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STUDIES ON
INDOOR AIR QUALITY IN CANADIAN HOMES

Exploring Low-Pollution Design

Prepared for

the Research Division

Canada Mortgage and Housing Corporation

Montreal Rd., Ottawa K1A 0P7

by

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FOREWORD

This paper explores potential indoor air quality problems in Canada and ways of designing homes to avoid such problems. Design suggestions contained herein are offered for discussion among government agencies, researchers, the building industry, and the housing consumer.

The report is part of a four-point project by the Canada Mortgage and Housing Corporation, to assist in defining the extent of any existing or potential indoor air quality problems in Canadian homes, and in defining effective means of addressing such problems.

The following areas were addressed during 1984/5:

- the legislative framework - to understand the existing and potential future role of the various governmental jurisdictions and regulatory powers in addressing indoor air pollution problems in Canadian housing,
- the research base - to identify Canada's research interests in the indoor air quality field, and recommend a means of making information more accessible to all interested persons,
- the people affected - to understand the extent of the Canadian population adversely affected by hazardous contaminants in indoor air,
- the solutions - to understand what building techniques and other practical measures can be incorporated into constructing, rehabilitating and operating Canadian homes in order to achieve low pollution indoor environments.

The study results have been consolidated into three reports:

Legislation, Regulations and Standards
Research and Information Base
Exploring Low-Pollution Design

Inquiries concerning these reports may be directed to the Research Division, Canada Mortgage and Housing Corporation, Ottawa K1A 0P7.

The Research Division of CMHC would appreciate receiving comments on and additions to this publication, as well as ideas on all aspects of residential indoor air quality issues.

The authors of this report are grateful for the advice and assistance received from many individuals, in Canada Mortgage and Housing Corporation, in other federal departments and agencies, in provincial governments, in universities and in the private sector, during this study program.

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1. INTRODUCTION

This report explores methods for resolving or preventing indoor air quality problems in Canadian homes. The reader is cautioned that most of the ideas presented have not been subjected to rigorous engineering and scientific testing. Rather, the presentation is designed as a basis for discussion among those people who are in a position to investigate the solution of residential indoor air quality problems, through appropriate design and construction practice.

Previous studies have established that materials and conditions which contribute to indoor air pollution are known to be present in some Canadian homes (Small, B.M., 1983, and Coon, D., 1984). These conditions are diverse in nature, including such widely varying situations as the incomplete exhaustion of combustion gases from furnaces, the accumulation of off-gassing products from building materials in poorly ventilated rooms, and the growth of mould following moisture intrusion. Their incidence has not yet been determined.

It has also been established that some Canadians suffer ill effects from pollutants within their homes (Small, B.M., 1982 and 1983 and references therein). Medical research has not advanced sufficiently, however, to estimate the total incidence of health impairment from indoor air pollution in Canada.

Many government agencies and research organizations in Canada are studying the question of indoor air quality (Small, 1985). It will take time to agree on acceptable residential indoor air quality levels, and to quantify the risk associated with various indoor air pollution exposures. In the meantime, some homeowners have expressed a desire to reduce present indoor air pollution levels in their homes, or to build new homes with lower indoor pollution levels. In many such cases, one or more family members has exhibited illness that appears to be related to the indoor environment. In addition, conditions in some Canadian homes are sufficiently dangerous to warrant immediate attention (Robinson, T.J., 1984). For example, the competition of ventilation appliances with furnace air requirements can cause backdrafting or stagnation of exhaust. This condition can lead to the accumulation of carbon monoxide in the home.

Most of the situations that have been identified to date can be corrected by relatively simple remedial measures. These vary in cost from a little effort (e.g. remove old solvent cans from the cellar) to hundreds or thousands of dollars per home (e.g. replace a defective furnace). And for many types of potential indoor air quality problems, it is not only possible, but relatively inexpensive in labour and materials, to avoid the problem by appropriate design and construction methods.

Where such methods are available, they may be preferred by the housing consumer to the alternative of assuming an unknown level of risk, however small. Avoiding risk at reasonable cost is the function of prudent design and construction practice.

2. EXPLORING INDOOR AIR QUALITY PROBLEMS AND SOLUTIONS

The following section explores a series of potential indoor air quality problems and for each, one or more measures for solving or preventing such problems. In most cases, the solutions have not been subject to rigorous engineering or scientific testing, although in many cases they have been implemented in one or more homes to the satisfaction of the occupants. The reader is therefore encouraged to pay particular attention to the sub-headings "Installations" and "Effectiveness" within each entry, so that he or she may be forewarned as to how much or how little experience has been reported with each suggestion.

Both the author and Canada Mortgage and Housing Corporation would appreciate comments and additional ideas from readers. We hope that ongoing discussions will lead to a more complete and more refined set of design and construction practices to address potential indoor air quality problems.

The ideas presented in the following pages are listed under eight categories:

- accumulation of pollutants
- furnishings and appliances
- building materials
- moisture, dust and mould
- combustion devices
- infiltration of exterior pollutants
- consumer products and activities
- plumbing systems

A complete table of contents of the problems and solutions discussed is given on the following page.

2. EXPLORING INDOOR AIR QUALITY PROBLEMS AND SOLUTIONS

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2.1 ACCUMULATION OF POLLUTANTS

A detailed analysis of potential individual sources of pollution in Canadian homes has been undertaken in a previous study (B.M. Small, 1983). This work and other studies (e.g. S.D. Colome et al, 1982) have suggested that there is often a variation between concentrations of pollutants inside a home and those in the ambient air. Some pollutants within the home are found at higher concentrations than in outside air, but with only a few exceptions, levels of contaminants are usually relatively low and within established ambient air or industrial guidelines. Sealing a home without providing adequate ventilation can increase concentrations of pollutants which are retained within the building envelope.

A household may contain a varied mix of gases and particulates, all at low concentrations, from which many hundreds of individual compounds can be identified (E.D. Pellizari et al, 1984). Often it is difficult or impossible to identify the specific source of each contaminant, and to determine the role that any one contaminant may play in building illness.

Nevertheless, it may be true that one or more occupants of a dwelling is experiencing discomfort or illness related to either specific contaminants in the home, or related to the total load of pollutants. Some individuals may be intolerant of some pollutants when they are present in a mix, or when the individual is under other stress.

The homeowner or building professional is faced with the task of adjusting the building to reduce illness, without knowing precisely which contaminants represent the most significant component of the problem. Methods which reduce the levels of all pollutants, such as dilution by ventilation, are often used to address the situation. This can be combined with a shotgun approach of reducing emissions from known pollutants by spot ventilation, treating intake air to reduce incoming pollutant levels, and other methods which are described in more detail in the pages following.

Subsequent sections deal more specifically with methods which can be applied when specific pollutants and pollutant sources are suspected or known to be contributing to building-related illness (e.g. furnishings, building materials, mould, combustion products, etc.).

Solution: **2.1.1 Fresh-Air Ventilation** (main entry)

Problem Addressed: General buildup of various indoor pollutants from interior sources.

Principles Employed: Dilute a pollutant with clean air.

Description of Solution: Introduce fresh air continuously into a home, and at the same time exhaust stale air at approximately the same rate.

Application: Applicable to all homes. Good indoor air quality cannot be maintained without adequate fresh air ventilation.

Implementation: There are many means of introducing fresh air into the home, from manual operation of openable windows, to automatic operation of an air-to-air heat exchanger. A number of these methods are described in more detail in supplementary entries following.

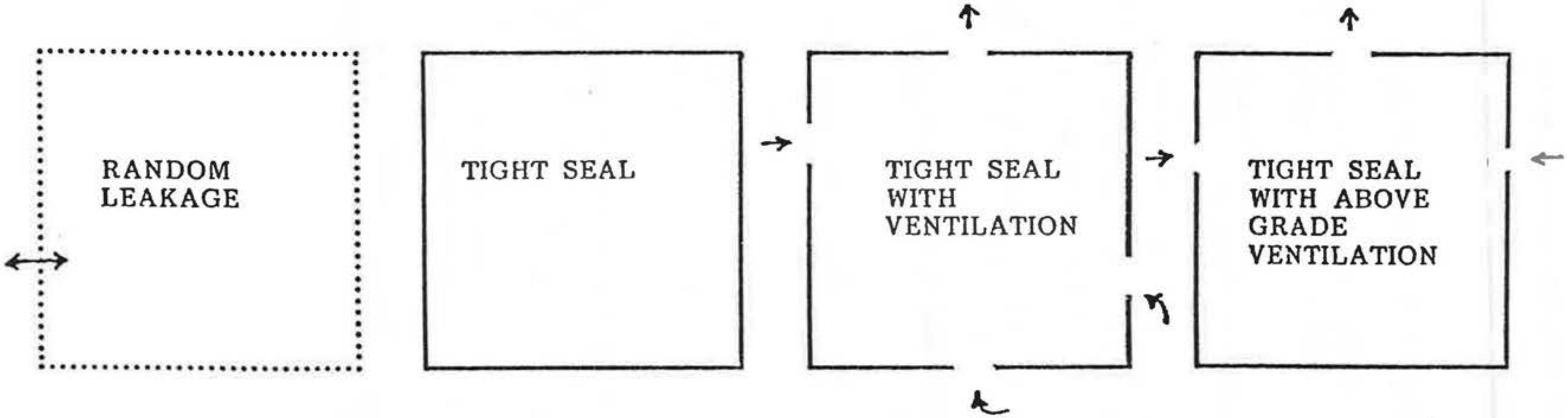
If the house is placed under positive pressure, (i.e. the intake fan is pumping air in from outside slightly faster than the exhaust fan is removing it) air will be forced outward through any cracks in the building envelope. This will tend to flush wall pollutants outside, but may cause some condensation within the walls in winter.

If the house is under negative pressure, (i.e. the exhaust fan is pumping air out faster than the intake fan or windows allow fresh air in), then air may be drawn inward through cracks in the building envelope. This may avoid winter condensation in the walls, but at the same time may flush pollutants from the walls into the building, or draw moisture and soil gases from the ground adjacent to the building, through cracks in the basement or slab.

Careful sealing of the building envelope above grade, and of the basement walls and floor slab below grade, are necessary in order to minimize possible problems which can be caused by positive and negative ventilation. A homeowner has greater control over intake air with a well-sealed home, than with a leaky home, provided intake devices are installed (e.g. special vents, air-to-air heat exchanger, and/or openable windows).

General exhaust of indoor air can reduce pollutant concentrations. Spot ventilation removes pollutants locally close to the source, and may allow greater reduction of pollution with less total ventilation (see following entries). Placement and size of openings for ventilation will affect pressure distribution, degree of mixing of fresh air with stale air, and ventilation efficiency.

EVOLUTION IN BUILDING DESIGN



2.1.1 Fresh-Air Ventilation (main entry, continued)

Window ventilation will, under most circumstances, provide some general home ventilation. However, air change within the home can only take place when the air is driven by pressure differences. If conditions are stagnant outside (no wind) and temperatures are such that there is no stack effect (e.g. some summer conditions) then, at such times, there may be little or no air change with the outdoors, even if all the windows in a home are open.

