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Indoor Air Quality: Issues and Opportunities

by D.S. Walkinshaw

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INDOOR AIR QUALITY: ISSUES AND OPPORTUNITIES

Douglas S. Walkinshaw, National Research Council Canada, Ottawa

In recent years concerns have arisen about the quality of indoor air as it affects human health, safety and comfort, in what were previously thought to be relatively benign climates such as those in offices, residences, schools and ice arenas. These concerns have been fuelled by the discovery that in many buildings, pollutants of concern are originating indoors and, with reduced ventilation rates, are now occurring at much higer concentrations indoors than outdoors. This fact, coupled with the realization that most people spend the largest portion of their time indoors, and that economics and technology are leading to further reductions in ventilation rates, has led to increased public concern and scientific attention. The problem and its solutions touch upon a range of disciplines within the health, building and environmental communities, and the responsibility does not rest clearly with any one agency. This paper reviews the range of chemical and biological hazards which have been discovered, the ventilation and pollutant standards and guidelines which are emerging, major issues requiring resolution, and social and market opportunities now apparent.

QUALITÉ DE L'AIR INTÉRIEUR: PROBLÈMES ET PERSPECTIVES

On se préoccupe depuis un certain nombre d'années de la qualité de l'air intérieur des environnements que l'on croyait jusque-là relativement sains, par exemple les bureaux, les habitations, les écoles et les patinoires intérieures, et de ses effets sur la santé, la sécurité et le confort des individus. On a découvert en effet que dans nombre de bâtiments les agents polluants proviennent de l'intérieur et, qu'en raison de la diminution des débits de ventilation, ils présentent maintenant des concentrations beaucoup plus fortes que celles enregistrées à l'extérieur. Cette constatation, à laquelle s'ajoutent les faits que la plupart des gens passent le plus clair de leur temps à l'intérieur et que la situation de l'économie et la technologie conduisent à réduire encore davantage les débits de ventilation, a contribué à accroître l'intérêt du public et des scientifiques pour cette question. Le problème et ses solutions ressortissent à un certain nombre de disciplines des secteurs de la santé, du bâtiment et de l'environnement, et la responsabilité n'incombe pas tout naturellement qu'à un seul organisme. Ce document décrit les risques de nature chimique ou biologique qui ont été identifiés, les normes et lignes directrices qui sont élaborées en matière de ventilation et de pollution, les grandes questions à résoudre, ainsi que les perspectives sociales et commerciales que se dégagent aujourd'hui.

INDOOR AIR QUALITY: ISSUES AND OPPORTUNITIES

Douglas S. Walkinshaw

Coordinator, Indoor Air Quality, Division of Building Research,
National Research Council of Canada, Ottawa, Ontario

INTRODUCTION

The quality of indoor air as it affects human health, comfort and safety, has emerged as an issue demanding public and scientific attention at a level that, for the Air Pollution Control Association, for example, parallels that being accorded to acid rain, as well as to the disposal of hazardous chemical and radioactive wastes (APCA, 1985). Twenty percent of the research budget of the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), which numbers over 50 000 members, is now targetted for indoor air quality (ASHRAE, 1985).

While the emergence of indoor air quality (IAQ) as a major health issue has coincided with the introduction of certain energy conservation measures in buildings beginning in the mid-1970s, IAQ implications extend far beyond this. For example, consideration of IAQ implications is beginning to have a new or increased influence on the design and selection of building materials and furnishings; on the design, selection, maintenance, and operation of building heating, cooling, humidification, and air handling systems; on the design and operation of cooking systems; on the acceptability of tobacco smoking indoors; and on the desirability of openable windows and tight-enclosure buildings. The complexity of the IAQ issue is shown in Figure 1.

As health authorities, building managers and scientists continue to discover new gaseous, particulate and biological pollutants indoors, often at levels exceeding those outdoors, there seem to be good reasons for the concerns being expressed. This is particularly true for the many Canadians and peoples of other cold climate regions who spend the majority of their time indoors in winter months, both in their own residences and in schools, offices, ice arenas and other facilities.

