Indoor Air Quality in Cold Climates: Hazards and Abatement Measures

Summary of an APCA International Specialty Conference

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THE FIRST APCA Specialty Conference on indoor air quality (Apr 29–May 1, 1985 in Ottowa, Canada) featured 67 presentations covering many aspects of the problems, with the focus on cold climate hazards and abatement measures. Almost 400 persons from a variety of building, health, and environmental disciplines and interests attended. The conference transactions contain 38 peer-reviewed research papers, 17 policy and practice papers, and the opening addresses of the Canadian Minister of Health and Welfare and the President of the National Research Council of Canada. The combined effort of the organizers, authors, and reviewers has resulted in a document which should be useful to all involved or interested in the field of indoor air quality.

Increasingly widespread concern has arisen during the past few years over the quality of air in residences, schools, offices, hospitals, and even ice arenas, as it may be affecting human health and comfort and the performance of materials and equipment within the building. In some cases specific indoor air pollutants have been identified as the causal agents in illness and death, as in the cases of Legionnaire's disease from bacterial water droplet aerosols, and of carbon monoxide poisoning from combustion product venting failures. More often, however, the concern is associated with perceived but not well understood problems which have been conveniently grouped together and labelled the "sick building syndrome."

The Transactions of the APCA Specialty Conference on Indoor Air Quality in Cold Climates are available for purchase. Contact APCA headquarters for price information.

With respect to the importance of indoor air quality (IAQ) at least three facts seem certain. First, concerns about three specific indoor air pollutants: asbestos, passive tobacco smoke and formaldehyde, are now resulting in some very costly corrective measures. Secondly, many potentially harmful gases, particulates, and microbial agents have been discovered in the indoor air in recent years for which no standards or policies yet exist. Finally, indoor air quality in cold climates has been closely linked to the energy conservation measures introduced in the last decade, particularly those reducing indoor-outdoor air exchange, since this directly raises the concentrations of the many pollutants originating indoors. Therefore, a measure of the importance attached to the efficiency of energy use in buildings. Based on savings achieved since the 1973 oil crisis, this turns out to be very significant.

As a result of these concerns, potential IAQ impacts are receiving increased attention, particularly in cold climates, where people spend so much time indoors during the heating season. Attention is being given: to the design and operation of combustion devices, air handling systems, and humidifiers; to the specification of the range of acceptable indoor human activities such as tobacco smoking; and to the selection and maintenance of building materials and furnishings. Action is being taken on the bases of available information on pollutant dose-human response, and of societal cost-benefit and relative risk trade-offs.

Many of the papers presented at the conference have multiple authors; only the first listed are referenced in this summary.

Opening Addresses

The Honourable Jake Epp and President Larkin Kerwin, the heads of two Canadian federal agencies with primary roles in dealing with indoor air quality concerns, underlined the importance of the subject and set the broad scope for its many aspects with their opening addresses.

One of these agencies, Health and Welfare Canada (HWC), has the federal role for the protection of the health of Canadians. Within that responsibility, HWC manages a chemical, microbiological, and radiological hazards health research and criteria program which is now addressing IAQ. In addition, HWC provides medical services workplace support to federal employees. In this role HWC staff have

become increasingly engaged in investigations into IAQ complaints in buildings across the country. In 1984 for example, they carried out 94 investigations, finding HVAC problems in 64 cases, reentry of building exhaust or entry of motor vehicle exhaust in nine cases, problems with copy machines and tobacco smoke in five cases, and emissions from glues and adhesives in two cases.[1]

In his paper, Mr. Epp, Minister of HWC, links the recent focus on IAQ to the extensive energy conservation efforts which followed the 1973 world oil crisis, and which in buildings have resulted in a reduction of air exchange with the outdoors. HWC and the Canadian provinces are currently engaged in a pioneering effort to develop guidelenes for maximum acceptable indoor air pollutant concentrations in residences. Minister Epp speaks of the hazards of exposure to tobacco smoke to both smokers and to nonsmokers, and indicates that HWC is developing a policy of limiting smoking in its own buildings. (As of January 1, 1986, HWC employees are allowed to smoke during working hours only at designated areas and then only during break periods.)

The other agency represented in an opening address, the National Research Council of Canada (NRC), conducts research into the basic sciences and engineering. Within that context the NRC provides technical support to the National Building Code of Canada, as well as to various national and international standards bodies, including the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), which maintains the internationally accepted building ventilation standard. To date, the NRC IAQ activity has focused on resolving the urea formaldehyde foam insulation (UFFI) problem, while at the same time developing the basis for a longer term multidisciplinary, multipollutant coordinated approach to the problem.