Mechanical ventilation can create the required pressure difference, but the homeowner must be aware that it is the net pressure difference, accounting for all driving forces, that will determine the ventilation of the home. For example, a furnace just starting up may be creating pressure which would cause combustion products to rise, if the chimney were already warm and there were no competing ventilation fans in the home. But back flow in a cold chimney, assisted by competing fans (e.g. kitchen exhaust, dryer) may create a net pressure difference of zero in the chimney, and combustion products may spill into the home air. (See also section 2.5 Combustion Devices.)

Advantages: All types of pollution may be reduced, without it being necessary to know where the sources are. Automatic continuous ventilation would avoid periods where householders forget to turn on fans, open windows, etc., or when atmospheric conditions do not provide natural pressure differences.

Use of a heat exchanger allows recovery of a significant fraction of the heat lost through ventilation.

Disadvantages: Ventilation above a basic minimum (which is a function of heat recovery efficiency) represents extra cost in heating and cooling.

Both negative and positive pressure ventilation can cause problems as described above under 'Implementation', if care is not taken to create a well-sealed envelope and thereby limit air inflow and outflow to controlled openings. Negative pressure ventilation may, in some circumstances, actually introduce more pollution than it removes (e.g. by introducing pollutants from wall materials, and moisture and soil gases, including radon, from ground adjacent to the building.) (See diagram on receding page.)

Installations: An airtight home in the Ottawa area, designed specifically to avoid indoor air pollution has an air-to-air heat exchanger installed, which provides approximately 165 L/s of intake air, for approximately 280 m^2 of living space. Sunnyhill Research Centre in Goodwood, Ontario, also a low-pollution building, has the capability of a variable ventilation rate up to a maximum of 940 L/s for approximately 560 m^2 of living space, including ventilation of bathroom, kitchen, various appliances, and special events.

Effectiveness: Various studies listed below and detailed in Appendix B (References) discuss the effectiveness of different types of ventilation, with

2.1.1 Fresh-Air Ventilation (main entry, continued)

respect to reduction of indoor pollutants. Effectiveness varies according to rate of ventilation, strength of pollutant sources, and air flow configurations. Positive pressure ventilation, combined with sealing of the building envelope, has been employed effectively in houses where urea-formaldehyde foam insulation had caused high indoor formaldehyde levels.

From recent research (Wadden & Scheff, 1983) it is apparent that ventilation is not completely effective in mixing with, and removing, indoor pollutants. When circulation fans are not working, the "mixing factor" (which identifies the effectiveness of that mixing) may be in the order of 0.3 (although values below 0.1 have been measured). Thorough mixing, through proper design and setting of indoor air circulation systems, may increase the mixing factor to approximately 1, thus reducing pollutant concentrations by more than 3:1. Continuous operation of circulation fans, plus a proper tune-up of the system may, therefore, be very cost-effective.

Source: Readers are referred to the National Research Council of Canada, Division of Building Research, Ottawa K1A 0R6, or to the UFFI Centre, Dept. of Consumer Affairs, Place du Centre, Hull, Quebec K1A 0C9, for further information on the use of ventilation to reduce UFFI emissions to the living space. NRC's publication 'Building Note 23' describes the use of positive pressure ventilation.

Inquiries about the Sunnyhill Research Centre should be directed to: B.M. Small, P.Eng., Sunnyhill Research Centre, R.R.#1, Goodwood, Ontario L0C 1A0.

A number of references listed below evaluate ventilation as a solution to indoor air quality problems. Detailed bibliographic information is included in Appendix B "References".

ASHRAE (1981)
Air Infiltration Centre (1982)
Beckman, R.T., and Holub, R.F., (1979)
Berglund, B., and Lindvall, T. (1979)
Berk, J.V. et al (1980)
Billings, C.E., and Vanderslice, S.F. (1982)
Cain, W.S. (1979)
Cain, W.S. et al (1979, 1981 and 1983)
Cain, W.S., and Leaderer, B.P., (1982)
Fisk, W.J., Roseme, G.D., and Hollowell, C.D., (1981)
Grimsrud, D.T., and Sherman, M.H. (1982)
Hollowell, C.D., Berk, J.V. and Traynor, G.W. (1978 and 1979)
Hollowell, C.D. et al (1980)
Huber, G., and Wanner, H.U., (1983)
Janssen, J.E. et al (1982)
Kusuda, T. (1976)
Kusuda, T., Hunt, C.M., and McNall, P.E. (1979)

2.1.1 Fresh-Air Ventilation (main entry, continued)

Lawrence Berkeley Laboratory (1980)
Lidwell, O.M. (1979)
Lorenz, F. (1982)
Lowenstein, H., Gravesen, S., and Schwartz, B., (1979)
Lundqvist, G.R. (1979)
Molhave, L. (1982)
Myers, G., and Nagaoka, M. (1981)
National Research Council of Canada (1977)
Offerman, F.J. et al (1982)
Presser, G.S. (1981)
Repace, J.L., and Lowrey, A.H., (1982)
Roseme, G.D. et al (1980)
Sandia National Labs (1982)
Sherman, M.H. and Grimsrud, D.T. (1982)
Skaret, E., and Mathisen, H.M. (1982)
Smay, V.E., and Shaul, B.-D., (1983)
Soedergren, D., and Punttila, A., (1983)
Sundell, J. (1982)
Thayer, W.W. (1982)
Traynor, G.W. et al (1982)
Turiel, I., and Rudy, J., (1980)
Van der Kolk, J. (1984)
Wadden, R.A. and Scheff, P.A. (1984)
Woods, J.E. (1979)
Woods, J.E. et al (1981)

Solution: **2.1.2 Exhaust of Pollutant Sources** (main entry)

Problem Addressed: Many individual items, appliances or areas within a home may be sources of indoor pollutants.

Principles Employed: Direct the pollutants away from people.

Description of Solution: An exhaust fan is used to draw polluted air away from a pollution source. For example, a kitchen exhaust hood is used to draw away odours and moisture from cooking. The same technique can be used on other devices, e.g. a television set or other electronic device. (Trace odours from warm plastic electronic components have been associated with adverse health effects in sensitive individuals). Specific areas within the home may also be vented locally with an exhaust fan, for example, a smoking room, or a storage cupboard.

Application: This technique can be employed in any home where known pollutant sources cannot be avoided. Gas stoves, for example, should always be vented locally. It is particularly helpful in homes where one or more householders are hypersensitive to low-level pollutant exposures. Local exhaust, whether by mechanical means or through windows, should always be used if activities in a particular area of the home involve chemical exposures that could be toxic in sufficient quantity, e.g. painting or furniture stripping.

Care should be taken, however, that an open window does not become an intake, forcing the pollutant throughout the house, before it is exhausted elsewhere.

Implementation: Three basic methods are suggested. The first involves a small exhaust fan locally, which removes air from above the polluting item and blows it through a duct to the outside. The second involves a central fan (on the exterior wall or roof of a house, or in a heat exchanger) which draws air through ducting from the area to be vented . The third method is merely opening enough windows to provide a cross-ventilation which adequately exhausts the polluting activity.

An exhaust system which is connected to an air-to-air heat exchanger allows energy savings over an installation which exhausts warm air directly to the outside.

In order to exhaust pollutants effectively, it is necessary to take account of local air velocities near the pollutant source, under varying conditions. For example, common range exhaust fans often do not always collect a great deal of the odour and moisture from the stove cooking surface, because only a slight amount of local movement (e.g someone approaching the stove to stir a pot) is sufficient to direct cooking vapours away from the fan inlet.

Local pressure and velocity changes can be very sudden, for example, when caused by the opening of a door, which acts like a piston in a tight room. Cupboards which may contain pollutants from individual sources can be abruptly exhausted into room air merely by opening the door. Deliberate ventilation of cupboards can minimize contamination of room air from stored

2.1.2 Exhaust of Pollutant Sources (main entry, continued)

possessions (e.g. newspapers and magazines), but local velocities, when doors are opened, may nonetheless cause some mixing of air.

Materials List: Materials required include an interior or exterior exhaust fan, ducting, an exterior exhaust fitting and wind flap. K. Raab (1983) also suggests the use of small quiet computer fans that are designed for continous operation. An air-to-air heat exchanger can also be used.

Advantages: Removal of pollutant at the source will prevent mixing with the indoor air, thereby avoiding risk of illness. Houses require some ventilation in order to maintain good air quality. Maximum benefit may be gained from this ventilation if exhaust vents draw air preferentially from those areas which are most polluted.

Disadvantages: Any ventilation represents an energy cost (but it must be recognized that some ventilation is always required). Negative pressures may invite backdrafting of a combustion furnace (see p. 11) and may draw pollutants into the living space from wall cavities or from the soil (see p. 9).

Cost: The cost will vary, depending on the installation.

Installations: Spot ventilation has been used for some time in industry to remove hazardous pollutants close to the source. The most common examples in the home are kitchen and bathroom vent fans. Informal experiments have been done at the Sunnyhill Research Centre in Goodwood, Ontario, regarding exhaust of kitchen appliances, televisions, and office equipment. This work suggests that it is cheaper and more effective to surround the pollutant source with walls, then exhaust the resulting enclosure, than it is to attempt to exhaust pollution from a source free-standing in a room.

Effectiveness: The effectiveness of an exhaust system varies widely with the design of the vent hood, position of the duct, and size of the fan. Some popular kitchen stove exhaust units are not very effective at directing stove odours to the outdoors. The noise from local exhaust fans (e.g. kitchen stove, bathroom fans) will sometimes discourage their use. Exhaust fans without shrouds or hoods are less effective at directing odourous air than are units which surround the pollution source as much as possible.

Source: Readers are referred to K. Raab (1983), B.M. Small (1983), and C.E. Billings and S.F. Vanderslice (1982).

Solution: **2.1.3 Reduce contamination of intake air from outside sources**

Problem Addressed: Contamination of intake air, with pollutants from outside sources (e.g. auto exhaust from a parking lot, stale air from a building exhaust vent, exhaust from a furnace chimney, etc.)

Principles Employed: Fix a condition so that less pollution is produced; separate pollutants from persons.

Description of Solution: Four actions appear possible, when intake air is being contaminated:

1. eliminate or move the source of contamination

   (e.g. park a car farther away from intake vent, store trash elsewhere, extend or reconfigure a gas furnace chimney (to redirect exhaust elsewhere), etc.)

2. move the intake vent

   (e.g. move the intake vent to a point higher on the building, or on another side of the building, further from the pollutant sources)

3. reduce air intake at times of greatest pollution

   (e.g. shut off or turn down the intake, or heat exchanger, during times when concentrated wood smoke from a neighbour's chimney is entering the intake)

4. filter incoming air

5. move the household to a less polluted area

Application: Measures to insure clean intake air are advisable for any household, and are often urgent in households where one or more members are hypersensitive to particular pollutants, or at some health risk when pollution levels are high (e.g. carbon monoxide levels, for persons with heart disease). In cases of severe sensitivity, or high concentrations of pollutants continually in outside air (e.g. from nearby industrial activity), some families may wish to move from the area. Filtration, dehumidification and cooling of intake air is commonly used as a means of combatting specific sensitivities such as pollen allergies (see Central Air Filtration, p. 18).

Materials List: Extra ducting is required if intake or outflows require moving. Care should be taken in the event the intake is altered in any way — materials such as certain caulking compounds and tar sealers may off-gas considerably and can contaminate the intake air. Filter materials are discussed under 'Central Air Filtration' starting on p. 18.