An extensive program has been underway in Canada for several years now to identify and alleviate the health impacts of urea formaldehyde foam insulation (UFFI) which had been used in many, often older residences, and was subsequently banned in 1980 (Shurb, 1985 and Broder, 1985). Other major programs are being carried out to assess and control residential radon exposures (Létourneau, 1985), and to develop mechanical ventilation techniques for tight-enclosure houses (Ficner, 1985).

In the United States and Europe, broad studies are focussing on identifying pollutants associated with "sick" buildings. They are also assessing the levels and impacts of unvented combustion pollutants, of involuntary or passive tobacco smoke inhalation, of formaldehyde exposures, particularly from pressed wood products in mobile houses, of exposure to radon in homes, and of biological pollutants, such as legionella bacteria, associated with pools of stagnant water in HVAC equipment and continuously wetted building materials.

INDOOR POLLUTANTS AND THEIR CONTROL

Pollutant Standards

While the U.S. Environmental Protection Agency (EPA) has set national ambient air quality standards (Table 1) (EPA), parallel standards for indoor air have not yet been promulgated. However, the World Health Organization (WHO) Working Group on IAQ has developed some guidelines, also shown in Table 1 (WHO, 1982).

The U.S. National Council on Radiation Protection and Measurements (NCRP) has recently recommended an indoor radon standard of 2 WLM/year which is equivalent to an indoor concentration of 8 pCi/L (NCRP, 1984).

The U.S. Housing and Urban Development Agency (HUD) has set a target formaldehyde level of 480 $\mu g/m^3$ (0.4 ppm) for mobile homes. It is expected that this target will not be exceeded if product emission standards for particle board and plywood as measured in large chamber tests are set at 0.3 ppm and 0.2 ppm, respectively, if the indoor temperature does not rise above 77°F, if the relative humidity is less than 50%, if the ventilation rate is at least 0.5 air changes per hour, and if there are no other major emitters of formaldehyde (HUD, 1985).

The U.S. National Institute on Occupational Safety and Health (NIOSH) has been investigating airborne particles of biological origin such as bacteria, moulds and fungi, and developing guideline levels based on the numbers of colony-forming units (CFU) present in the air. One number suggested is 1000 CFU/m^3 (Morey, 1984).

Finally, the level of ambient carbon dioxide due to human respiration is generally considered to be a reasonable proxy for ventilation rate and the overall level of indoor air pollutants. In Japan (NTIS, 1974), indoor carbon dioxide levels are to be less than 1.8 g/m^3 (0.1 percent or 1000 ppm). Where air-cleaning devices are employed or where there are non-human sources of CO_2, this value may not be appropriate.

Mechanisms for controlling these and other indoor pollutants include increasing indoor-outdoor air exchange rates where the outdoor air has lower concentrations, as is normally the case; improving internal air circulation; cleaning the air to remove particles and gases; and eliminating or reducing pollutants at source. Normally, control at source is the most effective mechanism. However, particular circumstances may govern the most cost-effective approach. Since many indoor pollutants cannot be eliminated at source or by air cleaning, at least some outdoor air will be required.

Ventilation Standards

Since 1973 ASHRAE has maintained a building ventilation standard which is generally applied in North American buildings (ASHRAE, 1973). Standard 62-73 specifies minimum and recommended ventilation rates, with the recommended rates generally exceeding the minimum rates by factors of 1.5 to 2.

However, ASHRAE Standard 90, which is concerned with energy conservation in new buildings, recommends adherence to the minimum ventilation values specified in 62-73 when it was first issued in 1975 (ASHRAE, 1975) and then again in 1980 (ASHRAE, 1980). With the increased IAQ concerns, a new version of the ventilation standard eliminating this minimum and recommended value approach was issued in 1981 (ASHRAE, 1981).

ASHRAE Standard 62-81 specifies two minimum ventilation rates in non-residential buildings, one for settings with tobacco smoking and a much lower rate for settings with no smoking. In this standard, a portion of the ventilation air can be recirculated provided it is treated to meet the ambient air quality standards. In addition, Standard 62-81 specifies an alternative air quality procedure in which lower ventilation rates can be used, provided specified pollutant concentrations are not exceeded and odour levels are acceptable to 80 percent of a 20-person panel of untrained observers.

