voluntary standard process is a very good process and is, in some cases, much faster than the mandatory standards process.

In other cases, the voluntary standard process is not faster and does not work. An example of such a case is pressed wood products. In 1985 and 1986, the Commission had a recommendation from the staff and a petition from the Consumer Federation of America, an activist consumer group, to initiate a rule-making on pressed wood products. The Commission chose in this case to use a voluntary standard approach. While a voluntary standard has been produced by the pressed wood products industry, it was the judgement of the staff that the standard was not adequate and did not address any of the issues that the staff had raised. The standard did not result in uniform labeling on the product, a test system on the product that could be adequately verified, or a test level that we believed would adequately protect the health of the consumers living in the homes where these products are used. In this case, we now have before the Commission the option of initiating a regulatory process on formaldehyde. I suspect that we will have to take some additional action to bring these parties to the table and to get a true dialogue going, but there has to be willingness on both sides to have negotiations proceed.

The Commission has also had an experience in IAQ that did not use a voluntary standard system, relying instead on what we call a voluntary action. We used a voluntary action approach with methylene chloride, a chemical widely used in consumer products as a solvent and flame suppressant. Methylene chloride is a carcinogen in animals. We believed that it was appropriate to label products that contained methylene chloride in any substantial amount. The labeling should tell the public that these products should be used outside or in an area with good ventilation because they contain a possible human carcinogen. So, the Commission staff sat down with the firms who make the chemical and the product, and we, along with the Consumer Federation of America and other consumer representatives developed a label. There were three things we were trying to achieve:

- Reformulation of products that contain methylene chloride where it is not a necessary ingredient;
- A cancer-warning label; and
- Consumer information to inform the public about the correct use of these products and the hazards involved.

We were able in four months time to develop a label, a research system for product reformulations, and the essential message for consumer information. Because of certain process concerns, the Commission decided that it would start to pursue a mandatory rule-making process. This decision put the voluntary process off track by about two years. After the Commission decided that it would discontinue the mandatory process, the voluntary effort was restarted. We developed the wording for the brochure and six months ago the industry had 200,000 copies of the brochure printed and distributed. It is likely that several hundred thousand more copies will be distributed by paint-stripper companies, who are the major users of methylene chloride, and that widespread product reformulation away from methylene chloride will occur. We feel that in this situation the consensus approach, although it did not result in a formal voluntary standard, did result in significant consumer protection with a minimum resource commitment on the part of the Federal government.

A Builders Guide to Healthy Homes

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Introduction

Over the past decade home builders, home buyers and regulators have become more aware of potential environmental hazards that may affect the quality of the home environment. One of the first major home health concerns was with improperly installed ureaformaldehyde foam insulation (UFI) in the 1970's which led to the demise of the UFI industry. In recent years, asbestos and lead hazards have caused EPA to ban these products from use in buildings. More recently, the threat of radon gas has caused builders to seriously consider modifying their standard construction details to prevent the entry of this cancer causing agent. The levels of formaldehyde are being controlled by HUD in products used in mobile homes and many builders are switching to low formaldehyde emitting products.

The trend to building homes with clean air and water is clear not only from a regulatory perspective but from a market perspective. Electronic air cleaners have become a popular feature of modern HVAC systems and builders are beginning to incorporate central ventilation systems into their homes. In addition, combustion furnaces and water heaters are beginning to use sealed combustion in an effort to improve energy efficiency.

As consumers continue to learn more about indoor air quality they will begin to demand more of the home builder. Many home buyers are already asking about radon and as consumer awareness grows they will be asking more about indoor air quality in general.

Some builders have already begun to respond to the increasing consumer demand for healthy homes. This paper provides a comprehensive look at what is involved in designing and building healthy homes and how to incorporate a healthy home upgrade package into a builder's current home line.

The Healthy Home

A healthy home is one that is designed to ensure its inhabitants breathe clean air and drink clean water. It provides a safe haven from the dangers posed by air and water pollution from outdoor sources, such as lead, radon, pesticides, and carbon monoxide and other gases contained in smog. A healthy home reduces the chances of allergic reactions and asthmatic attacks caused by pollens, dusts, and other outdoor pollutants. A healthy home is also not a major source of indoor pollutants, such as volatile organic compounds (VOCs), asbestos, combustion products, and microbiological organisms that can cause respiratory problems.

Maintaining a healthy home depends on the decisions and actions of the inhabitants once they have moved in -- for example, the choice of furnishings, the way in which combustion, ventilation, and air handling systems are maintained, and attention to preventing and/or cleaning up water damage.

Whether a home is healthy or not is not easily quantified and some people are more acutely sensitive to certain indoor air pollutants than are others and require more care in the construction of a home.

When building a healthy home, there are at least two and sometimes three levels of protection that can be built into the home. The first level is the minimum level of protection from the major indoor pollution sources and should probably be standard practice for all new homes.

The minimum level features include:

- A dry basement, with no mold or mildew problems:
- No elevated radon levels;
- No backdrafting of furnace, domestic water heater, or fireplace;
- No lead paint or solder;
- No asbestos;
- No unvented appliances;
- Humidity maintained at 30 - 50 percent;
- Pesticides applied carefully, if required;
- Kitchen and bathroom exhaust fans.

Beyond the minimum level the builder may choose to offer a Healthy Home upgrade package which has the potential for significantly improving the indoor environment. The upgrade package may include the following:

- Whole house ventilation system, with or without a heat recovery system;
- Filtration systems for air and/or water;

- Central vacuum system that exhausts house dust outside;
- Care in the use of certain potentially harmful building materials, such as plywood, particleboard, carpet adhesives, formaldehyde-containing paneling, cabinets, carpets, underlayment, paints, and finishes; and
- Non-toxic alternatives to pesticides, mildewcides, and formaldehyde.

For some chemically sensitive people even the Healthy Home upgrade package may not be enough. For these people special care needs to be taken to analyze each product that is used in the building for potential effects on the chemically sensitive occupant and extreme care needs to be taken in the construction, operation, and maintenance of the home.

General Considerations

Most potential indoor air and water quality problems can be effectively prevented or reduced during the construction process through the proper use of pollutant source control, ventilation, air cleaning, humidity control, and water filtration.

Source Control -- The first line of defense for preventing indoor air quality problems is reducing or eliminating the source of the pollutants. Many different toxic chemicals are contained in building materials but most of these chemicals offgas in a short period of time after construction. Formaldehyde, however, can take a much longer time, even years, to offgas. Avoid using products that contain high amounts of formaldehyde, such as urea-formaldehyde foam insulation (UFFI), particleboard, chip board, wafer board, composition board, and medium density fiber board. These products are commonly used in counter tops, kitchen and bathroom cabinets, floor underlayment, roof and wall sheathing, shelving, and furniture.

As an alternative, use solid wood or exterior grade plywood, which uses the less harmful form phenol-formaldehyde. Most oriented strand board (OSB) also uses phenol-formaldehyde. Most formaldehyde-containing products can also be sealed with alkyl-based paint or poly-urethane to reduce offgassing.

Mix all paints and finishes outside whenever possible to avoid breathing fumes and always apply these products in well-ventilated areas and continue to ventilate until all volatile solvents have evaporated and no odor is detected. If concerned about the toxicity of paints, solvents, finishes, and other products, you can request a statement of toxicity from the manufacturer (the Materials Safety Data Sheet, or MSDS). Non-toxic paints, stains, finishes, and wood preservatives are also available from some manufacturers.

Other important sources include certain consumer products, improper application of pesticides, high radon levels in the underlying soil, backdrafting furnaces, unvented appliances and excess humidity.

Ventilation -- Inadequate ventilation or poor air distribution throughout the home is a major factor affecting indoor air quality. Maintaining good ventilation is necessary both at the whole house level and in individual rooms, particularly the bathroom, kitchen, and other localized indoor air pollution sources. The rate at which indoor air is replaced by outside air is called the air exchange rate, and it is measured in air changes per hour (ACH). A constant 0.35 ACH minimum should be maintained for the whole house, although you may need to increase the ventilation rate in the kitchen, bathroom, laundry room, garage, and workshop during periods of use. Due to the fluctuating natural air infiltration rate a mechanical ventilation system may be necessary to ensure minimum ventilation. The simplest ventilation system consists of bathroom exhaust fans and a kitchen range hood vented to the outside (Figures 1 and 4). Recirculating range hoods are inadequate for removing pollutants generated in the kitchen. The bathroom exhaust fan should be quiet (less that 2.5 sones) and capable of exhausting at least 50 cubic feet per minute (CFM). The kitchen exhaust fan should be capable of exhausting at least 100 CFM.

The fans should be controlled such that at least one fan operates continuously to provide whole house ventilation. ASHRAE standard 62-89 "Ventilation for Acceptable Indoor Air Quality" suggests that the ventilation system should have a capability to provide a minimum of 0.35 ACH for living areas. For a 2,000 square foot home with eight foot ceilings, the ventilation requirement amounts to an air flow rate of 5,600 cubic feet per hour or 93 CFM continuous ventilation.

Many builders find it more convenient to install one central exhaust fan in the basement or attic and duct it to each bathroom, the laundry room, and the kitchen. The central fan will tend to be quieter because it is not in the room and reduces drafts, particularly in the bathroom, from leaky fan ducts (Figures 2 and 3).

Provision for fresh air intake to the home is an important component of the ventilation system. With the exhaust fans running, the house will be depressurized and outside air will be drawn in from all the holes and cracks in the building. This may be adequate to supply the house with air only if the home uses no combustion equipment with uses a natural draft chimney and there is very little risk of radon in the soil.

The exhaust system depressurizes the home and competes with a natural draft chimney for air. This may cause serious backdrafting problems. The depressurization may also draw in radon through leaks in the slab, floor or basement. To avoid this problem, dedicated fresh air intakes are recommended to distribute fresh air throughout the house. The fresh air is generally introduced into the bedrooms, living room, and recreation or family room.

The fresh air can be distributed in a number of ways. If the home has a ducted heating and/or cooling system, the fresh air can be introduced directly into the return duct of the air handler. A four to six inch insulated (R7 with continuous vapor barrier) duct is run from a screened outside vent to the house return duct ahead of the filter system (Figures 2 and 4).

The fresh air intake can be controlled by either a manual damper or an automatic control. A manual damper can be a motorized damper controlled by a switch located next to the thermostat. In this way, a homeowner can operate the heating/cooling system much like the car air conditioner. The homeowner can choose to recirculate house air or bring in the desired amount of fresh outside air. Some automatic systems give the homeowner the option to recirculate house air or bring in zero to 100 percent outside air depending on outside air conditions. In commercial buildings, this is called an "economizer."

If the home has no heating/cooling duct system, then fresh air can be either brought in to each room via a dedicated duct system or directly via specially designed "through the wall" vents. With a dedicated fresh air duct system, the air can be filtered and tempered before entering the room. In mild climates, "through the wall" vents may be appropriate. Several manufacturers provide both "through the wall" vents and automatic dampers that limit the inlet air flow to the desired 10 - 15 CFM per room as recommended by ASHRAE, thereby limiting the unnecessary increase in heating and cooling costs associated with high ventilation rates (Figures 1 and 3).

The vents should be placed so that they provide fresh air to the bedrooms and living areas. To avoid short circuits, the supply should be located opposite the door, which should be undercut. Avoid cold drafts by venting through the furnace, and locating vents so they spread the air across the ceiling. Fresh air vents may also be located in closets with louvered doors. This has the advantage of helping keep clothes fresh, and reduces mold and mildew. The outside air intake should be located a minimum of six feet from exhaust vents, the garage and driveway, dryer exhaust, gas meter, plumbing stacks, and should be above the snow line.

The exhaust fans are controlled to provide continuous whole house ventilation at the minimum ventilation rate and boosted ventilation at times of heavy use. The boost mode can be activated by either a timer switch in the bathroom or can be wired with the bathroom light. Automatic boost can be accomplished with a dehumidistat which activates the boost mode when the humidity rises. These controls can also be used in combination.

A heat recovery ventilator (HRV) is a device that transfers the heat of the exhaust air into the fresh air intake stream thereby recovering otherwise wasted heat (Figure 5). HRVs can be used as a stand alone ventilation system or be integrated into the existing ductwork.

The HRV is convenient to use because all of the components of the ventilation system (exhaust fan, fresh air supply fan, and heat exchanger) are included in the HRV package. Typical applications of HRV systems are illustrated in Figures 6 and 7. It is important that HRVs be installed with balanced air flows in and out to avoid excessive building depressurization.

Figure 1

Decentralized Exhaust Ventilation with Through-Wall Ports

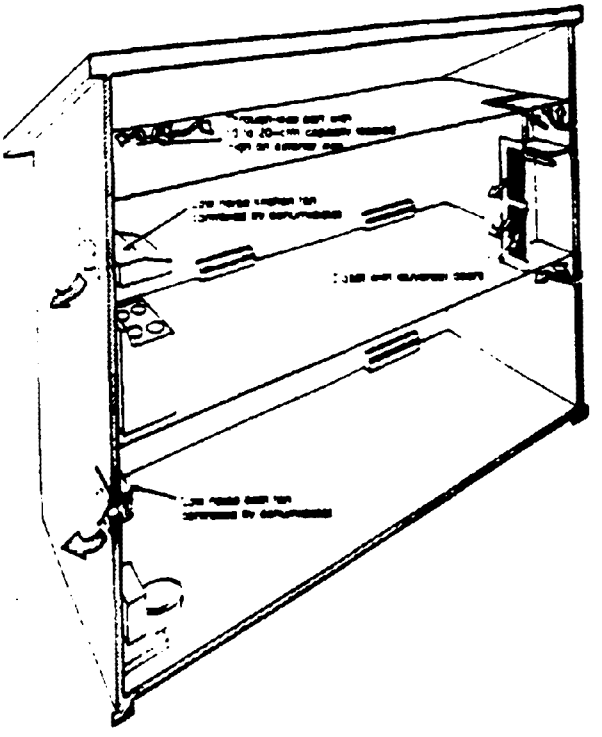


Figure 2

Central Exhaust System with Forced-Air Heating

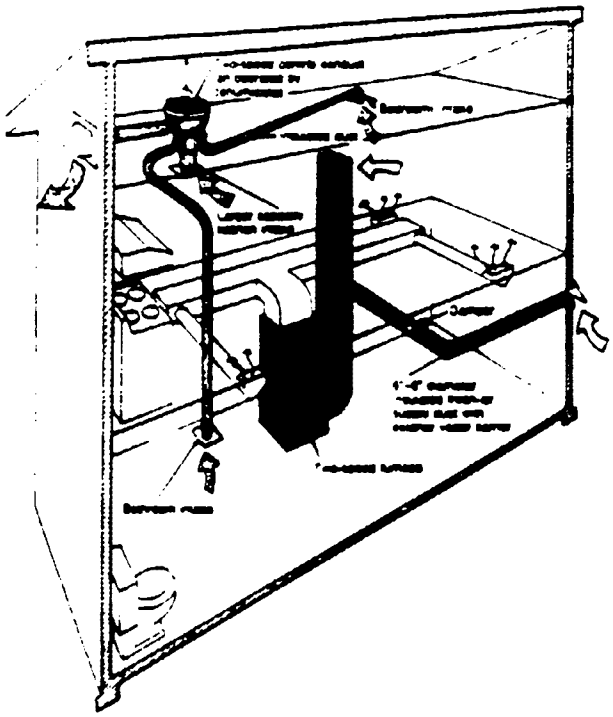


Figure 3

Central Exhaust System with Through-Wall Ports

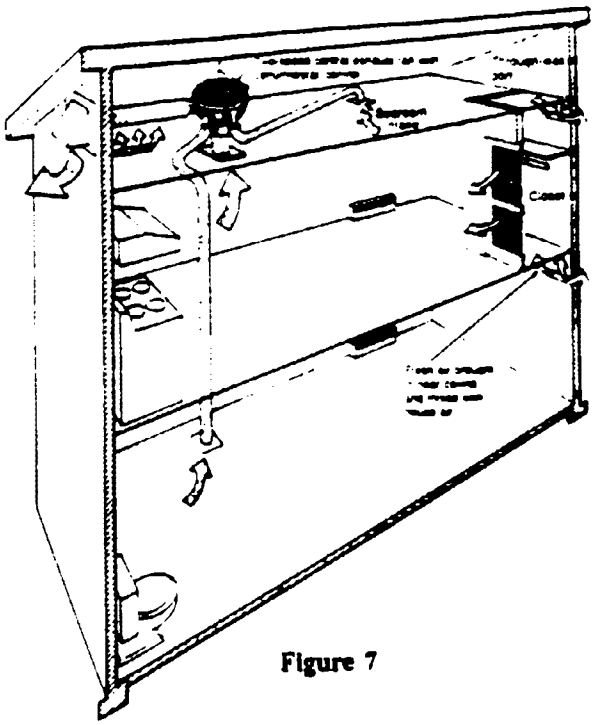


Figure 7

Figure 4

Decentralized Exhaust Ventilation with Forced-Air Heating System

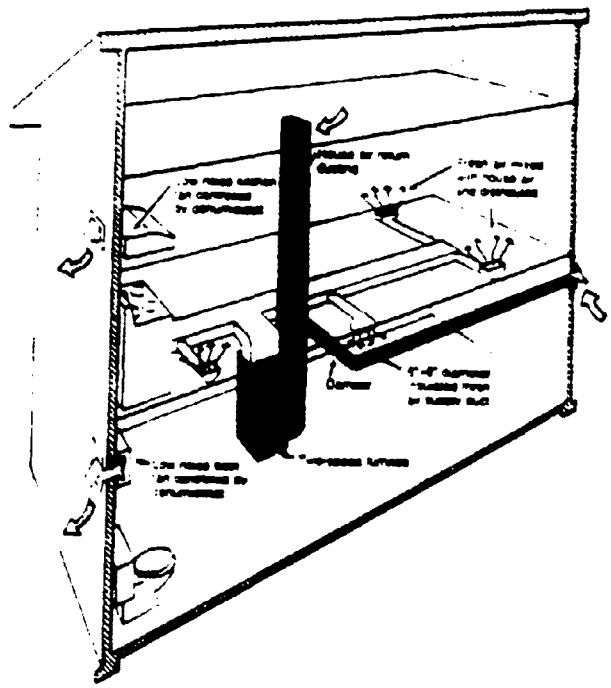


Figure 5

Typical Air-to-Air Heat Exchanger Components

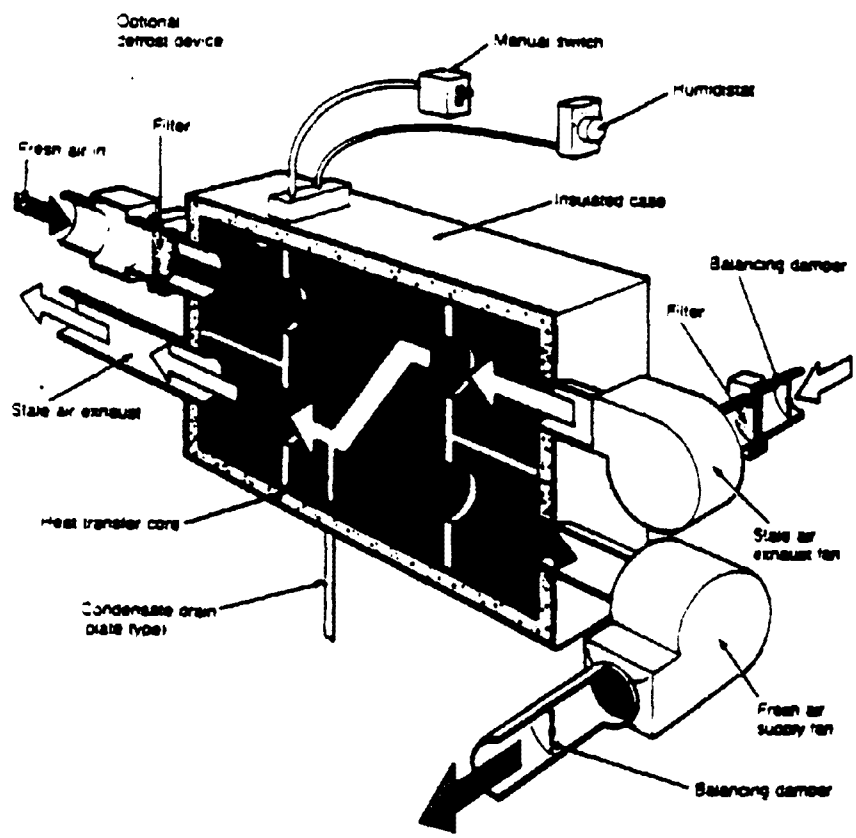


Figure 6

Air-to-Air Heat Exchanger with Area Heaters

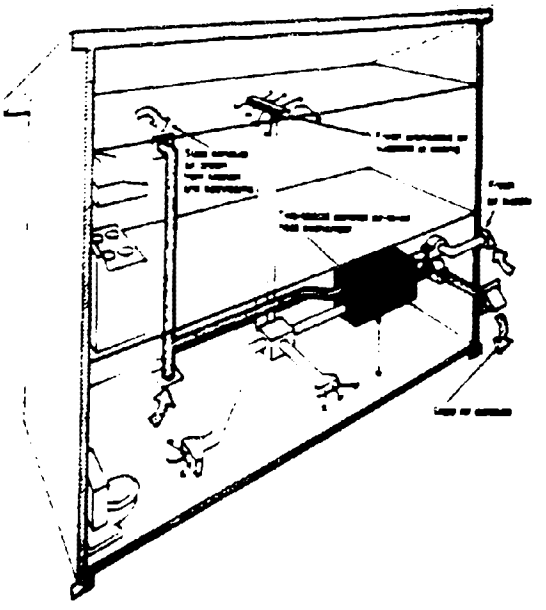
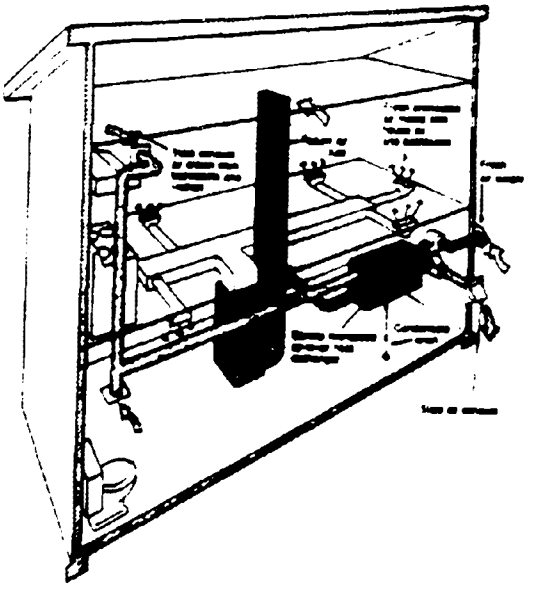


Figure 7

Central Air-to-Air Heat Exchanger with a Forced-Air Heating System



Air Cleaning -- An effective air cleaning system can remove 99.9 percent of the particles in the air as well as some odors and gases. The filter supplied with the furnace is inadequate in removing respirable suspended particles, and should be supplemented with other types of air cleaners, such as an electrostatic precipitator (ESP) or a high efficiency particulate air (HEPA) filter. Air cleaning systems, under the right conditions, can effectively remove certain particles and may reduce any associated health effects. However, some controversy exists about the effectiveness of air cleaners in alleviating the allergic reactions produced by larger particles, such as pollen, allergens, house dust, some molds, and animal dander. Larger allergenic particles settle out rapidly from the air. Because only a small proportion of these allergens are generally suspended in the air, air cleaners may not be 100 percent effective in their removal.

Air cleaners are usually classified based on the type of equipment they contain for removing particles of various size from the air. The two general types of in-duct air cleaners are mechanical filters and electronic air cleaners.

Mechanical filters come in three types: flat, pleated, and electret. Flat filters are the typical low packing density furnace filter and consist of coarse glass fibers, animal hair, vegetable fibers, or synthetic fibers. The fibers are often coated with a viscous substance (e.g., oil) which may act as an adhesive for particles. These filters remove only a small percentage of particles smaller than one micron and have little effect on the indoor air quality. They generally are used to keep the inside of the furnace clean and as a pre-filter for more efficient filters.

Pleated (i.e., extended surface) filters generally attain greater efficiency for removal of small particles than flat filters. Their greater surface areas allows a decrease in the fiber size and increased packing density of the filter without a large drop in the air flow rate. The resistance to air flow is greater with pleated filters, however, than with flat filters. When designing the HVAC system, the furnace fan must be sized to handle the increase pressure drop imposed by the filter. The filter could be installed with its own fan built in. The most efficient pleated filter, the high efficiency particulate air (HEPA) filter, has a particulate removal efficiency of nearly 100 percent for 0.03 micron particles.

Electret filters are specifically formulated filters embedded with a permanent static charge. Particulate material in the air is attracted to the charged fiber.

Electronic air cleaners are devices which trap charged particles using an electrical field. The most common type of electronic air cleaner is the electrostatic precipitator, which traps particles on a series of charged flat plates. Electronic air cleaners require electrical power to operate and must be cleaned regularly to maintain their effectiveness.

Published standards on the rated efficiency or effectiveness or air-cleaning devices can be used for comparison among different devices. ASHRAE Standard 52-76 and Military Standard 282 are used to certify the efficiency of in-duct air cleaners in removing particles. The ASHRAE Standard 52-76 atmospheric dust spot rating is useful in evaluating the relative efficiency of many air cleaning units. Figure 8 shows typical applications and limitations of filters rated using this standard and gives a general

indication of the types of particles which should be removed by a device with a particular rating.

Military Standard 282 (i.e., the percentage removal of very small particles of dioctylphthalate (DOP)) is used to rate high efficiency air cleaners -- those with ASHRAE atmospheric dust spot ratings above about 90 percent. HEPA filters, the highest efficiency air-cleaning filters, remove almost 100 percent of the DOP particles.

The actual effectiveness of an air cleaning system in a home is dependent on how well the system mixes the air. Effectiveness may be decreased if air exiting the HVAC system is not well-mixed with room air before re-entering the system. This can happen if air supply and return vents are too closely spaced and do not allow the air to sweep the room.

Figure 8

Filter Applications Based on ASHRAE Atmospheric Dustspot Test

Air Cleaner Efficiency Rating[1]

10%	20%	40%	60%	80%	90%
• Used in window air conditioners and heating systems. • Useful on lint. • Somewhat useful on common ragweed pollen (generally under 70%). • Not very useful on smoke and staining particles.	• Used in air conditioners, domestic heating, and central air systems. • Fairly useful on ragweed pollen (generally over 85%). • Not very useful on smoke and staining particles.	• Used in heating, air conditioning, and as prefilters to high efficiency cleaners. • Useful on finer airborne dust and pollen. • Reduce smudge and stain materially. • Slightly useful on non-tobacco smoke particles. • Not very useful on tobacco smoke particles.	• Used same as 40%, but better protection. • Useful on all pollens, majority of particles causing smudge and stain, and coal and oil smoke particles. • Partially useful on tobacco smoke particles. • Some types reasonably useful on bacteria.	• Generally used in hospitals and controlled areas. • Very useful on particles causing smudge and stain, and coal and oil smoke particles. • Quite useful on tobacco smoke. • Very useful on bacteria.	• Used same as 80%, but generally rated using Military Standard 282. • Excellent protection against all smoke particles and bacteria.

[1] Efficiency rating by ASHRAE dust spot test.

Humidity Control -- Very high and very low humidity levels in homes can cause adverse health effects in the form of respiratory infections and allergies. These health effects can be minimized by maintaining relative humidity between 30 and 50 percent. Molds, fungi, bacteria, and house mites proliferate in high humidity (above 60 percent) and the harmful effects of many chemicals, such as formaldehyde, may be enhanced with increased humidity. By installing a humidity meter, homeowners will be able to monitor and maintain the humidity.

High humidity levels can result from a very tight home without adequate kitchen and bathroom venting, or from water leaking through the roof or in the basement. One common cause of high humidity in air conditioned homes is an oversized air conditioner, which cools the house very quickly, but does not run long enough to reduce the humidity. Make sure that the cooling load is determined accurately and don't oversize the system. Homes that are built airtight (less than 0.5 ACH) should use mechanical ventilation to exhaust excess humidity from bathrooms, the kitchen, and the laundry room, and to bring in drier outside air.

Low humidity is generally a problem in houses with gas or oil furnaces because the high temperature generated by the equipment dries the air, and in drafty houses where the outdoor winter air dries the indoor air. Humidifiers can be used to maintain the relative humidity in the winter. Use a humidistat to control the humidifier so that the relative humidity of the house does not go above 60 percent. Cool mist or evaporative humidifiers (these have a reservoir of water) require regular cleaning to prevent the buildup of fungi and bacteria in the water and on the evaporator pads. Ultrasonic humidifiers, vaporizers, or steam humidifiers also require maintenance. If a humidifier is used, be sure that the homeowner is aware of the manufacturer's maintenance requirements.

Operating the Healthy Home

We can design and build homes that have the potential for being healthy but if they are not operated properly by the occupants we may have wasted our time and their money. It is vitally important that the new homeowner understand how to operate the home to get the maximum benefit from the systems installed.