2.1.3 Reduce contamination of intake air from outside sources (continued)

Advantages: Reduce pollutants at the source.

Disadvantages: Sometimes not under householder control. Separating intake air from pollutant sources is not always easy. (For example, variable wind direction may bring pollutants from a nearby source, part of the time, no matter where intakes are located).

Cost: Can be minimal, but could be significant if exhausts and intakes must be moved or extended.

Source: Readers are referred to K. Raab (1983) for further discussion of the technique described above.

Solution: **2.1.4 Central Air Filtration**

Problem Addressed: General accumulation of various odours, from building materials, furnishings, household products and activities, etc., throughout a home.

Principles Employed: Remove pollutants from air.

Description of Solution: Air is drawn through particulate, and/or other filters, in a central air circulating system.

Application: For both general and special purpose housing, depending on the degree and type of filtration, e.g.

general housing	- medium-efficiency particulate filtration
specialized housing	- high-efficiency particulate filtration and/or gaseous filtration with activated carbon or chemisorbant filter medium

Implementation: Filters are inserted in slots provided in furnace and fan housing, or if these are not appropriate for the type of filters chosen, special filter support ducting is custom-fabricated and installed in the duct system, usually upstream from the furnace and fan. The fan motor may require an increase in size, to allow for increased pressure drop over filters, especially high-efficiency or charcoal filters.

K. Raab (1982) recommends the use of medium to high-efficiency particulate filtration systems in general housing.

Materials List: See the reference below for further details.

Advantages: In general, central particulate and/or gaseous filtration can aid in the overall reduction of multiple pollutants. This method can be cheaper than making major renovations or heating system changes.

Disadvantages: Filter media cost money and the cost of replacement of media, for removal of gases (e.g. charcoal or chemisorbant), can be on the same order or greater than the annual heating cost of a home. Maintenance is required for medium- and high-efficiency particulate filters, as well as for filters for gases.

This author is also aware of some cases where people using the filters are believed to have developed a sensitivity to the smell of the filter medium itself.

Medium-efficiency filters are often 50 mm. thick, and may require changes in ductwork or filter slots in furnace housings.

2.1.4 Central Air Filtration (continued)

Cost: See Disadvantages above. Raab states that costs for medium-efficiency particulate filtration are marginally higher, initially, than conventional low-efficiency furnace filtration, but are equivalent in the long term.

Effectiveness: Varies according to the pollutant sources in the home, and the sensitivities of the occupants. This author is unaware of any scientific studies that have attempted to quantify the effectiveness of home filtration in reducing the incidence of illness. Product reports do confirm that various filtration media can lower pollutant levels.

Sources:

K. Raab (1982 and 1984)
P.E. McNall (1975)

Solution: **2.1.5 Local Air Filtration**

Problem Addressed: Accumulation of various odours from building materials, furnishings, household products and activities, etc. within local areas in a home.

Principles Employed: Remove pollutants from air.

Description of Solution: Portable air filtration units are used in local areas within the home to produce cleaner-than-average air in that particular area.

Application: Usually for the benefit of persons having a high degree of sensitivity to various pollutants. A typical application is in a bedroom or living room, where the person spends a considerable amount of time each day.

Implementation: The room to be filtered is usually separated from general air circulation in the home, by blocking off or restricting air ducts to and from the room. Separate intake air is supplied locally, for example by opening a window slightly. One or more portable filtration units are used in each room to be cleaned, depending on the size of the room and the capacity of the filter.

Filtration media usually include medium-effiency and high-efficiency particulate filters as well as activated carbon or chemisorbant filters. For persons with extreme sensitivities, the order of filters may be important (for example, persons sensitive to some chemisorbant media may often make use of them if they are followed, downstream, by a tolerated activated carbon filter.

An alternate method involves isolation of the major pollutant sources and filtration of air surrounding the sources, rather than that surrounding the susceptible individual.

Materials List: See more specific entries following.

Advantages: A greater degree of reduction of pollution can be obtained in a small area within the home, than can be achieved at similar cost for the whole home. This is particularly suited to situations where one individual is particularly hypersensitive to indoor pollutant exposures, and may require, during acute stages of illness, air that is significantly cleaner than that required for others with less sensitivity.

Disadvantages: Some people can develop a sensitivity to the mild odours of the various filtration media.

Cost: Room units vary from several hundred to about one thousand dollars, depending on the sophistication. Most machines designed for the chemically sensitive persons are presently being imported from the United States, but some custom units are now being manufactured in Canada.

2.1.5 Local Air Filtration (continued)

Installations: This author has used a number of units at the Sunnyhill Research Centre in Goodwood, Ontario. Others have reported their use particularly in bedrooms for chemically sensitive individuals, and in new houses, to accelerate the off-gassing of new materials, prior to a family with hypersensitivities moving in.

Effectiveness: No tests were conducted in the specific installations mentioned, to determine the degree of reduction of indoor pollutants, nor to obtain an objective measurement of any changes in health effects.

Sources:

The following companies have supplied filters to chemically sensitive individuals:

Allermed Corporation, 4324 Sunbelt, Dallas, TX 75248

Dust-Free, Inc., P.O. Box 454, Royce City, TX 75089

Air Conditioning Engineers, P.O. Box 616, Decatur, IL 62525.

Bionaire Filters, Biotech Marketing, 83 Galaxy Blvd., Rexdale, Ont. M9W 5X6

Clean Air Machine Filters, Houston Distributors, P.O. Box 549
Cobourg, Ontario K9A 4L3.

Engineering Dynamics, Attn. W. Pick, Hwy 29, Carleton Place, Ontario.

Solution: **2.1.6 Move to another home, to avoid indoor pollutants**

Problem Addressed: Multiple indoor pollution sources

Principles Employed: Separate pollutants from persons, by moving one or the other.

Description of Solution: Move the household to a different existing dwelling, or build a new home. If the choice is moving to a pre-existing dwelling, the choice of home is made with lower indoor pollution levels as a paramount consideration. If the decision is to build a new home, choices of materials, design of systems, etc. are made with the occupants' sensitivities in mind.

Application: Usually the decision is taken to move out of a home that has presented a health problem due to indoor pollution, under the following conditions:

a) it costs the householder less to move, (in dollars, time, or trouble) than to modify the present home to reduce indoor pollution to tolerable levels, or

b) the existing home cannot be renovated in such a way as to keep indoor pollutant levels low enough to suit occupant sensitivity.

Implementation: Since householders sensitive to indoor pollutants may also be susceptible to outdoor pollutants, care should be taken in choosing a location that does not add significant outdoor pollutants to the occupant's total load, or that is not slated for heavy industrial growth in the future.

If buying a pre-existing home, the householder must be sufficiently knowledgable about potential indoor pollutant sources, to predict whether each house considered could present a health problem for his or her own family (see references below). Householders with acute, immediate-type sensitivities can often rate potential homes by the severity of symptoms that occur during viewing of the home.

Some householders have specified, in an offer-to-purchase, that the sale is conditional on certain tests, such as for indoor formaldehyde levels, and that the home is free of certain known hazards, such as urea-formaldehyde foam insulation.

Homeowners wishing to build a new home, with lower than normal indoor pollution, often consult builders or designers with specific experience in this area (see references below). Assistance of the physician, or ability to self-test for reactions to samples of specific building materials, is a definite asset during the design phase. However, it is difficult to anticipate, from a small sample, what effects could arise from fully-finished room, and to take into account the natural decline of emissions during the lifetime of the product.

(**2.1.6 Move to another home, to avoid indoor pollutants,** continued)

Materials List: Householders searching for a suitable existing dwelling often ask for any or all of the following features, depending on their particular sensitivities:

- o electric heat;
- o hardwood floors, or at least not carpeted throughout;
- o little if any use of particleboard, or certain plywood panellings;
- o dry basement and no significant mould problems in the home;
- o no recent interior pesticide use;
- o no recent interior renovations, including painting;
- o no installation of certain insulations, e.g. UFFI or cellulose; and
- o a location free from significant exterior pollutants.

It is important to note that a house may be entirely suitable, that does not incorporate all of the features above. Usually some compromises must be made, but often a house with one or two problems can be made acceptable with a minimum of renovation (e.g. removing carpets in bedroom areas for dust-sensitive householders).

For new homes, the list is similar, and will also depend on the particular occupant sensitivities. For example, electric heat pumps have been used, but exterior gas boilers might also be considered. Ceramic and hardwood floors are commonly used, although certain types of carpets (e.g. polypropylene) have proven acceptable for some families. Usually foam insulation of all kinds, as well as cellulose insulation, are avoided. Particleboard, and often plywood and many softwoods, are avoided.

Advantages: A move is often seen, by the householder, as a way of solving many indoor air pollution problems at once. The householder has considerably more freedom of choice than in the case of renovating the present home.

Disadvantages: Homeowners, looking for existing houses with lower indoor air pollution levels, are often disappointed at the difficulty involved in finding suitable dwellings. Their choice in the real estate market is much restricted compared to the average home-buyer or renter.

Building is a time-consuming, costly, and often very stressful process. In some cases, householders who are very badly affected by an existing home may be better advised to move immediately to another pre-existing dwelling, than to remain in the building that is causing them problems, during the considerable period of time involved in designing and building a special residence.

(**2.1.6 Move to another home, to avoid indoor pollutants**, continued)

Cost: Purchase of existing houses need not involve any premium for a house with lower indoor air pollution levels. However, since there are few houses suitable for the highly sensitive householder, major additional costs usually arise for renovations, e.g. changing a heating system or changing floor materials before moving in.

So far, experience with specialized new dwellings has been limited in Canada, and no firm conclusions can be reached about the likely cost of low-pollution features. One builder estimates that perhaps 20% additional cost may be involved over conventional construction.

Installations: The author is aware of a number of people in Canada and the United States who have relocated because of indoor air pollution, or because of both indoor and outdoor pollution. These number in the low hundreds, rather than thousands, but the true incidence of this remedial action is totally unknown.

Effectiveness: No objective studies have been undertaken, to this author's knowledge, to assess the effectiveness of moving to a new location to reduce indoor air pollution exposures. In most cases known to this author, and in those cases reported in a householder survey performed as background to the present study, occupants who have relocated reported that this has been at least partially effective in addressing the problems they sought to solve.

Source: References, which may be useful to persons wishing to look for or build homes with lower indoor air pollution levels, include the following:

K. Raab (1982, 1983, and 1984)
B.M. Small (1982, 1983, and 1985)
A.V. Zamm and R. Gannon (1980)

Further information about features individual homeowners have installed in existing or new homes to reduce building illness, and a list of names of designers and builders who have had experience with low-pollution dwellings, are being assembled by Technology and Health Foundation, R.R.#1, Goodwood, Ontario L0C 1A0.

2.2 FURNISHINGS AND APPLIANCES

Many indoor air pollutants can be traced to movable furnishings or appliances within the home. They are, therefore, within the control of most householders, although renters may have less control than homeowners, and financial means plays a strong role whenever changes in furnishings are required.

In general, the levels of contaminants produced by any single item of furniture are not very high, although some items are by themselves sufficient to trigger reactions in hypersusceptible individuals. The total mix of contaminants, from a household full of furnishings, may have more bearing on health than pollutants emitted from any one item, with the possible exception of carpets and carpet underpadding, which often represent a considerable portion of the total surface area within a home. Some materials may not seem to have a very great emission rate per unit area, but their total effect on pollution in the home could be significant because of the considerable total area involved.