Until Standard 62-81, the ASHRAE ventilation standard had only been applied to mechanically ventilated buildings, which essentially excluded single-family residences, as these rely on infiltration and natural ventilation (windows and vents). During the review period, ASHRAE 62-81 was challenged by the Formaldehyde Institute because of the 0.1-ppm standard for formaldehyde. The Institute felt that inclusion of this new formaldehyde criterion in the standard would cause problems for residences, especially for manufactured housing with its extensive use of urea formaldehyde-bonded, pressed wood panelling, and other formaldehyde-containing materials. As a consequence, the standard was not endorsed by the American National Standards Institute. Since Standard 62-81 failed to gain general acceptance, ASHRAE is in the process of developing a revised standard (Janssen, 1985).

It seems probable that the revised ASHRAE standard will propose a single ventilation rate, likely the higher (smoking) rate of Standard 62-81 except in non-smoking settings where it could be lower, and that the IAQ procedure will not set a formaldehyde limit. The standard may also propose the higher NCRP radon limit of 8 pCi/L, and a lower carbon dioxide limit of 1000 ppm to be used as a proxy for other pollutants that affect comfort. In addition, concerns may be expressed about biological pollutants in HVAC systems, and unvented combustion products, such as those discharged from rink cleaners used in arenas.

In Canada, the 1985 version of the National Building Code (NBC, 1985) requires new dwelling units to have mechanical ventilation systems capable of providing at least one-half an air change per hour during the heating season, based on the interior finished volume of the dwelling unit. This code also draws attention to the possible risk of carbon monoxide poisoning due to chimney backdrafting in new houses stemming from increased enclosure tightness. To help avoid this risk, fireplaces are now required to have their own supply of combustion air.

Pollutants of Concern

There are several individual pollutants and groups of pollutants of particular current interest. Concerns about one of these, formaldehyde, a colourless gas with a pungent odour, have centered on its biological reactivity (Drucksache, 1985). Depending on individual sensitivity, formaldehyde exposure can result in irritation to the mucous membranes of the eyes, nose and throat. For example, exposure to levels ranging between 0.4 and 0.7 ppm appeared to be the reason for symptoms such as headache, nausea, dizziness, burning eyes and fatigue in a recently reported case (Marchant, 1985).

Action of formaldehyde in concentrations as low as 0.05% can cause allergic contact dermatitis. Perhaps the primary concern relative to formaldehyde is that it may be a carcinogen. However, this concern is based on nasal cancers which have been observed in tests on rats exposed to lifelong exposures at comparatively high levels. Epidemiological studies have so far failed to indicate carcinogenic effects on people (Drucksache, 1985).

Higher indoor levels of formaldehyde may result from the extensive use of: particle board without a covering layer, UFFI, or some sealing materials for parquet floors, adhesives, varnishes and lacquers, textiles, wall paper, carpets and curtains. Some of the highest non-industrial formaldehyde exposure levels have been recorded in mobile homes (Syrotynski, 1985).

Pressed wood products emit formaldehyde at rates that increase with temperature and humidity, and decrease as the ambient formaldehyde levels increase (Matthews, 1985). Long-term emission decay rates of these materials are not yet available, but emissions are known to continue for years. Studies show that particle board subflooring emissions can be reduced by a factor of two or more by covering the floor with polyethylene or vinyl linoleum (Matthews, 1985). Recent studies by NASA at the National Space Technology Laboratories in Mississippi have claimed that spider plants can cleanse indoor air of formaldehyde (Wolverton et al., 1984).

The question has been raised as to whether formaldehyde, or some other contaminant related to microbial activity, is the primary cause of UFFI-related health complaints (Samoiloff, 1985). Further, the question of the relative seriousness of the UFFI health effects is still unresolved. For example, 18 subjects, nine of whom had previously complained of non-respiratory adverse effects from UFFI, failed to show any significant pulmonary function reaction when exposed for 90 minutes to UFFI offgas (formaldehyde concentration of 1.2 ppm) in a chamber (Day, 1984). On the other hand, a study of occupants in 450 UFFI homes has tentatively indicated the possibility of some individuals suffering from irritation effects associated with the presence of UFFI, possibly due to the slightly higher formaldehyde levels which averaged 0.044 ppm vs 0.035 for 225 control homes (Broder, 1985).