In his paper, Dr. Larkin Kerwin, President of NRC, speaks of the broad nature of the IAQ issue and identifies a number of classes of indoor air pollutants of concern including:

- combustion pollutants from arena ice cleaners, gas cooking stoves, unvented space heaters, and automobiles parked indoors or passing building outdoor air intakes;
- bacteria and fungal spores and mycotoxins cultivated in wet building materials, and in humidifiers, hot water plumbing, and cooling towers; and
- gases from resins in building materials and furnishings.

President Kerwin observes that concerns about the potentially adverse impacts of energy conservation on IAQ in Canadian buildings have resulted in important changes in the National Building Code. Beginning with the 1985 edition, this model code requires that new dwellings, because of their very tight enclosures, must have mechanical systems which can provide ventilation at the rate of up to one-half air change per hour (ach). Fireplaces must have their own supply of combustion air to reduce the possibility of chimney backdrafting and carbon monoxide poisoning.

Dr. Kerwin states that IAQ warrants attention and a planned long-term multidisciplinary effort, combining the skills of researchers, and practitioners in industry, university, and government.

Hazards

This section comprises 23 of the 57 papers, with seven directed at office buildings and the remainder focusing on residential settings. Many of the IAQ hazards currently associated with buildings in cold climates are addressed. Included is the linkage between tight enclosure structures and increased concentration of various gaseous pollutants such as radon gas emanating from the soil, and formaldehyde gas in mobile homes and new residences.

There are studies on NO_x from unvented gas kitchen ranges and supplementary space heaters, and on organic compounds from a number of sources. The sick building syndrome in offices is addressed in combined health and environmental studies. In one survey, localized problems are stressed, while in a study of a large complex, there is a concern about the adequacy of the ventilation system. Another study indicates that, in buildings with multiple fume hood exhausts, a significant portion of the exhausted pollutants are reentering these buildings.

The UFFI problem is the subject of several health and environmental papers. However, with formaldehyde levels in UFFI homes now generally at lower levels than those of mobile homes, or even many newly built homes, research to trace the source of any UFFI related health problems is broadening to include fungi, particles, and trace gases.

The section begins with tandem papers by McDonald and Bénard documenting a study of a large office/hotel complex located in Hull, Québec, known as Les Terraces de la Chaudière. This complex con-

sists of a hotel and three office towers housing over 5000 federal government employees. Windows in the building are unopenable, and a variable air volume heating and ventilation system is employed. The building was first occupied in 1977 and since then nonspecific occupant health complaints have resulted in national media attention and prompted a series of environmental and ventilation system investigations.

The study reported on by MacDonald and Bénard took place over a three-month period in 1983-84, and consisted of a health questionnaire survey of over 1000 current and past employees chosen at random, and measurements, on nine floors, of outdoor air supply, indoor air distribution, temperature, relative humidity, total particulates, fungal spores, and total hydrocarbons. The floors were chosen on the basis of high and low frequencies of complaints. Of those persons surveyed, most had at some time suffered from upper respiratory and eye irritation when in the building. The authors suggest that a combination of high temperature and low humidity in some poorly ventilated areas could have initiated the illnesses reported, but they are unable to identify the causal environmental agents.

A paper by Samoiloff reports on a survey of IAQ in 18 nonresidential buildings and in seven residences which once had UFFI present. Of 336 workers interviewed, 68 percent complained about workplace air quality, which they associated with respiratory discomfort, eye problems, and skin irritation. Over 300 sites within these buildings were monitored with passive gas and particulate samplers, and the trapped gases and particles were bioassayed with the nematode *Panagrellus redivivus*. The results indicate that IAQ was heterogeneous within the buildings, with about 25 percent of the nonresidential sites and 9 percent of the residential sites having gases or particles which affected the nematode. Samples which were stimulatory to the nematodes were thought to be associated with bacterial or fungal products, such as might be associated with carpets or old papers, while those which were thought to be inhibitory included particles from tobacco smoke and dry copiers, and gases from printing chemicals.

Tobacco smoke is thought by many to be the primary irritant in office buildings. In fact, the ASHRAE ventilation standard 62-81[2] requires ventilation rates to be some four times higher in areas where smoking is permitted. In the Transactions, Urch reports on the results of exposing 24 nonsmokers in a chamber to tobacco smoke, while

they were exercising intermittently. The subjects showed a range of sensitivities to tobacco smoke and small decrements in lung function which were not dose-dependent.

A paper by Reible describes the results of several hundred tracer gas experiments, conducted over a ten-year period, on fume hood exhaust reentry into building ventilation systems. The results point out the importance of the problem, especially for buildings with poorly balanced ventilation systems, where up to 10 percent of the exhausted fume hood pollutants have been found to reenter the building.