The best way to accomplish this is to provide the new home buyer with an owner's manual for the home at the time of sale. The owner's manual should contain important information about the products and systems in the building, including:

1. Description of how the house works as a system of source control, ventilation, and air cleaning. A simplified schematic is useful.

2. Maintenance schedules and procedures, for example, for filters, fans, and humidifiers.

3. Manufacturer's manuals for the equipment used in the house, such as the furnace, heat recovery ventilator, humidifier, and air cleaner.

4. Phone numbers of whom to contact for service.

The builder should also provide the new homeowner with information about living in a healthy home. This includes information about consumer products and activities that affect indoor air quality. The builder may want to give the homeowner a copy of "The Inside Story: A Guide to Indoor Air Quality," which is available from the U.S. EPA or the Consumer Products Safety Commission (CPSC).

A good time to go over the owner's manual with the homeowner is during the final walk-through of the home. At this time, the builder can point out the features of the home and answer any questions the owner may have about operation and maintenance.

At each stage of the construction process, there are different considerations to be taken into account that will ultimately affect the indoor air quality of the home. Important considerations for each stage are listed and summarized in Table A.

TABLE A

Stage of Construction	Potential Problems	Pollutant	Solution
1. Site Selection	Water runoff causing wet basement	Biological growth on damp surfaces causing allergic reactions. Choose high ground with low water table	
	Ground water contamination	Variety of water pollutants including organic and inorganic chemicals and microorganisms	Test and filter water
	Radon gas in the soil	Radon decay products increase risk of lung cancer	Seal slab, 4" gravel under slab and sub slab vent
	Local pesticide use	Organophosphate poisoning	Avoid using organophosphates or avoid sites next to were it is being use regularly like golf courses
	Highway pollution	Noise, lead in air, smog, dust, carbon dioxide, carbon monoxide	Locate homes away from busy streets or build a buffer area
	Hazardous waste sites	Numerous toxic wastes	Investigate site before construction

TABLE A

Stage of Construction		Potential Problems	Pollutant	Solution
2.	Site preparation	Poor drainage	Wet basement or floors causing mold or mildew	Drain site well
		Trash in the backfill may attract termites and require pesticides	Pesticides	Use termite shields, clean backfill, natural predators, non-toxic pesticides like borax
3.	Foundation	Radon gas leaking into home	Radon decay products	Good waterproofing, 4" gravel under the slab. Radon vent
		Moisture from leaky basement, damp crawl space or damp floor	Mold, mildew	Good waterproofing and drainage
		Concrete additives cause reactions in some people	Various pollutants	Avoid use
4.	Building	Uncontrolled infiltration and exfiltration causing backdrafting, radon entry, termiticide entry	Combustion products from backdrafting, radon, pesticides	Build with air tight construction techniques and provide for mechanical ventilation
		Engine exhaust and toxins in garage may be drawn into home	Car exhaust, CO, CO_2, and various VOCs and pesticides stored in garage	Vent garage separate from the house with an exhaust fan and seal from the house

TABLE A

Stage of Construction	Potential Problems	Pollutant	Solution
	Building materials that contain formaldehyde - particle board, chip board, wafer board, composition board, medium density fiberboard	Formaldehyde	Use exterior grade plywood or low formaldehyde emitting boards or seal with alkyl-based paint or polyurethane
	Asbestos tiles or shingles	Asbestos	Avoid use and never cut or sand
	Offgassing of paint finishes and adhesives	Various VOCs	Use non-toxic alternatives, vent house well during and immediately after applying
	Saw dust from treated lumber	Penta and chromated copper arsenate	Wear respirator while cutting
5. HVAC System	General air quality problems	Various pollutants and humidity	Install a whole house ventilation system with kitchen, bathroom, and laundry room exhaust and fresh air intake
	Backdrafting of combustion products	Various combustion products	Use sealed combustion or electric appliances or forced vent or powered vent systems

TABLE A

Stage of Construction	Potential Problems	Pollutant	Solution
	Airborne particles and mold and mildew from wet duct liners	Fiberglass, mold, mildew	Avoid duct liners inside ducts, use exterior insulation
	Excess humidity from bathrooms and laundry rooms	Mold, mildew, bioaerosols	Install exhaust fans
	Short circuiting of supply and return vents reduce effectiveness of air cleaning and ventilation	Mold, mildew and localized build up of pollutants	Locate vents to sweep the room and undercut doors to maintain airflow with doors closed
	Furnace fan-induced depressurization of basement or crawlspace	Radon or pesticides	Tightly seal return ducts and supply register in furnace room
	Excess humidity from humidifiers, or undersized air conditioners	Mold, mildew	Maintain RH 30-50%, don't oversize air conditioners.
	Poorly maintained humidifiers	Bioaerosols	Disinfect humidifiers regularly
	Allergies from dust, mold, pollen, and other airborne particles	Suspended respirable particulates such as cigarette smoke, dust, pollen, mold, mildew	Install high efficiency air filtration system

TABLE A

Stage of Construction		Potential Problems	Pollutant	Solution
6.	Plumbing	Lead from solder in water	Lead	Use plastic pipe or lead free solder
		Water pollution from ground water or central system	Microorganisms, particles, organic and inorganic chemicals	Test water and filter if necessary
7.	Appliances	Combustion products from unvented appliances	Combustion products	Vent all combustion equipment
		Allergies caused by dust and bioaerosols during and after vacuuming	Various suspended respirable particulates	Use central vacuum cleaner with outside exhaust

Section IV

Indoor Air Pollutant Guidelines

WHO Air Quality Guidelines for Europe

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Ministry for Environment
Nature Conservation and Nuclear Safety
Federal Republic of Germany

The overall purpose of the World Health Organization is to contribute to the WHO goal of "health for all by the year 2000." Regional targets were set to achieve this goal in the European Region, which extends beyond the geographical borders of Europe and includes Greenland, Israel, and the Asian parts of the Soviet Union and Turkey. Target 21 of the European Regional Strategy deals with control of air pollution. Target 21 requests that "by 1995, everyone in the Region should be effectively protected against recognized health risk from air pollution." The explanatory text for this target states that achieving this target will require the introduction of effective legislative, administrative, and technical measures for the surveillance and control of both outdoor and indoor air pollution, in order to comply with criteria to safeguard human health. The time schedule specified in this target is quite ambitious and it is not likely that the target can be met in time in all parts of the region.

The Air Quality Guidelines project followed on the heels of the Drinking Water Guidelines, which were jointly developed by the WHO regional office in Europe and the WHO Headquarters in Geneva. The Drinking Water Guidelines were finalized in 1983. After those guidelines were published, the Dutch government approached WHO and suggested that Air Quality Guidelines (AQG) should be developed. In November 1983, the WHO Regional Office for Europe embarked on the AQG project, which was generously supported by the government of The Netherlands.

The decision to start the project was based on the consideration that a common basis for the control of air pollution was needed for the European Region. The only internationally agreed upon source of information are the environmental health criteria documents of the International Program on Chemical Safety (IPCS). These documents are scientifically of high value, but unfortunately the time interval between the publication of these documents may be rather long.

* Mr. Tuerck is the former project manager of the World Health Organization air quality guidelines project.

One of the main aims of the AQG project was to evaluate many substances during a relatively short time period. The primary aims of the Guidelines were twofold:

- Protection of public health and thus the elimination or reduction to a minimum of constituents of air that are known to be hazardous to human health and well being; and

- To serve as a basis for air quality management and development of standards, although guideline values are not standards in themselves.

The entire procedure for establishing the Air Quality Guidelines took three and a half years and consisted of four phases:

- 1st Phase: Planning and Preparation;

- 2nd Phase: Internal Review Process;

- 3rd Phase: External Review Process; and

- 4th Phase: Publication.

A planning meeting in early 1984 decided on content, format, workplan, and timetable as well as on the chemicals to be included in the project. The selection of chemicals was based on an established set of criteria:

- Severity and frequency of observed or suspected adverse effects on human health -- where irreversible effects are of special concern;

- Ubiquity and abundance of the agent in the human environment -- with emphasis on air pollutants;

- Environmental transformation or metabolic alteration -- as these alterations may lead to the production of chemicals with greater toxic potential;

- Persistence in the environment -- particularly if the pollutant would resist environmental degradation and accumulate in humans, in the environment, or in food chains; and

- Population exposed -- concerning the size of exposed population and special groups at risk.

A list of pollutants selected for study on the basis of the criteria is presented in Exhibit 1.

The planning and preparation phase of the project consisted mainly of a series of meetings to deal with specific substances or groups of substances. Subsequently, extensive internal and external review process followed, as well as a final plenary meeting.

Exhibit 1

Organic air pollutants	Inorganic air pollutants
Acrylonitrile	Arsenic
Benzene	Asbestos
Carbon disulfide	Cadmium
1,2-Dichloroethane	Carbon monoxide
Dichloromethane	Chromium
Formaldehyde	Hydrogen sulfide
Polynuclear aromatic hydrocarbons	Lead
(carcinogenic fraction)	Manganese
Styrene	Mercury
Tetrachloroethylene	Nickel
Toluene	Nitrogen oxides
Trichloroethylene	Ozone/photochemical oxidants
Vinyl chloride	Particulate matter
	Radon
	Sulfur oxides
	Vanadium

The entire process was aided by an editorial consultation group of ten scientists. As shown in Exhibit 2, working papers were prepared for each of the substances, and extensive review procedures were conducted. Drafts of the working papers were reviewed two and three times, and many comments were received.

The WHO guidelines consist of a general part describing the criteria used in establishing guideline values, a summary of the guidelines, and a description of how to use the guidelines. A more detailed scientific description of background information on the individual substances (based on the WHO EHC documents, other reviews, and original papers) and the derivation of guidelines is given in sections on inorganic and organic substances.

Exhibit 3 lists the substances and guideline values. The guidelines are divided into different categories depending on whether their health effects are carcinogenic or otherwise. Guideline values for non-carcinogenic effects are presented in terms of concentration (mg or μg per m^3) and a time-weighted average. It is believed that inhalation of an air pollutant in concentrations and for an exposure time below a guideline value will not have adverse effects on health, although compliance with the guideline values cannot guarantee the absolute exclusion of effects at levels below the guideline values, e.g., with regard to sensitive groups or in the case of combined exposure. On the other hand, if situations occur where the guideline values are slightly exceeded, this does not always mean that adverse health effects will occur.

With the exception of sulfur dioxide and particulate matter, guideline values are indicated for individual substances. In Exhibit 4, guideline values for the combined

exposure to sulfur dioxide and particulate matter are presented, reflecting the knowledge that health effects are more significant when both pollutants are present. Exhibit 5 presents the rationale and guideline values for substances based on sensory effects or annoyance reactions. These values are based on an average exposure time of 30 minutes.

Carcinogenic risk estimates are presented in Exhibit 6. Since most of the selected substances are proven human carcinogens, the estimates are based on human studies rather than animal studies. The carcinogenic risk estimate is indicated as a unit risk for lifetime exposure. No assumption was made that there would be a negligible or acceptable risk at a certain number e.g., 10^{-6} or 10^{-4}. Risk estimates for asbestos and radon daughters based on different units are presented in Exhibits 7 and 8.

As stated above, the guideline values are not standards in themselves. The values should not be used without looking at the background information, which explains the rationale for the guideline values. Furthermore, it should be noted "that the guidelines do not differentiate between indoor and outdoor exposure" because this distinction does not "directly affect the basic exposure-effect relationship." With regard to average times, experts agree that the current state of knowledge is insufficient to delineate concentrations for all exposure situations. Depending on the action mechanism in the environmental exposure range, short exposure times are indicated for the more acute type of effect, whereas long-term exposure times were attributed to substances that have chronic effects, particularly those which accumulate in the body. Regulators need "to select the most appropriate and practical standards in relation to the guidelines, without necessarily using the guidelines directly."

Since the publication of the guidelines, two meetings have been held with air pollution control experts from countries of the Region, one with experts of southern Europe and another with experts of eastern Europe. The purpose of these meetings was to discuss how the guidelines can best be applied by member states. Both meetings demonstrated a substantial interest from member countries which are ready to replace values based on historical approaches, with values based on a consensus of international experts. In conducting surveys of exposure situations, countries can now compare the results with air quality guidelines and rank substances for air pollution control measures in terms of importance.

I hope that the WHO Air Quality Guidelines will not only be used for ambient air pollution control but also for solving indoor air pollution problems.

Air quality guidelines for Europe
Copenhagen: WHO. Regional Office for Europe, 1987
WHO regional publications, European series; No. 23
ISBN 92-890-1114-9
Air/Analysis -- Air Pollution/Prevention and Control

Exhibit 2

Procedure in Establishing Air Quality Guidelines

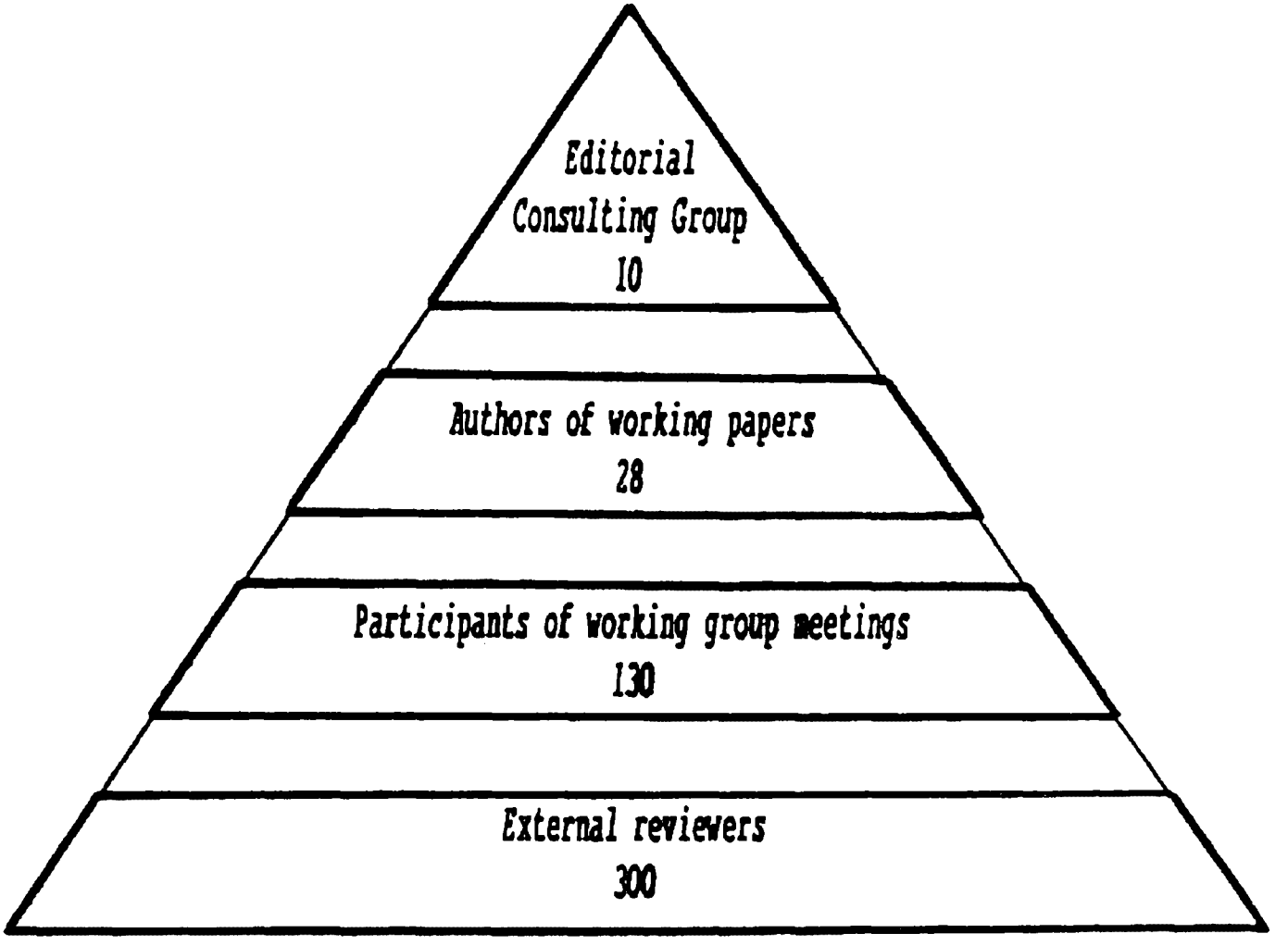

Exhibit 3

Guideline Values for Individual Substances Based on Effects Other Than Cancer or Odor/Annoyance[a]

Substance	Time-weighted average	Averaging time
Cadmium	1 - 5 ng/m^3	1 year (rural areas)
	10 - 20 ng/m^3	1 year (urban areas)
Carbon disulfide	100 μg/m^3	24 hours
Carbon monoxide	100 mg/m^{3b}	15 minutes
	60 mg/m^{3b}	30 minutes
	30 mg/m^{3b}	1 hour
	10 mg/m^3	8 hours
1-2,Dichloroethane	0.7 mg/m^3	24 hours
Dichloromethane (Methylene chloride)	3 mg/m^3	24 hours
Formaldehyde	100 μg/m^3	30 minutes
Hydrogen sulfide	150 μg/m^3	24 hours
Lead	0.5 - 1.0 μg/m^3	1 year
Manganese	1 μg/m^3	1 year[c]
Mercury	1 μg/m^{3d} (indoor air)	1 year
Nitrogen dioxide	40 μg/m^3	1 hour
	150 μg/m^3	24 hours
Ozone	150 - 200 μg/m^3	1 hour
	100 - 120 μg/m^3	8 hours
Styrene	800 μg/m^3	24 hours
Sulfur dioxide	500 μg/m^3	10 minutes
	350 μg/m^3	1 hour
Tetrachloroethylene	5 mg/m^3	24 hours
Toluene	8 mg/m^3	24 hours
Trichloroethylene	1 mg/m^3	24 hours
Vanadium	1 μg/m^3	24 hours

a. Information from this table should not be used without reference to the rationale given in the chapters.

b. Exposure at these concentrations should be for no longer than the indicated times and should not be repeated within 8 hours.

c. Due to respiratory irritancy, it would be desirable to have a short-term guideline, but the present data base does not permit such estimations.

d. The guideline value is given only for indoor pollution, no guidance is given on outdoor concentrations (via deposition and entry into the food chain) that might be of indirect relevance.

Note: When air levels in the general environment are orders of magnitude lower than the guideline values, present exposures are unlikely to present a health concern. Guideline values in those cases are directed only to specific release episodes or specific indoor pollution problems.

Exhibit 4

Guideline Values for Combined Exposure to Sulfur Dioxide and Particulate Matter[a]

	Averaging Time	Sulfur Dioxide ($\mu g/m^3$)	Reflectance assessment black smoke[b] ($\mu g/m^3$)	Gravimetric assessment: Total suspended particulates (TSP)[c] ($\mu g/m^3$)	Gravimetric assessment: Thoracic particles (TP)[d] ($\mu g/m^3$)
Short term	24 hours	125	125	120[e]	70[e]
Long term	1 year	50	50	---	---

a. No direct comparisons can be made between values for particulate matter in the right- and left-hand sections of this table, since both the health indicators and the measurement methods differ. While numerically, TSP/TP values are generally greater than those of black smoke, there is no consistent relationship between them, the ratio of one to the other varying widely from time to time and place to place, depending on the nature of the sources.

b. Nominal $\mu g/m^3$ units, assessed by reflectance. Application of the black smoke value is recommended only in areas where coal smoke from domestic fires is the dominant component of the particulates. It does not necessarily apply where diesel smoke is an important contributor.

c. TSP measurement by high volume sampler, without any size selection.

d. TP equivalent values as for a sampler with ISO-TP characteristics (having a 50 percent cut-off point at 10 μm); estimated from TSP values using site-specific TSP/ISO-TP ratios.

e. Values to be regarded as tentative at this stage, being based on a single study also involving sulfur dioxide exposure.

Exhibit 5

Threshold and Guideline Values Based on Sensory Effects or Annoyance Reactions, Using an Averaging Time of 30 Minutes

Substance	Detection threshold	Recognition threshold	Guideline value
Carbon disulfide in viscose emissions			20 $\mu g/m^3$
Hydrogen sulfide	0.2-2.0 $\mu g/m^3$	0.6-6.0 $\mu g/m^3$	7 $\mu g/m^3$
Styrene	70 $\mu g/m^3$	210-280 $\mu g/m^3$	70 $\mu g/m^3$
Tetrachloroethylene	8 mg/m^3	24-32 mg/m^3	8 mg/m^3
Toluene	1 mg/m^3	10 mg/m^3	1 mg/m^3

Exhibit 6

Carcinogenic Risk Estimates Based on Human Studies[a]

Substance	IARC Group Classification	Unit risk[b]	Site of tumour
Acrylonitrile	2A	2×10^{-5}	lung
Arsenic	1	4×10^{-3}	lung
Benzene	1	4×10^{-6}	blood (leukemia)
Chromium (VI)	1	4×10^{-2}	lung
Nickel	2A	4×10^{-4}	lung
Polynuclear aromatic hydrocarbons (carcinogenic fraction)[c]		9×10^{-2}	lung
Vinyl chloride	1	1×10^{-6}	liver and other sites

a. Calculated with average relative risk model.
b. Cancer risk estimates for lifetime exposure to a concentration of 1 $\mu g/m^3$.
c. Expressed as benzo(a)pyrene (based on benzo(a)pyrene concentration of 1 $\mu g/m^3$ in air as a component of benzene-soluble coke-oven emissions).

Exhibit 7

Risk Estimates for Asbestos

Concentration	Range of lifetime risk estimates
$500F^*/m^3$(0.0005F/ml)	10^{-6} - 10^{-5} (lung cancer in a population where 30 percent are smokers)
	10^{-5} - 10^{-4} (mesothelioma)

Note: F^* = fibers measured by optical methods.

Exhibit 8

Risk Estimates and Recommended Action Level for Radon Daughters

Exposure	Lung cancer excess lifetime risk estimate	Recommended level for remedial action in buildings
1 Bq/m^3EER (annual average)	(0.7×10^{-4}) - (2.1×10^{-4})	$\geq$100 Bq/m^3EER

The Approach to Control Indoor Air Quality in Italy

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Introduction

The expression "Indoor Air Quality" refers to the air quality of non-industrial closed spaces. The environments covered by such a definition include dwellings, public buildings, and offices; thus the problems of indoor air quality concern all the general population and, at least in the developed countries, the greater part of the working people. This accounts for the growing interest in this issue, the implications of which pertain to public health, the safety and comfort of the population, industrial production, architectural design and engineering, commercial regulations, and, in a word, the quality of life in our modern society.

Concern about indoor air quality was initially raised by occasional episodes of high pollutant concentrations in public buildings or dwellings, caused by agents such as formaldehyde, asbestos, and pentachlorophenol. A more systematic approach to the study of indoor spaces has led to the discovery of multiple sources of pollution and to the detection of irritants, toxic substances, neurotoxic agents, and proven or suspected carcinogens -- all of which are frequently present indoors at higher concentrations than outdoors. These findings, combined with the fact that populations in western countries spend 80 - 90 percent of their time indoors, have directed great attention to indoor air quality, comparable to that commanded by atmospheric pollution.

The interest in indoor air quality in Italy is rather recent: this paper provides an overview of the research experience gained so far in Italy and the activities undertaken by the public administration.

Characterization of the Sources of Indoor Pollutants and Assessment of Population Exposure

Organic Substances

During the last few years, the public has become aware of the fact that the pollutant concentrations observed in the outdoor atmosphere may not be representative of indoor

air, at least for many pollutants and particularly for VOCs. With the exception of formaldehyde, not much qualitative and quantitative data exists on the indoor occurrence of VOCs and on the indoor/outdoor concentration ratios. Published data showing indoor/outdoor concentration ratios greater than 1.0 for many compounds, derived from northern Europe and the United States, need to be verified as well as their applicability to other countries analyzed. Such information would aid in identifying pollution sources, assessing potential health risks, and establishing national or local priorities for action.

Recently, a significant study has been carried out in the northern part of Italy by scientists of the Joint Research Center of the Commission of the European Communities in Ispra. The study consists of two parts: (1) a comparison of indoor and outdoor concentrations of 35 selected VOCs, total VOCs and respirable suspended particulates in several dwellings; and (2) a detailed analysis of indoor air samples by GC-MS to identify the single VOCs present. The survey included five apartments and nine detached houses, located in urban, suburban, and rural areas of Lombardy, that were exposed to high, moderate, and low traffic densities.

The measurements of the indoor and outdoor concentrations of the 35 VOCs selected for this study (which included 3 aldehydes, 2 ketones, 6 halocarbons, 8 alkanes, 8 alkylbenzenes, 2 terpenes, naphtalene, and other VOCs) have shown that the VOCs were nearly always more at higher concentrations indoors than outdoors, often by an order of magnitude. The mean concentration of total VOCs was about 3 mg/m^3 indoors compared to 0.4 mg/m^3 outdoors. Among the substances of major toxicological concern for humans, elevated concentrations were detected for benzene, toluene, 1,4-dichlorobenzene, and dichloromethane.

Detailed analysis of air samples by GC-MS led to the identification of a much larger number of compounds, sometimes more than a hundred for a single sample. Most of the identified compounds were solvents derived from consumer products rather than from building materials. Many of these compounds have also been detected in northern Europe and the United States and are the constituents of paints, wood impregnants, glues, cleaning agents, liquid waxes, and polishes. Interestingly, this study did not find a significant correlation between the minimum air exchange rate of the houses and the indoor total VOC concentrations, thus indicating that the residents' behavior may be a factor prevailing over ventilation in determining indoor VOC levels.

The interest in consumer products as a possible source of significant indoor pollution has also led to an investigation of the VOC emissions from some widely used household products marketed in Italy. Ten commercial products for cleaning and conservation (eight waxes and two detergents), intended for application to large surfaces, were screened in laboratory tests for VOC emissions.

The products containing water as a main constituent were found to emit oxygenated compounds, among which were terpene alcohols and their acetates, aliphatic alcohols and esters, and alkoxy-alcohols. The products without water essentially emitted hydrocarbons (alkanes, alkenes, and terpenes). It is interesting to note that, on the whole, more than 90 individual VOCs were detected in only ten products, thus indicating that household

products may represent a rich and varied source of chemical indoor pollution. Even though it may be argued that indoor concentrations for most of these compounds are usually fairly low, it is also true that toxicological information for many of them is very scarce, especially with regard to the long-term effects these compounds may have on humans. Since the characterization of emissions from household products can be very informative regarding the nature of potential indoor pollution, these experimental tests should be encouraged (though taking into account their reasonable cost). Moreover, their results can also help industry design better and safer products.

One aspect of particular concern for household products is the occurrence of allergic reactions among users. This matter is not new, as it was abruptly discovered by the public when new biotechnologic detergents, possessing extremely powerful sensitizing properties, were introduced on the market in the 1970s. However, the problem is still acute and can be viewed as one of the major current "occupational" diseases in housewives. At present, a multi-focal survey is under way in Italy, in cooperation with the Institute of Occupational Medicine of Milano and the University of Bari, with the support of Assocasa, the Italian association of the industrial producers of household products. The two main purposes are to define the incidence of allergic diseases among housewives, and to identify the main causative agents. Several thousand subjects will be contacted and screened over two years to provide a better assessment of the problem as well as specific information for prevention.

Formaldehyde

Formaldehyde is perhaps the most well-known organic indoor pollutant, as can be deduced by the large quantities of data available on indoor formaldehyde concentrations. The main sources of formaldehyde pollution are urea-formaldehyde-glued particleboard and plywood, urea formaldehyde foams used for insulation, moquettes (a type of upholstery or rug fabric), textiles, adhesives, and cosmetics. The emission rate from these materials is greatly influenced by air temperature and humidity. Outdoor sources can also contribute to low-level concentrations in buildings, particularly in cities.

Several countries have set limits for formaldehyde exposure indoors. The current threshold concentration recommended by a Circular of the Ministry of Health in Italy is 0.1 ppm, which is the same value adopted by the Federal Republic of Germany, The Netherlands, Denmark, and Finland, and corresponds to the 0.12 ppm value endorsed by the World Health Organization for the general population.

Formaldehyde is a proven rodent carcinogen, and, as such, is a suspected human carcinogen. Moreover, a small part of the general population has proven to be hyper-reactive to formaldehyde exposure, either because of the hypersusceptibility of the airways mucosa or because of allergic sensitization. These facts may render questionable the validity of the recommended limits and should encourage a more comprehensive approach to prevention addressed at limiting exposure as far as feasible.

Pentachlorophenol

Pentachlorophenol (PCP) is a versatile pesticide, mainly used as an inhibitor of biological degradation in wood treatment, leather tanning, and paper production. Due to these widespread uses, PCP has become an ubiquitous pollutant of the general environment. However, concern for population exposure has been raised, particularly for log-home residents whose houses have been treated with PCP. Studies in the United States have indicated that log-home inhabitants (particularly infants) may have blood PCP concentrations two or three orders of magnitude higher than those found in the general population.