Items of furniture containing foam paddings, and surfaced with synthetic or specially-treated materials, are commonly believed (by householders affected by indoor pollutants and by physicians specializing in environmental medicine) to be among the worst offenders. If foam paddings and synthetic fabrics in such furniture 'breathe' at all, the effectively large surface area of the materials could be responsible for the difficulties reported. Measurement studies, and reviews of the compounds involved in the manufacturing of man-made fibers and materials, confirm that a wide variety of substances are contained in, and given off by, such fabrics or materials. (The reader is referred to Indoor Air Pollution and Housing Technology, page 110, by B.M. Small (1983), for full references.)

However, no comprehensive studies have been done, to this author's knowledge, to confirm the relative significance of different furnishing types as causes of illness, and whether furnishings that have been reported to trigger symptoms in particularly susceptible persons may also present some risk to other segments of the population.

Furnishings are not always constant pollutant sources. Some may off-gas only negligibly, until the sun hits them through a south or west-facing window. Window drapes, especially those with rubber-like backings may be particularly troublesome in the sun. Some furnishings may act as pollution 'sinks', absorbing pollutants such as formaldehyde, produced by building materials such as insulation. Humidity and temperature, as well as the concentration of gases from other sources, may affect both the emission and absorption rates. Water leakage, for example from kitchen taps to the underside of a particleboard counter, may also enhance odour problems from some materials.

(The role of particleboard will be discussed more fully under a subsequent section entitled 'Building Materials'. Particleboard is sometimes used in underlayment, but is also a component of products such as kitchen and bathroom cabinetry and furniture. It is a known source of formaldehyde. However, surfaces in the above applications are, to a large extent, sealed. Progress is being made, by manufacturers, in reducing emissions from this material.

Some furnishings may also be a vehicle for dust and moulds that may be the primary household pollutants. Chesterfields and mattresses, which absorb moisture from people while they rest, can harbour dust mites and support mould growth, if overall humidity in the home is sufficiently high. I. Andersen (1984) emphasizes that, below 45% relative humidity at 20-22 degrees C, almost no house dust mites are able to survive but, at higher humidities, the number of mites increases rapidly, up to several thousand mites per gram of house dust. When local humidity exceeds 75% RH in houses, there is a possibility that fungal growth will occur and the indoor Total Spore Count will increase (I. Andersen, 1984 and K. Holmberg, 1984). (The reader is cautioned, at the same time, that too low a relative humidity may be associated with increased incidence of respiratory illness (G.H. Green, 1984a).

A high local Relative Humidity can be caused by insufficient insulation of outer walls, leading to a low inside surface temperature in the cold seasons, which can lead to condensation and mould problems. Other conditions may produce condensation without a corresponding temperature difference, for example, the geometry of fibres and surface physics effects can cause condensation on carpets when the local air Relative Humidity is in the 70-80% range (J. White, 1984).

Furnishings which have been passed down from generation to generation, over many years, or furnishings which have been held in damp and mouldy environments, may present a particular problem for persons with strong mould allergies. These may include, not only fabric-containing items such as carpets, chairs, beds, and chesterfields, but also wooden furniture, pianos or organs, etc.

Electrical appliances are also a low-level source of pollutant emissions, due to the heating of plastic materials, or the generation of ozone within motors. In general, whenever power is consumed and heat generated, there will be at least small amounts of pollutant emissions. For example, mild odours emanate from the electronics of televisions and stereo systems, which may trigger symptoms in persons who are particularly chemically susceptible. No health studies have been performed, to this author's knowledge, to assess the extent to which such emissions may be significant in the course of such illness, and whether they may present any risks to persons who are asymptomatic.

Electric heating devices, which inadvertently trap dust on or adjacent to heating elements, can be a source of indoor pollution, due to the increased volatility of the dust (e.g. synthetic fabric fibres) at higher temperatures, or due to scorching or burning of the dust. High temperature electric baseboard heaters, with uncleanable fins, have been reported to cause problems in this regard. In general, low-temperature electric heating appears to have given rise to fewer reports of related illness than high-temperature systems. (Series wiring of multiple heaters can change high-temperature systems to low-temperature systems, at relatively low cost.)

Electronic air cleaners have been reported to cause health problems for some sensitive people, though no studies have been done to confirm this on a scientific basis. It is known that some models produce ozone, particularly if proper maintenance and cleaning has not been carried out.

This author has also received several reports of difficulties caused by new heat pumps. In one case, this was traced to two distinct sources within the unit. The first involved fibreglass insulation with a tar-like surface, which had been installed by the heat pump manufacturer on the inside of the main duct of the unit, adjacent to the heat exchanger. The householder reported an improvement when the insulation was removed and the casing sandblasted to remove any leftover traces of glue. To this author's knowledge, the use of insulation within heat pump units is now becoming commonplace. Its purpose appears to be the inhibition of noise from the unit.

The second heat pump complaint was traced to the operation of the back-up electric resistance heat within the heat pump unit. The householder in question was sensitive to the odour given off by the heated coils, and ultimately replaced the backup unit with a hot water coil heated by an electric boiler. The electric furnace had not at first been suspected, since the outside temperature was high enough that it was presumed to be inoperative. In this particular unit, however, the electric furnace was cycled on regularly each hour to temper the house air while the unit reversed its cycle and defrosted the exterior coil.

Refrigerators have been cited as sources of problems for the chemically sensitive. Two possible situations are as follows. In the first, symptoms arise primarily when the refrigerator is opened, presumably due to the odours of plastics that were confined in the interior. In the second, symptoms arise when the refrigerator is closed, and cycles on. Many modern refrigerators have the coils for discharging heat installed at the bottom of the cooling chamber, separated from the chamber by several inches of uncovered fiberglass insulation. When the compressor cycles on to cool the chamber, a small fan also cycles on to draw air over the hot coils and compressor, and to disperse this heat into the room. However, the dispersed air may also contain accumulated dust, bits of fiberglass, possible biogrowth from the drip pan, and the odours of warm insulation, compressor, fan motor, and plastic-coated wires. In this author's experience, the fan in such a configuration accumulates dust and is inaccessible for cleaning. This leads to fan failure through clogging and subsequent burnout, involving considerable odour, and sufficient pollution to trigger reactions in susceptible individuals.

Appliances, with which the householder must work in close proximity, sometimes present a problem. For example, a sewing machine or typewriter may emit trace concentrations of various chemicals, from the plastic casing and from lubricating greases and oils within the machine. The small lamps on some recent models are shielded by a translucent plastic guard, which, when heated, emits sufficient odour to affect some chemically susceptible persons.

Both dust-sensitive and chemically sensitive people have reported problems associated with portable vacuum cleaners. Some studies have explored the role of fine dust exiting through the collector bag, as a contributor to problems for the dust-sensitive householder (G.H. Green, 1984b, and H. Lehti, 1984). The extent to which chemical pollutants, associated with operation of the motor, may also be involved does not appear to have been studied.

Solution: **2.2.1 Selection of Low-Emission Furnishings** (main entry)

Problem Addressed: Emissions from home furnishings.

Principles Employed: Substitute low-pollution for high-pollution surroundings.

Description of Solution: Substitute furnishings are obtained, to replace furnishings that are shown to be contributing to health problems. For example, a number of people who are sensitive to various gases have reduced symptoms by removing synthetic rugs, drapery and furniture from the home and replacing them with similar items made from either natural fabrics or synthetics specifically known to be tolerated by the occupants.

Application: This method is used when it can be shown that specific items within the home are causing health problems. Often the emissions from the furnishing are at a relatively low level, and the householder may be hypersusceptible to those emissions (e.g. dust allergy).

Choosing furnishings that have low emission rates is also advisable when building very tight homes with minimal ventilation.

Implementation: To date, the primary method of choosing substitute materials has been by avoidance of materials known to be polluters. No studies have, to this author's knowledge, specifically listed and tested alternative low-emission materials. The references below include test results on various materials and furnishings.

Materials List: Untreated cotton and wool seem to be most popularly chosen as alternative materials, by those who are sensitive to synthetics, although both can be allergens for some people. One family surveyed indicated that polypropylene rugs were well tolerated, while other synthetic carpets were not.

Advantages: Reduction of emissions at the source.

Disadvantages: Often expensive. Households have considerable investment in existing furnishings, often built up over a considerable number of years.

Cost: Varies according to furnishings.

Installations: A number of persons, responding to a background survey, reported using this method, notably with respect to synthetic carpeting, synthetic drapery, polyester and other synthetic fabric coverings on various items of furniture, etc.

2.2.1 Selection of Low-Emission Furnishings (main entry, continued)

Effectiveness: To this author's knowledge, no studies have confirmed the effectiveness of this method. There have been numerous clinical reports, and similar anecdotal material presented at conferences, reporting that individual cases appear to have benefitted from changes in furnishings. Survey respondents all thought there was some benefit to substitutions they had undertaken.

Source: The following articles review pollutant levels of various indoor furnishings:

A. Billman (1981)
R.B. Gammage et al (1984)
Geomet Inc. (1981).
E. Libret et al (1984)
L. Molhave (1982a and 1982b).
J.A. Pickrell et al (1983)

Solution: **2.2.2 Reduction of particulates from carpets**

Problem Addressed: Much dust and dirt can be kicked up into room air, from carpeting, adding to the burden of respirable particulates that must be handled by householders' lungs.

Principles Employed: Fix a condition so that less pollution is produced.

Description of Solution: K. Raab (1983) suggests avoiding the use of footwear on carpeting, and vacuuming before dirt becomes apparent. Street dirt, that is carried indoors with the shoes, can include a wide variety of substances.

Application: Any carpeted home, but particularly in carpeted households where one or more members is known to be adversely affected by house dust and high levels of respirable particulates.

Implementation: Shoes are removed at the door, in order to avoid distributing contaminants over the carpet. Vacuuming is done daily, or in any event before dirt becomes visible. Raab (1982) also recommends steam cleaning instead of shampooing, to reduce the possibility of illness due to residual detergent on the carpet.

It has been suggested, by some researchers, that portable vacuums may cause a problem for dust-sensitive people (by stirring up dust during operation and allowing fine dust to escape in the exhaust). Recent reports indicate that the amount of dust escaping varies markedly, but is small compared to the total amount of dirt removed. Filter masks are recommended for dust-sensitive persons who may not be able to be absent during vacuuming. (See G.H. Green (1984b), and H. Lehti (1984)).

Homeowners should be aware that central vacuum cleaners may affect the operation of a gas heating system, by drawing air from the house and reducing the ability of the furnace to exhaust combustion products completely. (See backdraft checklist in section 2.5 Combustion Devices).

Advantages: Reduce pollution at the source.

Disadvantages: Some people may prefer to wear shoes within the home.

Cost: Pennies a day, for the cost of electricity for vacuuming. Periodic expense for steam cleaning, if used.

Effectiveness: To this author's knowledge, no studies have quantified the effectiveness of not wearing shoes on carpets.

Source: Readers are referred to K. Raab (1982 and 1983) for further discussion of the techniques described above.