Sinclair reports on a study of particle deposition in a well sealed, low occupancy telephone equipment switching building with a high efficiency air handling system. Comparison of results taken in Newark, New Jersey, to previous studies conducted in Kansas and Texas, indicates that the major water-soluble ions contained in the fine outdoor particles are ammonium and sulphate. Indoor particle levels of these ions in this type of building, which is analagous to many modern office buildings, are about 10 percent of the outdoor levels. Deposition velocities are reported, allowing prediction of surface accumulation rates when fans are running continuously.

Among the studies of residences, Dumont's paper on a survey of 46 tight enclosure houses built since 1978 in Saskatoon calls attention to the potentially negative impacts on IAQ. Eighteen of the 46 houses had formaldehyde levels exceeding 0.1 ppm, with those lacking mechanical ventilation devices having the highest concentrations. Twelve of 44 had radon concentrations exceeding 4 pCi/L, with basement drains connected above the water traps to weeping tiles as a major entry point of the radon.

Sentis reports on large scale radon surveys conducted in Saskatchewan; they combined airborne gamma-ray spectrometry over an area of 150,000 km^2 with direct measurements of radon daughters in almost 1000 residences. These surveys focussed on areas in the Precambrian Shield in the North and in the coal-bearing region in the South. These data, along with previous measurements of radon daughter concentrations in 1730 residences in Regina and Saskatoon in central Saskatchewan, are used to identify zones of relative levels of radon occurrence. Curves of percent probability of exceeding 0.1 wL versus house air change rate are calculated for each zone. Based on a 0.1 wL criterion, only one of 100 energy-efficient homes would require follow-up monitoring in areas of low radon concentration, while 20 percent of such homes would have to be checked in areas of higher concentration.

Burkart reports on radon studies in 32 conventional houses in the Swiss Alps in areas of high soil and rock radium content. Based on their average radon levels of 8.3 pCi/L in living quarters and 38 in cellars, he calculates that the risk from radon exposure over 50 years in a weatherstripped energy-efficient house (radon levels 50 percent higher) in areas of higher radon emanation yields a two percent chance of death from lung cancer, which approaches the risk from heavy tobacco smoking. Compared to the risks of centralized production of electricity and heat using coal, oil or uranium, the risk associated with conserving the same amount of energy through weatherstripping is calculated to be one to three orders of magnitude higher.

Syrotynski presents formaldehyde measurements taken since 1979 in New York State residences. Average concentrations were 0.18 ppm in 161 mobile homes, with levels generally decreasing with age, 0.06 ppm in 1954 UFFI complaint homes, 0.08 ppm in 153 non-UFFI complaint homes, and 0.03 ppm in 50 non-UFFI noncomplaint homes. Eighty-three percent of all samples taken were less than 0.1 ppm. In 1980 there were 119,417 mobile homes in New York State, a growth of 39 percent in the previous ten year period, and 70,000 UFFI houses. Continued increase in the number of mobile homes is expected.

Lamm reviews studies on mobile home formaldehyde exposures ranging up to two ppm in the states of Wisconsin, Minnesota, and Washington, and finds no relationship between upper respiratory symptoms and formaldehyde concentration. He suggests that some other factor may be causing the symptoms.

Marchant reports that exposure of an elderly couple to formaldehyde at levels ranging between 0.4 and 0.7 ppm in a new mobile home in Saskatoon appeared to be the reason for their headaches, nausea, and fatigue, since these symptoms disappeared when the couple moved.

Broder describes a Toronto study on occupant health and formaldehyde and carbon dioxide levels in 450 UFFI residences, 225 of which had their UFFI removed during the study, and in 225 control (non-UFFI) houses. In this study, which is not yet completed, significant increases are reported in throat, eye and skin irritations, and runny and stuffy noses in the UFFI removal group relative to the UFFI no action and control groups. Of the pulmonary function, and nasal airway resistance and cytology variables measured, only nasal

lining squamous metaplasia showed a significant increase in the UFFI removal group. Formaldehyde levels were fractionally higher in the UFFI homes at 0.045 ppm on average versus 0.035 ppm in the controls. These levels showed a direct relationship with a number of the symptoms present in excess in UFFI homes. Carbon dioxide levels were in the 700–750 ppm range across the three groups of homes.