In Italy, although log-homes are not popular, it is very common to find wooden surfaces inside homes. Moreover, the leather industry is very well developed; the three main clusters of tanneries, located in Lombardy, Veneto and Campania, each consume about 100 tons of PCP per year.

A survey completed in 1987 investigated the level of occupational and home exposure to PCP of wood and leather workers, and of selected subjects in the general population. While occupational exposure has been found to result in very high blood and urine concentrations of PCP (up to 4,000 - 5,000 μg/liter), urinary PCP levels in the general population have been found to vary according to whether wooden surfaces treated with PCP were present in the house (urinary excretion: 50 - 100 μg/l) or whether no known sources were detectable (urinary excretion: 2 - 15 μg/l).

It is interesting to note that increased urinary PCP concentrations were also observed in locations where indoor PCP application had occurred more than ten years before the study, thus indicating the long persistence of PCP release from the treated wood surfaces. The comparison of PCP concentrations in house dust and in urine of occupants gave a correlation coefficient of 0.9 in this study.

Since PCP can be easily absorbed through the skin, another remarkable finding was that finished leather after tanning as well as leather articles may contain hundreds of ppm of PCP, which can be transferred and deposited onto human skin by direct contact.

When some commercial PCP products marketed in Italy were analyzed for minor constituents and impurities, ppm concentrations of total dioxins and trace amounts (maximum concentration: 0.19 ppb) of 2,3,7,8-tetrachlorodibenzodioxin were detected. These findings account in part for the concern associated with indoor PCP pollution and human PCP exposure.

Inorganic Gases

Several inorganic gases have been recognized as possible indoor pollutants. Carbon monoxide, which can be released by combustion appliances, especially in the case of malfunction, is particularly insidious because it does not have warning properties and can easily lead to acute poisoning and fatalities. In Italy, due to the extensive use of open-

flame heating systems, such accidents are not rare, and a sustained effort would be desirable for preventing these casualties.

Besides acute effects, concern has been growing that low-level inorganic gas concentrations in confined living spaces may be responsible for long-term adverse effects in residents, notably in their respiratory systems. Nitrous oxides (NO_x), sulfur oxides (SO_x), and ozone are the agents most likely to be involved in such effects.

A map of indoor pollution and an assessment of the indoor population exposure to inorganic gases in Italy is not available. Exposure to these gases at low concentrations may affect a great portion of the population, while only a minority of the population is exposed to higher NO_x concentrations, and an even smaller number of people are exposed to SO_x and ozone in higher concentrations. SO_x and NO_x concentrations are regularly monitored outdoors in the large metropolitan areas, and these measurements have often shown critical values resulting from intensive traffic congestion and, particularly in the past, extensive use of fuel oil (instead of methane) for domestic heating.

The contribution of indoor sources to overall exposure to inorganic gases has not yet been characterized, however, some research projects on this subject have been planned. The indoor concentrations of inorganic gases, particulate, and polyaromatic hydrocarbons resulting from combustion appliances is being investigated in the Milan area under the initiative of the city gas supplying company (AEM), with the support of the Centro Informazioni Studi Esperienze (CISE) research staff. Another large survey has been planned by the National Board of Electricity (ENEL) and the National Research Council (NRC) in Emilia-Romagna, in an agricultural area around the coal-fired power plant of Porto Tolle and in the town of Pisa. This study is geared towards understanding the qualitative and quantitative importance of indoor pollution, in terms of exposure allocation between indoors and outdoors for the general population.

Asbestos and Man-Made Mineral Fibers

After recognizing the carcinogenic potential of asbestos in working environments, the public has been alerted to the possibility that a similar risk may also exist in living environments where asbestos has been extensively applied without long-lasting effective protection. This concern has prompted many surveys, primarily in the United States, and specific preventive actions were undertaken by EPA, particularly for schools and other public buildings in the late 1970s.

In Italy, testing for asbestos fiber concentrations in schools started in 1984 in the province of Milano and was soon after extended to other schools, hospitals, and some other public buildings of the Milan area. The bad condition of sprayed asbestos and/or the relatively high airborne fiber concentrations led, in many occasions, to the removal of asbestos and its substitution with other materials, or to the treatment of the asbestos surfaces with specifically developed encapsulants.

In 1985, the Administration of the Lombardy Region issued a Circular requesting systematic inspections for asbestos of schools and hospitals, and prescribing technical guidelines for action and for safe execution of the asbestos decontamination activities. The subsequent year, a national Circular was issued by the Ministry of Health, extending the same regulations, with some modifications, to the whole country.

At present in Italy, indoor asbestos pollution has been highlighted to the public attention but it is far from being a solved problem since remedial actions have been undertaken only in few regions and because of the difficulties in finding the necessary economic resources. The preventive campaign against asbestos, although incomplete, has achieved good results, namely characterization of indoor pollution of some buildings, development of decontamination procedures, standardization of the methods of measurement, and education of the public health officials.

Despite the intense research activity carried out in several countries on indoor asbestos, two main scientific questions are still unsolved: the occurrence of health effects at low levels of exposure (less than 0.1 fibers/ml), and the health significance of the ultra-small asbestos fibers that can be revealed and quantified only by electron microscopy.

Another field requiring further study is the toxicity to humans of man-made mineral fibers (MMMFs), such as glasswool and ceramic fibers. These fibers are being increasingly utilized and are becoming very popular as asbestos substitutes.

Radioactive Pollutants

Exposure of the population to natural radiation has become a prominent issue because of two main reasons: (1) natural radiation accounts for about 80 percent of the average effective annual dose equivalent received by the general population, and (2) according to some estimates, up to five percent of the observed lung cancer frequency in the general population might be associated with indoor radiation exposure.

Surveys of natural radiation exposures have been carried out in many European countries. The general results of these studies have shown that mean indoor radon concentrations range between 20 and 50 Bq/m^3, which correspond to effective dose equivalents in the order of 0.5 to 1.3 mSv/year. These values are more or less the same order of magnitude as the average doses delivered by external penetrating radiation of terrestrial or cosmic origin. In contrast to penetrating radiation doses that show a narrow distribution around the mean value, indoor radon concentrations and their related doses have been found to be log-normally distributed in the population, with small groups of people receiving hundred-fold greater doses than the median values.

Indoor radon pollution in Italy has been studied by research groups of the Istituto Superiore di Sanita (National Institute of Health), ENEA (the National Committee for Research and Development of Nuclear Energy and Alternative Energies), the Institute of Physics of the University of Milan, and CISE. About 330 houses have been investigated in Milano and in the Umbria region, and more than 1,000 in a national survey based on randomly selected dwellings. The regional as well as the national studies have generally

found average exposure values comparable to those measured in other European countries, with a national median value of 25 Bq/m^3 and a maximum value of 154 Bq/m^3.

In the study performed in Umbria, an area of higher exposure was detected in the town of Orvieto, with effective dose equivalents of 9.0 mSv/year. It is interesting to note that 90 percent of the houses in this town are made of tufa, a porous rock. Further studies have been planned to better characterize this area.

At present, a large national survey on radon exposure is underway in Italy under the coordination of the National Institute of Health and ENEA/DISP. This study plans to measure radon concentrations in several thousand houses throughout the country, selected with a random criterion. The first regional results of this survey will be available in 1990.

Strategies for Prevention and Control

Strategies for prevention and control of indoor pollution can be developed at different levels: educational, technical, and regulatory. Of course, each strategy level does not exclude the others, although different sources or agents may respond more or less favorably to each of these levels. A typical example of a source requiring an intensive action at the educational and social level is tobacco smoke; education may also be appropriate for other pollutants that are associated with bad habits or particular behaviors of the indoor occupants.

Intervention at the technical level is nearly always necessary and represents the effective completion of actions at regulatory or educational levels. Technical aids are necessary to develop safer building materials or products to be used indoors as well as to design proper buildings, appropriate heating or ventilation systems, and appliances having specific technical requisites.

Finally, regulatory action is often viewed as the principal instrument available to public administrators to set air quality standards and uniform criteria for verification as well as to establish means of surveillance and enforcement. However, it should also be recognized that the regulatory approach has some limitations, including inflexibility and difficulty of verifying compliance, particularly in the case of ubiquitous pollutants.

Recently, the Minister of the Environment of Italy has appointed a National Scientific Committee for Indoor Pollution, in order to review the state-of-the-art technology and to recommend actions to be undertaken by the Administration. The Committee, comprised of a Health Advisory Group and a Technical Advisory Group, is expected to prepare an extended document that should be released by the end of 1990.

Other activities have been planned at the local level, including a Project on Indoor Pollution Control launched by the Administration of the Municipality of Milano. This project will focus primarily on checking and controlling indoor air quality in school buildings and in other major buildings for public use that are owned by the Municipality.

Plans for Research

The current level of IAQ knowledge is not adequate to answer all the questions that concern community administrators and the public. The information collected so far, either by direct investigations or by extrapolation from related disciplines, is enough to indicate that indoor air quality is an emerging problem for health and human welfare, but many aspects of indoor air quality are not yet very well known, and the question of human health risks in particular remain open to investigation for many agents and conditions of exposure.

Several countries, including the United States, the Federal Republic of Germany, and France, have established nationally coordinated IAQ research programs. All these programs contain many points in common but differ in terms of local priorities and specific agents or sources studied. At the international level, groups active in indoor air quality are present in the World Health Organization and the Commission of the European Communities, where a Concerted Action on "Indoor Air Quality and its Impact on Man" was started in 1987 by initiative of the Environment Directorate of the Commission of the European Community.

In Italy, IAQ investigations have started only recently, but some results are already available and several groups have shown interest and strong research capabilities. An inventory made in 1989 by the European Concerted Action recorded 15 research profiles underway in Italy. Future plans include two major national indoor air research programs that will be coordinated by the National Research Council (NRC) of Italy. The first program will last three years, starting in 1990, and is part of a comprehensive National Research Plan for Atmospheric Environment supported by a joint effort between the National Board for Electricity (ENEL) and NRC. Here, research activity on the indoor environment is seen as a complement to outdoor studies to allow a better understanding of the effects of atmospheric pollution. The program is funded with about $25 million ($US).

The second program is a general National Plan for Research on Environment coordinated by the NRC, currently being considered for approval by the National Parliament. The plan includes ten major fields of research, one of which is "Urban Areas and Indoor Environment." If approved, this plan will last five years and will support research activities for a total amount of about $100 million ($US).

Section V

Ventilation Standards and Guidelines

Guidelines - Ventilation Classes

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The Indoor Air Climate Institute in Sweden has proposed three ventilation classes, based upon PPD-indices (predicted percent dissatisfied).

- Class A: Very good thermal comfort, good air quality
- Class B: Good thermal comfort, acceptable air quality
- Class C: Acceptable thermal comfort, acceptable air quality

Five standards were used in developing the classes:

- ISO 7730 "Moderate Thermal Environments - Determination of PHV and PPD indices"
- ISO 7726 "Thermal environments - instruments and methods for measuring physical quantities"
- ASHRAE 62-1981 "Ventilation for Acceptable Indoor Air Quality"
- ASHRAE 55-1981 "Thermal Environmental Conditions for Human Occupancy"
- NKB 40 1981 "Guidelines for Indoor Air Climate"

Each class is divided in two parts, according to individual regulation of temperature and/or air flow (e.g., Class A - IR means that the temperature and/or the air flow can be regulated individually in each room). In class A, recycled air is not allowed. In classes B and C, recycling is allowed under certain circumstances. Table 1 provides the PPDs in the different classes. Table 2 provides the operative temperature in each class. The air velocity (based upon a three minute mean value) is given in Table 3. The vertical

temperature differences and the acceptable floor temperatures are presented in Tables 4 and 5.

The lowest acceptable air flow in rooms where smoking is not permitted is given by:

- Class A: $Q = 0.75\ (8N + E)$
- Class B and C: $Q = 0.35\ (8N + E)$

Q = air flow (liter per m^2 floor)
N = number of persons per floor
E = emission factor

$E_A = 1$ (for low emitting materials [up to 40 μg per m^2/h])

$E_B = 2$ (for medium emitting materials [up to 80 μg per m^2/h])

$E_C = 4$ (for high emitting materials [up to 160 μg per m^2/h])

The proposed guidelines reflect both person load and emission from building materials in the flow rate calculation. The capacity of the ventilation system in the different classes is given in Table 6. This allows for variation in the air flow in the different rooms if the person load is changed, or if there is an increase in heat emitting equipment.

The guidelines are now being evaluated in Sweden. Some minor changes will come, but so far the main idea seems to be accepted. More details about emission test standards and other issues will be further discussed before the guidelines become official. Norway is also trying to adopt these guidelines.

For more details, contact Ulf Rengholt, The Indoor Air Climate Institute, Hantverkargatan 8, 11221 Stockholm, Sweden or Olav Bjoerseth.

Table 1: PPD in Different Quality Classes (%)

	Class A	Class B	Class C	Remarks
Thermal comfort	5 - 7	10	10	10% = ISO 7730
Sensory perception	10	20	20	20 = ASHRAE 62-1981
Inconvenience reactions	0 - 1	5	5	
Mucous membrane reactions	0 - 1	10	10	
Odor	10	50	50	

Table 2: Operative Temperature In The Different Classes (°C)

	Class A	Class B	Class C
Winter	20-22	19-23	18-25
Summer	23-25	22-26	21-27

Table 3: Maximum Air Velocity In The Different Classes (m/s)

	Class A	Class B	Class C
Winter	0.08	0.11	0.15
Summer	0.10	0.14	0.22

Table 4: Maximum Vertical Temperature Difference (°C per m)

	Class A	Class B	Class C
Summer and Winter	2.5	3.0	3.0

Table 5: Floor Temperature (°C)

	Class A	Class 8	Class C
Summer and Winter	22 - 26	19 - 28	16 - 32

Table 6: Capacity of the Ventilation System (%)

	Class A	Class B	Class C
Total system			
CAV	100 - 110	100 - 105	100
VAV	40 - 115	40 - 100	40-100
Separate room	60 - 140	80 - 120	80-120

CAV system: ventilation system with constant air flow
VAV system: ventilation system with variable air flow

Energy Consequences of Upgrading Indoor Air Quality

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Background And Description of the Situation

Energy Technology

Following the oil embargo of the 1970s, energy and conservation of energy have understandably received considerable attention. Some progress has been achieved in limiting the expected increase in energy requirements. Energy technology has become a field of its own, embracing energy production, energy supply, energy consumption, and energy conservation.

The pattern of energy consumption in modern office buildings has also been altered. Improved insulation standards, reduced infiltration, heat recovery, and other approaches have reduced heat loss. Increased use of computer equipment, paper handling equipment, fax machines, and other office equipment has affected work procedures in buildings and increased internal heat loads. Exploitation of passive solar heat technologies and increased use of glass have also become popular. Collectively, these efforts have led to an increase in surplus energy in buildings and a turn towards electricity as a main source of energy. Information concerning this trend is of considerable importance for planning expansions in energy supplies, including the potential for district heating.

Indoor Climate

The consequences of energy technology for the indoor climate have not received much attention. New developments in energy technology and the use of new materials in buildings have created buildings with indoor climate problems (e.g., sick building syndrome). Simultaneously, health, well-being, and productivity have become factors to which greater attention has been paid during debates about developments in society. When calculating the annual costs of a building, it is not only the financial costs that count, but also the value of occupants' well-being, health, and productivity.

The problem of the indoor climate can now be documented through inquiries in which people give their opinion about the indoor situation. Key complaints mentioned include the following:

- Drafts;
- Dust or dry air;
- Humming and noise from ventilators and other machinery;
- Heavy air, headaches, nausea, dry throats, tiredness and stinging eyes; and
- Air that is too cold or too warm.

Many individual cases also point towards conditions being worse in buildings that have small ventilation volumes. The minimum requirements of the building regulations often do not contain adequate reserve capacity for the following factors that can affect indoor air quality:

- Processes in the building (the work being performed in the building);
- Cleaning and cleaning agents;
- Copying equipment, computers, terminals, and printers;
- Degassing from furniture and fittings;
- Textile fibers;
- Floor adhesives;
- Other "hairy" surfaces;
- Rock-wool fibers and other man-made mineral fibers (MMMFs);
- Fall-out from paneled ceilings (especially MMMFs) & dust;
- Textile fibers from staff; and
- Dust in the duct network.

Hypotheses

A Norwegian research project has developed four working hypotheses regarding indoor air quality:

1. The present-day indoor climate in Norwegian office buildings must be improved.

2. Such an improvement will best be attained by changing the materials used and by upgrading the air standards.

3. Modern office buildings contain considerable surplus energy -- enough to heat the extra ventilation air.

4. The value of health and well-being must be included in a concept of total annual costs -- increased IAQ investment will result in the lowest total annual costs.

These hypotheses have already been confirmed by the massive frequency of complaints from a large number of buildings, forming some of the background for the research and development project.

How Do We Define Air Quality?

Can Air Quality be Measured?

Everyone who has tried to measure air quality, either in the laboratory or in actual buildings, has had difficulty in identifying the substances in the air which correlate with people's notions of good or bad air quality. This difficulty may be related to the existence of thousands of chemical compounds in the air, most of which are in extremely small concentrations -- it is very difficult to measure such low concentrations, and we have no knowledge of how human beings react to each substance or to combinations of several substances.

This difficulty is the chief reason why Professor P.O. Fanger [1] points out that the human sense of smell is the best "instrument" for judging air quality. He has, therefore, developed a technique for determining the necessary volume of air, which uses a person's ability to judge air quality. This technique can be readily compared with sampling in the food industry or to wine-tasting.

"Olf" - a New Unit for Indoor Pollution

The human being has traditionally been considered the chief source of pollution in office buildings. Pioneering research by Pettenkofer [2] and Yaglou [3] expresses the volume of pollution introduced per person. Pollution from human beings is well studied and familiar, and can therefore be used as a reference. Fanger [1] has consequently introduced the olf unit (from the Latin "olfactus" for sense of smell), which is the emission rate of air pollution from a standard person (Fig. 1). Any other pollutant source can be expressed in olfs (i.e., the number of standard persons that emits a subjectively equivalent amount of pollution), since it will lead to the same dissatisfaction with air quality under otherwise equal conditions.

The olf-values for some sources of pollution are:

- Sedentary person 1 olf
- Active person 8 olf
- Smoker, while smoking 25 olf
- Smoker, on average 6 olf
- Materials in an office 0 - 0.5 olf/m^2

Since sense of smell is the "measuring instrument" used for judging air pollution, groups of people will have to be established who are trained to use their sense of smell to determine olf values from different pollutant sources. These "smell-detection panels" will also need to be able to determine the degree of satisfaction with air quality in a room

with given volumes of ventilation. Fanger has taken such a group of people to different buildings. The statistical results of this study are shown in Figure 2.

Ventilation Volume per Olf

A common ventilation volume used nowadays is 3 liters/second (l/s) per olf. At this level as much as 35 percent of the "smell detection panel" will consider the air to be unsatisfactory. In order to reduce this number to five percent, the air volume will need to be increased to as much as 15 l/s per olf.

Even the Ventilation System Pollutes

The visit of the "smell-detection panel" to many diverse buildings has also revealed that the ventilation system itself pollutes, as determined by carrying out smelling tests in the same building, with and without operation of the ventilation system. Figure 3 shows an average olf-load in 20 investigated official buildings.

This frightening picture shows that there is a challenge for the heating, ventilation, and air-conditioning (HVAC) industry to design and operate ventilation systems in such a way that the systems do not adversely affect the indoor climate. At the same time, it offers a challenge to the architect who must select materials and methods that release the smallest possible amounts of pollution into the indoor air. In Scandinavia, the notion of "low-olf buildings" has become a building objective. This objective requires a building pollution load of 0.2 olf/m^2. Present-day buildings, in which smoking is permitted, have a load of perhaps 0.7 olf/m^2.

Energy Requirements in Office Buildings

The energy required for heating modern office buildings has been reduced in recent years. This reduction has occurred because the need for energy conservation has resulted in buildings with improved insulation, triple glazing, reduced air infiltration, and reduced ventilation volumes.

Despite this trend, we often see that modern office buildings have large total energy requirements, perhaps just as large as before the trend began. We also see that the energy requirements, to a greater extent than previously, must be met by electricity because buildings are now filled with electrical equipment, such as computer equipment, printing and copying equipment, and general office equipment. Large data processing and communication centers are also common. All this equipment produces excess heat which needs to be cooled by the air-conditioning system, which also requires electricity.

A low energy consumption in modern office buildings is only possible if the air-conditioning system is designed in such a way that transferred heat can be exploited to cover heat losses. Figure 4 shows the "energy flow" in a modern building. Heat loss, ventilation loss, and domestic hot water requirements, determine the thermal energy

requirement. At the same time, we have a great need for electric power to run equipment.

If the heat excess from equipment operation, the sun, and human beings can be recovered and used to meet the thermal energy requirements, then the necessary input of thermal energy will be merely a balancing item. This "superfluity" of thermal energy in our office buildings offers us possibilities for upgrading the indoor climate without especially significant consequences for energy consumption.

Energy Requirements in an Actual Building

To put this into a more tangible form, we looked at a building planned for an oil company in Norway. The building has a total floor space of approximately 25,000 m^2 and serves the needs of approximately 750 office jobs. We assumed that the building has present-day standard materials, and smoking is permitted, representing a pollution load of approximately 0.7 olf per m^2 in the work-place area. A separate electronic data processing department is attached to the building, requiring 300 kW of energy to operate the data processing equipment. The building has a combined cooling unit, which cools the electronic data processing machines, office ceilings, and summer ventilation air. The excess heat is transferred to a water-based heating system. This energy can thereby be exploited to meet a substantial portion of the thermal requirements.

We will first calculate the energy requirement of such a building having a ventilation volume in the office space corresponding to 3 l/s per olf (2 l/s per m^2), which is a very common figure today. Figure 2 shows that we can expect 35 percent of the building occupants to complain about the air quality. Subsequently, we will calculate the energy requirement if the air volume is increased to 4 l/s per olf and 6.5 l/s per olf. In the last case, we can expect approximately 20 percent of the occupants to complain about the air quality.

Energy Requirements per Square Meter

Figure 5 shows the energy requirements per square meter of this building, with the three different demands on air quality. We see that the need for electric power for lighting, operating equipment, and other needs is greater than the need for thermal energy for air conditioning. Furthermore, exploiting possibilities for recovering heat from electrical equipment, the sun, and other sources will significantly reduce the actual supply of thermal energy. If we want to improve the air quality in this building by increasing the air volume, we see that it results in only marginal increases in total energy consumption. To reduce the expected number of complaints from 35 percent to 20 percent calls for an increase from 226 to 244 kWh/m^2 per year, or approximately eight percent will be necessary.

This calculation confirms hypothesis 3, that there is a large amount of excess energy present in modern office buildings. When there is an increase in energy consumption with increases in air volume, this increase is largely related to increased energy for operating fans.

Financial Consequences of Increased Ventilation

In this case, an eight percent increase in energy consumption means that operating costs will increase by approximately NOK 315 ($45 US) per year for each employee. The consequences for investments are apparently larger. A doubling of the air volume, which is what we are talking about here, means an increase of investment of approximately NOK 15,000 ($2,143 US) per employee. With a real interest rate of six percent per year and depreciation over 15 years, this value translates into NOK 1,500 ($214 US) per year for each employee. With an air volume of 4 l/s per olf, the figures for increased energy consumption and capital costs increase by about one-third.

Performance and Well-Being

Status

Pollution in the external environment, primarily air and water, is the central environmental theme with which politicians and the media are preoccupied. The fact that people are mostly indoors is rarely pointed out. The reason seems to be that we have not considered it a health hazard to be indoors at home and places of work, except for at a few industrial work-places.

Nowadays in Scandinavia, there seems to be a change in attitude. More and more people are realizing that the internal environment is also important for public health. Professional building owners have long since realized that investment in a good indoor climate is an investment in the well-being of employees and in increased productivity [4].

In our project, it is not our goal to carry out a broad investigation of the relationship between air quality and productivity. Such a study would demand too many resources.

We nonetheless believe that information available from official statistics and related research projects can illustrate such a connection [5] and [6].

The Effect on Health of an Adverse Indoor Climate

Problems related to the indoor climate seem largely to arise from the irritating effect of pollutants on the skin and on the mucous membranes of the eyes and respiratory passages. The irritation is chiefly felt as a sensation of "dry air" and results from the combined effect of irritants in the internal environment. Smell also plays an important role in our perception of our surroundings, and may be a stress factor. Formaldehyde is a common indoor irritant arising from building materials and smoking. In addition to eye irritation, changes in the mucous membranes of the nose have been demonstrated with exposure to high formaldehyde concentrations.

Hyperactivity may result from irritation of mucous membranes, (and intensified by infections) which in turn reduces resistance to infections and increases risks for developing allergies. Epidemiological data suggest that internal climatic conditions may be important causes of a large proportion of allergies, respiratory ailments, and diseases. There seems, therefore, to be a very large preventive potential in improving these conditions, on health as well as economic grounds. In view of the data available, it is not unreasonable to assume that half the respiratory ailments and diseases in our population can be attributed to factors in the indoor environment. Several studies have also revealed considerable tiredness and occurrence of headaches, particularly where there are damp areas. This discovery opens the question of whether the central nervous system is also affected, or whether it is a form of allergic reaction.

Rock-wool fibers, glass fibers and other MMMFs from construction materials and insulation are another cause of discomfort. Other significant fiber-induced health effects, such as itching and irritation, have not been documented, but major studies dealing with this problem are underway.

Productivity

Through controlled laboratory investigations using test subjects, Wyon [7] has studied how indoor temperature extremes affect achievement capabilities of human beings. Wyon has shown that productivity is a function of finger temperature. It is important, therefore, to be aware of the factors affecting this temperature. When it is cold, the hands quickly become cooler because blood circulation to peripheral parts of the body is reduced. This will rapidly reduce ability to work efficiently with the hands, or perform similar tasks (see Figure 6). Movement and clothing also affect finger temperature. Figure 6 also shows accident proneness and mental performance at various air temperatures.

Wyon has also examined the interaction between thermal stress and other stress factors, such as noise and light. Relationships with air quality have not, however, been investigated. Nevertheless, there is reason to believe that stress caused by poor air quality will also result in reduced achievement levels. Figure 6 shows that extremely small

departures from an optimal indoor climate will quickly reduce productivity by five to ten percent for some individuals.

Official statistics [8] show that males have, on average, 31 days a year with reduced activity due to illness; the corresponding value for females is 46 days. Moreover, we know that approximately one-fourth of these values results from diseases of the eyes, ears and respiratory system. This finding suggests that there is room for improvement.

Proposals for Remedial Measures

To solve the problems of poor air quality by merely increasing the air volume is not technically and economically acceptable. We must, therefore, do whatever is possible to reduce the pollutant concentration. The aim must be to achieve "low-olf buildings."

Smoking

Smoking often creates the most serious pollutant concentrations in the indoor climate. In practice, smoking will demand such large amounts of air that it is impossible to dilute the air to an acceptable level. With a consumption of one to two cigarettes an hour, a smoker will pollute the air as much as would six people who do not smoke. If smoking indoors is to be permitted, it must take place in separate smoking rooms with separate ventilating systems.

Buildings Materials and Processes

Evaporation of pollutants from construction materials, interior walls, floors, ceilings, and other sources may result from many factors. In new buildings, evaporation can take place from hardening materials, including paints, adhesives, and wallboard. This evaporation can lead to a need for increased ventilation in the initial phases, perhaps as long as one year after occupation. The half-life for evaporation may vary from several weeks to four months. This evaporation rate can be partially reduced by knowledge about and sensible use of construction materials. For example, damp wallboard may give off formaldehyde, drying adhesives and paints release solvents or fission products from plastics and hardeners.

Failing to clean the building before it is brought into use, particularly in places where users cannot see, can cause poor indoor air quality. The building must therefore be thoroughly cleaned before being used.

The accumulative or storage effect of pollution in the materials increases with increasing surface area and thus is greater on "hairy" surfaces. This effect can support a strong argument against carpeted floors. The negative effects of carpeted floors are increased by damp conditions, condensation on cold floors, heavy wear, and inadequate cleaning. Proper everyday cleaning can reduce indoor air problems. Vacuuming, however, may pollute the air with large quantities of fine particles. This problem can be alleviated

by installing a central vacuum-cleaning system. It is theoretically possible to filter the air, but vacuum cleaners with "allergy filters" have not been adequately tested so far.

Photocopying machines, paper-shredding equipment and other frequently used paper handling machines should be situated in areas with separate exhaust zones. Use of impact paper can lead to problems because of the release of chemical exhaust steam. Paper dust and pollutants can be prevented by using enclosed shelving and files, and by having these extend to the ceiling, thus avoiding unnecessary dust-traps.

More investigation needs to be conducted to learn whether using lower paneled ceilings leads to problems with the indoor climate because of the large horizontal surface areas which are inaccessible for cleaning. If this hypothesis is confirmed, lowered ceilings should be avoided.