2.3 BUILDING MATERIALS

Previous work has reviewed the role that a number of building materials have played in indoor quality problems (B.M. Small, 1983, pp. 42, 72, 124). The bulk of work reviewed, at that time, concentrated on formaldehyde, primarily from particleboard and urea-formaldehyde foam insulation. Some measurements of other organic vapour emissions from building materials, including solvents, adhesives, paints and resin products were also cited.

The reader is referred to the above-mentioned text for the full references. The discussion below will concentrate on the 'how' and the 'why' of pollutants off-gassing from building materials, by grouping the problems some materials present into a number of categories.

Firstly, it is important to recognize that most building materials give off trace odours. Builders and homeowners are familiar with characteristic odours from composition wood products, softwood lumber, from different kinds of insulation, from unfinished drywall, from wet cement, from paint, etc. Some of these materials have been reported to be related to health problems in a number of individuals, others only for an isolated few.

Few materials reviewed in the scientific literature have been proven, in a scientific manner, to be hazardous for the general population. Few have been through the kind of analysis that has been applied to urea-formaldehyde foam insulation (UFFI), which has been banned for use in Canada. It would be difficult to demonstrate, with present information and technology available, that the individual building materials now on the market present a significant health hazard to the general population.

As with furnishings, however, there are two significant facts which must be taken into account:

(1) A number of materials which individually do not appear to adversely affect the health of an individual may, combined in a home, present a total air pollution problem that is big enough to represent a risk. Medical research has not yet provided sufficient practical means to verify when associated health complaints are related to such pollutant mixes, and which components of the mixes are the most important.

(2) What is known, from small-scale medical testing, is that low levels of pollutants, off-gassing from various building materials, can affect <u>some</u> individuals, and that, generally, the individuals affected react to extremely low levels of contaminants.

What must be understood about pollution from building materials, before ways can be designed of averting potential problems? The following conditions may contribute to creating health problems:

1. materials with relatively high off-gassing rates, particularly of residual solvents and other compounds remaining after the process of manufacturing;

2. materials which break down to form other compounds (e.g. urea-formaldehyde foam insulation;

3. confinement of the off-gassing products within living spaces, e.g. by lack of ventilation;

4. flushing of the off-gassing products into living spaces, e.g. by wind penetrating a building envelope and passing through insulation;

5. alteration of the properties of the material, through changes in humidity, water damage, heating, etc., and;

6. Individual hypersusceptibility to specific off-gas products, even at extremely low levels.

Houses which inadvertently combine a number of the situations described above may present greater risk of causing health damage, than others.

For example, materials such as urea-formaldehyde foam insulation, with high off-gas rates from product breakdown, do not constitute a hazard if the building structure is arranged so as to preclude a flushing of the off-gas products, through the wall, into the interior of a home.

Kitchen cupboards, made with exposed particleboard surfaces, may present elevated formaldehyde concentrations, if the room and the cupboards are inadequately ventilated.

Other combinations of the above factors, which appear to have created situations affecting health, include:

- plywood panelling, in mobile homes or basement recreation rooms, (high off-gas materials, in confined or badly ventilated spaces, subject to high moisture levels);

- unsealed particleboard surfaces in cabinetry (high off-gas materials, in confined spaces);

- particle board in flooring (high off-gas materials, subject to air circulation past the material and into living spaces);

- softwood trim, unsealed
(high odour material, combined with individual hypersusceptibility);

- various surface finishes, e.g. paint, varnish
(material with high residual solvents, combined with air circulation past the material into the living space, and confinement of fumes due to inadequate ventilation);

- cellulose insulation with fire retardant
(material with residual compounds emitted, and air circulation past the insulation into the dwelling interior);

- caulking and other sealants
(material with residual compounds off-gassing, and air circulation from the material to the living space; possible individual susceptibility); and

- new heating ducts
(material with residual oils off-gassing, and air circulation from the material to the living space).

The state of the art, of both measurement studies and associated medical research, makes it difficult to be more definitive about building materials at this time. Many have been proven to give off various compounds, some of which are suspected carcinogens, but the medical risks for the general population have not been quantified. It is known, however, that hypersusceptible individuals can experience adverse health effects from exposure to a variety of materials.

Research on building material problems can progress on two fronts at once. One direction is to experiment with those situations known to cause problems for certain hypersusceptible individuals, and find ways of altering the material, or its application in the home, so that pollutant concentrations and householder symptoms are reduced. If the methods found can be practically applied, without additional cost in the general housing stock, then potential problems could be short-circuited without additional research into their present effects. For example, proper sealing of air barriers and vapour barriers will seal out potential pollutants, while offering an energy cost saving. It is cheaper to do it than to study it.

Sometimes the only techniques for mitigating potential problems involve additional expense (e.g. extra ventilation in kitchens having exposed particleboard and elevated formaldehyde concentrations, or extra material or finish to seal the particleboard). In these cases, much more definitive measurement and health studies are required, to quantify the extent of risk and to assist in decisions on the advisability, or not, of introducing such changes on a wide scale.

Solution: 2.3.1 **Selection of Low-Emission Building Materials** (main entry)

Problem Addressed: Emissions from building materials (e.g. formaldehyde from particleboard)

Principles Employed: Substitute low-pollution for high-pollution surroundings.

Description of Solution: Substitute materials are used in renovation or new construction, to avoid the use of materials known to introduce offending pollutants into the home environment. For example, plywood may be used for underlayment instead of particleboard. Substitution of one brand for another may also accomplish sufficient reductions to make a building tolerable to hypersensitive individuals, since manufacturing methods are gradually being modified to take into account off-gassing products.

Substitution has been used as the base method in construction of low-pollution dwellings, and additional methods such as ventilation are used primarily to address residual pollutants that are considered unavoidable.

There is considerable brand-to-brand variation in off-gassing of many building products. If housing is to be adaptable to the wide range of vulnerability of the general population, it may be particularly important to incorporate materials which off-gas least, in those parts of a home that are least likely to be changed by new occupants (e.g. hidden materials such as sub-flooring and insulation, built-in features such as permanent cupboards and shelving, etc.)

Application: This method is used when it can be shown that specific building materials are causing, or could cause, health problems for the individuals concerned. Often the emissions from the material are at a relatively low level, and the householder may be hypersusceptible to those emissions (e.g. low concentrations of borates from the fire retardant in cellulose insulation have been associated with health problems in a small number of cases).

Choosing building materials that have low emission rates is also advisable when building very tight homes with minimal ventilation, and particularly when designing to minimize risk to persons known to be affected by various indoor air pollutants.

Implementation: Better data is needed to help homeowners and builders choose among alternative materials on the basis of off-gassing. Many now recognize materials which appear to have caused health problems, e.g. a particular brand of paint, sealer, caulking or wood product. But choosing the best among remaining alternative brands or materials is not easy, and a number of hypersensitive individuals claim to have experienced difficulty, over time, with alternatives that appeared at first to be acceptable.

Selection of Low-Emission Building Materials (main entry, continued)

Andersen et al (1982) note, from a review of product labels, that less than one half of products reviewed contained known eye and airway-irritating organic solvents. The types of substances reviewed included sealants, glues, adhesives, paints, lacquers, wall and floor coatings. They conclude that it should be possible to select some building materials in these groups that are less harmful than others.

Materials List: (see more specific entries following)

Advantages: Eliminate undesirable emissions at the source.

Disadvantages: It is difficult to change building materials in existing houses. For example, particleboard used as sub-flooring cannot be easily removed and replaced without major renovations.

Cost: Varies according to materials and installation.

Installations: In a new home near Ottawa, built specifically for a chemically sensitive person, solid hardwood has been installed, in lieu of composition wood products, in all cabinetry in the home. In a similar home near Toronto, particleboard, laminated on all sides, has been used in lieu of particleboard with any exposed faces or edges.

Effectiveness: To this author's knowledge, no studies have confirmed the effectiveness of this method, although it makes sense that there is variation in pollutant emissions between materials, and that choosing the lower emitters will yield less overall pollution.

There have been numerous clinical reports, and similar anecdotal material, presented at conferences, that some people have benefitted from changes in materials. Respondents to a survey, done as background to the present study, as well as the homeowners of the installations cited above, all thought there was benefit to substitutions they had undertaken.

Source: The following references report on pollutant emissions from various building materials:

I. Andersen (1972 and 1975)
K.C. Gupta et al (1982)
L. Levin and P.W. Purdom (1983)
T.G. Matthews et al (1983)
R. Miksch (1980)
L. Molhave (1979, 1982a and 1982b)
J.A. Pickrell et al (1983)
F.W. Williams and H.W. Carhart (1975)

Solution: **2.3.2 Continuous Air-Barrier** (main entry)

Problem Addressed: Pollutants from materials in the building envelope flushing through cracks into the living space

Principles Employed: Seal people off from the pollution source.

Description of Solution: A continuous air-barrier, impervious to wind pressure, is installed within the building envelope. The barrier may or may not also be a vapour-barrier. The air-barrier prevents transport of air through cracks under pressure, and thus helps to avoid infiltration of pollutants from the exterior, including pollutants from the building envelope itself.

Application: There are a number of reasons why a homeowner may choose to improve an existing air-barrier, or why a continuous air-barrier may be installed in new housing. These include:

a) energy conservation, to avoid leakage of warm air to the exterior;
b) building integrity, to avoid condensation of moisture within the wall; and
c) indoor air quality, to avoid flushing of wall pollutants to the inside.

If a homeowner is focussing solely on an indoor air quality problem in an existing building, sealing the air-barrier would be undertaken, as a first step, only if there were evidence that the air entering the living space, through the wall cracks, was contaminated and affecting the occupants. Some sensitive individuals have been able to determine this by sniffing incoming air at outlets or at baseboard level, when wind pressure outside is sufficient to cause major leakage. Measurement of contaminants, both in indoor air and in stud spaces, is a more expensive, but more rigorous, method.

Implementation: The exterior wall is surfaced with a well-sealed vapour-barrier and subsequently by a drywall interior wall. This interior wall is taped and sealed as the final air-barrier, to assist the vapour-barrier in resisting wind pressures on the outside wall. Outlet openings and cracks between walls and floors are also caulked. Special air-barrier papers (e.g. Tyvek) are also available, with greater strength against ripping than normal polyethylene vapour-barrier materials, and are usually installed on the outside, as a combined wind- and air-barrier.

Many variations can be implemented, but the principles remain the same as in the example above. The use of a parged interior structural wall, behind an exterior cavity faced with brick, is described in the entry following.

Advantages: In general, a continuous air-barrier provides the following advantages:

a) control of intake air — fresh air may be deliberately filtered, since it will enter through a small number of vents rather than through cracks distributed throughout the building;

2.3.2 Continuous Air-Barrier (main entry, continued)

b) energy conservation — heat from exhaust air may be partially reclaimed through heat exchange devices, since it will be exiting through a small number of vents, rather than through many cracks;
c) pollutants generated within the building envelope can be vented to the exterior, rather than flushed into the living space;

Disadvantages: A continuous air-barrier can aggravate indoor air quality problems from interior sources, if adequate ventilation (both fresh air and indoor circulation) is not provided. Sealing an existing wall, to form a continuous air-barrier, can also aggravate indoor air quality problems, if the materials used for sealing are not tolerated by the occupants (e.g. certain caulking materials have a persistent odour that can affect some people). Care must therefore be taken, whatever the reason for creating the air-barrier, to observe these three cautions:

1. provide adequate fresh air ventilation and indoor air circulation
2. choose sealing materials that will not cause illness
3. check, and if necessary reduce, interior pollution sources

Cost: Varies by method, but can be largely labour cost for careful attention to detail, for example, while taping or caulking the barrier.