Day reports on a series of three-hour exposures of 27 asthmatics, in a polyethylene tent, to pure formaldehyde (0.54 ppm), and complexes of gaseous emissions (formaldehyde concentration of 0.02 ppm) and particulates (0.5 particles/mL containing fungal spores including *Penecilium fellutonum* and *Paecilomyces voriotii)* from some wet, moldy UFFI. Twenty-three of the asthmatics had a history of UFFI exposure, possibly inducing or exacerbating their asthmatic state. Eight (including two placebo responders) of the subjects showed a 15 percent reduction in the pulmonary function variable FEV_1, after exposure to one or other of the products. There was an overall 43.3 percent increase in blood eosinophilia cell counts after the exposures, with the increase being somewhat greater for the responders. Day suggests that mold hypersensitivity may be a factor in the development of UFFI-related asthma.

A second study by Samoiloff found that 27 percent of the UFFI samples from a Winnipeg house were toxic to the nematode *Panagrellus redivivus,* while 48 percent were stimulatory, leading him to suggest that microbial activity had occurred in some of the UFFI.

In a London, Ontario, study, Sullivan monitored room air and wall cavity formaldehyde concentrations in 26 UFFI houses, and in six control houses built since 1977, over a one-year period in 1982/83. While all of the UFFI homes had significantly higher wall cavity formaldehyde levels in summer in comparison to winter values, eight of the houses showed no corresponding increase in room air concentrations in the summer, remaining in the 0.05 ppm range. This was thought to be due to differences in the sealing between the wall cavities and the interior. The control home room air formaldehyde levels were higher than both the UFFI-nonresponder and UFFI-removed houses for five of the six series of measurements, and only marginally lower than the UFFI-responder houses.

Tsuchiya used GC/MS and atmospheric pressure chemical ionization MS/MS procedures in laboratory tests to identify 35 off-gases other than formaldehyde from seven UFFI samples. Gases such as dichlorobenzene, methylene chloride, xylene, toluene, and naphtha-

lene were thought to have originated from other indoor sources and been stored on the UFFI. Gases common to both techniques which approached or exceeded TLV/100 when purged from the 57 percent humidity-conditioned UFFI at 23C and analyzed by MS/MS, were acetic acid, dioxane, diethylene glycol, and methyl furfural. At 30C, GC/MS head space tests indicated increased quantities of dibutylphthalate, 2-furyl methanol, and naphthalene.

Otson reports on a study of ten Canadian homes monitored for respirable and total levels of volatile (VO) and nonvolatile (NVO) organic compounds during winter and late summer. He detected 56 compounds, including 21 polycarbons, seven halogenated hydrocarbons, five alcohols, three phthalates, and two organophosphates. Twenty-eight were detected at concentrations greater than 1 $\mu g/m^3$. Overall, the number of NVO compounds and PNA, and the concentrations of NVO and VO compounds were greater in winter than in summer. Relatively high organic concentrations were found in two homes where the greatest numbers of cigarettes were smoked.

Pleil monitored 26 homes in North Carolina for volatile organic compounds. In the five homes which were monitored in both summer and winter, summertime concentrations tended to exceed wintertime levels, possibly due to changes in material outgassing. Higher levels were associated with indoor storage of paints and gasoline, fossil fuel heat, and attached garages. Propane was thought to be associated with natural gas, benzene, toluene; *o*-xylene with fuels and solvents; Freon 11 with carpets.

Hosein reports on two studies, one on some houses where housewives had reported chronic cough and phlegm, and the other on houses with asthmatics. Measurements of RSP, SPM, NO_2, and SO_2 were made in these houses in summer and again in winter. Gas ranges were found to be the main contributor of NO_2, with two houses having two-hour values exceeding 1000 $\mu g/m^3$ (0.55 ppm). Winter values were higher than summer values. RSP concentrations were directly related to the number of smokers, while SPM levels were higher in carpeted homes. Sulphur dioxide levels were low, with generally higher values outdoors. Crowding, air tightness, and the presence of pets had no consistent effect on pollutant concentrations.

Godish measured NO_2 concentrations during the heating season in a number of residences grouped by six variations of cooking and space heating systems. Nitrogen dioxide levels were highest in residences using gas for cooking or kerosene heaters for supplemental

space heating, averaging in the 25 ppb range versus less than 15 ppb for houses with other cooking and heating systems.

Cohen measured CO, NO, and NO_2 emissions from a portable gas cooking stove and a gas lantern, and used a model to estimate the potential concentrations for a range of air change rates when these appliances are used in a backpacking tent and a family tent. This indicated that use of the stove in a backpacking tent could cause ill effects.

Pollutant Abatement

The 15 papers included in this section address studies on a number of measures available to reduce the concentrations of some indoor air pollutants. There are papers on HVAC performance monitoring, on pollutant and environmental measurement techniques, on the effects of various ventilation standards on office building energy costs, on techniques to reduce particulate levels, to avoid ventilation exhaust reentry, and to radon-proof basements, on approaches to reducing formaldehyde from particleboard sources, on methods to identify and avoid combustion product venting failures, on a way to reduce NO_x production by gas burners, and on the removal of some gaseous pollutants with an air purification device.