Other Precautions

- Concrete must be well dried before painting and carpeting to avoid fungal growth and bad odors.
- Rock-wool and glass fiber insulation-products must be sealed to avoid MMMFs from entering occupational zones.
- All particle board, including that in furniture, must be coated to avoid formaldehyde emissions.
- Glues and paints must be tested for emissions.
- Avoid plastic materials which emit odors.

Ventilation Installations

Ventilation installations must be cleaned before the building is brought into use and must be kept clean. Failure to do so can cause IAQ problems. Ducts should be degreased, and delivered to the site where they will be used with caps on the ends to be removed prior to fitting. Deposition of dust and other pollutants in the installations can also cause IAQ problems. Recirculated air must not be permitted anytime.

Induction units permit local recirculation in the room and lead to reduced air quality, both because dust is recirculated and because substantial quantities of pollutants quickly build up in the unit itself. Additional problems can occur when cooling takes place because it can result in condensation in the unit, which provides favorable conditions for mites, fungi, and bacteria to develop when food particles are present in the unit. Induction units must therefore be avoided.

Hygroscopical, rotating, heat recovery units can also develop water-soluble impurities. All rotating heat recovery devices recover cooking fumes. There is still some uncertainty

as to whether they also recover other pollutants, but it is clear that non-hygroscopical heat recovery units become hygroscopical and recover pollutants when their surfaces become contaminated [9]. These units must therefore be easily accessible for inspection and cleaning.

Heat recovery units must also be installed in such a way that leakages and excess pressure do not occur from the used air side. The installations must be checked for leakages both on delivery and during subsequent follow-ups.

Poorly located inlet openings can result in large numbers of insects entering the air inlet plant and causing unacceptable air quality and the development of allergies and asthma. Dampness in the plant also leads to undesirable biological activity. Humidification should generally be avoided. If humidification takes place in the plant, technology must be used which safeguards against this sort of development. Intermediate storage of water can also promote biological development. Even though this water is subsequently boiled in a steam humidifier, the organic material produced in the intermediate storage tank may lead to undesirable effects. Intermediate storage tanks should therefore not be used. There is also a risk of condensation precipitation in the ducts.

Use of contaminated materials in the ventilation installation must be avoided. When sound absorbers made of fiberglass and rock wool are being installed, ensure that the plant is cleaned after fitting and use materials that do not allow fibers to be introduced into the air handling system. This principle applies to internal surfaces from the air inlet through and including the supply valves. The installations must be accessible for inspection and cleaning; this must be written into the contract, and be verified on acceptance.

Annual Costs and Optimal Indoor Climate

The annual costs of a building consist of capital costs, administrative, operating, and maintenance costs. It has become more and more common to use annual costs as a decision-making tool when new buildings are being planned. The reason for this practice is because the costs during the operating phase increase relatively, particularly labor and power costs. The annual costs are often evaluated per square meter floor space. Obviously, the costs should be as low as possible.

Employees are at the Center of the Stage

All modern businesses stress the fact that their staff is their most important resource and the most significant production factor. Therefore, it is only natural that investments and operating costs related to the health and well-being of the employees be viewed in relation to productivity and annual costs.

What is the Value of Improved Productivity?

It is difficult to give an unambiguous answer to this question with regard to office workers. One approach may be to examine wage-related costs. In Figure 7, the value of improved productivity is shown for different wage levels.

Can the Indoor Climate Influence Productivity?

There are strong indications that the indoor climate can influence productivity. The best figures demonstrate the connection between performance and thermal indoor climate. Apart from this, we must resort more to assumptions and assessments of the influence that the person with the complaint has on productivity, and whether the number of days absent through illness can be reduced. In extreme cases, we have seen health authorities threatening to close buildings whose indoor climate has obviously been the cause of people's absence (e.g., sick building syndrome). It is, therefore, not unreasonable to assume that an improvement in air quality indoors can help promote a productivity improvement of up to three percent.

Is there an Optimal Air Quality?

In Figure 7, we have included a scale for air quality, measured in air volume per olf which suggests that an improvement in air quality from 3 to 6 l/s per olf will result in productivity improvements of up to three percent. In the same figure, we have included bars showing increased capital costs and energy costs when air quality is upgraded by increasing air volume. Increased energy costs account for only a small portion of this total increase. It is likely that some of these relationships may differ somewhat. But the margins seem to be so large that the main conclusion is clear: it is very profitable to upgrade air quality.

How do we Upgrade Air Quality?

A good principle for HVAC engineers has always been to first eliminate the source, and then dilute; the same principle applies here. The correct approach must be to carry out measures to reduce the sources of pollution in our buildings, but it is also necessary to increase air volumes. The short-term objective must be to obtain fewer than five percent complaints about the indoor climate from users, as opposed to the present 35 percent.

Total Costs - Office Building

I would again like to focus on the connection between building-related and employee-related costs in a building. A perfect indoor environment is the goal, and low energy consumption is a must, but not if energy conservation interferes with the indoor environment. Total costs are far more than investments, energy, maintenance, and cleaning.

Costs such as these are related to the building characteristics and its operating practices. But why do we put up a building in the first place? It is, of course, because we have some work to be done, and this can be accomplished in a less expensive way if productivity is high. A good indoor environment is one of the most important methods of improving the efficiency of any staff. This is elementary - but do we in the building industry or the building owners act as we should? I am afraid not, and therefore I have started to develop an extended expression for total costs. Total costs must be related to the sum of wage-related costs and building costs. Let's look at an example:

The task is putting up a new office building for 150 employees; size: 300 sq. ft. per employee; equivalent to 45,000 sq. ft.

	ALT. I Normal IAQ ($US)	ALT. II "IAQ top" ($US)
Average costs/sq. ft.	$130	143
Total costs (millions)	$5.85	6.43
Office costs pr. year (7%, 15 years)	$3.9	4.3
Running costs/year	$850	900
Wage-related costs	$53.0	53.0
TOTAL COSTS	$57.75	58.2
House rental in percentage	$\frac{3900 + 850}{57750} * 100 = 8{,}2$	$\frac{4300 + 900}{58200} * 100 = 8{,}9.$

Difference: 0.7%

Conclusions

By means of a current research project in Norway, we intend to find out how to upgrade the air quality indoors, and at the same time discover the consequences of doing so. The need for such an upgrading is recognized through the ever-increasing numbers of complaints from persons in modern office buildings. Even though the research is at an early stage and more information needs to be collected and systematized, we can draw the following conclusions:

- **All substances, materials, fittings, and equipment must be looked upon as sources of pollution.**

- **We need to develop methods for characterizing IAQ.** Training groups of people to use their noses to judge air quality seems to be a useful way of accomplishing this characterization. All architects and planners must be made conscious of the need to minimize the pollution load. It is always cheapest in the long run to make the right decisions before beginning any drawings. All offices and electronic data processing equipment in our office buildings produce a heat surplus which can be exploited for heating. The air-conditioning systems must be designed in such a way that heat recovery is possible. This practice, however, leads towards using more electricity and less thermal energy in order to meet the energy requirements. In upgrading the air quality, we can scarcely avoid increasing the air volume above the small volumes that have been implemented due to the energy conservation drive.

- **Optimal air quality is capable of increasing productivity.** With regard to the thermal indoor climate, a five to ten percent reduction in productivity has been shown to occur with only small departures from an optimal climate. Moreover, we know that of registered cases of illness, approximately one-fourth are related to the eyes, nose, and the respiratory system. We assume that productivity can be readily increased by up to three percent by improving the air quality. Even a productivity improvement of only one percent would more than cover the increased costs of upgrading the IAQ. These increased costs include energy costs and capital costs.

- **Increased energy consumption as a result of upgrading the air quality may be as much as eight percent.** This increase has little financial significance for the individual employer or owner-builder. Any increase in energy consumption is undesirable from the viewpoint of society at large. A marginal increase for upgrading the air quality must, nevertheless, be looked upon from the viewpoint that demands for energy conservation have for a long time taken place at the expense of air quality.

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FIGURE 1

Fig: One olf is the pollution from a standard person

Professor P. Ole Fanger, DTH Copenhagen

FIGURE 2

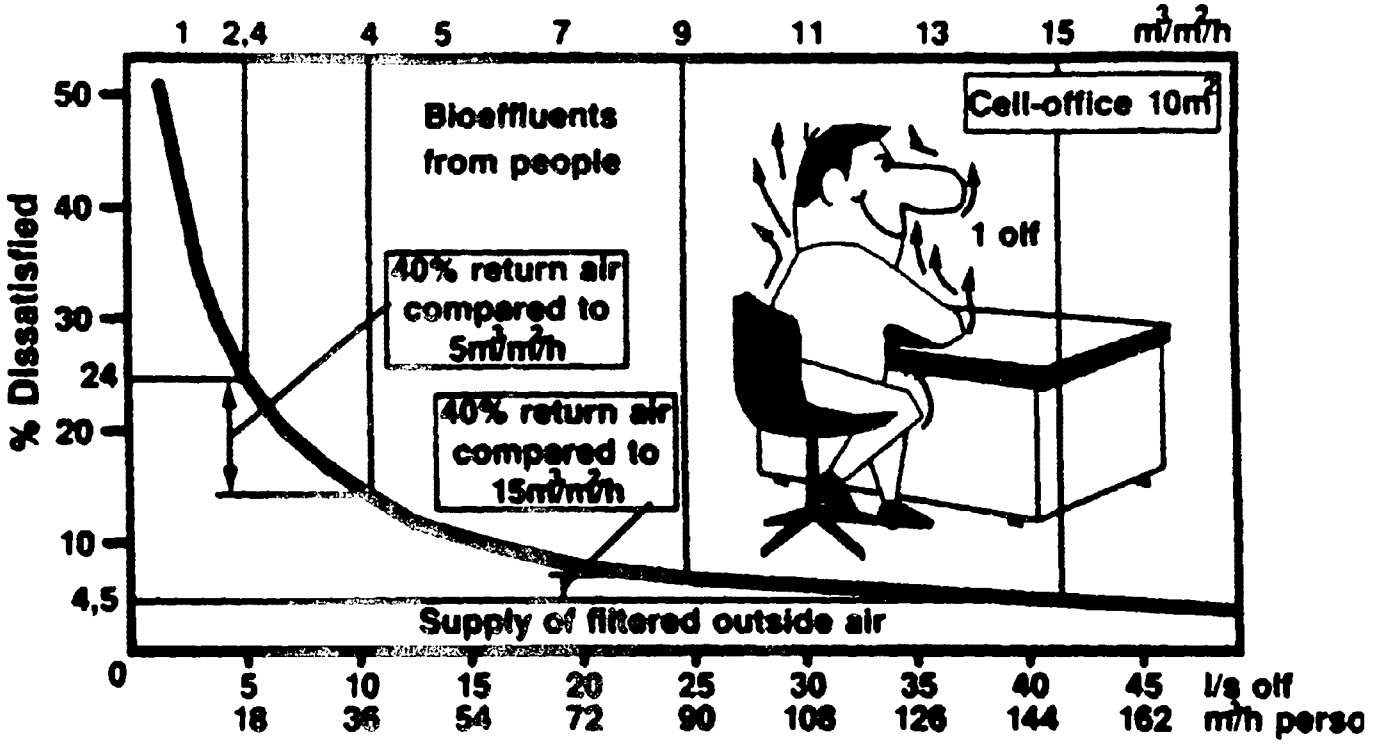

Fig: Dissatisfaction when using one olf at different ventilation volumes

Professor P. Ole Fanger, DTH Copenhagen

FIGURE 3

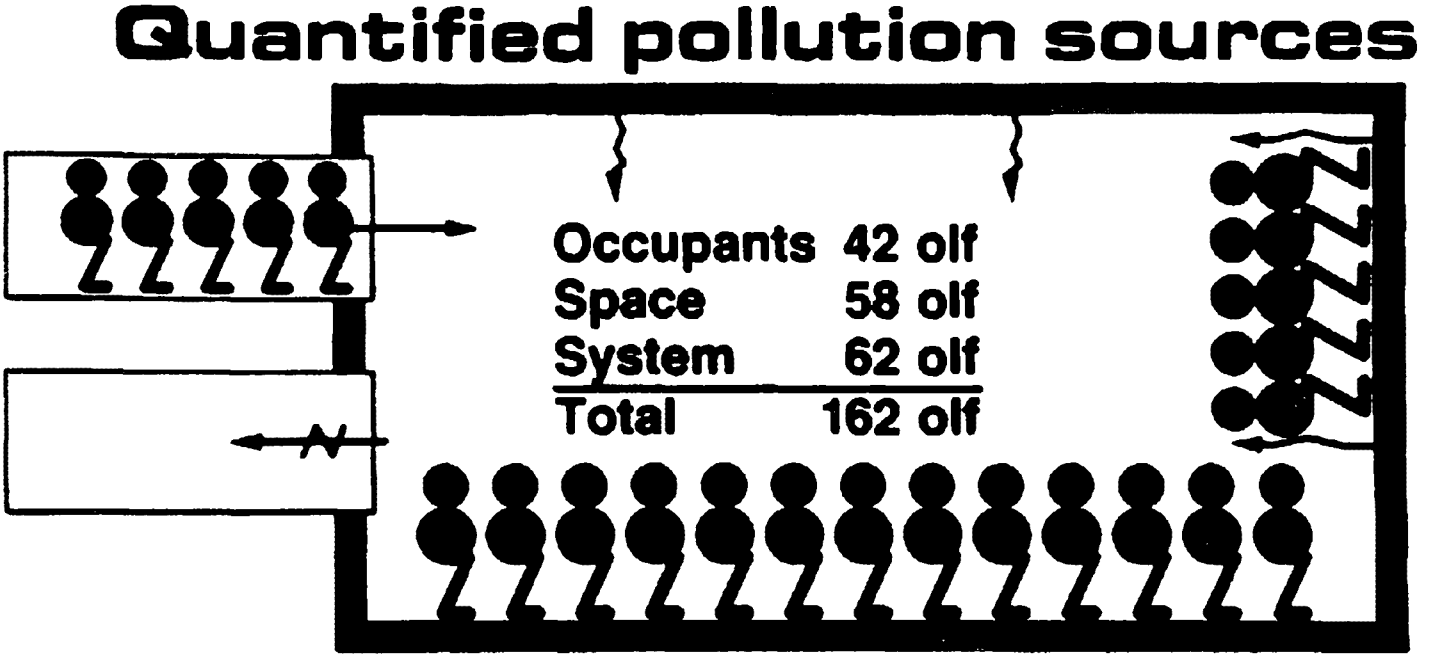

Fig: Mean values of pollution sources quantified in 20 offices and assembly halls in Copenhagen

Professor P. Ole Fanger, DTH Copenhagen

FIGURE 4

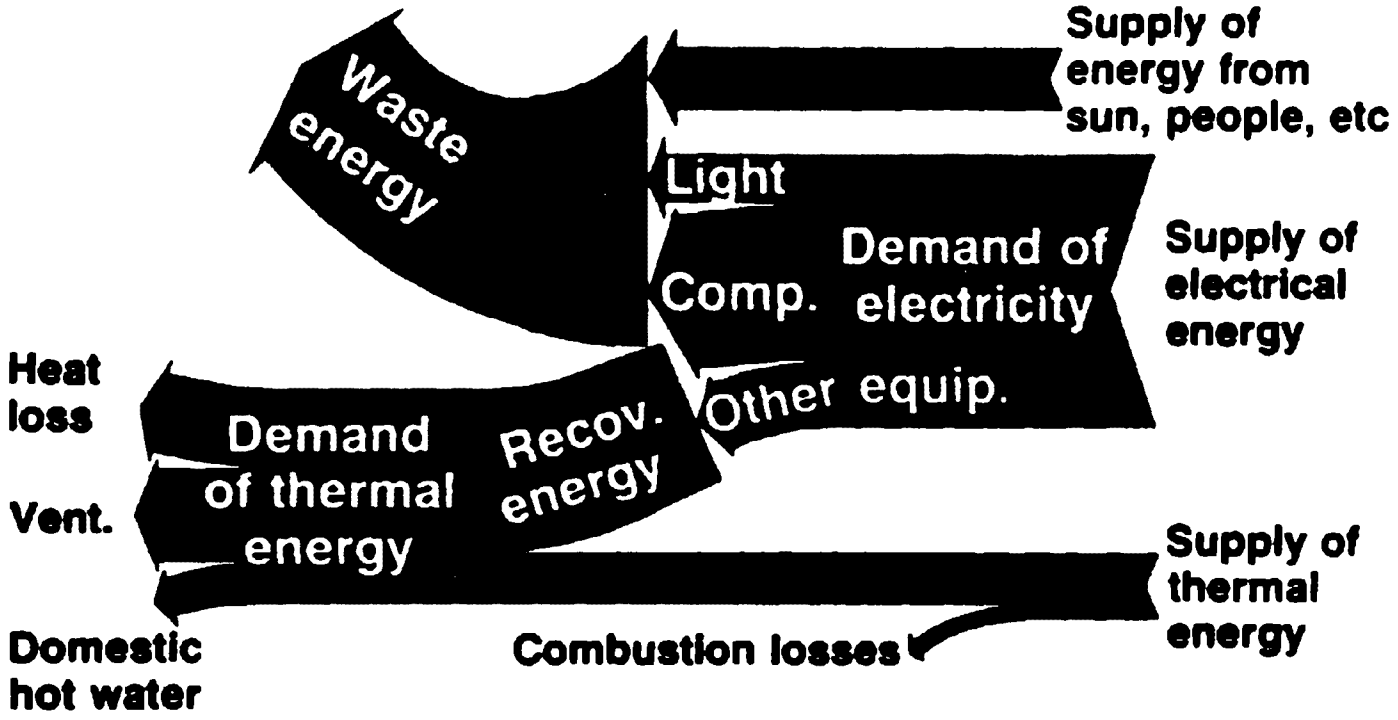

Fig: Power flow of energy in an office building

FIGURE 5

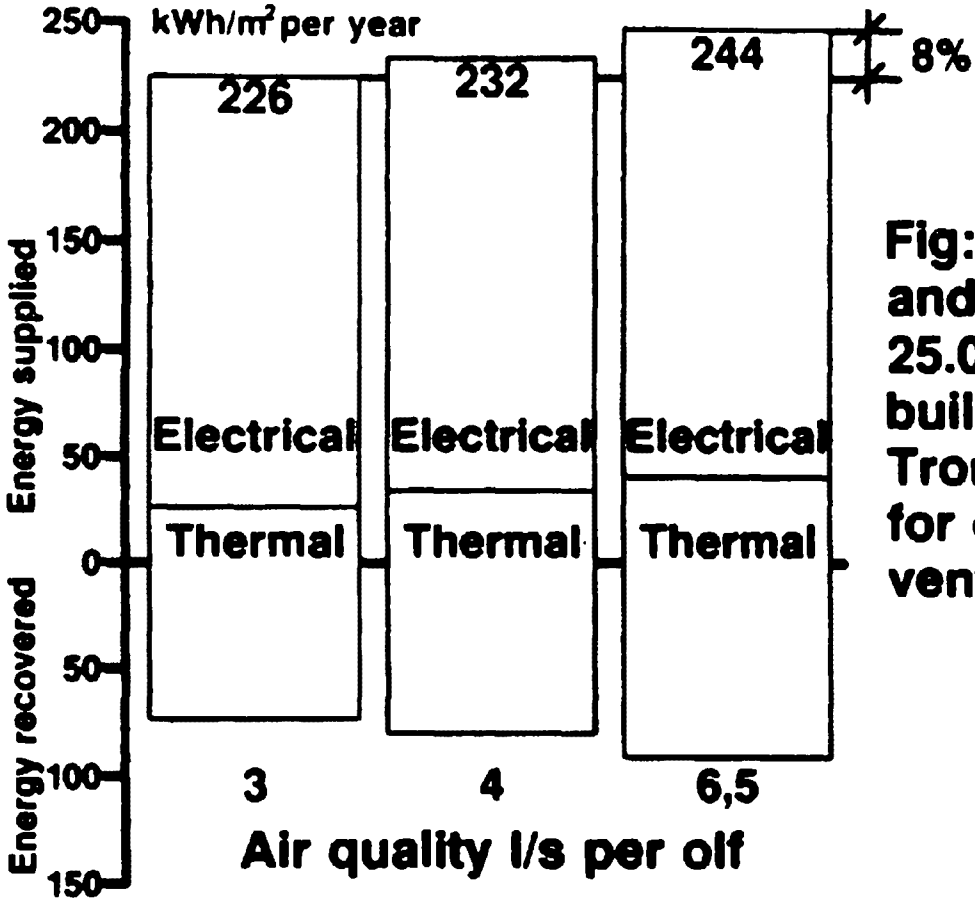

Fig: Energy demand and supply in a 25.000 m² office building located in Trondheim, Norway, for different ventilation volumes

FIGURE 6

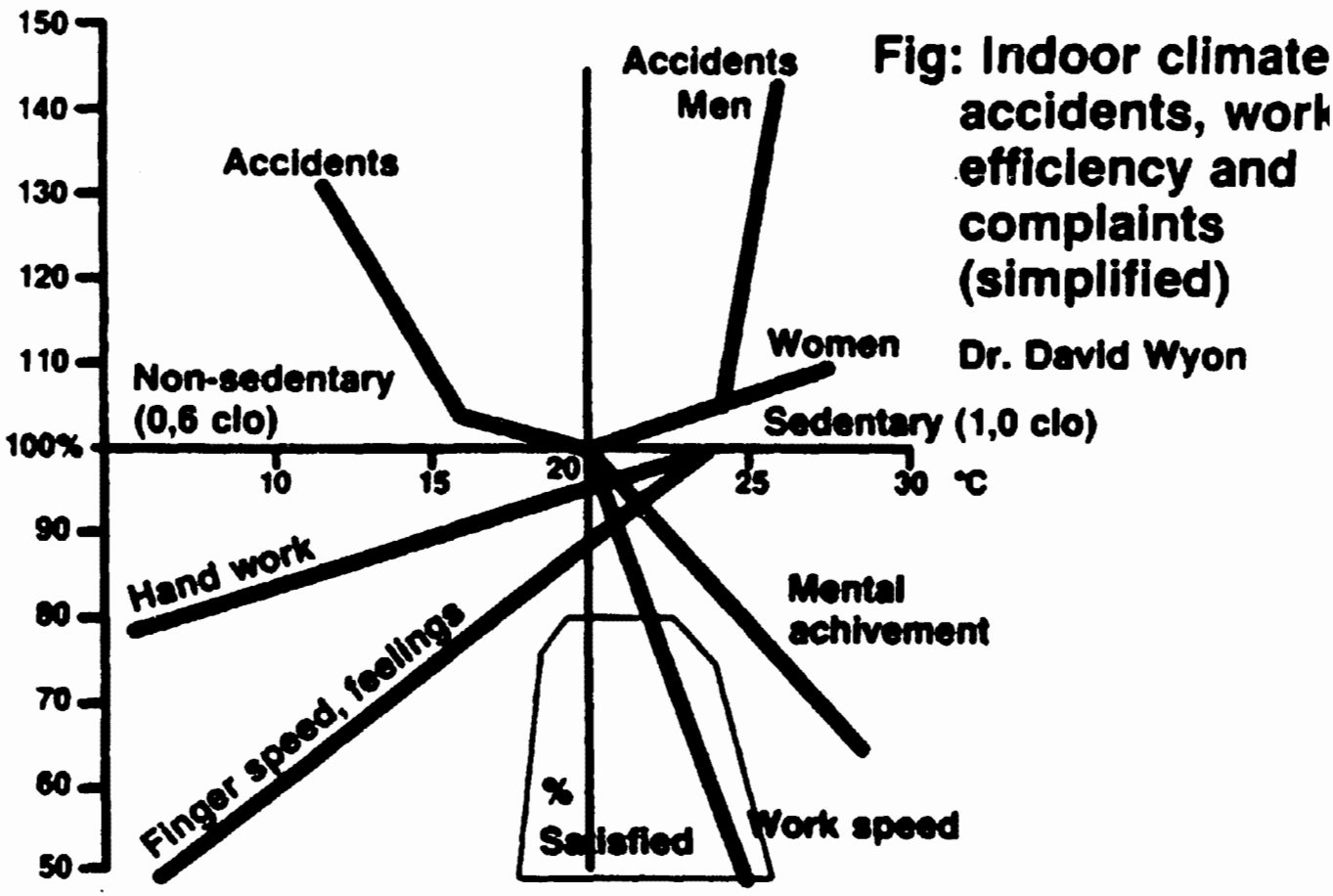
150
140
130
120
110
100%
90
80
70
60
50
Accidents
Accidents Men
Women
Non-sedentary (0,6 clo)
Sedentary (1,0 clo)
10
15
20
25
30
°C
Hand work
Finger speed, feelings
Mental achivement
Work speed
%
Satisfied
Fig: Indoor climate accidents, work efficiency and complaints (simplified)
Dr. David Wyon

FIGURE 7

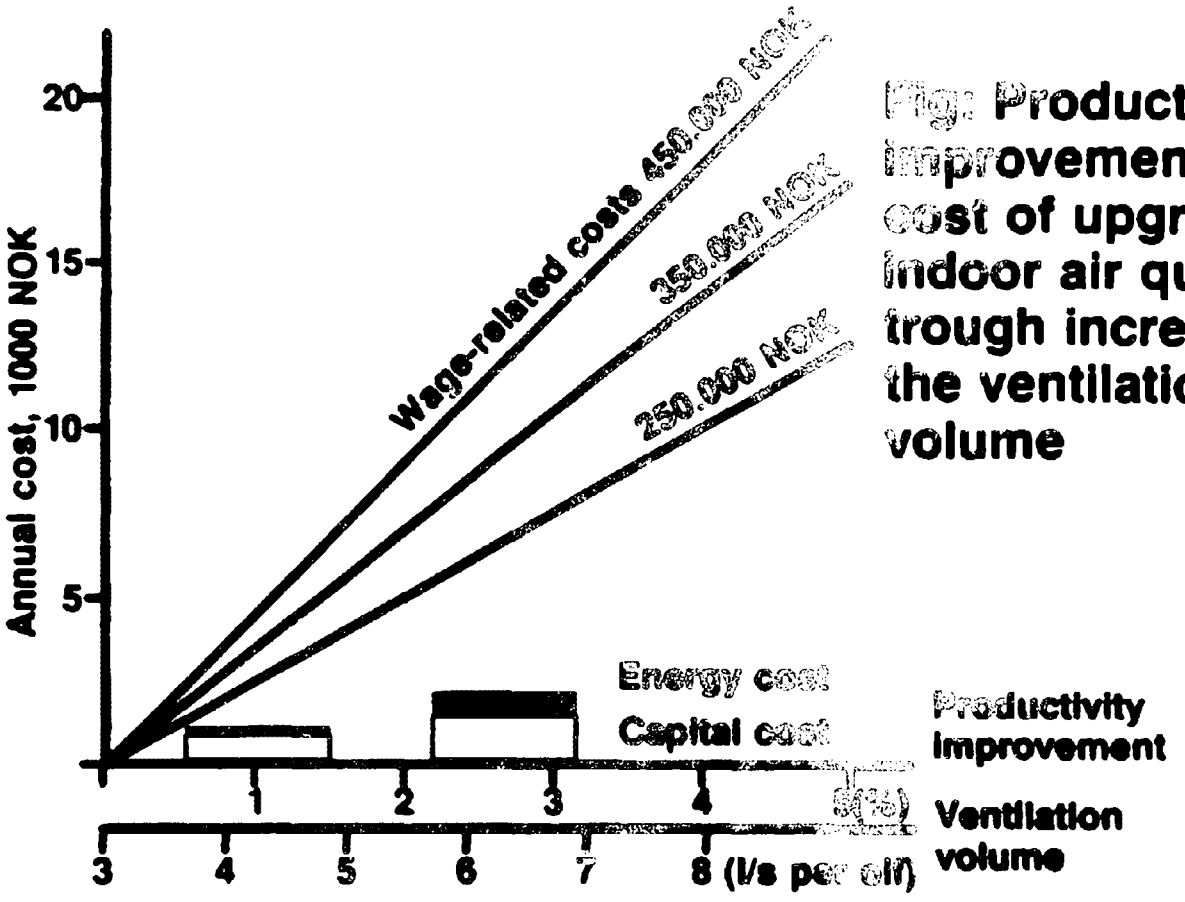

Fig: Productivity improvement versus cost of upgrading indoor air quality trough increasing the ventilation volume

Canada's Guidelines for Residential Indoor Air Quality: Rationale and Scope

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Introduction

In Canada, responsibility for developing and implementing measures to protect public health resides largely with the provincial governments. At the federal level, the Department of National Health and Welfare provides advice to the provinces on matters relating to public health and, through a federal/provincial committee structure, endeavors to establish health-based standards or guidelines in a consistent manner. Figure 1 shows the reporting relationships for committees involved in IAQ-related work: other committees have been convened to deal with health-related issues, such as drinking water quality, recreational water quality, noise, and risks posed to the pregnant worker.