Installations: A continuous air-barrier has been installed in a small number of Canadian homes, as a technique for ensuring indoor air quality for hypersensitive individuals. It has also been used as a retrofit technique on many homes which have urea-formaldehyde foam insulation in the walls, in lieu of complete removal of the foam.

Effectiveness: No tests have been conducted, to this author's knowledge, to confirm the effectiveness of the technique in special low-pollution construction. However, it was observed, during one construction project, that considerable odour could be detected at some openings when the wall was almost, but not quite, completely sealed. This was particularly strong at times when full afternoon sun heated an exterior wall. (see following entry re cavity-wall construction).

Sealing exterior walls has been successful in reducing formaldehyde levels to acceptable levels in a number of UFFI homes (the advisability of this method depends on initial stud space concentrations).

Source: Readers are referred to the National Research Council of Canada, Division of Building Research, Ottawa K1A 0R6, for information on vapour and air-barrier construction, and to the UFFI Centre, Dept. of Consumer and Corporate Affairs, Place du Centre, Hull, Quebec K1A 0C9, for further information on the sealing of walls to reduce UFFI emissions to the living space. NRC's publication 'Building Note 23' describes the application of this method (C.J. Shirtliffe and R.P. Bowen, 1981).

Solution: 2.3.2 **Continuous Air-Barrier** (using cavity wall)

Problem Addressed: Flushing of pollutants from insulation into the living space.

Principles Employed: Seal off people from the pollution source.

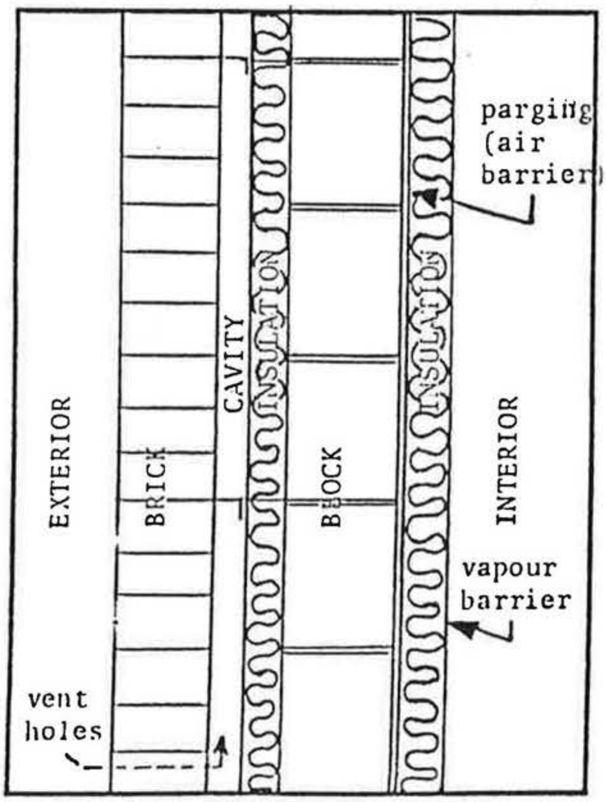
Description of Solution: A wall is built with a cavity between an interior structural wall, and an exterior facing. The interior structural wall is sealed as a continuous air-barrier. Insulation is installed in the cavity, and is vented to the exterior.

Application: New construction, for energy conservation, building integrity and indoor air quality reasons.

Implementation: In the installation described below, a cavity wall was created with a 150 mm. concrete block as the inner structural wall. The interior surface of this wall was parged with mortar. An exterior facing of brick was built, separated from the block wall by a 75 mm. cavity, and tied to the block wall with steel block ties. Cavity wall insulation (rigid fiberglass) was installed against the exterior of the block wall, held between the block ties.

Materials List: The blocks used were standard autoclaved concrete blocks, 150 mm (6 in.) nominal width. The parging consisted of a mortar made from Portland cement, sand, and mason's lime. The cavity wall insulation was Fiberglas Canada AF530 rigid yellow fiberglass insulation, 50 mm (2 in.) nominal width, insulation value RSI 1.1 (R6).

Diagram:



Continuous Air-Barrier (using cavity wall, continued)

Advantages: The cavity wall provides an inner structural wall that is insulated and therefore less subject to expansion and cracking than a wall fully exposed to seasonal variations. Deliberate venting of the cavity removes excess moisture and flushes pollutants to the exterior.

Disadvantages: The parged wall surface was covered with a further layer of insulation, and in turn by a finished plaster wall. It is therefore inaccessible for repair in the event cracks develop. The cavity width is regulated by building codes, and cannot be increased for additional insulation without requiring greater ties between the brick and block wythes, and therefore more heat loss. See also 'cost', below.

Cost: Cavity wall construction is considerably more expensive than standard wood frame and brick veneer construction, since an additional structural wall is created.

Installations: This method has been employed as a deliberate indoor air quality technique at the Sunnyhill Research Centre, in Goodwood, Ontario.

Effectiveness: No tests have been undertaken to confirm the effectiveness of this technique. However, it was observed, just prior to the sealing of the last opening at a doorway, that air from the cavity had considerable odour, particularly when the exterior brick wall was warmed by the late afternoon sun. Final sealing excluded the odour.

Source:

B.M. Small, 1983

Specific questions regarding this installation can be referred to: Sunnyhill Research Centre, R.R.#1, Goodwood, Ontario L0C 1A0.

2.4 MOISTURE, DUST AND MOULD

Dust and mould are two of the most common type of indoor pollutants. Their effects can range from relatively mild discomfort, to disabilitating and life-threating asthmatic reactions. Illness due to dust and mould exposure is usually associated with the allergic population. It should be noted, however, that excess exposure to dust may precipitate an allergic sensitivity in predisposed individuals, and certain mould spores are capable of infecting and precipitating disease in either allergic or non-allergic people. Recent research also suggests that fungal growth can produce volatile organic compounds, including short-chained alcohols and aldeydes, that may be associated with adverse reactions in some people (R.A. Samson, 1985).

House dust may contain a wide variety of potential allergens, including pieces of fabric, dyes from materials, skin cells, dust mites, animal danders, bacteria, pollen and moulds. Both dust mites, one of the chief causal agents in dust allergy, and mould spores, tend to be more common in homes with high moisture levels.

The reader is referred to pages 50-54 of Indoor Air Pollution and Housing Technology (B.M. Small, 1983) for full references to studies on dust and mould in homes. The following discussion will outline some of the primary circumstances under which either pollutant may present a problem.

This author is not aware of definitive studies concerning the maximum amount of dust or mould exposure which is advisable for the general population. Since allergic individuals represent almost 10% of the population, however, awareness of chronic moisture problems in homes may be essential, in order to minimize adverse health effects.

Recent studies by Canada Mortgage and Housing Corporation (A. Houston et al, 1984) review the problems of moisture and accompanying mould growth in Canadian homes. These can be caused both by moisture penetration from the exterior, and moisture accumulation in the interior, particularly during the winter months when condensation on cold exterior walls and windows may cause damage and fuel mould growth.

The dust-sensitive person often reports that one or more activities in the home may precipitate symptoms that are presumed to be related to high dust exposure. These may include:

- general vacuuming, sweeping or dusting. All of these activities may actually stir up dust and increase the airborne concentrations. Vacuum cleaners spew out very fine dust particles in their exhaust. (See also G.H. Green (1984) and H. Lehti (1984), as well as additional discussion in other sections of this report, listed in the subject index under 'vacuum').

- searching through old boxes or other storage. Dust is often allowed to settle on boxes and loose items in cupboards, attics, basements or other storage rooms, due to the difficulty in cleaning cluttered areas. Searches may stir up clouds of dust which can cause reactions.

- outside air, particularly in rural areas with unpaved roads, or well-travelled urban areas, may bring in a great deal of particulate matter. There is a high particulate content, for example, in automobile exhaust.

- furnishings with coverings that cannot be easily removed often accumulate (and generate) dust. Even the act of sitting down may produce an almost invisible cloud of dust, from the pressure on the padding of stuffed furniture. (see also G.H. Green, 1984)

- gatherings where a number of people are walking across carpets, or making sufficient movement to stir other loose dust (e.g. adults dancing, children playing inside) (see also K. Raab, 1983)

- laundry areas, where clothes are dried, shaken and folded may present problems for the highly dust-allergic person. Fabrics gradually fall apart, leaving tiny fibers in the air.

- mattresses and pillows may cause distress for people who are sensitive to dust generally, or dust mites in particular. The level of humidity generated in a mattress or pillow, during an eight-hour sleep, can be sufficiently high to allow growth of mites.

Typically, the mould-sensitive person may indicate that one or more rooms in a home tend to precipitate the adverse reactions, which are presumed to be related to mould spores in those rooms. The following situations are common:

- basement musty smell: Sometimes a basement will smell 'musty' or mouldy, yet it may be difficult to pinpoint any visible mould growth. (see I. Samuelson, 1984)

- basement mould growth: Some basements show visible mould growth, particularly where there is obvious water leakage through the wall or floor.

- vegetable cellar: Some houses have small uninsulated rooms below a porch, accessible from the basement. They can be damp and may harbour mould, either directly due to condensation and leakage of moisture, or secondarily due to the vegetable storage.

- bathrooms: When ventilation to bathrooms is insufficient, or when water is allowed to lie at the base of tile walls adjacent to bathtubs or behind sink taps, mould growth may be visible in a bathroom and can cause reactions for those who are sensitive. Wet towels, hung in poorly ventilated bathrooms, may also acquire a musty smell. Bathroom fixtures, such as toilet tanks, may 'sweat' in the summer, and the condensate may also encourage mould growth. (See also K. Holmberg, 1984.)

- attics: insufficient attic ventilation, in winter time, may lead to condensation on cold roof surfaces, when moisture-laden house air leaks upward due to stack pressures. When sunlight strikes and heats the roof, the frost and ice thaws, penetrates roofing boards and drips into insulation and sometimes through to ceilings below. Mould may begin to grow on any of the wet surfaces, and stored items may also begin to acquire a musty smell.

- windows: in homes with inadequate winter ventilation and/or unusually high moisture generation inside, condensation will appear on windows, when outside temperatures are low. The moisture drips to the sill and accumulates, often encouraging mould growth.

- wall cavities: some homes allow air leakage between the living spaces and the wall cavities. In winter, moisture-laden air may reach the cold materials on the far side of any insulation that may be present, and condensation within the wall cavity results. If this remains without drying, mould can grow within the cavity. The same air leakage paths can allow the spores and musty odour to enter the living space.

- insulation: urea-formaldehyde foam insulation has, in some instances, fostered mould growth, partly due to the high initial moisture content of the foam, and partly due to its selective inhibition of common mould types, which allow less common moulds an opportunity to thrive. Mould generation, due to UFFI, may cause illness in those with existing mould allergy, or those susceptible to developing mould allergy upon prolonged exposure.