Bearg describes how measurement of CO_2 indoors, outdoors, and in the supply air can be used to assess the effectiveness of ventilation systems and building enclosure infiltration, and indicates a number of the pollutants which might be monitored. Three case studies illustrate the usefulness of tracer gas techniques to identify pollutant sources by tracing their air movement paths from one location to another.

Cowan uses CO_2 measurements in two 30-year-old Toronto office towers to estimate their ventilation and enclosure leakage rates, and then with a computer energy analysis program calculates energy costs associated with different ventilation standards for a similar hypothetical ten story 130-ft square building. For this type of building he finds only a negligible energy cost increase with ventilation increases up to levels of 50 cfm per person, since much of the air can be used for space cooling or is entering through infiltration anyway. Cowan points out that while economizer systems used by many buildings have capacities ranging up to 200 cfm per person. compartmental systems introduced in the 1970s and 80s are designed for

only 10 to 20 cfm per person. He estimates that retrofit costs to upgrade compartmental systems for higher standards could cost up to $1,000/ft^2$ for fans, ducts, and dampers.

McIntosh models the transient effects on indoor pollutant concentration of air mass acceleration and building elasticity for infiltration and ventilation rates of up to 10 ach and concludes that these transient effects can be ignored.

Lee found that the implementation of a tobacco smoking policy on one floor of a large office building in Hull, Québec, which restricted smoking to the staff lounge, resulted in a 23 percent reduction in RSP and a 7.2 percent reduction in CO on that floor. This reduction was thought to be due to the proximity of the lounge to the general floor and washroom exhausts, and air recirculation through filters.

Weschler monitored particulate concentrations in two telephone office buildings, one in Wichita, Kansas, and the other in Lubbock, Texas, and developed a model for predicting the increases in concentrations of fine and coarse airborne particles for such buildings when their air circulation systems are operated only when heating or cooling, rather than continuously. Depending upon filter efficiencies, the model predicts increases in particle concentrations of 2 to 15 times as a result of this energy conservation measure which resulted in nonoperation of the HVAC fans for most of the time.

Wilson presents a model for the dilution of exhaust pollutants in the outdoor air and the extent of their reingestion by nearby air intakes. He points out that while the greatest pollutant hazards occur for exhausts in laboratories, hospitals, and industrial buildings, the problem is now of concern for energy-efficient residences which use mechanical ventilation devices with nearby air intakes and exhausts. The model indicates that the fraction of exhaust air which is reingested can change by a factor of five with only minor design changes, such as the removal of a rain cap.

Desrochers studied four recently built, forced-air, electrically-heated houses in northern Ontario in the occupied and the unoccupied condition, monitoring ventilation rate, humidity, radon, formaldehyde, 36 trace organic gases, and energy consumption. All four families included smokers. Occupany increased ventilation rates by 10 to 150 percent, the number of contaminants present, and the concentrations of formaldehyde, humidity, and odors, while radon and many organics decreased. The trace gases measured ranged from 1 percent to less than 0.001 percent of their TLV. Radon daughter

concentrations were low and appeared to emanate primarily from the basement concrete, indicating that the rubber water stop installed at the basement wall-slab joint was keeping out soil radon. Continuous air circulation reduced local contaminant elevations and radon daughter levels, probably due to particle filtration and plate-out, while raising average winter heating energy consumption from 96 to 103 kwh/d. Average ventilation rates of 79 m^3/h in these open plan houses, each occupied by five persons, met the ASHRAE commercial standard of 5 cfm per person and residential standard of 10 cfm per room. However, humidity and odors were only marginally acceptable. By adding an outdoor air intake to the furnace return air duct, ventilation was increased to between 102 and 133 m^3/h or 0.23 to 0.29 ach, and air quality was more acceptable. This added ventilation increased average energy consumption from 103 to 111 kwh/d.

In another study of over 70 houses built in the last 30 years in the same Ontario community, Desrochers found that occupied ventilation rates ranged between 0.06 and 0.77 ach, with the lowest values in summer when windows were closed. Ventilation rates of the modern electrically heated houses were on average one-half of those of older, oil heated houses. Outdoor air induction into the furnace return air ducts raised rates in eight newly built houses from an average of 0.13 to 0.24 ach during the heating season, and improved high humidity and poor air quality conditions. Installation of perforated pipe in coarse fill beneath the basement floor slab and exhausting with a 100 cfm fan to control radon ingress from the soil raised average ventilation rates in nine electrically heated houses from 0.15 to 0.32 ach during the heating season. However, in two houses with basement cracks sealed, there was no increase in ventilation rate using this radon control technique.