In the fall of 1980, the conference of Deputy Ministers of Health approved the establishment of the Federal-Provincial Working Group on IAQ to consider "a definition of acceptable air quality," the need for "objective and/or maximum acceptable concentrations for substances," and a "specification of ventilation rates, or recirculation criteria" for housing. The scope of the work was to be restricted to "domestic premises," with recommendations being developed to protect the general public, assuming continuous exposure to residential indoor air. It was not expected that economic factors be accounted for in arriving at the recommendations.

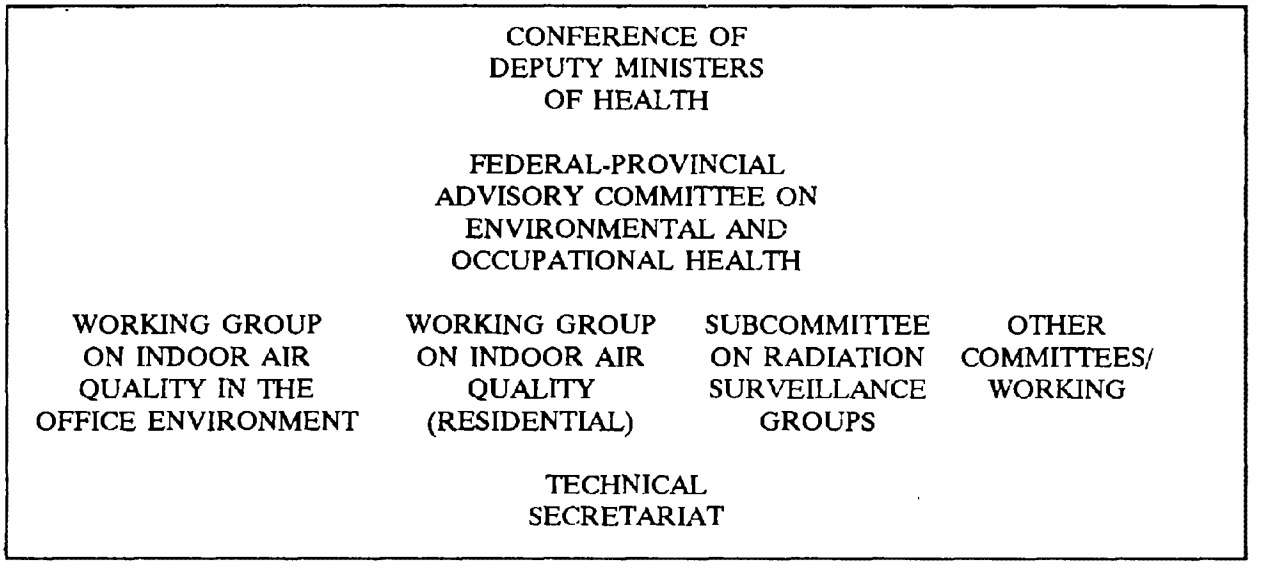
The Working Group, comprising members from eight of Canada's provinces, was convened in September 1981 and, over the subsequent four years, reviewed the scientific literature on 17 substances or groups of substances (those listed in Tables I and II as well as relative humidity and formaldehyde). Technical support, including the preparation of criteria documents, was provided by the Federal Department of National Health and Welfare. Radon was also included initially, but assessment of this element was

subsequently referred to the Federal-Provincial Subcommittee on Radiation Surveillance because of its specialized knowledge on radioactivity.

The Working Group presented its recommendations to the Federal-Provincial Advisory Committee on Environmental and Occupational Health in September 1985; the Advisory Committee slightly amended some of these recommendations based on an assessment of economic factors and practicability, after which the report was approved by the Conference of Deputy Ministers of Health. Since all of the provinces are represented on these two senior committees, the guidelines, in effect, are endorsed by all provincial agencies which have an interest in indoor air quality.

Figure 1

Organizational Structure For Developing Exposure Guidelines In Canada



Methodology Used in Setting the Residential Guidelines

Selection of Contaminants

The Canadian Exposure Guidelines for Residential Indoor Air Quality were formulated with the objective of protecting the health of the vast majority of the general public, including susceptible populations, such as the very young, the elderly, and persons with pre-existing health problems. These groups are especially of interest with respect to indoor air quality since they often spend most of their time indoors. Two broad objectives were set:

- To develop guidelines for the concentrations of selected contaminants of residential indoor air, taking into account such factors as the sensitivity of groups at special risk, and the sources and mechanisms of action of contaminants; and

- To develop, where practicable, other guidelines or recommendations for measures that will preserve or improve air quality in domestic premises.

Individuals at special risk were defined as "those whose physiological processes are either not fully developed or are deteriorating or for whom pathological or physiological changes impair the ability to surmount the adverse effects of exposure to a pollutant." The Working Group recognized that the exposure guidelines may not provide complete protection for the allergic or hypersensitive portion of the population. The second objective was established on the basis that lifestyle factors and actions taken by the homeowner or occupants can have a significant impact on the quality of residential indoor air.

The 17 substances (or groups of substances) were chosen for inclusion in the guidelines because of their potential to adversely affect health and because they were considered to be representative of the categories of pollutants that might be present in the home. In part, the selection was based on the availability of information from which recommendations could be formulated. The list did not fully represent the range of compounds found in the home; guidelines for additional substances will be developed as new data become available.

An important consideration in deriving exposure guidelines for air quality is the possibility of interactive effects, since many pollutants are likely to be present simultaneously in the home environment. Where possible, the potential for synergistic and additive effects was considered in deriving the guidelines. However, in most cases, there was insufficient data to adequately address this aspect.

Selection of Studies to Support Guidelines

Despite the recent widespread interest in indoor air quality, reliable information on the health effects of exposure to the low levels and mixtures of contaminants found in the indoor environment is still inadequate. In most cases, the results of laboratory experiments using animals, clinical studies with human volunteers, and epidemiological investigations of populations in the urban and occupational environments were used as a basis for developing the numerical guidelines. The principles followed in the evaluation of the results of these different types of studies as a basis for the recommended IAQ guidelines are outlined below.

Epidemiological Studies - Most of the relevant epidemiological studies of populations are observational (non-experimental) in nature and are either of the descriptive (cross-sectional) or analytical (cohort and case-control) type. The results of these studies were evaluated against the following features of study design:

- ***Estimation of Exposure*** - In most observational studies of populations exposed to air pollutants, data on exposure are usually obtained from one or several outdoor monitoring stations. Exposure, however, can vary

greatly between individuals living in the same neighborhood, because of local climatic conditions and special features of the indoor environment, e.g., use of unvented combustion appliances.

- ***Role of Confounding Variables*** - In observational studies of populations exposed to air pollutants, a host of confounding variables (e.g., socioeconomic status, smoking, occupational exposure, meteorological factors), many of which have greater effects than air pollution, must be considered.

- ***Measurement of Outcome*** - There is substantial variation in the method of measurement of many of the health-related parameters in the studies conducted to date; such parameters include lung function, hospital admissions and frequency of symptoms. In many of the studies, outcome (e.g., frequency of symptoms) is determined by questionnaire, and responses may be subject to bias.

For these reasons, the epidemiological studies considered most relevant for developing the guidelines were longitudinal investigations in which (1) there was adequate control of appropriate confounding factors; (2) objective health outcomes were determined; and (3) there was some attempt to take into account individual variations in exposure.

The results of epidemiological investigations of effects in the general population were considered more relevant than those of occupationally exposed populations for deriving the exposure guidelines since the young, the elderly, and other high-risk groups are not normally represented in the workforce. Moreover, exposure periods and the mixture of pollutants present in the occupational environment generally vary considerably from those in the general environment.

Clinical Studies: Clinical studies provide the most reliable data from which to derive exposure-response relationships that form the basis for air quality standards. However, these studies are restricted for ethical reasons to the examination of mild, temporary effects of short-term exposures to one or a few pollutants in a limited number of subjects. As such, clinical studies are most suitable for developing short-term exposure limits.

The clinical studies considered most relevant for the derivation of the exposure guidelines were those in which there were appropriate control groups and in which subjects were randomly allocated into control and treatment groups. Studies in which both the investigator and subjects were "blind" (i.e., unaware of which subjects were exposed) in order to minimize bias were also preferred.

Animal Studies: Although numerous studies of the effects of airborne pollutants in animal species have been conducted, levels of exposure have, in general, been much higher than those in ambient air. Extrapolation of these results in order to predict the risks to humans is complicated by the distinct anatomical differences between the respiratory tracts of animals and humans. In addition, studies are frequently confined to unusually high

concentrations of no more than one or two pollutants, rather than to the low concentrations and mixtures of substances general found in the home. However, the results of such studies were used mainly to clarify the toxicity mechanism and to assess carcinogenicity, particularly with regard to formaldehyde.

The reliability of carcinogenesis bioassays in animal species was evaluated on the basis of several features of the design and the results of the study. These features included the size of the experiment (i.e., the numbers of exposed and control animals); the influence of environmental factors (e.g., diet); the route and method of exposure; the doses administered; the species, strain and sex of the animals; the type, site, incidence and time to development of tumors; and the nature of the exposure-response relationship. Information concerning kinetics, metabolism, and the mechanism of action was also considered in assessing the relevance of the results of carcinogenesis bioassays for man.

Derivation of Numerical Guidelines

Non-carcinogenic Substances: For some types of adverse health effects that result from exposure to toxic substances, it is assumed there is a threshold level of exposure below which it is believed that adverse effects will not occur. For such effects, the exposure guidelines were derived by division of the "lowest" or "no-observed adverse effect level" documented in epidemiological or clinical studies by uncertainty factors; the size of these factors varied depending on the adequacy of the available data, the nature and severity of the effect, and variations amongst individuals.

Based on these principles, the guidelines listed in Table I were developed. In order to take into consideration the possible effects of both prolonged exposures and shorter-term, higher-level exposures, two types of guidelines were established, provided that adequate data were available:

- ***Acceptable Long-Term Exposure Range (ALTER)*** - the concentration range to which it is believed from existing information that a person may be exposed over a lifetime without undue risk to health; and

- ***Acceptable Short-Term Exposure Range (ASTER)*** - the concentration range to which it is believed from existing information that a person may be exposed over the specified time period without undue risk to health.

The World Health Organization has used a factor of two to account for uncertainties in data from observational studies in deriving guidelines for daily and annual exposure to air pollutants; this value was adopted in deriving the upper limit of the ALTERs for carbon dioxide, nitrogen dioxide, particulate matter, and sulfur dioxide. It must be stressed that the guideline for carbon dioxide was developed to protect against undesirable changes in acid-base balance and consequential adaptive changes, such as the release of calcium from the bones. The establishment of a more stringent guideline for carbon dioxide on the basis that it would serve as a surrogate for adequate ventilation was not recommended by the Working Group.

Table I:

Contaminants With Numerical Exposure Guidelines

Contaminant	Health Effects[a/]	Acceptable Range $\mu g/m^3$ (ppm) ASTER	ALTER
Aldehydes	Eye, nose, throat irritation	c_i/C_i < 1[b/] 5min	
Carbon dioxide	Acidosis		<6300 (<3500)
Carbon monoxide	Adverse effects on cardiovascular system	(<11)[c/] 8h (<25)[c/] 1h	
Nitrogen dioxide	Respiratory disease;	<480 (<0.25)	1h <100 (< 0.05)
Ozone	respiratory	<240 (<0.12)	1h
Particulate matter[d/]	irritation; and impaired lung	< 100	1h <40
Sulfur dioxide	function	<1000(<0.38)	5 min <50 (<O.019)

a/ Health effects considered are described in relevant sections of reference 1.

b/ C_i = 120 $\mu g/m^3$ (formaldehyde); 50 $\mu g/m^3$ (acrolein); 9000 $\mu g/m^3$ (acetaldehyde), and c_i are the respective measured concentrations.

c/ In parts per million only, so as to be independent of ambient pressure.

d/ < 2.5 μm mass median aerodynamic diameter.

In instances where there was sufficient evidence of transient changes in groups at risk (for example, changes in pulmonary function in exercising asthmatics) in well-conducted clinical studies, an uncertainty factor was not incorporated in the derivation of the upper bound of the ASTERs. Reliable data were available on transient physiological or biochemical changes in human subjects with pre-existing health problems who were exposed to carbon monoxide, ozone, sulfur dioxide, and particulate matter, and, therefore, an uncertainty factor was not incorporated.

Clinical studies indicate that both normal and asthmatic subjects can experience detrimental respiratory effects when exposed for brief periods to nitrogen dioxide

Table II. Contaminants for which Numerical Guidelines were not set

Contaminant	Possible Health Effects[a]
Biological Agents	Infectious disease; allergies
Consumer Products[b] - chlorinated hydrocarbons - pest control products - product aerosols	Damage to central nervous system; allergic reactions
Fibrous Materials	Lung cancer; skin irritation
Lead	Learning impairment; neurological disorders
Polycyclic Aromatic Hydrocarbons (PAHs)	Lung cancer
Tobacco Smoke	Lung cancer; sensory and respiratory irritation

a Health effects considered are described in relevant sections of reference 1.

b Data on the three subgroups were considered separately,

concentrations of about 960 $\mu g/m^3$ [3,4]. However, it was not possible to identify the level at which no adverse effects occur; in addition, no data were available from clinical studies for children, a sensitive subgroup. Therefore, an uncertainty factor of two was applied to derive the ASTER for this substance. Because of the wide variation in individual susceptibility to the irritant effects of aldehydes, the ASTERs for acrolein, acetaldehyde, and formaldehyde were derived by applying a factor of five to the lowest concentration reported to cause a significant increase in symptoms of irritation. The guideline is expressed for total aldehydes to account for the possible presence of more than one of the aldehydes.

Carcinogenic Substances: It is generally accepted that carcinogenesis is a non-threshold phenomenon; therefore, it is assumed that there is a probability of harm at any level of exposure. While exposure to known or suspected carcinogens should therefore be avoided, it is not possible to eliminate certain carcinogens from the environment. Moreover, the incremental risks associated with exposure to the low levels of carcinogens present in the environment may be sufficiently small so as to be essentially negligible in comparison with other risks encountered in society.

Available data indicate that formaldehyde may be carcinogenic to man. This substance was found to be carcinogenic in two strains of rats, producing a high incidence of nasal squamous cell carcinomas (38 -50 percent) following exposure to a formaldehyde concentration of approximately 18 mg/m^3 (15 ppm) [5,6]. Formaldehyde was also found to be genotoxic in a number of assays and weakly mutagenic in cultured human cells as well as in other mammalian cells, *Drosophila*, fungi, and bacteria.

Although the epidemiological studies conducted to date provide little convincing evidence that formaldehyde is carcinogenic in human populations, this possibility could not be excluded by the Working Group because of limitations of the data. Therefore, the long-term exposure guidelines for formaldehyde were set as low as possible taking into account the feasibility of remedial measures. The guidelines, are expressed both in terms of an "action level" of 120 $\mu g/m^3$ (0.10 ppm), the lowest concentration considered to be feasible at the present time, and a longer term "target level" of 60 $\mu g/m^3$ (0.05 ppm). The guidelines also state "that in the future, and where remedial measures are taken, every effort be made to reduce (formaldehyde) concentrations to below the target level."

Based on a model which takes into account some of the mechanistic toxicological data, the maximum risk of cancer for continuous lifetime exposure to the levels specified in the guidelines is in the range of 1 in 10,000 to 1 in 100,000. It seems likely that these calculated risks are overestimated because of the conservative assumptions upon which the mathematical model is based, and the lack of understanding of the mechanisms by which formaldehyde may induce cancer.

Relative Humidity: Extremes of humidity are primarily associated with sensations of discomfort or annoyance. The Canadian Working Group on IAQ, however, developed its relative humidity (RH) guidelines to protect occupants from health hazards that might arise indirectly from too much or too little humidity. Several species of bacteria and viruses survive best at low or high, rather than intermediate, levels of humidity.

Condensation of water on cold surfaces (e.g., on windows in winter, and on basement floors and plumbing in the summer) can also promote the growth, and hence potential for airborne dispersion, of mites and allergenic or mycotoxin-producing molds. Furthermore, the behavior of other pollutants, notably the release of formaldehyde from wood products and insulation, can be affected by humidity levels. Two guidelines were therefore specified; 30 - 80 percent RH for the non-heating season, and 30 - 55 percent RH for the heating season. In the latter case, a provision was allowed to relax the lower limit so that condensation on windows does not occur.

Guidance Respecting Other Indoor Contaminants

Table II lists other contaminants or groups of contaminants which are likely to be present in residential indoor environments and which are potentially hazardous to human health. The development of quantitative exposure guidelines for these parameters was, however, considered to be inappropriate for the following reasons:

- For some groups of substances, individual components have widely differing toxicological properties -- the complexity of the mixtures precluded establishing a guideline for each constituent or for the group as a whole;

- Limiting airborne concentrations was not considered to be the appropriate strategy for effectively reducing intake, especially where inhalation is not the most significant route of exposure; and

- Available scientific data were inadequate.

For these substances, information on possible sources in residential indoor air and potential adverse health effects was provided; in addition, recommendations that should help to eliminate or reduce exposure were given.

Application of the Residential Guidelines

In Canada, no single agency or organization has sole responsibility for investigating and controlling the potential health impacts of indoor air pollutants. Moreover, in the case of residential buildings, involvement by government may, on the one hand, be viewed as an intrusion and, on the other, as a necessity. The complexity of the situation is well illustrated by the wide variety of approaches that are possible for controlling exposure to airborne pollutants that may be present in indoor environments. These approaches include:

- Ventilation;
- Source removal or substitution;
- Source modification;
- Source avoidance;
- Air purification;

- Restrictions on the use of potentially hazardous chemicals in the home;
- Certification programs for builders and trades people;
- Mandatory courses for engineers and building designers; and
- Educational programs for the general public.

These approaches need not be mutually exclusive and corrective measures could involve a balanced application of several or all of them. The extent to which controls need to be exercised should be determined to a large degree by specifications or criteria, which define a quality of air that is conductive to good health and comfort. It was for this reason that the "Exposure Guidelines for Residential Indoor Air Quality" were developed. Although these guidelines have been approved by government departments across the country, they are neither mandatory nor enforceable as standards. It is expected, however, that the guidelines will assist individuals and public health agencies in making consistent judgments about the need for remedial measures. In the longer term, it is anticipated that the national guidelines will be used as a basis for developing or modifying building codes, product standards for construction materials and furnishings, and ventilation requirements. In this regard, the committee, which participated in the revision of ASHRAE 62-1981, proposed that the Canadian guidelines be included in an appendix of the new standard.

It must be stressed that the Canadian exposure guidelines are not intended to apply to other indoor environments, such as office building or other work places where factors such as multiple occupancy may be important.

Related Programs

Residential Guidelines for Radon

The development of a guideline for radon in Canadian housing has been under review since 1985 by the Federal-Provincial Subcommittee on Radiation Surveillance and the Federal-Provincial Advisory Committee on Environmental and Occupational Health.

Inhalation of radon and radon daughters leads to exposure of the bronchial tissue of the lungs to radioactive substances with a resultant risk of cancer. More than 95 percent of the radiation dose results from the deposition of the radon daughters. The increased risk of lung cancer among uranium miners exposed to radon and radon daughters has been well documented in a number of epidemiological studies. Therefore, since radon is a documented human carcinogen, indoor levels should be reduced as much as possible.

The Federal-Provincial Subcommittee on Radiation Surveillance initially proposed that a single "action level" of 800 Bq/m^3 be adopted as an exposure guideline for radon in Canadian housing. The subcommittee recommended this level as the annual average concentration above which remedial measures should be initiated in existing homes. This proposal is under review by the federal and provincial governments, and it is likely that a more stringent "target level" will also be specified. The target level, in effect, would be

a long-term goal that should encourage both the development of technology that would enable or facilitate the implementation of remedial measures, and attainment of lower levels in new buildings in the future. The approach would thus be similar to that followed in developing the long-term exposure guidelines for formaldehyde.

Guidelines for the Office Environment

As a result of an increasing number of complaints about air quality in Canadian office buildings, the Conference of Deputy Ministers of Health approved, in February 1987, the establishment of a Working Group to assess the problem of air quality in the office environment and to develop recommendations for actions to deal with this issue. The Federal-Provincial Working Group on Air Quality in the Office Environment subsequently met twice and concluded that complaints about office air quality should be addressed by developing a standard investigation protocol. The protocol should involve various levels of investigation and include a walk-through inspection; measurement of contaminant levels, ventilation rates, and thermal comfort; and an assessment of the prevalence of symptoms of ill-health and discomfort. It is likely that this approach will be examined in further detail by a working group under the auspices of the Federal-Provincial Advisory Committee on Environmental and Occupational Health.

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Canadian Ventilation and Venting Standards

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Introduction

Field, laboratory, and theoretical research has shown a strong relationship between ventilation practices and venting problems with combustion appliances. The ventilated house can become a much better competing chimney than the designated combustion appliance venting system, causing the supposedly vented appliance to spill combustion products into the house, sometimes completely and in a totally stable mode. Even in leaky houses, this situation is undesirable, because of the total volume of combustion products that can be released each year. As a result of this research, new test equipment, products, and procedures, have been developed. In addition, building and installation codes for appliances, as well as equipment and component standards, are being modified.

The Codes and Standards System

The Associate Committee for the National Building Code (ACNBC) revises its model document on a five-year cycle. The next revision will take effect in 1990 [revisions have been completed].

The code is used for Federal buildings and for the territories, but the provinces have the direct responsibility for housing and health matters. The provinces may choose to adopt the model code unchanged, or may amend it, by addition or deletion, to suit their unique requirements and/or perceptions. Most municipalities are given the authority and responsibility for enforcing the codes. The provinces arrange for inspections in areas which do not have their own capability. The code may reference standards developed by Standards Writing Organizations (SWOs), or may select specific requirements from those standards (or from their own requirements, based on local experience) for incorporation into their provincial codes.

Coordinating Committee on Combustion Venting of the ACNBC

The ACNBC has authorized the establishment of this new committee to coordinate the interrelated requirements for venting of combustion products and ventilating indoor spaces. The committee is composed of representatives of the many ventilation and

venting code and standards groups and committees, and their associated industries. The committee's task is to ensure that a coordinated set of requirements, and changes in requirements, is submitted for the 1995 revision of the code, especially as they pertain to Part 9. The development of CSA F326, "Residential Ventilation Requirements," is intended to set the stage for this coordination, but other codes and standards will require amendment.

The 1990 Code Requirements

Continuous mechanical ventilation, at 0.3 air changes per hour averaged over any 24-hour period, must be installed, subject to Part 6 of the code, if the system installed is not a simple, exhaust-only system; and subject to prescriptive requirements of Section 9.33, for simple systems. The prescriptive requirements include incorporation of make-up air openings, if appliances susceptible to pressure-induced spillage are installed, unless testing shows excessive depressurization is not a problem. A table of sizes of make-up air openings is provided, based on a depressurization limit of five Pascals. An Appendix to the Code Requirements provides an extensive commentary and examples.

CSA F326 on Residential Mechanical Ventilation Requirements

CSA F326 is essentially an interpretation of ASHRAE 62-1989 for single-family dwelling units under normal occupancy conditions. CSA F326 is designed so that the system can supply the greater of a room rate summation of flows or 0.3 ACH (but can be switched off by the occupant). The system can be a supply-only, exhaust-only, or nominally balanced mechanical system. CSA F326 ignores uncontrolled ventilation. Pressurization is limited to ten Pa, or to a flow of 0.12 l/s/m^2 of envelope area to limit forced-outflow condensation. Depressurization is limited to ten Pa (only for the ventilation system). For a system with a clothes dryer, with the two largest exhaust devices operating, CSA F326 provides for five Pa if spill or backdraft sensitive appliances are installed; ten Pa if only induced draft appliances are installed; or 20 Pa if only sealed (or not any) combustion appliances are used.

CSA documents and status are as follows:

- F326.1 Requirements (preliminary standard issued)
- F326.2 Installation Requirements (in printing)
- F326.3 Performance Verification (drafted)
- F326.4 Design Guidelines (under preparation)

Appliance Installation Codes

Some effort is underway to revise all of the major installation codes and appliance standards. The installation codes (plus one equipment standard) include:

- CSA B139 - Installation Code for Oil Burning Equipment
- CGA B149 - Natural Gas Installation Code

- CSA B365 - Installation Code for Solid Fuel Burning Appliances and Equipment
- CSA A405 - Design and Construction of Masonry Chimneys and Fireplaces

CSA B139 - Installation Code for Oil Burning Equipment

The committee is preparing a major revision, after many years of inaction. The new version will include revised sizing requirements for vents, plus a minimum allowable chimney-base gas temperature, designed to eliminate steady-state condensation. The version incorporates sizes of newly-designed liners which incorporate mechanical alignment (spigots, rabbets, etc.), with sizing based on a flue gas velocity range (one to two m/s). Gas temperatures at the chimney base are designed to prevent the liner temperature at the exit from going below 60°C. This change may lead to radical redesign of chimneys, with more effective insulation values, and more reliable venting.

CGA B149 - Natural Gas Installation Code

The committee is awaiting a major, system-level study of sizing and insulation requirements for depressurized house conditions. The committee has already recommended downsizing of vents from historical levels. The next major revision is due in 1991. The changes should result in more reliable venting, even in competitive situations.

CSA B365 - Solid Fuel Burning Equipment Installation Code

CSA B365 is presently under a significant revision program, under which fresh air intakes will be given much more prominence. Flue sizing recommendations are being redeveloped, and may result in significant downsizing. Coordination with CSA A405 on masonry chimneys and fireplaces is assured through multiple common memberships.

CSA A405 - Design and Construction of Masonry Chimneys and Fireplaces

A405 is being significantly revised, with the intent of having it become more of a stand-alone document, and better justified by theory as well as laboratory and field testing, so that CSA A405 can be used by more local authorities. Sizing recommendations are being developed by CMHC for use with oil appliances (as per B139), and by Energy, Mines and Resources Canada, CCRL, for fireplaces. In both cases, recommended sizes will be smaller and insulation will be required. Much more research must be done before all important questions have been addressed.

Section VI

Solving Problems in Buildings

Indoor Air Quality Building Surveys Case Studies

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In view of the general principle that a provincial legislature or municipal council cannot bind the Parliament of Canada, the Government of Canada has the exclusive responsibility to take such measures as may appear necessary or advisable to protect the property of Canada, and to provide safe and healthful working conditions and procedures for all persons who occupy or visit this property.

The Canada Labor Code, Pan II, Occupational Safety and Health states that in the undertaking of any federal work and for companies under inter-provincial charter every employer shall:

- Ensure that the safety and health at work of every person employed is protected [124];
- Ensure that all permanent and temporary buildings and structures meet the prescribed standards [125(a)];
- Ensure that the levels of ventilation, lighting, temperature, humidity, sound and vibration are in accordance with prescribed standards [125(n)]; and
- Ensure that all hazardous substances in the workplace are controlled in accordance with prescribed standards [125.1(a)].

The Canada Labor Code authorizes the Department of Labor to prescribe and enforce concentration limits of chemical, biological, and physical agents in the workplace. Canada Occupational Safety and Health Regulations specify that the limit shall be less than the threshold limit value (TLV) adopted by the American Conference of Governmental Industrial Hygienists (ACGIH). Unfortunately, ACGIH threshold limit values are set for industrial workplaces and not for office environments. As a result, the TLV may be several orders of magnitude higher than office workplace levels.

Treasury Board Personnel Management Manual Chapter 3, also deemed part of collective agreements with civil service unions, cites that, to the "extent practicable," ASHRAE standards should be applied in the workplace environment. To the extent practicable, the environmental conditions to be maintained in office buildings shall conform to the requirements specified in ASHRAE Standard 55-1981, "Thermal Environmental Conditions for Human Occupancy" and ASHRAE Standard 62 -1981, "Ventilation for Acceptable Indoor Air Quality."

ASHRAE Standard 62-1981 has been revised to 62-1989 and prescribes two methods for ensuring acceptable IAQ. One method, the Ventilation Rate Procedure, provides a ventilation rate in liters per second (l/s) per person chosen to control CO_2 and other contaminants. For offices, 10 l/s per person is prescribed, which is equivalent to approximately 800 ppm CO_2.

The other method, the IAQ procedure, provides a direct solution by restricting the concentrations of certain contaminants to some specified acceptable level. This method recognizes that there may be strong sources of contaminants irrespective of occupant density (e.g., CO_2). Examples of such sources are: processes (such as a printing shop); building materials or furnishings; cleaning and maintenance materials; and improper building system operation and maintenance.

While the ASHRAE standard is a good one, it does not mitigate the need for expert help and judicious interpretation. Certainly a CO_2 reading of under 800 ppm does not guarantee a good environment. In addition, ventilation is simply a process of dilution: contamination levels are decreased by increasing ventilation. More expedient (and cheaper) methods of insuring good indoor air quality include removing the contaminant source (if possible), directly exhausting the contaminant, and selecting a less toxic contaminant substitute.

While the regulatory aspects of indoor air quality are based on ACGIH and ASHRAE standards, there are certain shortcomings in this approach:

- ASHRAE's definition of acceptable air quality is very broad: "Air in which there are no known contaminants at harmful concentrations determined by cognizant authorities and with which a substantial majority (80 percent or more) of the people exposed do not express dissatisfaction."