Radon is a colourless, odourless, radioactive noble gas produced by the alpha decay of radium. Radium is present in trace amounts in all geologic materials. Radon decays to a series of short-lived (<30 minutes) daughters, exposure to which can eventually cause lung cancer (Walsh, 1984).

Radon gas can enter buildings from the soil through basement cracks and openings, or via untreated well water. It is also emitted by masonry materials (Bruno, 1983). Control of soil radon entering through the basement, often the major source of indoor radon, can be achieved through sealing of the subgrade cracks, such as those between foundation wall and slab, in combination with introducing sub-slab ventilation utilizing, for example, an existing sump and its lead-in water draining pipes (Nitschke, 1985). Circulating basement air seems to control radon daughter levels by causing plate-out of the host dust particles (Desrochers, 1985). Dust filters and electrostatic precipitators may also help (Hinds, 1983).

Unvented combustion products, including carbon monoxide, carbon dioxide, nitrogen dioxide, and particulates, can accumulate to levels of concern where adequate precautions are not taken. In ice arenas, for example, the hourly cleaning of the ice surface with machines powered by gasoline, propane or heating oil can raise carbon monoxide levels beyond safe limits if the building is not properly ventilated. Symptoms of carbon monoxide poisoning include headache, fatigue and nausea. In a recent survey in British Columbia, 32 of 64 arenas had CO levels above the B.C. guideline of 25 ppm, with 19 above 50 ppm. The highest recorded level was 206 ppm. While most of the arenas surveyed had ventilation fans, 73% were not being operated. Evidently many arena managers thought that the accumulation of CO from exhaust is accompanied by an odour and that only at that time need the fans be operated (Hillman, 1984).

Automobile fumes from attached and underground parking garages can be drawn indoors. Gas stoves produce nitrogen oxides, the amounts of which can be reduced through use of new burner flame inserts (DeWerth, 1985), elimination of pilot lights, and fumehood exhausting (Tamura, 1984).

With the sealing of housing enclosure leaks, the possibility of chimney backdrafting as a result of the coincident operation of furnaces and fireplaces, and bathroom and clothes dryer exhaust fans, has increased. One study of 100 Canadian homes of various styles and ages showed that 34% were at risk, with depressurization by fireplaces the major contributing factor (Moffatt, 1985).

In mechanically ventilated buildings, the fraction of exhaust air recirculated as intake air can change by a factor of five, depending on the use of rain caps, the placement of exhausts and intakes, and the ratio of exhaust to wind velocities (Wilson, 1985). This can be a real concern for buildings with multiple fumehood exhausts where up to 10 percent of the exhaust has returned through the ventilation system (Reible, 1985).

Epidemics of Legionnaires' disease, a bacterial pneumonia, have been associated with aerosols from cooling towers and evaporative condensers and with dusts from landscaping and construction (Walsh, 1984). The recent incident of 37 deaths and 163 persons infected with the disease in a U.K. hospital has been attributed to faulty design (ENR, 1985). The problem appeared to be with the connection of a vertical drain pipe from a roof-top cooling tower to a horizontal drain pipe from a lower floor air conditioner. Evidently, at night and on weekends when the fans were off, polluted water from the cooling tower reached the air conditioner drip trays where bacteria were identified on the mastic around the trays.

Legionella bacteria can also proliferate in hot water systems to be released in showers. Control measures against this latter possibility include maintaining hot water tanks above 60°C, continuous chlorination and periodic hyperchlorination, and, possibly, avoidance of plastic shower hoses (Kallings, 1984).

In general, allergenic and pathogenic biologic organisms can replicate in HVAC system components such as water spray systems, humidifiers, air handling and drain pans, and fan-coil units (Morey, 1984). Complaints in homes, schools and work-places of eye, nose and throat irritation as well as fatigue can be correlated with unpleasant earthy, musty odours produced by abundant saprophytic mould growth (Samson, 1985).