Nitschke describes a range of control techniques for soil-sourced radon, tested in 14 upstate New York houses. These cost between $15 (to seal a floor drain in one house) and $1246 (to seal a cinder block wall, a sump and a floor-wall crack in another). The average cost was $640. Of the several control techniques tested, increased general ventilation with air-to-air heat exchangers was only marginally effective, while ventilation of unpaved crawl spaces, and combined sealing of below-grade cracks and openings and ventilation of the subslab provided the greatest radon concentration reductions.

A study in some unoccupied research houses of the relative effectiveness of placing carpet and cushion, vinyl linoleum, and polyethyl-

ene vapor barriers over particleboard underlayment to reduce indoor formaldehyde concentrations is described by Matthews. Two-fold to 2.5-fold room air formaldehyde concentration reductions were achieved with linoleum and polyethylene barriers, while the nylon foam carpet and urethane foam cushion were ineffective.

Kalnins applied a series of formaldehyde abatement measures in an apartment in Montreal; this reduced formaldehyde levels from 0.52 to 0.15 ppm. To achieve this reduction, particleboard floor underlay and pantry and linen closet shelving were removed, while the undersides of particleboard kitchen countertops were sealed with a polyurethane-based varnish and plywood subflooring was treated with sodium bisulfite. The remaining formaldehyde came primarily from infiltration from adjacent apartments.

The potential for chimney backdrafting as a result of coincident operation of furnaces, fireplaces, and bathroom and clothes dryer exhaust fans, is of increasing concern as enclosures are tightened. Swinton describes a model which predicts the critical conditions. Calculations indicate that fan and fireplace exhaust flows can readily depressurize houses with typical Canadian enclosure tightnesses. Other factors impeding the proper flow of air up chimney flues include downdrafting winds, caused by high adjacent structures for example, and high envelope leakage sites. Increased chimney height and horizontal wind tend to draw air up the flue.

A study of 100 Canadian homes of various styles and ages, reported by Moffatt, found 34 at risk of chimney backdrafting under worst case conditions, with depressurization by fireplaces the major contributing factor. A further 17 had spillage potential. Remedial measures included cautionary labels, air balancing retrofits of circulation systems, alarms, failsafe devices, and chimney alterations. These measures were thought to resolve all potential problems with the exception of fireplace backdrafting at low burn. A detailed description of the safety check is given.

A paper by DeWerth describes an approach to reduce the amount of NO_x generated by a gas flame. This involves inserting a ceramic or metallic device into the flame. Using this device in a residential gas range, for example, reduced NO_x emissions by 45 percent and NO_2 by 25 to 30 percent. At the same time there was some decrease in burner thermal efficiency and increase in carbon monoxide production.

This section concludes with a paper by Collins describing the prin-

ciples and performance of a porous alumina low temperature copper chloride/palladium chloride catalytic air cleaner. This gaseous air cleaner employs catalytic oxidation (CO), chemisorption (CO, NO_2, SO_2) and chemical reaction (ozone) to lower pollutant concentrations at rates which vary with temperature and relative humidity.

Policy and Practice

The fourth and last section of the Transactions contains 17 papers by government and industry policy makers and program managers, by individuals involved in the development of IAQ and ventilation standards, and by persons providing IAQ-related medical and building technology services to the public.

Janssen describes the problems being encountered in updating the ASHRAE ventilation standard. These include the need to compromise between energy-consuming, high ventilation rates and lower rates which may pose threats to health or comfort in the absence of accepted concentration criteria for most pollutants. Items of specific concern include defining the ventilation rate to dilute tobacco smoke, microbial contaminants, and the effectiveness with which ventilation air is sometimes used. Also, the specification of residential ventilation rates is troublesome since most housing does not use mechanical ventilation and there are a number of uncertainties in estimating the effectiveness of infiltration and natural ventilation.

A paper by Wyile describes a Canadian federal/provincial effort begun in 1981 to develop residential air pollutant guidelines. Acceptable concentration levels are being proposed for several gases including formaldehyde, and for particulates, while for another group of pollutants, including biological agents and tobacco smoke, there will be recommendations on ways to limit exposure.

Llewellyn discusses options available to regulatory agencies for dealing with indoor air pollution and the specific measures which have been taken in the U.K. with respect to asbestos, formaldehyde, pesticide residue, radon, and products of combustion. In general, an educational approach has been adopted, although national standards, industry self-regulation and some regulatory measures have been used.