- Exposure limits are designed for use in industrial occupational environments, where there is exposure to high concentrations of a small number of pre-identified compounds. The existing occupational health standards rely only on studies addressing one compound at a time, and do not reflect the possible additive or synergistic effect of multiple exposures in office spaces. In fact, office workers are exposed to a broad spectrum of contaminants, present at very low concentrations relative to permissible exposure levels.

- Only a fraction of the possible number of contaminants in indoor air have an exposure limit. New materials, products, office equipment, and processes generate tens of thousands of chemicals, especially organic compounds. Buildings cultivate and disseminate a multitude of micro-organisms, including fungi, spores, mold, and bacteria. Epidemiological studies and limits on exposure to these contaminants, some of which are mycotoxic or carcinogenic, have not yet emerged.

- Occupational standards do not seem to apply to office requirements. The composition of the work forces is also different and perhaps a contributing factor: there are more healthy, younger males in industrial workplaces. Neither does the standard address the hypersensitive individual nor the differences in "environmental expectations" between industrial and office workers.

It is clear that a lot more research and study is needed before adequate and complete IAQ standards are available.

This discussion on IAQ standards and regulations may appear rather daunting; however, in the majority of problem building cases, a solution is found. According to the National Institute for Occupational Safety and Health (see Table 1) studies, no cause could be determined in only 12 percent of the buildings.

In conducting an IAQ survey, a standard protocol should be followed:

1. Preliminary discussions and interviews to establish the possible problem areas, a walkthrough and inspection of the building systems, and a review of the drawings, control logic, and other pertinent documentation;

2. Simple measurement of selected parameters, such as CO_2, CO, temperature, humidity, presence of microbials, and air movement;

3. More complex measurement of volatile organic compounds (pump, charcoal tube, GC/MS or photoionization detector), particulates (pump, filter or light-scatter detector), radon (alpha etch detector, sniffer), air velocity (hot-wire anemometer), air volume (flow hood), and ventilation effectiveness and circulation (tracer gas, GC).

In many cases, the problem (and possible solution) becomes apparent during the walkthrough, and simple measurements may be taken to confirm the hypothesis.

Finally, why do we care about comfort criteria? Because poor indoor air lowers productivity and increases absenteeism costs! Over a 50-year span, building capital costs two to four percent, building operating costs six to eight percent, and salaries cost 88 - 92 percent of the total building expenditure.

TABLE 1

NIOSH IAQ INVESTIGATIONS (1979 - 1986)

Problem Type	Completed	Percent
Inadequate Ventilation	232	52
Contamination (inside)	75	17
Unknown	54	12
Contamination (outside)	50	11
Contamination (microbial)	22	5
Contamination (building fabric)	13	3
TOTAL:	446	100

Complaint	Percent of Buildings
Eye Irritation	81
Dry Throat	71
Headache	67
Fatigue	53
Sinus Congestion	51
Skin Irritation	38
Shortness of Breath	33
Cough	24
Dizziness	22
Nausea	15

CASE STUDY - A

Description

Large downtown office building, 25 floors with a four-story underground garage. Floor area of 26,000 square meters.

Problem

Complaints of headaches, lethargy, and fainting spells from personnel in the 3rd floor conference translation booths. A study has been previously done, sampling six sites for CO_2, temperature, and humidity (at a cost of $1,350). All measurements were found to be within ASHRAE standards. Recommendations were made to increase the outdoor air supply.

Measurements

CO	8 ppm booth (10:00 a.m.) 12 ppm corridor (2:30 p.m.) 16 ppm stairwell (2:30 p.m.) 170 ppm garage (5:00 p.m.)
CO_2	450 - 500 ppm
Temperature	20.5 - 21.2°C
Humidity	12 - 19% RH
Formaldehyde	0.05 ppm
Total VOCs	2.13 - 4.20 mg/m^3 (hydrocarbons)

Observations

- Boards placed to close to garage fresh air louvers;
- Garage heating system shut off;
- Main humidification boiler shut off;
- Humidistats and controllers defective and/or disconnected;
- Air handling filtering system and mixing plenums dirty and in disrepair; and
- Roll filter system not operating, frames damaged.

Recommendations

- Open and operate garage ventilation/heating system. ASHRAE CO standards are 9 ppm (8 hours) and 50 ppm (1 hour).

- Monitor garage attendant booth for CO levels, pressurize if required.

- Operate at a minimum humidity level of 20 percent RH; calibrate humidity controls.

- Repair, clean, and maintain air handling and filtering systems.

- Implement operating and maintenance guidelines for building systems operation.

Notes

- A meeting was required prior to survey due to the questions and concerns of employees, union, management, and the building owner.
- A court injunction was obtained against landlord to unblock and operate garage ventilation system.
- Volatile organic compounds sampling was conducted but analysis was not required.

CASE STUDY - B

Description

Rectangular, two-story multi-purpose office building, 32,500 square meters, facing a ten lane road. Occupancy between 800 - 1,200 employees. Built in 1955.

Problem

Belief that vehicle emissions were entering building fresh air intake situated at ground level, facing the road. Complaints of headaches and general lack of well-being.

Measurements

CO	0 - 4 ppm (7 ppm outside)
CO_2	375 - 650 ppm
Lead	not detected (sampled by pump and filter; analyzed by X-ray fluorescence spectroscopy)
Temperature	22 - 24.5°C
Humidity	24 - 34% RH
Formaldehyde	less than 0.1 ppm
Total VOCs	17.98 mg/m^3 (toluene 3.7 mg/m^3, n-decane 2.8 mg/m^3, methylcyclohexane 1.6 mg/m^3)

Observations

- Three offset printers in print shop unvented (except via return air);
- Improper storage of solvents and disposal of cleaning rags;
- Poor maintenance and housekeeping;
- Ceiling tiles missing, broken or soiled, dirty and cluttered hallways, storage of boxes, racks, and other items in hallways; and
- Humidity control for each system achieved by measurement of the supply air humidity level (by probe and gauge) and then by manual adjustment of the humidifier.

Recommendations

- Install a dedicated exhaust system for the offset printers.
- Install an approved vented paint and solvent storage cabinet and refuse container.
- Repair and paint ceiling tiles.
- Increase housekeeping efforts and schedule day-shift cleaning.
- Remove all items stored in hallways.

- Automate humidity control.

Notes

- A total volatile organic compound (TVOC) level of 17.98 mg/m^3 is way above expected values. Although no standard or guidelines currently exist for TVOC levels, research by Molhave of Denmark suggests that complaints of sensory irritation and dryness in nose and eye, which are frequently symptoms of sick building syndrome, occur at concentrations above 2.0 mg/m^3 (ASHRAE Transactions 1986 V.92). The American Industrial Hygiene Association (AIHA) proposed a TVOC guideline of 5.0 mg/m3 (approximately one ppm) at the 1987 IAQ Berlin Conference. ACGIH TLVs exist for toluene (375 mg/m^3) and for methylcyclohexane (1,600 mg/m^3). The measured values are 1/100 and 1/1,000 of the TLV respectively, underscoring the problem of using industrial workplace standards in the office environment.

  Public Works building TVOC samples have ranged from 0 to 6 mg/m^3. Clearly more investigation is required, especially in the related areas of material off-gassing, "bake-off" of new buildings, and building commissioning, retrofit, and re-carpeting.

CASE STUDY - C

Description

A twin-tower, 11-story downtown office building, containing three interconnected commercial floors and an 11-story atrium in each tower. Built in 1976, each floor is 3,000 square meters, containing both open plan and enclosed offices.

Problem

Non-specific occupant complaints concerning poor IAQ and temperature variations. Multi-disciplinary studies (lighting, thermal comfort, ventilation, acoustics, functional space analysis, and air quality) were conducted.

Measurements

CO	0 - 0.5 ppm
CO_2	525 - 750 ppm (fresh air supply 380, 420, 425 ppm and 400, 450, 475 ppm in two mechanical rooms)
Outdoor CO_2	370 ppm
Temperature	21.4 - 24°C
Humidity	19 - 22% RH
Formaldehyde	0.15 - 0.22 ppm (ASHRAE 0.1 ppm)
Total VOCs	0.12 - 5.77 mg/m^3 (13 samples)
Particulates	10 $\mu g/m^3$ (respirable)

Observations

- Fresh air supply CO_2 levels indicate an external pollutant source;
- Inspection on roof confirmed re-entrainment of exhaust air (25 percent by calculation); and
- High levels of formaldehyde and TVOCs due to new fit-up of space (off-gassing of furnishings, partitions and carpeting) and re-entrainment of exhaust air.

Recommendations

- Redesign two exhaust systems to eliminate re-entrainment into the fresh air intakes, and operate ventilation system continually (24 hours per day) in retrofit areas to reduce VOC emission.
- Increase humidity to a minimum of 25 percent RH.

Notes

- Eight out of 13 sampling sites had TVOC concentrations greater than 2.0 mg/m^3, including two locations greater than 5.0 mg/m^3. Individual compounds were measured between 0.015 - 0.004 percent of the TLVs.

- No other major environmental problems were noted in the other disciplines.

CASE STUDY - D

Description

A four-story, "E" shaped building, 12,000 square meters, consisting of office space and a cafeteria. Six HVAC systems condition the interior environment. Built in 1955.

Problem

Sick building symptoms, complaints of discomfort such as allergic reactions at work, which disappear on weekends. Streaking of ceiling adjacent to air diffusers.

Measurements

CO_2	575 - 725 ppm
Temperature	21.3 - 23.8°C
Humidity	21.3 - 28.6% RH
Particulates	ND - 0.14 mg/m^3 (no metals or fibers)
Formaldehyde	ND - 0.02
Total VOCs	0.108 - 0.387 mg/m^3 (10 samples)
Microbials	6 - 807 colony forming units/m3 (CFU) (five samples)

Observations

- Microbial count of 807 colony forming units too high (perhaps 60 - 70 times normal) and *penicillium viridicatum* fungus is hazardous because it can produce mycotoxins. Although microbial guidelines are sketchy at this point, a count of over 100 CFU indicates that the species should be identified, and a count of over 500 CFU indicates a problem. Clearly, a problem existed. Fortunately, during the walk-through, a non-maintained water spray humidifier system and blocked drainage tank were noted. The system was unblocked on day one, cleaned with undiluted Javex on day two and subsequent days, and all associated ducts, diffusers, carpets, drapes and surfaces were cleaned on the following weekend.

  Further sampling resulted in counts of 6 CFU in the affected areas, indicating that the fungal contamination had been eliminated. Monitoring will continue every three months for a year. The summer may produce other possible fungal "amplifiers" to reactivate the microbial growth. The humidification system has been drained and shut down pending a decision whether to replace it with a steam unit or reactivate the existing system.

  To quote the laboratory research scientist: "People in casual contact with the office in the past are in no risk. People who worked in the office may have acquired an allergy and possibly suffered other discomfort if the fungus is toxigenic, or if mild hypersensitivity pneumonitis occurred. It is unlikely that any permanent health problems have been caused."

- New computer control and monitoring system for all six HVAC systems had recently been installed;
- High readings of CO_2 (600 - 720 ppm) at 8:30 a.m. indicates that there is possibly no overnight flushing of the building;
- Pipe insulation slightly damaged in the mechanical rooms; analysis indicates 50 - 75 percent composition of chrysotile asbestos;
- Presence of desk fans and evidence of occupant tampering with the ventilation supply highlight possible air balancing problem; and
- Changes to the building's mechanical systems have not been recorded completely; building operating and maintenance manuals did not exist.

Recommendations

- Carefully monitor microbial levels every three months.
- Establish an operating procedure and maintenance schedule.
- Ceiling areas near diffusers had particulate buildup consistent with 30-year old systems. The areas should be cleaned and painted, the ducts and the mechanical rooms, which serve as mixing plenums, should be vacuumed.
- The kitchen exhaust system should be removed from the mechanical room to stop the migration of cooking odors to the supply air.
- The amount of fresh air should be determined. Either ten liters per second per person or a minimum amount of 15 percent should be maintained.
- Ventilation rate should be checked and system re-balanced if necessary.
- Damaged pipe insulation should be repaired and encapsulated.
- Higher humidity levels (25 - 30 percent RH) should be maintained.

Notes

- Due to the unfamiliarity with microbial contamination, it was difficult to mount a coordinated and concerted clean-up, and no single knowledgeable contractor existed. Workers were not informed of the risks and no protective clothing or face masks were provided.

Design of Indoor Air Quality Studies

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Procedures currently used by environmental investigators to assess the quality of air in buildings vary widely and can result in contradictory conclusions. With vaguely defined goals and no widely accepted standard protocol available, many IAQ complaint investigations fail in terms of either not identifying the cause of building-related symptoms or falsely accusing the wrong "suspect." The most common reasons that IAQ investigations arrive at such misleading conclusions are (1) an overemphasis on sampling, (2) an underemphasis on deductive reasoning (common sense), and (3) a tendency to blame the obvious (e.g., dirty ducts) when the most critical factors are more subtle. The purpose of this paper is to summarize general guidelines for conducting such studies in a systematic manner.

Over the past several years, IAQ studies have increasingly been conducted for non-research purposes. Such investigations can be categorized as follows:

- Investigation of occupant complaints or suspected problems;
- Pre-occupancy consultation; or
- Baseline surveys (sometimes with periodic follow-up).

The interior building environment represents a dynamic and complex "eco-system." An understanding of how key factors change over space and time within the building and how they interact is critical to the success of any IAQ study.

Sources of indoor air pollutants have been characterized in the technical literature and often sensationalized in the popular press. Interior pollutants may commonly originate from building occupants and their activities, equipment emissions, new furnishings, contaminated building materials, or outside sources drawn into the building. Ventilation is often the single most important factor determining whether these emissions present a problem. Air movement determines which building areas are actually affected by any given source. With an absence of IAQ standards, the bottom line for exposure often is whether a complaint situation exists. A building-related complaint could include anything from an acute health problem, to a health risk perceived as unacceptable, to false allegations originating from disgruntled employees.

General Strategies

In a complaint situation, allegations should be characterized as objectively as possible to determine if there are any patterns which tend to implicate or rule out actual building conditions. The most conclusive data are generated by medical exams and statistically-based epidemiology. Complaint data for most IAQ studies are constrained by project limitations to interviews or qualitative epidemiology. Such evaluations should be designed to spot, at a minimum, any consistent symptoms which suggest general syndromes and any special times, locations, or conditions where they appear to be most notable.

The early stages of any IAQ study should also include a characterization of potential sources. While pollutant measurements are only a "snapshot" in time, a source characterization should ideally include a description of the range of potential emissions including worst case conditions and affected areas. Background information can be obtained from building plans and interviews with operating personnel. Historical descriptions of past episodic events are of particular interest. On-site inspection should document any indicators of source emissions, such as unusual odors, excessive dust, or staining.

Similarly, an IAQ assessment should include a general evaluation of HVAC systems. Critical observations relate to ventilation rate, ventilation efficiency, pathways for contaminant movement, and equipment sanitation. Not only should conditions at the time of inspection be checked, but the range of conditions expected over a typical year should also be considered.

Ideally, air sampling should not be initiated until most of the preceding information is available. Because air quality can fluctuate widely over space and time within any building, a successful sampling strategy should be based on a comprehensive understanding of how the building operates, the nature of the complaints and any visual or odor observations resulting from the inspection. The minimum goal of sampling should be to reflect both average and worst case conditions. At each sampling site, key factors that determine air quality should be documented. Although most samples are generally collected in the occupants' breathing zone, diagnostic samples (to locate sources and potential pathways for contaminant movement) may also be needed. Routine parameters commonly used to characterize indoor air include carbon dioxide, carbon monoxide, respirable suspended particulates, temperature, relative humidity, and smoke tube observations. Other parameters should be carefully selected based on specific building concerns.

A scientific approach to resolving IAQ problems should include formulating and then testing a series of hypotheses. Information generated from building inspections and interviews and sampling data should then be compared to an hypothesis. If a consistent pattern is not demonstrated, then other hypotheses should be considered, not necessarily limited to IAQ issues.

A series of hypotheses may necessitate an increasingly detailed evaluation to resolve complex IAQ problems. This process can be conducted in phases, beginning with an initial, in-house effort to document obvious conditions. The next phase often consists of a comprehensive screening by specialized investigators. In such a screening, the number and types of air samples are generally limited. The final phase, if needed, includes detailed, quantitative studies designed to evaluate specific issues.

Special Considerations

The outcome of an IAQ study can be easily prejudiced by the selection of study boundaries. A common client request is to study the IAQ complaint in only one room. Ideally, an IAQ study should include the entire building in order to evaluate all factors and put them into perspective. At a minimum, an investigation should include the complaint area, adjacent areas, any other potential sources, related air handling equipment, and a control site (e.g., similar area without complaints).

A standard protocol for the assessment of asbestos-containing material (ACM) involves dividing the building into homogeneous areas where similar suspect material is present. Representative bulk samples are then collected and the results applied to the entire area. While the number of variables present in an IAQ investigation is much greater, a similar approach can be applied by dividing the building into homogeneous areas, based on the key factors identified in the initial building inspection and interviews. Examples of how a building might be divided include:

- Individual HVAC zones;
- Types of HVAC zones (i.e., interior vs. perimeter);
- Complaint vs. non-complaint areas;
- Complaint types; and
- Relationship to major sources (i.e., spaces directly, indirectly or not impacted by smoking areas).

Although each area may not be identical, the key factor within any grouping should be similar. Test sites can then be selected to represent complaints, controls, and potential sources with a reasonable number of samples.

The most effective control for an intermittent IAQ problem is to schedule IAQ investigators on-site, full-time. If the odor or symptoms only occur occasionally, they inevitably do not occur during the scheduled IAQ study. An intermittent odor or illness situation may be very difficult to track down in one or two visits (i.e., "You should have been here last week!"). One cost-effective approach to this type of problem is for the IAQ investigator to assign appropriate building personnel to document changes over time. For example, if an odor episode occurs, the building engineer could inspect the air handler and intake area while the building manager walks by three potential sources. Obvious odors detected at this critical time may identify the source. In another approach, occupants could keep a daily diary, noting symptoms and building conditions. Simultaneously, the building engineer could record the daily status of HVAC systems and

suspect sources. A correlation (or lack thereof) could help resolve the complaint. Building conditions can also be manipulated to recreate worst case situations during the scheduled on-site IAQ investigation (i.e., arrange for the trash truck to idle at the loading dock or HVAC intake dampers to be manually set at minimum). Finally, tracers can be used to estimate where emissions would travel during worst-case conditions. For example, peppermint oil released at a roof top exhaust or flushed down a drain might identify important source/receptor relationships. Similar observations of smoke tubes can also define areas affected by intermittent emissions.

In addition to the routine IAQ indicators noted above, numerous other chemical, microbiological, and physical parameters may be included in a building assessment. These parameters should be selected very carefully with advance consideration as to how the data will be interpreted. Ideally, additional test parameters should only be included where potential source problems are observed or symptoms suggest a certain agent is present in the environment. When clients insist on "testing for everything," efforts must be made to provide appropriate controls and present information on normal background levels. Traditional industrial hygiene procedures may not be optimal for an IAQ assessment. Care must always be given in selecting a meaningful detection limit and averaging time for the IAQ setting.

Where specific exposure problems are documented, the development of remedial measures may require more detailed diagnostic testing to locate major sources. For example, the control of microbial or pesticide contamination may involve surface or bulk sampling. Sites with the highest residues can be highlighted for cleanup efforts. Diagnostic testing may also involve the use of tracers to locate pathways of contaminant movement.

One last issue important to the design of IAQ studies is the degree of detail. The quickest and cheapest way to resolve a relatively simple IAQ complaint is a qualitative study in which sampling is kept to a minimum. At the other extreme, a statistically-based study design presenting quantitative epidemiology and sampling results may be needed where there are complex technical or legal issues. In all cases, realistic study goals should be determined initially, with a corresponding study design based on cost, time, and practical constraints on the project.

Interpretation of Data

Unlike the more regulated environmental program areas, there are no IAQ standards defining whether test results are acceptable. Guidelines, available for some parameters, are subject to conflicting opinions among experts and should be tempered by site-specific considerations. IAQ data can also be interpreted by comparing elevated readings to control areas or to the expected background range for buildings without perceived IAQ problems. In a complaint investigation, unusual readings should be evaluated further for possible associations with symptom patterns. In a baseline study, elevated readings might highlight the need for revised operations and maintenance procedures which could improve air quality. As emphasized earlier, IAQ studies should

attempt to define worst-case conditions. In this regard, sampling results can be extrapolated (at least qualitatively) to estimate worst-case occupant exposure.

Absolute or relative air quality concentrations may not provide the solution in an IAQ complaint investigation. These readings comprise only a part of the data base needed to develop possible associations between building conditions and symptom patterns. This process should also take into account how air quality changes in the building over time and space. If unusual exposure conditions are generally consistent with major complaints, then a positive association can be tentatively concluded. A "perfect fit" is very rare, due to mobility of building occupants, varying sensitivities, and psychosomatic complaints. A general inconsistency between building conditions and complaints can form the basis of a negative finding. Failure to show either a positive or negative association may indicate the need for more diagnostic data, or a trial and error approach (i.e., eliminate or modify one building factor at a time).

Positive associations should be clarified as to whether they represent hypersensitive individuals only or suggest risk to the general population. Identified air quality problems should also be classified as to whether they are primarily due to excessive source emissions or to inadequate ventilation.

In addition to looking for specific associations, IAQ results can be reviewed for unusual findings which suggest a potential risk to health. Positive conclusions may result where readings are considered to be elevated or emission sources and general indicators (e.g., odors) are suspect. Positive findings from an IAQ investigation should be presented in perspective with efforts to differentiate between minor and major problems. Conversely, air quality concentrations within a pre-determined background range or HVAC operation within ASHRAE standards may be considered negative findings.

A detailed assessment of indoor air quality in a facility should rarely result in simple, uniform conclusions. Care should be taken to distinguish between differences in various occupant groups, building areas, and time periods. For example, a positive association with microbial contamination may be found, but only with allergic individuals in zones A and D during the cooling season. At the same time, potential ventilation problems could be found in zones B and C.

In summary, an IAQ investigation is much more than the simple collection of data evaluated for compliance with "standards." A multi-disciplinary study team with an understanding of the unique technical and practical aspects of IAQ is a prerequisite to the successful implementation of the protocols outlined in this paper.

Summary Findings of the Inter-Ministerial Committee On Indoor Air Quality (Ontario)

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Preface*

The environmental awareness of the 1960s and 1970s has spilled over into other areas. One new area of concern is the indoor environment of our homes, offices, and schools. The indoor environment has received increasing attention from the occupants, ventilation engineers, and other specialists. Not only do people spend on average 70 - 90 percent of their time indoors, but most new jobs in Ontario are created in the service sector and these employees are usually located in modern offices.

The energy crisis of the early 1970s prompted building owners to construct energy efficient buildings. Building owners achieved this by constructing "air tight" buildings in which air infiltration and exfiltration were reduced. However, as buildings become more energy efficient, occupants' complaints of "stuffiness" or "stale air" increased. Several terminologies are used to describe these complaints such as sick building syndrome (SBS), tight building syndrome (TBS), and closed building syndrome (CBS).

The Ontario Ministries of Labor (MOL), Health, Education, and Government Services (MGS) and local health units have investigated more than 2,000 indoor air complaints since 1976. Most complaints concerned air-tight, multi-story buildings equipped with central HVAC systems, with some complaints from schools with or without HVAC systems. In many cases, the causes of the symptoms could not be found.

* This article summarizes the key findings of the report entitled, "Report of the Inter-Ministerial Committee on Indoor Air Quality, Ontario Ministry of Labor." Tables, figures, and appendices referred to in this article are contained in the original report, which may be obtained from the author.

IAQ complaints will likely persist in the future and the Ontario Government needs a guideline for defining indoor air parameters and a uniform protocol for investigating "sick building" complaints. This concern is shared by many ministries. On March 30, 1987, at the second meeting of the Deputy Ministers' Committee on Occupational and Environmental Health, a decision was made to set up an Inter-Ministerial Committee to review and evaluate potential health hazards from buildings and to develop a protocol for investigations of "sick building" complaints. The committee was established and named the Inter-Ministerial Committee on Indoor Air Quality (henceforth, referred to as the Committee).

The Committee met for the first time on July 14, 1987. During its initial deliberations, the Committee sought an approval from the Deputy Ministers' Committee to exclude residential buildings from its deliberations because:

- A recently released Federal-Provincial report (April 1987) defines acceptable indoor air quality in residential buildings;
- The Ministry of Housing alone has jurisdiction in regulating construction and provision of ventilation methods in residential buildings; and
- Legislative authority with regard to IAQ in residential buildings is not clearly defined.

The Committee also sought approval to exclude deliberations on second-hand cigarette smoke exposure because the committee expected a Government-wide policy on this issue.

At their February 2, 1988 meeting, the Deputy Ministers agreed that the Committee's scope would be limited to commercial and institutional buildings, and would exclude residential and industrial buildings. However, the Deputy Ministers asked the Committee to reconsider its decision regarding second-hand smoke exposure. The general opinion of the Deputy Ministers' Committee was that it was neither appropriate nor realistic to exclude the consideration of cigarette smoke because in many cases, it is the most easily identifiable and most easily remedied cause of IAQ problems. The Committee reconsidered their position on second-hand smoke at their March 1988 meeting and agreed to address second-hand smoke in their terms of reference. Thus, the final terms of reference agreed upon were as follows:

- Define the terms related to indoor air quality.
- Review and evaluate health hazards related to IAQ.
- Develop a uniform protocol for investigating IAQ concerns and a protocol for field measurements.
- Recommend acceptable criteria for IAQ including second-hand smoke exposure.

During the period from July 1987 to August 1988, the Committee met 11 times to discuss and review the scientific literature as well as reports on indoor air quality in view of the terms of reference, and to develop a uniform protocol for the investigation of IAQ complaints. In addition, several Canadian and American governmental personnel working on IAQ problems were also contacted to obtain their views on IAQ standards.

While the review of the IAQ literature helped the Committee arrive at the guidelines and recommendations made in its report, the protocol for investigating IAQ concerns, including the detailed questionnaire, was developed by the Committee with input from MOL hygienists, medical consultants, and a statistician. The Committee's protocol is reactive rather than proactive. The Committee did not develop a recommendation for radon because another inter-ministerial committee has dealt with this issue. Asbestos, lighting, and noise are discussed briefly because the regulations dealing with these agents are either in existence (e.g., asbestos) or in the development stage (e.g., noise and lighting).

The Committee has prepared its report to guide government inspectors, occupational health professionals, building design professionals, and property managers in recognizing IAQ problems in non-residential and non-industrial buildings and in recommending remedial measures to address these problems. It is also hoped that the report will lead to a formal IAQ policy by the Government of Ontario.

The Committee is fully cognizant that, in spite of all the work being done, the understanding of indoor air quality and its health hazards is still incomplete because of the many contaminants involved, the low concentrations of contaminants, and the non-specificity of the reported symptoms. As knowledge grows, the information contained in the report will need updating.

Executive Summary

The Committee recommends adoption of uniform definitions of IAQ terminologies and a uniform protocol of IAQ investigations. Details are given in the report. A portion of the recommended protocol is a comprehensive questionnaire and its analysis.

Because the sources of indoor pollutants cannot be avoided in most cases, the Committee proposes that adequate fresh air supply is the single most effective solution to IAQ problems, provided that HVAC systems are properly designed, operated, and maintained. For buildings without a complete mechanical ventilation system, full advantage should be taken of the ventilation provided by openable windows.

The Committee also presents IAQ guidelines, which provide reference points for assessing the extent of remedial measures in buildings.

The Committee was unable to find any regulatory IAQ standards specifically established for children in schools. However, the guidelines proposed in the report are stringent enough to protect the health of school children.

The Committee recommends adoption of a non-smoking policy by Ontario Ministries due to the presence of several known or probable carcinogens as well as other toxins in "mainstream" and "sidestream" cigarette smoke. Until such time as the non-smoking policy is adopted, buildings should be provided with designated smoking areas with a separate exhaust and ventilation system.

The Committee recommends that appropriate changes be made to the Building Code to reflect the findings of this report.

Introduction

In the last number of years, IAQ problems became common when energy conservation measures were introduced for buildings. These measures caused buildings to be more tightly sealed and to have less fresh air circulated. The complaints and symptoms of illness are the same in most of these buildings. The symptoms are usually not specific, therefore, likely causes of the problems are not easily identified.

IAQ Issues

The Committee identified seven IAQ issues to address. The first issue was defining the IAQ terms. Since several terminologies exist to describe "non-specific IAQ complaints" (e.g., sick building syndrome and tight building syndrome), it was necessary to first define indoor air quality and then to choose and define appropriate terms to characterize the common complaints associated with IAQ problems (e.g., eye and upper respiratory irritation, headache, dizziness, nausea, fatigue and perceived stuffiness in the air). Likewise, it was necessary to define "health" before developing the protocol for investigating IAQ complaints.