A recent study has linked the presence of the fungal species, Stachybotrys atra, found in a house in Chicago, to recurring occupant illnesses suggestive of trichothecene toxicosis. These maladies included headaches, fatigue, dermatitis, intermittent localized hair loss, and general malaise (Croft, 1985). In this study the mould occurred in a section of a cold air return duct with a 2-cm layer of dust containing moist lint and carpet fibres, and in sections of wood fibreboard wetted by a leaking roof and plumbing. Contaminated areas had a black, sooty appearance. Evidently moist materials of high cellulose and low nitrogen content such as fibreboard, straw, dust and lint which are subjected to temperature fluctuations in the 0 to 40°C range provide ideal conditions for S. atra toxin production. Continuous water accumulation can result from faulty plumbing, ceiling or basement leaks, or condensation at moisture barriers.

ISSUES

The emerging IAQ concerns just described have potentially significant implications for Canadians who, because they live in a colder climate, spend the great majority of their time indoors. In addition to potential impacts on the building and health care industries, there are economic implications for the chemical industry relative to the use of consumer products and building materials, the tobacco industry and the growing public concern over passive smoke exposures, and the energy industry in terms of IAQ impacts on building energy conservation and fuel selection. The extent of the implications will depend on three questions:

1. To what extent is IAQ now affecting human health, comfort and productivity, and what are the future trends?

2. How readily will these trends be adjusted to accommodate IAQ concerns as they become defined?

3. What role will government, industry and the public assume in seeking answers to questions 1 and 2, and in supporting regulatory standards for the indoor environment?

As indicated above, the impact of IAQ on health, comfort and productivity is very poorly understood at present. Certainly, Legionnaires' disease, a building-related illness, is known to have caused deaths in hospitals and hotels on an epidemic scale. However, the incidence of this pneumonia, particularly from residential exposures, is unknown and could be under-reported.

While formaldehyde residential exposures at levels of 0.04 ppm are widespread in Canada (Shurb, 1985), and levels above 0.1 ppm are not unusual in new, tight-enclosure homes (Dumont, 1984), the sensitivity of the population to this irritant is not statistically calibrated.

The incidence of lung cancer due to indoor radon exposures is not known and while small compared to that due to tobacco smoke (Létourneau, 1985), the implementation of low cost construction and ventilation techniques for its avoidance might still eliminate a significant number of lung cancers each year (Love, 1985).

While many people are no longer willing to tolerate the irritating effects of passive tobacco smoke inhalation, the extent of illness caused by this pollutant is still being defined with particular concern being expressed for children (Shopland, 1985).

Although there appears to be significant potential for chimney backdrafting in residences, the amount of combustion product backdrafting and related discomfort, illness and death is unknown.

A recent study of 1091 out of 5292 employees in a large Canadian office complex indicated that most employees had suffered from upper respiratory tract and eye irritation which was troublesome at work but not at home (McDonald, 1985, Bénard, 1985). Symptoms also included headaches, drowsiness, exhausting sleeplessness and irritability, and skin dryness and irritation. As is typical for such symptoms, the etiology of these problems was not established.

In 1984, IAQ investigations were carried out in 94 Canadian federal buildings (Kirkbride, 1985). NIOSH is doing similar studies. In general, in the majority of office buildings where such complaints occur, the problem is addressed through improvements to the ventilation system. This includes better air circulation, and humidity and temperature control. In only some of the cases are specific pollutants identified. The re-entry of building exhaust, the entry of motor vehicle exhaust, copy machines, tobacco smoke and newly glued carpets are among the most frequently identified sources.

Current trends in building design and operation are toward increasingly tighter-enclosure, mechanically ventilated structures. The temptation to save energy costs by reducing outdoor air intake in such buildings will be strong, particularly if the associated health risks are unquantified. Increased use of air conditioning in offices and residences reinforces the trend to lower air exchange rates with the outdoors. As a result of these trends, which will tend to increase indoor pollutant levels, standards developed by ASHRAE and the National Building Code of Canada call for increased mechanical ventilation. Whether these standards can be met in practice, and whether the result will be more or less outdoor air being circulated to occupants when compared to that previously experienced with leaky enclosures and openable windows, is not known.