- condensation on piping: 'dripping' in basements, during the summer time, often occurs when cold water piping lines are uninsulated and warm, moist outside air is circulating to the basement. Water damage to items beneath the pipes can occur, and mould growth may be encouraged. If moisture levels are particularly high, more general condensation on cool uninsulated walls may take place, again increasing the likelihood of a musty smell or visible mould growth.

- cupboards and closets: Mould may also appear in cupboards and closets, particularly those on outside walls. The cupboard or closet, and its contents, act as insulation, but the cool outside wall is accessible to warm moist air from the living space, giving rise to condensation and mould growth. Any furnishings which likewise tend to insulate outside walls, without fully blocking off air flow, may give rise to this effect (for example, floor cushions or mattresses pressed against an outside wall).

- water leakage from rain penetration, plumbing leaks, etc.: Sometimes major amounts of water leakage accumulate in wall cavities, due to rain penetration (from freak weather conditions, chronic weather conditions, wall or roof construction in need of repair, or plumbing in need of repair, etc.). These conditions rapidly give rise to mould growth within the cavity, which may in turn affect occupants as air transfers between the cavity and the living space.

- food or garbage storage: Storage of waste food cuttings can quickly give rise to mould growth within containers collecting these items. Opening the containers, to add new cuttings, can cause significant mould spore exposure, which may precipitate symptoms in persons sensitive to mould. Similarly, storage of root vegetables may introduce mould on attached soil, which may cause reactions when containers are opened. If temperatures are not sufficiently low for storage, more mould may grow, and the stored food may rot, giving rise to additional odours and larger mould colonies.

- plant rooms: Mould is very likely to be present in rooms containing indoor plants. This can be present in the soil of the planting pots, and may grow excessively on the soil surface if plants are watered often. If ventilation is not sufficient to lower overall moisture levels, high humidities in such rooms may lead to condensation on windows and other cold surfaces (in winter), which in turn will encourage further mould growth. Leakage from pots, and spillage during watering, can further encourage conditions in which mould will thrive. The amount of mould present, under such circumstances, will be sufficient to adversely affect some mould-allergic people.

- penetration of outside air, during high outside mould conditions: Mould spores are a natural constituent of outside air, and mould is a common inhabitant of soil. Mould-sensitive persons will often notice increased reactions when conditions outside are particularly moist, or when the snow first uncovers the soil in spring. There may be variations throughout the day as well, and some mould-sensitive persons take the precaution of shutting windows at night during the summer, to limit penetration of mould and plant-related odours to which they are sensitive. Certain mould-sensitive persons may require special filtration of air brought into the home through a heat exchanger.

- soil gases: Soil gases, penetrating through cracks in basement floors and walls, may bring musty smells, and possibly mould spores, along with various other pollutants such as radon gas, methane, and other products of decomposition within soil.

Solution: **2.4.1 Removal of Mould or Mouldy Items**

Problem Addressed: Mould growth within the home.

Principles Employed: Separate pollutants from persons; substitute low-pollution for high-pollution surroundings.

Description of Solution: Remove materials or furnishings from the home that have become mouldy. Remove mould, where possible, from materials that cannot be removed. This solution should be combined with elimination of the conditions which caused mould growth in the first place (e.g. high moisture).

Below certain relative humidities (usually around 70%), mould spores will not germinate, but once a growth is established, one of its by-products of metabolism is water. Mould can therefore continue to grow even when the ambient conditions are too dry to germinate mould spores elsewhere.

Application: In any home where mould growth has occurred. Mould growth can contribute to health problems, and eventually leads to deterioration of building components such as wallpaper, plasterboard and timber. P. Kozak et al (1980) emphasize that allergenicity of mould spores is independent of their viability (alive or dead) and therefore advises that killing spores by chemical means is of limited value. Rather he suggests that mould spores must be physically removed and the conditions that led to their production corrected.

I. Samuelson (1984) reported on a study of 394 buildings in Sweden suffering from mould growth, the vast majority of which were single-family homes. The most common type of damage was in the form of an unpleasant odour caused by mould. He points out that, in the majority of foundation structures, levels of 70-75% Relative Humidity or greater are reached as long as there is residual built-in moisture, and that these levels are sufficient to support mould growth. Slab-on-ground construction, without properly installed vapour-barriers, and crawl-space construction with no vapour-barriers, were commonly affected by mould.

Implementation: Remove and discard furnishings where mould growth is severe. Steam cleaning and quick thorough drying may help to eliminate musty odours in items where there is not extensive growth. Where possible, remove and discard building materials that have experienced extensive mould growth (e.g. ceiling tile, wallboard in areas that have been subject to moisture leakage, flooding, etc.)

Homeowners have used a number of substances on wall surfaces to remove mould growth, particularly in basements. Chlorine bleach, Zephiran and industrial detergents have been suggested, but this author cautions readers to take into account any occupant sensitivities before proceeding with any method involving additional odours or chemical residues.

2.4.1 Removal of Mould or Mouldy Items (continued)

Reduction of moisture sources is essential (see following entries) if mould is present. Restricting entry of soil gases from cracks and other openings below grade may also reduce incoming mould and incoming moisture.

Materials List: Check wall surface materials, flooring, underflooring, insulation, furnishings and loose objects (books, etc.) Garbage pails, compost pails, old fruit baskets, etc. may contain mould growth from forgotten food items. Wicker materials, especially those which regularly receive moisture (e.g. laundry basket) are highly susceptible to mould growth.

Advantages: Halts the spread of mould growth, and removes mould, a potential allergen, from the home.

Disadvantages: Some building materials or furnishings may require replacement.

Cost: Replacement costs depends on particular material or item.

Installations: The references below cite specific examples of homes where mould growth has been identified and where health problems related to mould allergy were present. Removal of materials with mould growth was carried out as a remedial measure.

Effectiveness: In the cases cited in the references, health improvement was reported as a result of removal of the mouldy items from the home. This author knows of no comprehensive studies or surveys which have yet been done, which would confirm on a more scientific basis, the degree of effectiveness of this measure. However, it would appear to be standard practice for general physicians, or allergists, to advise mould-sensitive patients to reduce mould within the home, as much as possible.

Source: The reader is referred to the following articles for further information on mould, mould allergy, and mould removal:

A.F. Bravery (1980)
G.W. Brundrett (1981)
P. Kozak et al (1980a and 1980b)

Solution: **2.4.2 Reduction of High-Humidity Conditions in the Home**

Problem Addressed: Excessive moisture and mould growth in the home. Mould growth can arise when areas within the home experience high relative humidity levels (usually 70% or more). Once established, the mould growth can continue on its own, since moisture is one of its products of metabolism. Reduction of high-humidity conditions, along with physical removal of the existing mould, will prevent further mould growth.

Principles Employed: Fix a condition so that less pollution is produced.

Description of Solution: Various means are used to reduce moisture levels in different parts of a home which may experience mould growth. Some of these are discussed in more detail in subsequent entries:

- sealing of basement walls to reduce infiltration of moist soil gases (sealing of surfaces, to reduce diffusion through walls, and of cracks, to reduce direct leakage)
- dehumidification by air conditioner or dehumidifier
- ventilation of high-moisture areas (e.g. kitchen, laundry, bathroom)
- insulation of cold exterior walls (adequate insulation, particularly exterior insulation, can bring most interior surfaces well above condensation temperatures)
- general increase of ventilation (e.g. when windows experience condensation in winter)

Application: In any homes where high moisture conditions and potential for mould growth exists. Mould is a potential allergen, and can cause deterioration of building materials.

Implementation: (see specific entries following)

Materials List: (see specific entries following)

Advantages: Eliminates conditions in which mould will thrive. Prevents high airborne mould spore levels. Prevents deterioration of building materials. May also reduce exfiltration of moisture through the building envelope, which may otherwise lead to condensation, mould growth within walls, and deterioration of the building envelope. Sealing basement walls may also reduce radon influx.

Disadvantages: If the interior is made too dry, airborne dust may increase, as may static electricity. Ventilation of high humidity areas may create backdrafting of combustion appliances (see pp. 9 and 11), and is energy-expensive, since latent heat in humid air is lost.

2.4.2 Reduction of High-Humidity Conditions in the Home (continued)

Installations: CMHC is presently studying moisture in housing, but no comparison studies have been done involving levels of mould growth before and after remedial measures. This author is aware of numerous individual cases where homeowners who were sensitive to mould have corrected high-moisture conditions in their homes. Some of these were reported in a recent survey among persons sensitive to indoor air quality factors, carried out as background to the present studies.

Effectiveness: There have been no comprehensive studies, to this author's knowledge, which have scientifically evaluated the effectiveness of moisture reduction relative to mould growth, health effects, and building deterioration.

Source: For references on mould and mould reduction, the reader is referred to sources listed under 'Removal of Mouldy Items'. The following source describes the kind of moisture problems that are commonly found in Canadian homes:

Marshall Macklin Monaghan Limited (1983)

Additional suggestions for reduction of moisture in homes are found in the following section and in:

J. H. White (1984)

Solution: **2.4.3 Ventilation for humidity control**

Problem Addressed: Condensation on piping, wall or window surfaces can lead to building damage, or mould growth and its associated potential for causing health problems.

Principles Employed: Fix a condition, so that less pollution is produced; direct the pollutants away from the people.

Description of Solution: Fresh air ventilation and simultaneous exhaust of stale air is used to reduce indoor humidity levels which may be contributing to condensation and mould problems.

Application: In homes where condensation presents a problem, for example, on windows in the winter. Ventilation is likely the most effective way to remove reasonable amounts of moisture that are generated within a home. It is most cost-effective when unnecessary sources of moisture are restricted, e.g. basements well-drained and sealed to reduce moisture infiltration from leakage of water or soil gases.

Implementation: Ventilation of moisture near the source, while moisture is being produced (e.g. by using a bathroom fan during a shower) is more economical than continuous general ventilation of the entire home, since less total ventilation may be required to remove the same amount of moisture.

The rate of ventilation required is dependent on a wide variety of factors including: outdoor and indoor temperatures; the rate of generation of moisture in the home; and the desired moisture levels. Generally, ventilation in the winter should be adjusted to the minimum level required to keep windows clear of condensation. This rate will be greater in homes with single-glazed windows, compared with homes that have double or triple-glazed windows. General experience and theory are not yet in agreement of the rate of air change required to eliminate condensation. Theory predicts that between 0.14 and 0.25 air changes per hour should be sufficient to avoid window condensation, but practical experience indicates that condensation can still occur at higher air change rates. (Rates of 0.5 ach and above are required to maintain low indoor pollutant levels).

Local ventilation of windows, i.e. ensuring that air is circulated past a window prone to condensation, may, in some cases, be sufficient to warm up the window to the point that condensation stops (similar to defrosting a car windshield). This may be an acceptable energy trade-off, compared to whole-house ventilation.

Whenever general mechanical ventilation is introduced, the homeowner should be careful to ensure that the gas furnace is still able to properly exhaust its combustion products, despite competition from other fans (see backdraft checklist, under 2.5 Combustion Devices).

2.4.3 Ventilation for humidity control (continued)

Materials List: Central or local fans and air ducts, or passive (heat or wind-powered) ventilation system.

Advantages: Potential for building damage and mould growth is eliminated or reduced.

Disadvantages: Energy costs associated with evaporation of water and heating intake air to replace humid air exhausted from the building. Air-to-air heat exchangers, or air-change heat pumps, may minimize this energy cost.