A paper by Létourneau presents calculations on the projected costs of avoiding lung cancers due to radon for radon daughter standards of 0.02, 0.05, and 0.1 wL. These calculations are based on radon measurements made in 17 Canadian cities, long term studies of

smaller groups of homes, and national housing statistics. Remedial costs assumed are $7500 for each existing house and $1200 for each new house. These were the average costs incurred for reducing radon levels in houses in Elliot Lake, Ontario. Calculations are presented for three of the 17 cities—Winnipeg, Sherbrooke, and Vancouver. These had respectively the highest, middle, and lowest of the mean radon daughter concentrations of the 17 cities. Létourneau estimates that by taking remedial action on, for example, those Winnipeg houses with levels above 0.02 wL, 10.8 lung cancers per year (0.7 percent of all Winnipeg cancers) would be avoided at a cost of $14 million each. By enforcing a 0.1 wL standard, only 1.7 (0.1 percent) Winnipeg cancers would be avoided yearly but the cost per avoidance would be reduced to $4 million.

Following the Canadian ban on UFFI in 1980, the federal government offered a program of assistance to an estimated 80,000 UFFI homeowners, 57,000 of whom eventually registered with the program. Shurb describes this program of assistance. It includes the provision of information and financial support of up to $5000 per dwelling for corrective action to remove the UFFI, to seal cracks in the inside of the dwelling enclosure against UFFI product ingress and to install heat recovery mechanical ventilation. As of April 29, 1985, 41,000 Canadian homeowners had received UFFI financial assistance totalling $200 million. The mean formaldehyde level before corrective measures in their homes was 0.062 ppm and after corrective measures it was 0.049 ppm. Twenty-two percent of the homes had higher formaldehyde levels after the corrective measures. Of those homeowners who stated they had health problems, 80 percent reported improvement after the corrective action was taken.

In 1984 the U.S. Surgeon General concluded that children exposed to parental smoking in the home have an increased prevalence of reported respiratory symptoms and an increased frequency of bronchitis and pneumonia early in life; such children also have small but measurable differences in tests of pulmonary function when compared to children with nonsmoking parents. Shopland provides this and other information in a review of the potential hazards of passive smoking and a summary of the tobacco smoking legislation which has been enacted in the United States over the period 1975 through 1983.

The U.S. Federal Government has set up a 16-agency committee to plan and coordinate federal IAQ research, and Millhone reports on

the strategy which has now been adopted. This strategy encompasses six research tasks including the conduct of a national multipollutant field survey in order to determine the priority to be given to the other IAQ activities. This survey will measure air pollutants and identify factors influencing their concentrations, including ventilation rate and use of supplementary heating sources.

Ficner describes a Canadian government program to build super energy-efficient homes across Canada. These homes, labeled "R2000," have extremely tight enclosures and their ventilation requirements are met by mechanical heat recovery ventilation. Naturally aspirating gas furnaces and hot water heaters are not permitted, thereby avoiding backdrafting. Fireplaces and woodstoves must have an outside combustion air supply. Monitoring of some 200 R2000 homes and 60 control homes indicates that formaldehyde levels are in the 0.060 ppm range in the R2000 homes and somewhat higher in the control homes. Radon levels are comparable at 0.013 to 0.014 wL, while NO_2 is at 0.005 to 0.006 ppm for the two groups. Air change rates averaged 0.37 ach for R2000 houses and 0.34 ach for the control homes over a 30-day February/March period.

Love describes the results of an environmental assessment carried out by the Bonneville Power Administration prior to supporting enclosure tightening residential energy conservation measures for the 1.5 million electrically heated homes which it serves in the northwestern United States. Measures considered to be air-infiltration-reducing were adding storm windows, caulking, and weatherstripping. Projections of increased concentrations of radon, formaldehyde, and benzo*(a)*pyrene were based on an estimated 30 percent air change reduction. The associated increased rates of cancer were then extrapolated based on available information to be about 15 percent, or 25 additional cancers yearly. However, the uncertainty range of the increased cancer risk was very large and the decision was made to permit enclosure tightening in all homes, raising potential annual savings to 300 Mw from 200. Radon monitoring is offered, and financial assistance of up to $1000 is provided for the installation of air-to-air heat exchangers in the estimated 5 percent of the homes where radon levels exceed 5pCi/L. As well, all homeowners receive information on how to recognize the presence of indoor air pollutants and steps to mitigate them.

Billick describes IAQ programs being carried out by the U.S. Gas Research Institute (GRI) working with various federal agencies in-

cluding the Consumer Product Safety Commission (unvented natural gas space heater standard), and the Environmental Protection Agency (NO_2 standard). The current emphasis is to establish the magnitude of the exposure risk with a smaller effort on appliance emission control technology. The paper provides emission rates for NO_x, CO, and SO_2 for various gas appliances. References are given to a number of personal exposure field surveys, appliance user surveys, and health effects studies, all of which will eventually be incorporated into the assessment of the health risks of gas combustion pollutants.