With respect to one indoor pollutant, tobacco smoke, there is a move to reduce involuntary exposures in office buildings, hospitals, airplanes, hotels, and restaurants by limiting smoking to restricted, separately ventilated areas (Shopland, 1985).

Because of the off-oil emphasis of national energy policies, there is increased use of electricity, gas and wood for heating and cooling Canadian buildings (NEB, 1984). Use of unvented kerosene heaters for individual room heating has increased substantially. The full impact on IAQ of these changes in mode of heating is not yet known.

There seems to be an increased use of pressed wood products, such as particle board, in building structures as subflooring, wall finishes, and in furniture. As a result of the formaldehyde concern, particle board emission standards are now in place in Germany (ETB-Baurichtlinie, 1980).

While the use of synthetic building materials and furnishings with their associated increases in indoor levels of organic gases may well continue to rise, changing fashions such as the trend in residences to hardwood floors with centre area rugs, rather than wall-to-wall carpets, make forecasting difficult.

In general, the relative influence of building materials on the level of air pollutants versus maintenance practices and other sources of pollutants needs to be put in perspective.

With respect to human factors, the aging of the Canadian population and the trend for more women to work outside the home could both influence the incidence of IAQ problems.

The fact - that there are so many air pollutants indoors, ranging from gases and dust to bacteria and fungal spores;

- that buildings, their equipment and their occupants are the pollutant sources;
- that there are human productivity as well as health concerns; and
- that the economic impacts of regulation will be large,

makes IAQ a difficult issue for governments to address on more than a pollutant-by-pollutant basis. Nevertheless, in Canada (Walkinshaw, 1985) and the United States (Millhone, 1985), many federal agencies have become involved in developing coordinated approaches to the issue. However, as a result of recent cutbacks in energy-related research, this activity had to be reduced in Canada.

In addition to the federal government activity in Canada, a workshop of 37 persons from industry, universities, the provinces, and municipalities indicated a desire to see more IAQ research done on a cooperative basis between the building and health disciplines (Wilson, 1985). This group saw the need for a central industry/government coordinating committee and the establishment of centres of excellence.

With respect to indoor pollutant standards, a federal-provincial working group on IAQ is developing residential guideline limits for carbon monoxide, radon, nitrogen dioxide, humidity, ozone, formaldehyde, other aldehydes and carbon dioxide (Wyile, 1985).

In the United States, the gas (Billick, 1985, DeWerth, 1985), electric (Purcell, 1985), and building controls (Lane, 1985) industries, several states such as California and Minnesota, and universities such as Harvard and Princeton, are carrying out a number of studies.

In projecting those aspects of IAQ on which government attention and action are likely to focus, Douglas and Wildavsky (1982) point out that societal selection of risks to be avoided may depend more on cultural biases than on scientifically based cost-benefit projections. For example, the societal health costs resulting from typical rates of tobacco smoking most probably far exceed the costs incurred through involuntary passive smoking. However, society is moving to reduce the involuntary risk by providing additional ventilation or restricting smoking locations, rather than regulating the voluntary consumption of tobacco.

By analogy, this suggests that non-residential building environments will eventually be subject to regulations while individual home environments, where more time is spent, will not. Nevertheless, as information on the concentrations and impacts of indoor pollutants become clear, it may reasonably be expected that deepening concerns will result in changing attitudes toward individual rights and in a stiffening resolve to insist on corrective action. In this vein, the movement is growing for the designation of separate smoking areas in public places, in airplanes, in restaurants, and in hotel rooms. As a result of individual initiatives, there is already a small market for low-pollution residences (Small, 1985a and Leitch, 1985). In response to case studies of children showing that their learning ability had been severely hampered by the presence of indoor pollutants in schools (Maclennan, 1985), one school board is attempting to alleviate the problem (Small, 1985b). In the United States, Bonneville Power Administration is promoting residential energy conservation measures while informing consumers about potential IAQ problems and, where radon levels exceed 5 pCi/L, subsidizing cost for ventilation with heat recovery devices (Love, 1985).