The second issue was to design a protocol for IAQ investigations which provides consistency in the investigative approach throughout the province. A portion of the protocol is a comprehensive questionnaire and its analysis. The purpose of the questionnaire is to allow the investigator to (1) establish whether IAQ problems exist, (2) establish to what extent the problem exists, and (3) determine the possible sources of contamination. We believe that our protocol will help the investigator in identifying easy, low cost, energy effective solutions if the prescribed three stages are carefully followed.

The third issue was to group the sources of contaminants causing IAQ problems into broad categories. The enormous number of contaminants that have so far been isolated from indoor air were reviewed and categorized according to whether they originate from "internal" sources or from "outdoor" sources. Internal sources were classified as building components, the HVAC system, people, furniture, office supplies and equipment, and parking garages. External sources were defined in terms of ambient air infiltration.

Common to both types of sources were temperature, humidity, carbon dioxide, carbon monoxide, formaldehyde, micro-organisms, organic solvents, and odor. Noise, radiation, asbestos, as well as ergonomic and working conditions, were excluded from both groups.

The fourth issue was to develop a list of offices and buildings which may encounter IAQ problems due to sealed windows and the presence of HVAC systems. In developing this list, only those buildings which have extended occupancy periods, such as buildings in which people are present all day, were considered as opposed to intermittent occupancy buildings, such as underground concourses. This decision was necessary because places with intermittent occupancy cannot be properly evaluated using our protocol.

The fifth issue was to determine factors affecting indoor air quality and propose IAQ guidelines. In Chapter 4 of the report, IAQ guidelines** are given, which provide reference points for assessing the extent of remedial measures in buildings. The committee did not find any IAQ standards established for children in schools. It has been reported that factors related to younger age groups include a higher respiration rate per unit body weight and less ability to comprehend and communicate adverse health effects. Another factor to be considered is aggravation of pre-existing diseases in children. The guidelines developed for residential buildings by a Work Group of the Federal/Provincial Advisory Committee on Environmental and Occupational Health (see Chapter 4 of the report) appear to be stringent enough to protect the health of adult office workers as well as school children, hence the recommendation for its adoption.

The sixth issue was to recommend remedial measures for IAQ problems. Adequate fresh air supply appears to be the single most effective solution to IAQ problems, both in office buildings and schools, because the sources of an indoor pollutant in most cases cannot be avoided or reduced. Properly filtered air, free from CO_2, bacteria, and tobacco smoke, is the primary means of control of air contaminants in occupied spaces. ASHRAE Standard 62-81R prescribes the rates of outdoor air intake to achieve acceptable indoor air quality. The Committee has reviewed and accepted these rates as sufficient to dilute contaminants that are generated internally to acceptable levels. These prescribed rates correspond to the MOL and MGS experience, especially where these rates control CO_2 to a concentration of 1,000 ppm or less. CO_2 is used as a surrogate measure for other contaminants, including odors.

The seventh issue was exposure to second-hand tobacco smoke. This topic has captured public attention over the past several years. The most serious health hazard is demonstrated by the fact that second-hand smoke exposure, in an office where many people smoke, is equivalent to one to five cigarettes per day, and that approximately 5,000 persons in the USA die annually from lung cancer caused by exposure to second-hand smoke. Children exposed to second-hand smoke have been shown to have an increased

** These guidelines are contained in Table 4.8 of the Interministerial Report. These guidelines are also contained in Table 1 of Doug Walkinshaw's presentation on page 134.

incidence of respiratory illness. Nevertheless, no single satisfactory method is available to measure the amount of cigarette smoke present in a workplace.

Definitions

Indoor Air Quality (IAQ): IAQ refers to the physical, chemical, and biological characteristics of indoor air in non-residential workplaces (with no internal industrial processes or operations) which can affect the comfort or health of the occupant.

Tight Building Syndrome (TBS): TBS refers to non-specific symptoms of discomfort and ill-health, such as eye, nose and throat irritation, mental fatigue, headaches, unspecific hypersensitivities, and other similar complaints, in a significant number of occupants of non-industrial workplaces (mainly offices with HVAC systems).

Health: Health refers to a state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity.

Population at Risk

The Committee derived a list of those buildings and offices in which the work population may encounter IAQ problems (Table 4.5 of the report). The list is based on the Ministries' experience and by no means is all inclusive. Building types are subdivided in the list and the groupings are based on the nature of the occupancy.

Cost Implications

The report does not address the capital and operating costs of introducing recommended amounts of outdoor air into non-residential buildings. The Committee did not consider this to be part of their terms of reference. However, the Committee refers readers to a conclusion of the Federal-Provincial Work Group on Indoor Air Quality, which was contained in the first report to the Advisory Committee on Environmental and Occupational Health. According to the Work Group, implementing their recommended ventilation requirements for offices will have minimal energy cost implications for large offices. In addition, it should be possible to provide 200 cfm (cubic feet per minute) of ventilation for each person without significant building modifications. As far as schools and especially portables are concerned, no similar energy cost estimates are available in the published literature.

Protocol for Indoor Air Quality Investigations

Introduction

The protocol for IAQ investigations first requires the acquisition of useful information at the least effort and cost. The protocol is based on investigating the building and, if necessary, the symptoms of the workers; both of these may be needed to identify the causes of indoor air problems before remedial measures are applied.

The protocol for IAQ investigations developed by the Committee has four stages:

Stage 1. Preliminary Assessment

Stage 2. Questionnaire

Stage 3. Simple Measurements

Stage 4. Complex Measurements

In the Preliminary Assessment, physical factors and chemicals and their sources that cause IAQ problems may be identified. The Questionnaire amplifies this process and provides for the evaluation of workers' responses to poor IAQ. The Simple and Complex Measurements should be undertaken if the results of the Preliminary Assessment and the Questionnaire do not identify the causes of the problems, or if the remedial measures that have been taken do not alleviate them. The Questionnaire can also be used to check the effectiveness of any remedial measures taken in Stage 1. For each stage of the investigation, a separate decision should be made based on the information available. Stages 3 or 4 of the investigation should not be conducted without a clear indication that the problem cannot be identified at Stage 1 or after the administration of the Questionnaire.

Preliminary Assessment

The preliminary assessment stage does not use instruments, but relies on an inspection and the collection of information on the building. The information comes from observations made in the building, knowledge of the operation of the HVAC system, and details of the complaints.

Two activities are involved in the preliminary assessment: collection of information about the building (the Building Checklist), and interpretation of this information to provide evidence for or against the various causes of the problems. For a complete inspection, the Building Checklist, given in Appendix A of the report, should be used. The checklist is a questionnaire to be filled in with information about the building. Note that whenever possible, ventilation systems should be visually checked to ensure that they are performing in a satisfactory manner,.

The Building Checklist is divided into five parts:

- Carbon Monoxide - Combustion Byproducts;
- Other Pollutant Sources;
- HVAC Operations;
- Maintenance and Design; and
- Complaint Area Observation Sheet.

Once information has been collected, the second activity in this stage is to interpret the results. Guidance on how to use the Building Checklist information to identify probable causes of problems is given in Part 6 of the report, the Assessment Summary. The report from the preliminary assessment should include assessment of information collected and recommendations for eliminating the problem. If the cause of the problem is not identified, the Questionnaire should then be administered.

Questionnaire and Analysis

Overview of the Questionnaire

A comprehensive questionnaire has been developed as part of the protocol for IAQ investigations. The questionnaire is given in Appendix B of the report and it is based on questionnaires that were developed by the Ministries of Labor and Health, and by J.D. McDonald of McGill University. Drafts of this questionnaire were reviewed by participating ministries' staff and, where applicable, their suggestions have been incorporated by the Committee.

The purpose of the questionnaire is to gather information on the problems that are experienced in the indoor environment. The questionnaire is designed to allow one to establish whether, and to what extent, IAQ problems exist, and to determine the possible sources of contamination.

Questions have been defined which indicate symptoms typically associated with IAQ complaints. In addition, the questionnaire investigates the incidence of the more general complaints regarding exposure to physical conditions in the working environment, such as those relating to noise, lighting, humidity, temperature, and air movement. The format and language of the questionnaire is simple to allow individuals to complete it without assistance.

The questionnaire results can also be analyzed in conjunction with the results of the contaminant measurements carried out in Stages 3 and 4. Among the contaminants which can be assessed are: VOCs; carbon monoxide, ozone, particulates, microorganisms, and formaldehyde. Indicators of exposure to carbon dioxide, which itself is not regarded as a major contaminant, suggest the presence of ventilation problems. The questionnaire also assesses indicators of exposure and symptoms related to tobacco smoke.

Questionnaire Analysis

The analysis of the questionnaires for each IAQ investigation case is performed in three stages: (1) analysis of each questionnaire; (2) compilation of the results for all questionnaires; and (3) interpretation of the results. The responses (health symptoms) of highest frequency are determined. If responses are only directed to specifically one or a few health symptoms, it may be easy to infer a cause. If responses are directed at many, non-specific health symptoms, then this finding may indicate the effects of "tight building syndrome" and the lack of fresh air.

For each contaminant, questions relating to symptoms indicate the presence of complaints typically associated with the contaminant under review. The higher the symptom's score, the greater the likelihood/severity of the symptoms associated with the contaminant in question. To simplify matters, it is assumed that each indicator of symptoms or exposure will have equal weighting. It is important to note that only symptoms which manifest themselves during regular working hours are of significance. For each contaminant, exposure levels for individual responses are estimated in the same manner. High total exposure scores indicate a greater likelihood of exposure to the contaminant in question.

A series of worksheets are developed to assist in the analysis of the questionnaire (Appendix D). The "Lotus 1-2-3" software package is used in simplifying the analysis (Appendix E). A summary table for individual questionnaires will provide information about each contaminant and severity of exposure (Appendix F). Summary results of all questionnaires, for both symptoms and exposures, for different contaminants are compiled in a single table (Appendix F).

To compare scores for all individuals in an investigation case, exposure and symptom scores can be plotted in the form of a frequency distribution chart (Appendix F). This chart provides information on the extent to which individual responses (relating to exposure and symptoms) vary among individuals in the survey. If high exposure and symptom scores are observed for only a small minority of individuals in the survey, the frequency distributions will reveal this.

Some indoor air problems are more severe at times in the day and/or week when the rate of fresh air distribution is lower and/or when contaminants have had an opportunity to reach a higher concentration. A frequency distribution for days of the week may assist in identifying the source of the problem (Appendix F).

The exposure and symptom scores can be compared for individual responses. High exposure and symptom scores may suggest that symptoms are indeed linked to the presence of a particular contaminant. If many of the responses in the survey exhibit the same pattern of high symptom scores associated with high exposure scores, then this result would further suggest that there may be a widespread problem with a particular contaminant. A contingency table can be constructed and tests of significance can be performed (Chi Square) to determine whether or not there is a significant relationship between indicators of exposure and symptom intensity (Appendix F).

In the long term, the analysis of different IAQ investigation cases will provide information on some of the trends, such as the relationship of IAQ problems to the sex of the respondents, type of office occupied, impact of stress and other factors.

Stage 3 - Field Measurements with Simple Instruments

The third stage of the investigation involves simple instruments to take the following measurements:

- Temperature;
- Relative humidity;
- Carbon dioxide;
- Formaldehyde;
- Carbon monoxide; and
- Air movement.

This stage is needed only if Stage 1 does not identify the problem and Stage 2 indicates prevalence of certain symptoms.

In Stage 3, it is important that the above measurements be taken in the proper location and appropriate time of the year, week, and day. The tables in Appendix G indicate the suitable locations (including "control" locations) and time for measuring pollutants.

Because the types of measurements made are unfamiliar to most people, the Data Assessment Table in Appendix H provides ranges of acceptable and unacceptable values for various pollutants. The measurement results can be compared against these ranges. The measurements can also be used in conjunction with the health symptoms from the Questionnaire.

A list of simple pieces of equipment, which are often used for the monitoring of some basic pollutants, is given in Appendix I. The measurements should be easy, quick to perform, and are designed to be used by non-specialists who have received a minimum of training, for example, a building operator, property manager, or safety officer.

It is expected that the data collected will prove or disprove the presence of hazardous levels of air pollutants in some cases, but not necessarily all cases. It may be necessary to go to Stage 4 to measure other potential pollutants which require complex measurement techniques.

Stage 4 - Field Measurements with Complex Instruments

If the problem is not identified in Stage 3 and it is suspected that the air contamination is occurring from specific sources within or outside the building, or in the event that harmful chemicals, dust, or microorganisms are suspected, it is necessary to use complex instruments to carry out further measurements of other pollutants:

- Microorganisms;
- Respirable suspended particulates;
- Organic vapor;
- Ozone;

- NO_x; and
- Asbestos.

The complex measurement techniques are more time consuming and expensive to conduct than simple measurement techniques. The techniques also require an experienced consultant or specialized organizations, such as the Ministry of Labor or the Ministry of Health. These measurements are usually only used after Stage 1, 2, and 3 evaluations have failed to resolve the situation. The measurements can also be used in an analysis with the health symptoms from the questionnaire (see Section 5.4 of the report).

Interpretation of Field Measurements

Stage 3 and 4 measurements should be compared with Appendix H which gives ranges of acceptable and unacceptable values for carbon dioxide, carbon monoxide, formaldehyde, nitrogen dioxide, ozone, and physical factors. The guideline levels for microorganisms in Chapter 4 of the report can be used to make comparisons against measurements of microorganisms.

Several situations are possible:

- If all control and test location data fall in the normal outdoor and indoor ranges, any problems suspected are not due to this cause/pollutant.

- If control locations yield numbers in the normal ranges and one or more test locations yield numbers in the "do not exceed" range, there are problems to be corrected.

- If control location data is in the normal range and one or more test locations yield numbers in the "possible problem" range, more detailed testing may be necessary.

- If test and control locations yield numbers in the "possible problem" range, the problem may have been caused by outdoor air or the the testing equipment.

Recommendations

The Inter-ministerial Committee on Indoor Air Quality recommends the following for consideration of the Deputy Minister's Committee on Occupational and Environmental Health.

Existing Buildings

- The "Protocol for Indoor Air Quality Investigation," including Questionnaire and Analysis, should be adopted to provide consistency throughout the province.

- A minimum of 15 cubic feet per minute per person of outdoor air should be provided so that carbon dioxide (an indicator of adequate fresh air) does not exceed 1,000 ppm. For buildings without a complete mechanical ventilation system, full advantage should be taken of openable windows.

- Air velocity of an average of 30 (within a range of 20 to 50) feet per minute should be provided at the work station.

- Winter temperatures should be between 19.5°C and 24.6°C, and summer temperatures between 22.6°C and 27.2°C.

- Pollutants (e.g., copy machines, odors) should be removed at their source.

- The levels of pollutants should be below the levels specified in Tables 4.7, 4.8, and 4.10.

- Viable organisms should not exceed 1,000 CFU/m^3 in indoor air.

New Buildings

For new buildings, the opportunity exists to design to ensure adequate indoor air quality. Items (B), (C), (D), (E), (F), and (G) listed above are pertinent. Reference is usually made to ASHRAE as good engineering practice. In addition to the above combinations, the following items require careful attention in new building design:

- In areas where openable windows are not provided, mechanical ventilation throughout the occupied zone should be provided at a minimum of 15 cubic feet per minute per person and air velocity provided at the work station of approximately 30 feet per minute on average.

- Fresh air intakes should be located to avoid contamination, e.g., from street traffic.

- HVAC systems and materials should be designed to minimize the opportunity for growth of microorganisms, such as having self-draining pans to avoid standing water.

- The building design should provide for readily accessible inspection and maintenance.

- The building design should provide for pollutant removal at the source.

- Where practical, materials should be used that are low in pollutant emissions, e.g., using drywall instead of particleboard, and using tile instead of carpeting.

- The above changes should be incorporated in the Building Code.

Second-Hand Smoke

These recommendations are based on the premise that second-hand smoke is a potential health hazard.

- All building areas normally occupied by the working population should be classified as non-smoking.

- Until such time as the previous recommendation can be implemented, buildings affected should be provided with designated smoking areas. In designated smoking areas, at least 60 cfm of outdoor air per person should be provided and exhaust air from these areas should not be recirculated to other areas. However, in existing buildings, this level may be economically impractical.

Future Recommendations

- The Deputy Minister's Committee on Occupational and Environmental Health should continue to review, assess, monitor and coordinate IAQ issues.

- The Deputy Minister's Committee should support the formation of a national body to review these issues and to carry out applied research towards resolving these issues.

- The Deputy Minister's Committee should support the development of maintenance guidelines for new and existing buildings by the HVAC industry.

NOTE: To obtain a copy of the original report, please contact: G.S. Rajhans, Health and Safety Support Services Branch, Ontario Ministry of Labor, 400 University Avenue, Toronto, Canada, M7A177, Canada (416) 326-1401.

The Quebec Approach

Jean-Claude Dionne
IRSST- Montreal (Quebec)

The number of complaints related to indoor air pollution in different work places (excluding industrial milieu) has increased in the province of Quebec during the last few years, as in other industrial societies. In order to solve a high percentage of these problems, we have developed an innovative, proactive strategy.

The Institut de Recherche en Sante et en Securite du Travail du Quebec (IRSST) conducted a study in three office buildings. The goals were to understand the phenomenon of tight building syndrome and to develop different tools, for example: sampling techniques and strategies, analytical techniques, observation sheets, questionnaires, and so on. In a second step, 12 governmental buildings selected by the employer and union representatives were fully studied by a multi-disciplinary team in a very comprehensive manner. A document "Strategy for Studying Air Quality in Office Buildings" was then written by two members of the team.

This guide has been developed for building owners, managers, employers, and workers who must solve air quality problems in their buildings. The guide is an action tool allowing problems related to the physical performance of a building and its HVAC system to be identified, evaluated, and controlled.

The proposed procedure has been developed for air quality studies in office buildings. Cases related to other non-industrial work environments, such as hospitals, schools, and day-care centers, present more complex problems and require adapted strategies. Nevertheless, the same steps (understanding the environment, evaluating suspected problems, and implementing corrections at the source) apply to all these environments.

The factors included in the procedure are ventilation, comfort, chemical contaminants, bioaerosols, and work environments. Different tables (observation questionnaire on the ventilation system, contaminant-emission sources, noise and lighting; sampling strategy for chemical contaminants and bioaerosols; summary of concentrations of chemical contaminants and bioaerosols measured in the air of the 15 office buildings by a team from the IRSST) are also included.

In 1988, I convinced the Association Quebecoise pour la Maitrise de L'energie (AQME) and the Bureau de L'efficacite Energetique to work on a guide for HVAC systems operators. A working group was mandated by AQME to construct this guide, which was published in French and in English in September 1989.

This "Practical Maintenance Manual for Good Indoor Air Quality" does not attempt to solve all of the problems; however, it will allow the technical personnel involved to make the necessary verifications when a problem arises. Above all, it will help prevent such problems from arising by suggesting proper and regular equipment maintenance steps, thus efficiently managing energy. It is important to keep in mind that good indoor air quality is not contrary to an efficient energy management program. Indoor air quality and energy management are not only compatible, but one benefits from the other.

This document is unique; it is the first of its kind in North America. Furthermore, AQME will organize training workshops in many cities across Quebec. The workshops will help users to better understand and use the procedures outlined in the manual, therefore ensuring a better application.

During the last three years, we have held many IAQ seminars and conferences in different cities of the province. The Commission de la Sante et de la Securite du Travail du Quebec (CSST) has developed a manual titled "Guidance for Indoor Air Quality Investigations" and information sessions for inspectors. IRSST has a few ongoing research studies, in particular, techniques of decontamination in hospital ventilation systems, and the use of CO_2 probes to control fresh air entry. Finally, a report of a preliminary IAQ study in six day-care centers in Montreal will be published in two weeks. The study was conducted by Dr. J. Soto (from a community health department) and myself.

Employee Survey: EPA Headquarters

Kevin Teichman
Office of Research and Development
US Environmental Protection Agency

Introduction

EPA's Office of Research and Development is conducting a number of IAQ and work environment studies in four large office buildings in Washington, DC: the three EPA headquarters buildings and the Library of Congress Madison Building. The studies include two components: (1) administering a survey questionnaire to all building employees, requesting information on health symptoms, comfort concerns, and other background factors; and (2) conducting pollutant and ventilation measurements in selected building locations. A number of organizations are participating in the design and execution of this comprehensive study: EPA, the National Institute for Occupational Safety and Health (NIOSH), the J.B. Pierce Foundation of Yale University, and the National Institute of Standards and Technology.

The initial results of the studies, i.e., the descriptive reporting of the building survey results, were not available at the time of the meeting. The EPA study is now available through the Office of Administration Resource Management of EPA. The Library of Congress study will not be available until after the summer of 1990 through the Publishing Office of the Library of Congress, Room LM602, Phone Number (202) 707-5093. Subsequent reports will present the results of the monitoring data and attempt to correlate the survey responses with the monitoring results.

Background

In recent years, employees at the three headquarters buildings of the EPA have expressed their concerns about indoor air pollution and work environment discomforts. Because of the difficulties encountered in determining the "actual" causes of such concerns about building environments, EPA has undertaken a systematic study of the nature and spatial distribution of employee health symptoms and comfort concerns in an attempt to determine if associations exist between employee responses and specific work place conditions.

This paper summarizes the first of three volumes of a report that investigates the perceived and actual quality of indoor air at EPA headquarters. Volume I documents the design of the study and the results of the detailed survey of all EPA employees that was conducted in February 1989. Three work complexes were surveyed: Waterside Mall and the Fairchild Building in Washington, DC, and Crystal Mall in Arlington, Virginia. Volume II presents a descriptive summary of the survey data. Results of the environmental monitoring will be presented in Volume II; multi-variate analyses of both sets of study results will be presented in Volume III.

The research effort at EPA was integrated with a parallel study at the Library of Congress Madison Building. Both the EPA and the Library of Congress surveys made use of common study designs and survey instruments, although separate reports have been prepared for each agency. While certain features of the study are specific to the particular buildings involved, the survey was designed to be applicable to any building suspected of environmental problems.

Information continues to be obtained by both labor and management on the health symptoms of EPA employees and the quality of indoor air at EPA headquarters. For example, both the National Federation of Federal Employees Local 2050 and the American Federation of Government Employees Local 3331 have accumulated information on the illnesses experienced by EPA employees. This information is provided in a supplement to Volume I entitled, "Additional Employee Adverse Health Effects Information."

Study Design

Because of the lack of prior information on employee health that could be used as benchmark data, and because of the spatial variability of ventilation, thermal factors, and other conditions that influence health and comfort, a comprehensive survey of all EPA employees at each of the three headquarters locations was required. A self-administered questionnaire was distributed to all employees in February 1989, asking for information about health symptoms and comfort concerns, along with data on background health and demographic characteristics. Among the topics covered in the questionnaire were:

- Location of workstation (to detect associations between the survey and monitoring data);
- Description of workstation, both current and changes over the previous year;
- Amount of time spent at workstation;
- Health symptoms experienced while in the building, both in the previous week and in the previous year;

- Other health characteristics and risk factors: (e.g., wearing of contact lenses and eyeglasses, smoking, allergies, and asthma);
- Eye, nose, throat, or respiratory irritation from tobacco smoke or other chemicals during the previous year;
- Gynecological problems during the previous year;
- Comfort issues (e.g., temperature, humidity, air movement, noise, dust, light, odors, and furniture use during last year);
- Job characteristics, including job satisfaction and job stress; and
- Education, job pay plan and grade, and job classification.

To increase participation in the survey, both management and unions were given the opportunity to review the draft questionnaire, and their endorsements were communicated to all employees prior to the survey. Stringent measures were taken to ensure the confidentiality of all responses.

Findings from the employee survey were used to rank all rooms in the building on the basis of a health symptom index, and then to select approximately 100 locations for environmental monitoring and physical measurements. Environmental monitoring was conducted three weeks after the employee survey. All locations were monitored for temperature, relative humidity, carbon dioxide, and carbon monoxide. A subset of locations was also sampled for nicotine, biological contaminants, particles, formaldehyde and other aldehydes, other volatile organic compounds, and pesticides. In addition, ventilation parameters were measured.

While the monitoring was in process, a supplemental questionnaire was also administered to all employees near the environmental equipment. This questionnaire provided a basis of comparison between air measurements and employee experiences on the same day.

Results of the Survey

The overall response rate for the survey questionnaire across all three buildings was 81 percent, with 3,955 of an estimated 4,900 EPA employees completing the survey. More than 1,400 employees also took the opportunity to volunteer additional comments in the "essay" question provided at the end of the survey form. Key results are reported below, first for health symptoms and then for comfort issues. It is important to note that the health symptoms and comfort issues reported in the survey are self-reported by the respondents, and the study did not attempt to verify the symptoms by a physician's diagnosis. No attempt is made in this report to associate health or comfort outcomes with possible risk factors in the building. These analyses will be the focus of Volume III.

Health Symptoms of the Building

The most frequently occurring health symptoms reported by respondents were roughly similar across the three buildings -- headaches, contact lens problems (among contact lens wearers), stuffy nose, dry/itchy skin, dry/itchy/tearing eyes, strained eyes, and sleepiness.

To focus the findings on health symptoms that are potentially building-related, the report uses the concept of "cases." Each case represents an employee who reported experiencing a health symptom "often" or "always" in the previous year and whose health symptom reportedly got better when the employee left work. The use of "cases" is intended to focus on symptoms that are recurring rather than occasional and that appear to be connected in some way to the building.

As Exhibit ES-1 shows, the highest percentages of cases were reported for the same top seven symptoms across all three buildings (although ranked in different orders in each building):

- headache;
- stuffy nose/sinus congestion;
- dry, itching, or tearing eyes;
- sore/strained eyes;
- unusual fatigue or tiredness;
- sleepiness or drowsiness; and
- contact lens problems (among contact lens wearers).

Each of these symptoms was experienced "often" or "always" by at least ten percent of respondents and was reported to improve after the employee left work. Another view of the same data is provided in Exhibit ES-2, which groups the symptoms into three categories:

- **Indoor air quality symptoms**, typically associated with acute discomfort, such as headache, runny nose, stuffy nose/sinus congestion, dry, itching or tearing eyes, burning eyes, dry throat, fatigue, and sleepiness.

- **Respiratory or flu-like symptoms**, which may be manifested in clinically defined illnesses that may require prolonged recovery times after leaving the building. Such symptoms include cough, wheezing, shortness of breath, chest tightness, fever, and aching muscles or joints.

- **Ergonomic symptoms**, which include back pain or stiffness, and pain or numbness in the shoulder, neck, hands, or wrists.

As Exhibit ES-2 shows, the predominant symptoms reported in each building are those associated with poor indoor air quality. Headache, fatigue, and symptoms associated with mucous membrane irritation have often been reported in published IAQ evaluations.

The use of "cases" may be considered by some as representing a conservative estimate of symptoms experienced by respondents. For example, it may be useful to consider the prevalence of symptoms reported by respondents "sometimes," in addition to "often" or "always." Therefore, for comparison, Exhibit ES-3 provides the percent of all respondents who had symptoms "sometimes," "often," or "always," and who "got better upon leaving work." In addition, it is recognized that certain symptoms that may be building-related do not improve upon leaving work (e.g., muscle pains, hypersensitivity reactions, and immune responses). The main body of the report includes exhibits that eliminate the "got better upon leaving work" criterion.

About a third of respondents (28 - 38 percent) in each of the three buildings indicated that their symptoms reduced their ability to work at least some of the time. About a quarter of respondents indicated that their symptoms resulted in having to stay home or leave work early "sometimes" or "often" in the past year (22 - 25 percent at each building).

Among Waterside Mall employees, 62 percent of respondents associated one or more of their symptoms with their work building, compared to 56 percent of Crystal Mall respondents and 49 percent at the Fairchild Building. Of those employees reporting that they "often" or "always" experienced symptoms, the percentage who reported that their symptoms improved when they left the budding generally ranged between 60 and 70 percent.

More employees in Waterside Mall than in the other buildings reported that both the frequency and duration of their infections had increased since they began work in their building. At Waterside Mall, 39 percent of respondents reported more frequent infections (compared to 31 percent for Crystal Mall and 23 percent for the Fairchild Building), and 36 percent of Waterside Mall respondents reported longer lasting infections since beginning work at the building (compared to 31 percent for Crystal Mall and 23 percent for the Fairchild Building).

Paint and tobacco smoke were among the top four irritants in all three buildings, for nine listed possible sources of eye, nose, throat, and respiratory irritation. At Waterside Mall, fumes from new carpeting, paint fumes, and tobacco smoke were mentioned as the three leading sources of irritation. Crystal Mall respondents were more likely to identify paint fumes, tobacco smoke, and fumes from copy machines. Fairchild Building respondents pointed primarily to new carpeting, tobacco, smoke, and fumes from new drapes and paint. About one third of all respondents reported that they consider themselves especially sensitive to the irritants mentioned.

Health Symptoms at the Waterside Mall Sectors

A fairly clear pattern of health symptoms emerges when one breaks down the Waterside Mall complex into six separate "sectors." A greater prevalence of the problems reported in Waterside Mall are associated with the second floor Mall, third floor Mall, and Southeast Mall sectors. Respondents in these three sectors were also more likely to

report that their symptoms reduced their ability to work and they perceived a stronger association of their symptoms with the building than respondents in other sectors.