Lane describes a joint project involving the state of Minnesota and Honeywell, Inc. to develop energy efficient ventilation for various types of residences and HVAC systems. An analysis of the potential benefits and problems which can result from such a joint government/industry venture is provided, which should prove useful to others contemplating similar ventures.

Purcell outlines the five-year, $2.8 million U.S. Electric Power Research Institute IAQ research program. To date EPRI has funded a residential monitoring project, developed a manual on IAQ, and conducted seminars.

A community indoor air pollution program in Saskatoon is described by Marchant. This program involves a sharing of expertise of public health inspectors, a ventilation engineer, an aerosol physicist and a consultant in environmental medicine. Two hundred thirty-nine residences have been visited under the program and of these, 103 had formaldehyde levels above 0.1 ppm, and 173 had occupants with symptoms of formaldehyde irritation. The majority of complaints occur during the winter heating season.

Maclennan provides two papers on the diagnosis and treatment of individuals, including school children, who are reacting to indoor air pollution. A wide range of possible symptoms or manifestations of reactions to indoor air pollution are identified. Dr. Maclennan's management of the problem involves avoidance of pollutants and stimulation of the immune system. The papers are very descriptive and, along with several case histories, provide the reader with an intimate perspective of the so-called "20th century disease" and practical ways of dealing with it.

Small describes principles for designing low pollution housing, some of which are also energy conserving. For example, sealing the building envelope above and below grade is energy conserving and at the same time eliminates soil gases, which include radon, water

vapor, and mildew odors, and wall cavity condensation, which promotes mold growth. Spot ventilation of appliances and of storage cupboards, along with the selection of low pollution building materials, are other techniques suggested.

The last paper, by Raab, provides a commentary on the merits of a number of practical techniques to minimize IAQ problems in residences, including the use of forced air heating systems with continuous air circulation and particle filtration, and ways to avoid elevated humidity problems.

Conclusions

The 57 research, policy, and practice papers contained in the Transactions of this conference provide the reader with up-to-date and authoritative information on a variety of facets of indoor air quality. In them can be found new information on some relatively unfamiliar trace gases and fungi, as well as on many of the better known indoor air pollutants. Studies reported range from those concerned with human health and biological indicators, to those concentrating on pollutant emissions, to those addressing building ventilation. Some studies combine all three aspects. Policymakers, standards setters, and practitioners outline their thinking on the problems they face and indicate the status of their current IAQ activities, thereby facilitating dialogue with the research community.

Papers identifying symptoms of sick building syndrome in offices; irritation, nasal, and respiratory function responses in mobile and UFFI homes; and responses and treatment of environmentally sensitive individuals; confirm the importance of good indoor air quality as well as the difficulties encountered in linking these responses to specific air pollutants.

The pollutant and ventilation surveys help to identify building features of concern, and current ranges of natural and mechanical ventilation rates and pollutant concentrations. They should be of great help in the planning of future surveys, the development of pollutant and ventilation standards, and the conduct of health studies. The work in the northern Ontario community which showed that moisture problems and air quality were experienced in some homes with infiltration occurring at rates specified by ASHRAE 62-81, and the high ventilation and infiltration rates measured in the Toronto office buildings with energy efficient economizer cooling, have important ramifications.

The papers dealing with pollutant abatement point the way to industrial opportunities and areas for further innovation. They will also help policymakers to weigh the merits of pollutant source control options versus more general ventilation and air cleaning solutions.

Naturally, not all of the conceivable cold climate hazards are addressed. Two of the more potentially serious ones that come to mind are the carbon monoxide hazard in ice arenas, and the microbiological hazards sometimes associated with humidification systems. With respect to the former problem, a recent survey by Hillman[3] in British Columbia found that 32 of 64 arenas monitored had CO levels above the B.C. guideline of 25 ppm, with 19 above 50 ppm. The highest recorded level was 206 ppm. The source of this pollution is the exhaust from gasoline and propane powered ice cleaners.

The importance of the IAQ issue for cold climates is perhaps best emphasized by a calculation based on a report by the Canadian National Energy Board.[4] This indicates that building energy conservation measures are currently saving Canadians some $5 billion annually in comparison to pre-1973 energy usage rates. Ventilation reductions comprise a significant but unknown amount of that $5 billion. The challenge facing people living in cold climates is to maintain and even increase these building energy savings while minimizing indoor air pollutant concentrations so that they can live in healthful and comfortable, yet economical, indoor environments.

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