OPPORTUNITIES

The field of IAQ presents an opportunity for industry and government to work together in several areas of mutual interest.

One of these areas would be to develop IAQ screening methods for building materials and furnishings which would help to avoid costly future crises such as those that occurred with asbestos and UFFI. This would minimize the risks to building owners, builders, manufacturers, and governments when new materials are introduced. In the case of UFFI, for example, total remedial costs and property value losses probably exceed $1 billion, yet with the lower formaldehyde levels now being recorded in houses that contain UFFI, the causes for concern remain unclear.

As IAQ standards are adopted by government health authorities for various indoor pollutants, there will be a broad market for related pollutant sensors and pollution-testing services, and government and industry should coordinate their efforts so that these can be put in place in a timely fashion. Coincidently, the demand for low-pollution residences and building materials will increase.

The era of electro-mechanically controlled indoor environments, begun in the 1960s in non-residential buildings with the introduction of air conditioning and large-scale floor plans with offices remote from windows, is now extending to Canadian residences as a result of the revolutionary adoption of polyethylene vapour barriers and flexible sealants to eliminate enclosure leaks. As a result, there is a growing demand for heat recovery ventilation devices, and sensors and controls which condition the indoor environments for energy-efficient housing.

Owing to energy conservation and health and comfort concerns, the demand for air cleaners is growing for the residential and office environments, but there is uncertainty as to the relative merits of the various technologies being employed. The cooperation of government and industry in developing more comprehensive air cleaner performance standards would provide this industry with an opportunity to market its best products and to increase its market penetration. For buildings in the Far North where energy costs are high, there is a particular opportunity for using air cleaners and recirculated air to minimize ventilation costs.

Because of the magnitude, complexity and newness of the IAQ issue, there are a number of reasons for multi-disciplinary, multi-organizational and multi-lateral cooperation. For example, large-scale scientific surveys of building environments are required to identify pollutants, their sources and building ventilation characteristics, in order to assess the gravity of the IAQ problem.

Such surveys could most certainly benefit from international cooperation so as to share test protocol development costs, and to establish and evaluate a more comprehensive and meaningful IAQ and building parameter data base. With these data on hand, building research priorities could be set, and meaningful clinical and epidemiological studies would follow.

Increased multi-disciplinary cooperation will ensure that health science and building science IAQ research efforts are focussed on common objectives, iterate quickly toward useful results, and remain complementary. Such cooperation will facilitate the study of synergistic effects of groups of contaminants, and the development of innovative IAQ measurement devices and indicators, and practicable remedial measures.

The real opportunities, of course, are for the safeguarding of public health and productivity through the avoidance of building-related illnesses and discomfort, whether these be episodic like Legionnaires' disease, or chronic like the so-called twentieth century disease of hypersensitive individuals.