Exhibit ES-4 shows data on cases reported for each of the six sectors of Waterside Mall. The same seven symptoms noted above were associated with most cases. The second and third floors of the Mall and the Southeast Mall report the highest percentages of problems, with 20 percent or more of respondents reporting cases of stuffy nose/sinus congestion (third floor Mall); dry, itching, or tearing eyes (second floor Mall and Southeast Mall); sore/strained eyes (second floor Mall); and sleepiness or drowsiness (Southeast Mall). Among respondents who wear contact lenses at work, the percentage who reported problems with their lenses reached 45 percent in the second floor Mall and 38 percent on the third floor Mall.

Health Symptoms Reported Last Week

Respondents were asked on how many days in the previous week they experienced the individual symptoms while working in the building. This question was intended to provide a more immediate, and perhaps more accurate, measure of the extent of symptom occurrence since the recall period was much more recent. In addition, this question was used to select sampling locations. The results reported in Exhibit ES-5 show the percentage of respondents experiencing the symptom at least one day on the previous week; also shown are the number of days respondents experienced the symptom in the previous week.

In general, the results appear consistent with the relative ranking of cases in the previous year (Exhibit ES-1), although the percentages reporting symptoms are much higher. This result is not surprising, however, since the percentages of symptoms experienced during the past year represented only those who responded "often" or "always" and whose symptoms got better when they left work. Forty percent or more of respondents in each building reported experiencing headaches, stuffy nose, fatigue, or sleepiness in the week before the survey. Respondents indicated an average duration of between two and three days for most symptoms.

Comfort

Overall, respondents were generally satisfied with their immediate physical workstations (e.g., chair comfort and lighting). This finding may be due to employees' ability to adjust these factors. For example, desk lamps are used regularly by 42 - 46 percent of respondents. Dissatisfaction with building-related factors, however, was reported in each building, and at somewhat higher levels in Waterside Mall than in the other two buildings.

As one measure of dissatisfaction, for example, last year 48 percent of Waterside Mall respondents reported bringing in portable fans to their offices, compared to 45 percent at Crystal Mall and 36 percent at the Fairchild Mall. Waterside Mall respondents

also regularly made use of portable heaters in substantial numbers (22 percent). As Exhibit ES-6 shows, 40 - 51 percent of respondents "often" or "always" wanted to adjust air movement, and between 38 - 55 percent of respondents "often" or "always" wanted to adjust the temperature.

In all three buildings, respondents reported the air to be often or always too dry rater than too humid, with too little as opposed to too much air movement. For example, in Crystal Mall, 38 percent reported the air to be "too dry" as opposed to eight percent who reported the air to be "too humid," and 48 percent reported having too little air movement as opposed to three percent who reported too much air movement. The desire to adjust temperature was seasonally dependent in all three buildings, with respondents wanting to adjust temperature more during winter and summer. For example, over two-thirds of all respondents in Waterside Mall reported wanting to adjust temperature during winter and summer months.

Exhibit ES-7 breaks down these responses by Waterside Mall sector. A need for adjustments in air movement and humidity was reported most by respondents on the 2nd and 3rd floors of the Mall and the Southeast Mall. Temperature adjustments were desired most in the 2nd and 3rd floors of the Mall, West Tower, and Southeast Mall.

Volume I also outlines the findings of the survey regarding respondent background characteristics -- including employee demographic characteristics, health factors not related to the building, job satisfaction and sources of stress, and the physical work environments in which employees work. These factors will be used in the Volume III analyses as background variables to help explain patterns of health symptoms and comfort problems. These analyses will provide a more detailed context in which to understand the differential health and comfort problems experienced by different types of employees, and employees in different buildings and sectors. The analyses will thus help to determine to what extent the health and comfort symptoms described in this report can be attributed to building conditions and to what extent they can be attributed to other independent factors.

Exhibit ES-1: Percent of All Respondents Who Had Symptoms Often or Always Last Year that Got Better Upon Leaving Work, by EPA Headquarters Building

SYMPTOM	BUILDING		
	WATERSIDE MALL	CRYSTAL MALL	FAIRCHILD
Headache	16%	11%	16%
Nausea	1%	1%	1%
Runny nose	8%	9%	7%
Stuffy nose/sinus congestion	16%	17%	15%
Sneezing	7%	7%	8%
Cough	4%	5%	4%
Wheezing or whistling in chest	1%	1%	2%
Shortness of breath	2%	1%	2%
Chest tightness	2%	1%	2%
Dry, itching, or tearing eyes	17%	12%	15%
Sore/strained eyes	16%	12%	18%
Blurry/double vision	4%	3%	5%
Burning eyes	10%	8%	11%
Sore throat	4%	3%	4%
Hoarseness	3%	2%	1%
Dry throat	10%	7%	9%
Unusual fatigue or tiredness	15%	14%	11%
Sleepiness or drowsiness	15%	19%	13%
Chills	5%	1%	2%
Fever	1%	1%	0%
Aching muscles or joints	4%	4%	2%
Problems with contact lenses*	28%	19%	27%
Difficulty remembering things	2%	2%	2%
Dizziness/lightheadedness	3%	2%	1%
Feeling depressed	5%	5%	4%
Tension or nervousness	10%	11%	8%
Difficulty concentrating	7%	6%	5%
Dry or itchy skin	6%	4%	6%
Pain or stiffness in upper back	6%	6%	6%
Pain or stiffness in lower back	6%	6%	4%
Pain or numbness in shoulder/neck	6%	5%	5%
Pain or numbness in hands or wrists	2%	2%	2%

*These percentages are based upon only the people who wear contact lenses at work "sometimes, often or always" (Part II, Question 1.a), as opposed to all respondents in the building.

Reference: Part II, Question 7.

Exhibit ES-2: Percent of All Respondents Who Had Symptoms Often or Always Last Year that Got Better Upon Leaving Work, by EPA Headquarters Building and by Group of Symptoms

SYMPTOM	BUILDING		
	WATERSIDE MALL	CRYSTAL MALL	FAIRCHILD
Indoor Air Quality Symptoms			
Headache	16%	11%	16%
Runny nose	8%	9%	7%
Stuffy nose/sinus congestion	16%	17%	15%
Dry, itching, or tearing eyes	17%	12%	15%
Burning eyes	10%	8%	11%
Dry throat	10%	7%	9%
Unusual fatigue or tiredness	15%	14%	11%
Sleepiness or drowsiness	15%	19%	13%
Respiratory or Flu-like Symptoms			
Cough	4%	5%	4%
Wheezing or whistling in chest	1%	1%	2%
Shortness of breath	2%	1%	2%
Chest tightness	2%	1%	2%
Fever	1%	1%	0%
Aching muscles or joints	4%	4%	2%
Ergonomic Symptoms			
Pain or stiffness in upper back	6%	6%	6%
Pain or stiffness in lower back	6%	6%	4%
Pain or numbness in shoulder/neck	6%	5%	5%
Pain or numbness in hands or wrists	2%	2%	2%

Reference: Part II, Question 7.

Exhibit ES-3: Percent of All Respondents Who Had Symptoms Sometimes, Often or Always Last Year and that Got Better Upon Leaving Work, by EPA Headquarters Building

SYMPTOM	BUILDING		
	WATERSIDE MALL	CRYSTAL MALL	FAIRCHILD
Headache	41%	30%	42%
Nausea	10%	7%	19%
Runny nose	20%	18%	15%
Stuffy nose/sinus congestion	29%	26%	29%
Sneezing	22%	20%	20%
Cough	14%	12%	12%
Wheezing or whistling in chest	4%	3%	2%
Shortness of breath	7%	5%	6%
Chest tightness	6%	12%	6%
Dry, itching, or tearing eyes	35%	29%	34%
Sore/strained eyes	37%	35%	40%
Blurry/double vision	12%	8%	14%
Burning eyes	27%	22%	27%
Sore throat	14%	12%	11%
Hoarseness	10%	6%	8%
Dry throat	23%	18%	23%
Unusual fatigue or tiredness	34%	32%	32%
Sleepiness or drowsiness	41%	42%	40%
Chills	16%	10%	11%
Fever	4%	3%	3%
Aching muscles or joints	10%	7%	9%
Problems with contact lenses*	47%	38%	46%
Difficulty remembering things	10%	8%	8%
Dizziness/lightheadedness	15%	17%	9%
Feeling depressed	19%	17%	15%
Tension or nervousness	32%	33%	28%
Difficulty concentrating	27%	27%	23%
Dry or itchy skin	12%	11%	11%
Pain or stiffness in upper back	16%	14%	18%
Pain or stiffness in lower back	16%	15%	19%
Pain or numbness in shoulder/neck	14%	12%	16%
Pain or numbness in hands or wrists	7%	6%	7%

*These percentages are based upon only the people who wear contact lenses at work "sometimes, often or always" (Part II, Question 1.a), as opposed to all respondents in the building.

Reference: Part II, Question 7.

Exhibit ES-4: Percent of All Respondents Who Had Symptoms Often or Always Last Year that Got Better Upon Leaving Work, by Sector in Waterside Mall

SYMPTOM	WATERSIDE MALL SECTOR					
	EAST TOWER	WEST TOWER	MALL 2ND FLOOR	MALL 3RD FLOOR	NE MALL	SE MALL
Headache	14%	13%	18%	19%	16%	18%
Nausea	1%	1%	1%	2%	2%	14%
Runny nose	7%	9%	9%	10%	8%	8%
Stuffy nose/sinus congestion	15%	13%	16%	21%	16%	16%
Sneezing	6%	7%	7%	8%	7%	6%
Cough	4%	5%	6%	6%	4%	2%
Wheezing or whistling in chest	1%	1%	1%	2%	1%	2%
Shortness of breath	1%	2%	3%	3%	3%	2%
Chest tightness	1%	1%	3%	2%	2%	2%
Dry, itching, or tearing eyes	14%	15%	21%	18%	13%	20%
Sore/strained eyes	15%	14%	22%	18%	14%	19%
Blurry/double vision	4%	4%	7%	3%	3%	3%
Burning eyes	9%	10%	13%	11%	9%	10%
Sore throat	3%	3%	7%	5%	3%	9%
Hoarseness	3%	3%	5%	3%	2%	4%
Dry throat	8%	9%	15%	12%	8%	14%
Unusual fatigue or tiredness	12%	15%	17%	17%	12%	15%
Sleepiness or drowsiness	13%	14%	18%	17%	14%	20%
Chills	2%	5%	5%	5%	6%	4%
Fever	4%	0%	0%	1%	1%	5%
Aching muscles or joints	3%	4%	5%	5%	4%	6%
Problems with contact lenses*	24%	25%	45%	38%	31%	29%
Difficulty remembering things	2%	2%	3%	3%	3%	1%
Dizziness/lightheadedness	3%	2%	5%	4%	3%	4%
Feeling depressed	5%	5%	4%	5%	6%	5%
Tension or nervousness	9%	10%	12%	10%	9%	12%
Difficulty concentrating	6%	6%	10%	10%	6%	10%
Dry or itchy skin	6%	6%	8%	8%	6%	5%
Pain or stiffness in upper back	4%	8%	5%	7%	6%	4%
Pain or stiffness in lower back	4%	7%	4%	6%	7%	6%
Pain or numbness in shoulder/neck	4%	5%	6%	7%	6%	4%
Pain or numbness in hands or wrists	2%	2%	4%	2%	1%	2%

*These percentages are based upon only the people who wear contact lenses at work "sometimes, often or always" (Part II, Question 1.a), as opposed to all respondents in the building.

Reference: Part II, Question 7.

Exhibit ES-5: Percent of All Respondents Reporting One or More Days of Symptom and Average Symptom Days Last Week, by EPA Headquarters Building

SYMPTOMS	WATERSIDE MALL		CRYSTAL MALL		FAIRCHILD	
	% 1+ Days*	Avg. Days	% 1+ Days*	Avg. Days	% 1+ Days*	Avg. Days
Headache	53%	2.0	47%	2.0	49%	2.2
Nausea	13%	1.7	12%	1.7	13%	1.6
Runny Nose	42%	2.7	36%	2.8	36%	2.7
Stuffy Nose	51%	2.9	47%	3.0	51%	2.8
Sneezing	40%	2.3	38%	2.3	40%	2.4
Cough	31%	2.6	30%	2.5	30%	2.5
Wheezing	8%	2.5	7%	2.6	8%	3.0
Shortness of Breath	11%	2.4	10%	2.6	9%	2.4
Chest Tightness	9%	2.3	11%	2.4	9%	2.3
Dry, Itching, or Tearing Eyes	41%	2.6	35%	2.7	40%	2.6
Sore/Strained Eyes	41%	2.6	37%	2.5	44%	2.6
Blurry/Double Vision	16%	2.5	13%	2.6	17%	2.7
Burning Eyes	28%	2.5	23%	2.6	29%	2.5
Sore Throat	25%	2.2	22%	2.2	22%	2.1
Hoarseness	15%	2.3	13%	2.5	14%	2.1
Dry Throat	31%	2.6	25%	2.7	26%	2.6
Unusual Fatigue	44%	2.6	40%	2.7	43%	2.5
Sleepiness	50%	2.4	49%	2.6	48%	2.4
Chills	18%	2.4	9%	2.2	15%	2.2
Fever	8%	1.9	6%	2.6	8%	1.9
Aching Muscles	26%	2.5	26%	2.7	21%	2.4
Problems w/ Contact Lenses**	46%	2.8	39%	2.6	44%	2.3
Difficulty Remembering Things	21%	2.4	18%	2.2	19%	1.9
Dizziness/Lightheadedness	18%	2.0	13%	2.2	15%	1.8
Feeling Depressed	27%	2.2	26%	2.4	26%	2.3
Tension or Nervousness	37%	2.3	39%	2.6	35%	2.4
Difficulty Concentrating	33%	2.3	33%	2.3	32%	2.0
Dry or Itchy Skin	36%	3.3	30%	3.2	34%	3.1
Pain in Upper Back	23%	2.5	22%	2.6	24%	2.6
Pain in Lower Back	27%	2.5	25%	2.7	24%	2.3
Pain in Shoulder/Neck	21%	2.6	21%	2.6	19%	2.5
Pain in Hands or Wrist	11%	2.6	11%	2.6	10%	2.6

*Based on the total number of responding employees.

**These percentages are based upon only the people who wear contact lenses at work (Part II, Question 1.a), as opposed to all responding employees.

Reference: Part II, Question 7.

Exhibit ES-6: Number and Percent Reporting Often or Always Wanting to Adjust Environmental Comfort Last Year, by EPA Headquarters Building

	WATERSIDE MALL		CRYSTAL MALL		FAIRCHILD	
	Number	Percent	Number	Percent	Number	Percent
Adjust Air Movement	1,574	51%	210	46%	164	40%
Adjust Temperature	1,708	55%	174	38%	162	40%
Adjust Humidity	1,077	35%	160	35%	131	32%

Reference: Part III, Questions 1c, 1f and 1i.

Exhibit ES-7: Number and Percent Reporting Often or Always Wanting to Adjust Environmental Comfort Last Year, by Waterside Mall Sector

	WATERSIDE MALL SECTOR											
	EAST TOWER		WEST TOWER		MALL 2ND FLOOR		MALL 3RD FLOOR		NE MALL		SE MALL	
	N	%	N	%	N	%	N	%	N	%	N	%
Adjust Air Movement	759	45%	581	49%	392	61%	489	58%	432	51%	216	58%
Adjust Temperature	765	52%	594	59%	394	62%	491	59%	431	54%	221	57%
Adjust Humidity	756	33%	589	34%	392	40%	484	41%	429	33%	217	42%

Reference: Part III, Questions 1c, 1f and 1i.

Pollution in Closed Spaces and Its Consequences in Conservation of Works of Art

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The concept of pollution, as it relates to conservation of works of art in closed spaces, differs from the one used for human environments. In this context, pollution may be defined as anything that damages the physical integrity of a work of art, by modifying its original and/or best condition, either in the case of a work which still stays in the place where it was made (e.g., art in churches and monumental buildings), or in the case of a work which has been moved (e.g., to a museum).

The latter case, studied using the science called museography, is the best known because in many countries, especially in those without an ancient history, museums are the only place where people can have a direct exposure to works of art. In addition, the problems pertinent to museums are rather well-known, and not only among specialists. The factors which must be considered in planning or in re-planning a museum are as follows.

Museum Factors which Affect Art

Temperature and Humidity. The ideal values for art conservation (especially paintings and, in particular, panel paintings), are 18 - 20°C and 50 - 60 percent humidity. In order to reach and maintain these values, most important museums install air-conditioning systems. In Italy, on the contrary, only a few museums have air conditioning systems, because an air-conditioning system is very expensive to install and operate, and its installation is often incompatible with the building architecture, since almost all Italian museums are placed in historical buildings.

The air conditioning system must be operated continuously because its temporary inactivity can cause serious damage. Studies have demonstrated that sudden variations of temperature and humidity can harm works of art, although gradual variations may not.

Dust. Dust caused by plaster and floors can be eliminated by avoiding the use of materials or buildings systems that produce dust, for instance, cement plasters or tiled

floors. In order to reduce the dust brought in by visitors, the entrance of the museum must be preceded by a long covered passage. Dust produced by atmospheric pollution can be eliminated by the air-conditioning system or by an air-filtering system.

Lighting (natural and artificial lighting). Museums must avoid the use of lighting that damages works of art. The infrared and UV rays in both natural and artificial light can harm works of art; the most sensitive works of art are drawings and prints, followed by textiles (e.g. carpets and tapestries) and paintings. Therefore, it is necessary to employ filters that eliminate these dangerous rays, and it is also useful to avoid lighting when the museums are closed. For small works, such as drawings, prints, books, illuminations and other objects that are kept in glass show-cases, it is also necessary to avoid lights that generate heat.

Case Studies of Art Conservation in Enclosed Spaces

The Ministero per I Beni Culturali began to pay attention to the problems caused by pollution (especially air pollution) 20 years ago. We were struck by the damage to stone and marble sculptures placed in open air. We have carried out many studies and conservation activities and have reached a good level of knowledge and practice concerning open air art.

Studies in the conservation of works placed in enclosed spaces started much later. These studies especially concern a kind of painting typical of Italian art mural painting, in particular fresco painting. Italian art of this type was painted from the 13th to 18th centuries, and is important and well-known, for example, the frescoes by Giotto at Assisi and Padua; by Piero della Francesca at Arezzo; by Michelangelo and Raphael in Rome; by Tiepolo and other Venetian painters all over Europe.

Fresco painting has been popular due to its durability, but it is vulnerable to air pollution, especially in the presence of airborne sulfurous anhydride. Fresco painting, which is prevalently made of calcium carbonate ($CaCO_3$), when it contacts sulfurous anhydride (SO_2), tends to transform itself into gypsum (hydrated calcium sulphate) and then disintegrate. To address this problem, brilliant solutions have been recently found: for example, it is possible to recreate the film of calcium carbonate by using compresses of ammonium carbonate. Two important examples illustrate the reasons for the degradation of fresco mural paintings.

Leonardo da Vinci, Last Supper, Milan, Refectory of the Convent of Santa Maria delle Grazie, 1495-1497.

In the refectory of the Dominican Convent of Santa Maria delle Grazie in Milan, a room of nine by 36 meters, Leonardo painted, probably at the request of the Duke of Milan, Ludovico Sforza, between 1495 and 1497, a large painting representing the Last Supper with Christ and the Apostles. In the same year, 1495, a minor painter from Milan, Donato Montorfano, painted on the opposite wall a Crucifixion. This other

painting was made with fresco technique and, except for some damage caused by the 1943 bombing, is perfectly well-preserved.

Leonardo did not carry out his work a fresco but with the tempera (distemper) technique. Fresco painting requires a quick execution, does not allow corrections (pentimenti), and requires very light colors, without light and shade or relief effects. Leonardo, for aesthetic reasons, wanted to employ for this mural painting the same technique that in the Italian Renaissance was employed for panel paintings. With the tempera technique, pigments are mixed with water and an organic glue (e.g., egg, animal glue, gum-arabic, or milk). With this system, the actual painting process could take as long as was necessary. The painting could be changed during its execution, and could have a much richer palette and more realistic effects of relief and chiaroscuro (light and shade). The wall chosen for the Last Supper (the wall is on the north side of the refectory) was covered with a preparation coat (the imprimitura) made of gypsum and glue. Leonardo painted on this coat for about two years, sometimes working night and day, sometimes staying in complete inactivity. He could also correct the picture as he liked.

Leonardo was, from an aesthetic point of view, entirely successful. From a technical point of view, however, the painting was a true failure. By 1517, it was apparent that the Last Supper was going to deteriorate. The main reason for the painting's deterioration is that it was painted on a wall facing northward. The wall was the coldest one and therefore attracted all the dampness produced in the room, which must have been considerable, because friars had their meals at least twice a day in the refectory. Dampness caused the increased production of gypsum (a high hydroscopic substance) contained in the preparation coat, and this increase caused a loss of color in the painted coat.

Restorations of the Last Supper have been documented since the 18th century, but they were merely overpaintings to reverse the color loss. The scientific approach to the environmental conditions, the main reason for the damage, was started at the beginning of the 20th century. A very simple but efficacious remedy was adopted: the little room behind the painted wall was heated; the wall was no longer the coldest point in the room and the deterioration began to slow.

In 1943, the refectory of Santa Maria delle Grazie was almost completely destroyed by war-time bombing. Leonardo's painting was miraculously saved (it had been protected by sand sacks), and a short time afterwards it was restored for the first time according to the modern concepts of art conservation. A new restoration, carried out with strictly scientific methods, was started in 1978. The restoration is not yet complete but it has given rise to many surveys that have studied every aspect of the painting and its conservation. The surveys have studied the humidity and temperature conditions in the refectory, the pollutants in the indoor air, the materials employed by Leonardo (pigments and glues), the microorganisms on the painting's surface, and the characteristics of the painted wall.

Almost all the studies have been published, but almost none has had practical consequences. The condition of the refectory is still as it was before the beginning of the restoration -- not only because the Italian state government pays little attention to its artistic inheritance, but also because the studies themselves had indicated that the situation is not so dangerous. The only measures to be adopted will be a filtering air system and a longer closed passage for the visitors before entering the refectory.

Hieronymus Bosch (attr.), Christ before Pilate. Milan, Chiaravalle Abbey, approx. 1499.

This painting is a precious fragment I discovered in a little chapel of the ancient abbey of Chiaravalle near Milan. This fragmentary picture was made with the fresco technique, but it is extremely rare because it is a work of a Flemish painter, whom I believe to be Hieronymus Bosch. Flemish painting of the 15th and 16th centuries is known almost exclusively through panel paintings, therefore this fragment must be considered as an unicum -- so we paid a considerable amount of attention to it after its discovery. The fresco, Christ before Pilate, has been studied by the technicians of the Opificio delle Pietre Dure of Florence. Their inquiries have clarified that it is a real fresco painting, although it is made in a quite different manner from Italian frescoes. They have also determined the causes of deterioration of the painting, now that it is no longer protected by the plaster that had hidden it previously. The damage is due to the presence of salts within the wall; the salts can leach out (in the direction of the painting) when the internal temperature is higher than the external temperature. The wall is particularly rich in salts (especially nitrates) because it rests on soil which is also rich in salts, derived from the decomposition of organic substances.

To prevent further degradation, we have excavated a deep trench behind the wall. This trench helps the evaporation of water, which otherwise have been absorbed by the wall. We have also avoided any internal heating. At the end of the restoration, we will install an air-filtering system, because tests have revealed the presence of airborne sulfurous anhydride.

How Norwegian Health Authorities Will Handle Indoor Air Quality Problems

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Introduction

The awareness of the increasing number of complaints regarding indoor air quality and the adverse health effects thereof, even in new, well-insulated and energy efficient buildings, has made maintaining the indoor environment a task for the Norwegian health authorities as well as for those technically in charge of building construction and use. In Norway, the responsibility for the indoor environment resides in five Ministries:

- The Ministry of Health and Social Affairs, represented by the Directorate of Health, assisted by the National Institute of Public Health, the National Institute of Radiation Hygiene and the National Council on Smoking and Health;
- The Royal Ministry of Local Government and Labor, represented by the Directorate of Labor Inspection and the National Office of Building Technology and Administration;
- The Ministry of the Environment, represented by the State Pollution Control Authority;
- The Ministry of Consumers Affairs and Government Administration assisted by the Consumer Council; and
- The Ministry of Petroleum.

Research Institutes

Research institutes are working on parts of the indoor environmental factors:

- Norwegian High School of Technology in Trondheim (ventilation, testing of materials);
- National Institute of Building Research (ventilation);
- National Institute of Occupational Health (indoor environment problems in offices and industrial workplaces);
- National Institute of Public Health (infectious diseases);
- National Institute of Radiation Hygiene (radon, electromagnetic fields);
- Central Institute of Industrial Research (microbiological growth in building materials); and
- Norwegian Institute of Air Research (air pollution).

The coordination of responsibility and labor and the communication between the different organizations has not been optimal. This finding was the conclusion of a report "Who Does What" (in the indoor environment) based on two seminars arranged by HK-HTT (the Central Committee for Health and Indoor Environment, an interdisciplinary committee appointed by the Norwegian Society of Chartered Engineers) in 1987-88.

Policy and Regulations

The work of the Ministry of Health and Social Affairs in the indoor environmental sector is warranted under the Law on Municipal Health Services enacted in 1982. The law's goal states that the Norwegian population shall be protected against known adverse health effects due to environmental pollution, indoor as well as outdoor, by the year 1995. The responsibility is delegated to the local health authorities who are encouraged to initiate projects on indoor climate. Most projects up to now have been performed in kindergartens. However, very few physicians and hygienists have updated knowledge and experience with regard to indoor air quality and sick building syndrome.

Indoor Air Quality Guidelines - Work Group

At present, no official indoor air quality guidelines exist in Norway. Different practices are used in the evaluation of air quality, mainly based on subjective interpretation of various measurements. It is agreed upon that the norm for the industrial environment (TLV) is not applicable for residential and non-industrial workplaces, nor for kindergartens, schools and health-institutions. With regard to formaldehyde; the TLV in the work environment has been reduced from 1.2 mg/m^3 to 0.6 mg/m^3 in 1989. The

recommended maximum level for CO_2 in public place schools and kindergartens is 1,200 ppm (0.12 percent). CO_2 is used as an indicator of ventilation efficiency. This concentration is often exceeded and the air quality is regarded as sub-optimal.

The Directorate of Health financially supported the publication "Indoor Climate - a Guide" in 1986 (published only in Norwegian). The same year, a Working Group was appointed by the Ministry of Health and Social Affairs to prepare "criteria documents" that should serve as bases for health-based recommendations on indoor air quality with regard to air contaminants. The Working Group selected the following components as most relevant for Norwegian indoor air quality: CO, CO_2, formaldehyde, VOCs, ETS, particles (combustion products other than ETS), MMMFs, and biological particles (primarily allergenic and irritant-like mites and molds, but, if possible, infectious biologicals as well). The drafts should be ready in April 1990.

A separate criteria document on asbestos has not been developed. Asbestos is regarded as a carcinogenic substance and by law (1986) prohibited from use in new construction. Hence, asbestos is not acceptable in the indoor environment.

The first draft of a "Radon Guide" was prepared by the Forum for Technical Hygiene and the National Institute of Radiation Hygiene, and is being circulated for comments. The Radon Guide recommends an action level of 800 Bq/m^3 radon gas (not radon daughter products) in existing homes (one-year average), and moderate remedial action in the case of levels between 200 and 800 Bq/m^3. In new construction, the goal is an average annual radon level of less than 200 Bq/m^3.

Tobacco Regulations

Tobacco advertising is prohibited by law ("Act relating to prevention of the harmful effects of tobacco" -- an English translation is available from the National Council on Smoking and Health). The Act was extended in July 1988 to protect non-smokers from ETS exposure. Smoking is prohibited in public rooms and indoor workplaces. Alternative facilities must be provided for smokers. Smoking is also prohibited on national airplane flights, and beginning November 1, 1989, on intra-Scandinavian flights. The "Norway smoke-free year 2000" goal was presented by the Norwegian Medical Association in 1986.

Official Responsibility

In October 1989, the Directorate of Health of the Department of Preventive Health began to coordinate IAQ efforts between the different Ministries, including the Directorate of Labor Inspection. The latter has the responsibility for the Norwegian TLVs ("Administrative norms of air pollution in workplace atmosphere") in industrial as well as non-industrial indoor workplaces, and published guidelines for office climate in 1983.

The National Office of Building Technology and Administration is continually revising the building regulations. The recent edition (1987) states that "the indoor air quality shall be satisfactory," without stating specifically the air exchange, temperature, and humidity in

the regulations. These levels are, however, mentioned in an appendix. A common Nordic basis will be used for the new Norwegian building regulations planned for 1992.

Activities initiated by the State Pollution Control Authority include the following:

- Work with regulations for formaldehyde emissions from materials (chipboards),
- "Datasheet" on toxic materials that are used in building materials and for surface treatment, and
- Composition of water-based paints with regards to emissions that may cause adverse health effects.

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