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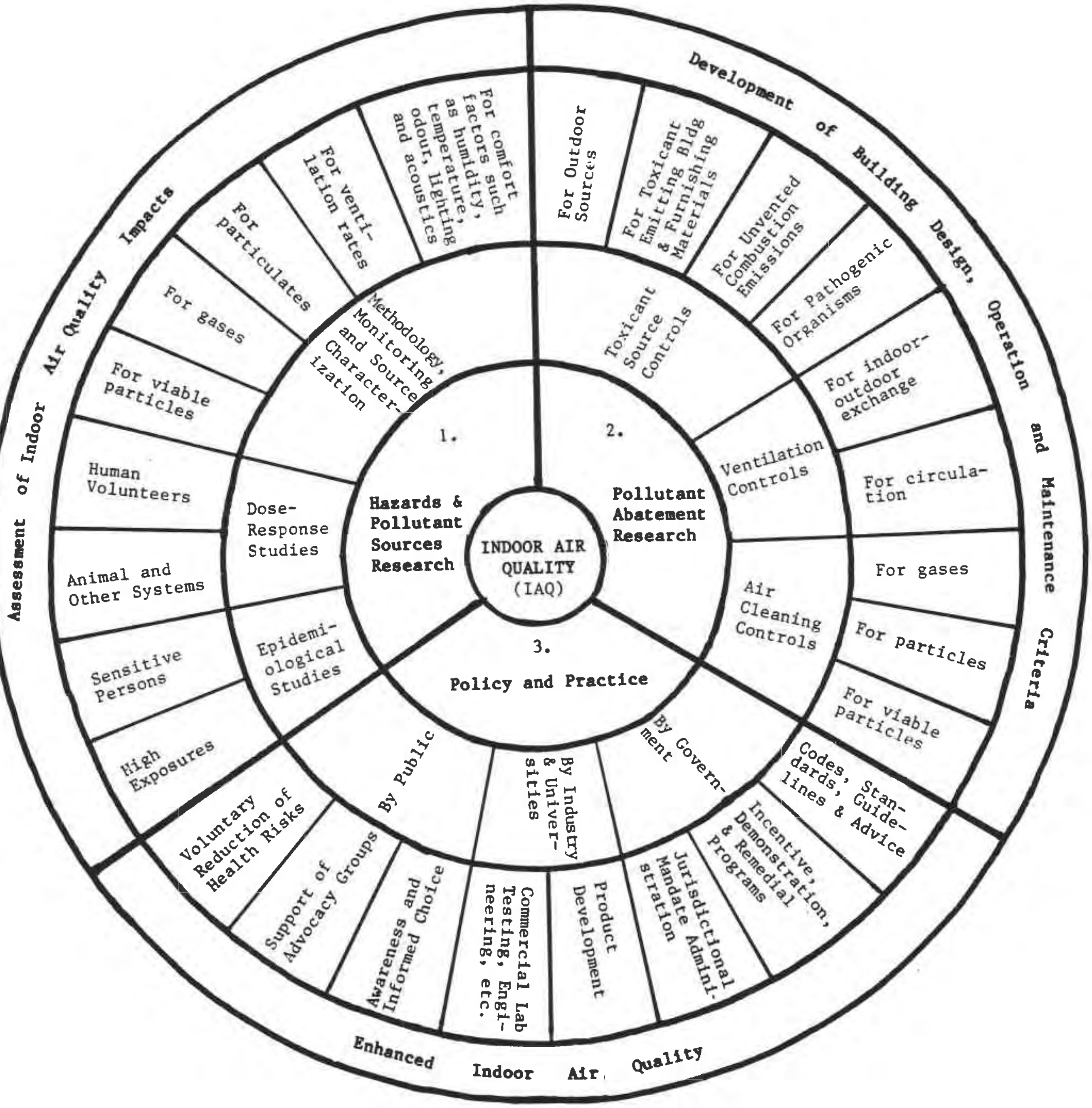

FIGURE 1 SCOPE OF THE INDOOR AIR QUALITY ISSUE

TABLE 1. Some Air Quality Contaminant Concentration Criteria*

Contaminant	EPA Ambient Air Standards		WHO Indoor Air Guidelines	
	Time	Level	Concentration of Limited or No Concern	Concentration of Concern
Carbon monoxide	1 h 8 h	40 000 (35 ppm) 10 000 (9 ppm)	11 000 (9.6 ppm)	30 000 (26 ppm)
Carbon dioxide			4.5 g/m^3 (2500 ppm)	12 g/m^3 (6700 ppm)
Lead	3 mo	1.5		
Nitrogen dioxide	1 yr	100 (0.055 ppm)	190 (0.1 ppm)	320 (0.17 ppm)
Ozone	1 h	235 (0.12 ppm)	120 (0.06 ppm)	150 (0.08 ppm)
Sulphur dioxide	24 h 1 yr	365 (0.14 ppm) 80 (0.03 ppm)	500 (0.2 ppm)	1350 (0.5 ppm)
Formaldehyde			60 (0.05 ppm)	120 (0.1 ppm)
Particulates	24 h 1 yr	260 75		
Asbestos			0	0.1 fibre/cm^3
Radon			0	70 Bq/m^3 (2 pCi/L)

*Units are μg/m^3 unless noted otherwise.
EPA — Environmental Protection Agency (U.S.)
WHO — World Health Organization (UN)