Cost: The cost of removal of moisture by ventilation has been estimated at about $200 per annum (at average electricity rates) for the average house (J.H. White, 1984). However, water removal costs are a normal and acceptable part of operating a house in a cold climate and, unless moisture generation levels are excessive, the ventilation required to remove moisture may not exceed that normally required to maintain proper air quality.

Installations: CMHC is presently studying moisture in housing, but no comparison studies have been done involving levels of condensation and mould growth before and after remedial measures.

Effectiveness: There have been no comprehensive studies, to this author's knowledge, which have scientifically evaluated the effectiveness of ventilation to control condensation and mould problems in residences.

Source: The reader is referred to the following references which deal with moisture problems and moisture reduction in homes:

Marshall Macklin Monaghan Limited (1983)
J. H. White (1984)

Solution: **2.4.4 Dehumidification to reduce mould growth**

Problem Addressed: Musty smells and mould growth particularly in basements during the summer.

Principles Employed: Fix a condition so that less pollution is produced.

Description of Solution: A chemical or mechanical dehumidifier is placed in a high-moisture area, in order to reduce the relative humidity, and thereby reduce condensation of moisture on cold surfaces. In many Canadian homes, warm, humid summer air entering a basement will lead to condensation on uninsulated cold water pipes and tanks and, in some cases, on the walls themselves.

Application: In homes where this particular combination of conditions (i.e. humid air and cold surfaces) cannot be avoided by other means such as ventilation. For example, in some parts of Canada, summer air can be extremely humid and may represent the major source of condensate in a cool basement. Increased ventilation, in this situation, might increase rather than decrease condensation. In such circumstances, dehumidification may be used in conjunction with other solutions (e.g. insulation of the cold surfaces, reduction of infiltration of humid air, etc.)

Implementation: For dehumidification to be most effective, infiltration of humid air should be reduced at the same time (e.g. by closing windows to the minimum required for fresh air, and/or by sealing or redirecting other moisture sources, such as leakage through basement walls, exhaust from clothes dryers, etc.)

Chemical dehumidifiers have not made significant inroads into the household dehumidifier marketplace in Canada. Electrically operated dehumidifiers are more commonplace. These pass indoor air over chilled surfaces and cause condensation on cooling fins. The condensed water is either stored temporarily in the dehumidifier or drained automatically.

Room or central air conditioners will also act as dehumidifiers, removing moisture from both recirculated and fresh intake air.

Materials List: Room dehumidifier, available at appliance or hardware stores.

Advantages: Reduces moisture levels and therefore potential for mould growth, damage to structure and possessions, and health problems. A properly functioning dehumidifer can reduce the relative humidity to about 35 per cent (see reference below).

2.4.4 Dehumidification to reduce mould growth (continued)

Disadvantages: Ongoing electricity cost. Periodic emptying of condensate collection bucket, if not piped directly to a drain. Low ventilation rates can allow buildup of other indoor air contaminants. If the condensate container is left unattended, the standing water can become contaminated with moulds, viruses or bacteria. Failure to drain the bucket may lead to periods where the dehumidifier does not operate, due to automatic shutoff. If the automatic shutoff does not work, spillage of water could cause damage.

Cost: Up to several hundred dollars initial investment, depending on the capacity of the dehumidifier, plus ongoing cost of electricity.

Installations: No documentation was found citing specific cases of installations. It is, however, a commonly applied solution for basement moisture in Canada.

Effectiveness: No studies were found which have scientifically evaluated the effectiveness of this technique.

Source: The reader is referred to the following reference for a discussion of moisture-removal methods, including dehumidification:

J. H. White (1984)

2.5 COMBUSTION DEVICES

Various combustion devices have been reported in the scientific literature to produce significant quantities of indoor pollutants under various conditions:

- gas and oil furnaces;
- gas stoves;
- unvented gas and kerosene heaters; and
- wood and coal furnaces and stoves.

The reader is referred to B.M. Small (1983) "Indoor Air Pollution and Housing Technology", pp. 9, 101-109 for full references to relevant studies. The pollutants of concern are:

- carbon monoxide;
- carbon dioxide;
- nitrogen oxides;
- sulphur dioxide;
- formaldehyde;
- benzo-a-pyrene;
- various hydrocarbons;
- respirable particulates;
- unburned natural gas;
- vapours from unburned fuel oil; and
- vapours from unburned kerosene.

This section describes the circumstances during which combustion devices can contribute to indoor air pollution and increase risk to health of occupants.

High Carbon Monoxide Levels

During 1983, a survey of carbon monoxide poisoning episodes was initiated jointly by the Department of Energy Mines and Resources, Canada Mortgage and Housing Corporation, and Health and Welfare Canada. (Reference "Hazardous Heating and Ventilating Conditions in Housing", T.J. Robinson (1984). This initial survey identified some 300 episodes and over 200 deaths involving carbon monoxide poisoning over the period 1973 to 1983.

One of the prime causes of the carbon monoxide incidents was inadequate exhaustion of combustion products from fuel-burning equipment. One mechanism cited was the blockage of chimneys after deterioration of masonry. This can occur when gas furnaces are installed without simultaneously installing a chimney liner, to protect the masonry from high moisture levels in the exhaust from such furnaces.

Another common mechanism involves either the stagnation or reversal of flow of furnace exhaust, spilling combustion products into the home, rather than exhausting them up the chimney. This can come about when negative pressures are induced by other exhaust devices in the home, such as a fireplace or dryer. Particularly when a house has been tightened, the inlet offering the least resistance, under negative pressure, may be the chimney.

Whether or not spillage of combustion products leads to dangerous carbon monoxide incidents depends a great deal on what is backdrafted and how. When there is a downward flow of air from the chimney, there still may be relatively complete combustion, with less CO than in an oxygen-starved situation. When the flow is stagnated, however, the furnace may re-inhale oxygen-starved air, leading to higher and higher levels of carbon monoxide production and a potentially dangerous accumulation of carbon monoxide within a home.

Safe operation of vents and chimneys cannot be assumed in houses that are either air-tight or that have chimneys on the outside wall, subject to cold Canadian winter temperatures. In order to gain a better understanding of the operation of vents and flues, another series of studies has been initiated, by Canada Mortgage and Housing Corporation, to investigate dynamic flow theory, extend and apply it to the problem of flues and vents, and to recommend changes to codes and standards, based on the knowledge developed.

Furnace Exhaust Leakage

This author's experience, reports by homeowners, and ongoing studies by S. Moffatt, for Canada Mortgage and Housing Corporation, indicate that there may be a number of mechanisms by which these devices can contribute to indoor air pollution problems, short of full backdrafting. Typically, the levels of exhaust contaminants are relatively low, and carbon monoxide levels may be low enough that no reading on standard Draeger tubes can be detected, even though there may be obvious homeowner symptoms and detectable exhaust odours.

There are many possibilities: for example, that exhaust is leaking from the front, the middle, or the back of the furnace, or from chimney piping. In this discussion, the "front" of the furnace refers to the access door which allows a maintenance person to inspect the chamber in which the gas or oil is burned. Particularly on older model furnaces, there may be leakage of exhaust gases out the front (if the access is not 100% sealed) during the initial startup of the furnace, when full draft has not yet been established. The homeowner is familiar with this phenomenon as "the puff" when the furnace starts up. It is also possible that pilot flame exhaust leakage, from gas furnaces, may occur through the same route.

The "middle" of the furnace in this discussion means the heat exchanger -- the chamber which contains the combustion, and which passes heat to air which circulates around it in the furnace plenum (the surrounding duct). After years of service, the heat exchanger may develop tiny holes and cracks, possibly due to corrosion and repeated expansion and contraction. The existence of these holes can be diagnosed by examination of the heat exchanger in the dark from the top, while a flame is burning inside, or by the introduction of a tracer smoke, or 'smoke bomb' into the combustion chamber. (This latter method has been proven, by experience, to be risky for chemically susceptible persons.)

If the heat exchanger has tiny cracks or holes, leakage may occur, albeit at a low rate, at times during the start-up, operation, or shutting-down of the furnace.

The "back" of the furnace, for the purposes of this discussion, means the part where the exhaust pipe leaves the combustion chamber and joins to the base of the chimney. Care must be taken during chimney installation and cleaning to insure that no unsealed piping joints for the exhaust pipe lie within the cold air return duct. If, for example, a chimney pipe elbow at the back of a furnace is pushed in too far, the joint between it and the pipe from the combustion chamber may feel negative pressure from the fan, and exhaust gases will be drawn directly into the circulating air stream.

Removal of the access panel at the back of the furnace may, in some installations, allow pressure changes large enough to draw combustion products out of the draft hood and circulate them through the house.

It also appears to be common that chimney ducting may leak combustion products. There are both in-leaks and out-leaks, and these may be a function of the geometry of the ducting and the physics of the exhaust flow within the pipe. There may be leaks from these cracks, or other parts of the furnace itself, particular during start-up, when backdrafting may force exhaust into the home. Startup may be accompanied by rapid expansion of gases within the furnace, without an accompanying draft, leading to some exhaust spillage. Spillage may also occur through furnace draft hoods or barometric dampers.

Furnace Fuel Leakage

Unburned fuel has also been suggested, to this author by many homeowners and physicians, as the cause of symptoms for many householders. Certainly, it is common knowledge among Canadians who have had experience with oil-burning furnaces, that there may be leakage of oil around the oil tank and, in some cases, leakage of fumes to the home through faulty level valves or fill pipes. Many homeowners recognize an odour that sometimes fills the basement on the day the heating supply contractor fills the tank.

One household surveyed in background studies to the present report, as well as one other household in the past year, have reported, to this author, incidents in which major amounts of oil were leaked into the basement, due to breaks in pipes or pipe joints.

Natural gas leakage has also been cited, in medical reports and by individual householders, as being related to adverse symptoms. Often the incidents reported to this author involve low levels of leakage, and gas company maintenance personnel often visit several times before the source of the leak is identified and fixed. Chemically susceptible persons can be more sensitive to trace odours of natural gas than others, and a typical incident will involve a householder claiming to smell natural gas, but company officials insisting that there is no smell at all, and therefore no leakage. Such extremely low level leakage has nevertheless been confirmed to trigger adverse health effects in certain people.

Oil space heaters, with attached tanks, are also well-known by many Canadians for their associated smell of unburned fuel.

In a Statistics Canada survey of household income, facilities and equipment published in 1982, some 3.64 million households in Canada were estimated to be heated by either piped or bottled gas, and an additional 2.6 million by oil or other liquid fuel. Of 3.57 million housing units with piped gas heating, 2.6 million use piped gas with hot air furnace heating, providing shelter to about 7.9 million people. Of the 3.57 million units with piped gas heating, 71%, or 2.54 million are ground-oriented. The total number of households represented in the survey was 8.43 million, housing a population of 23.8 million Canadians. (Statistics Canada, 1982).

Gas Stoves

Natural gas cooking stoves are perhaps the best-documented indoor air pollution source (B.M. Small, 1983, p. 103). The most common cooking fuel in Canada is electricity, used in over 90% of Canadian households, but piped or bottled gas is used in about 613,000, or roughly 7% of the 8.43 million Canadian households represented in a 1982 Statistics Canada survey (Statistics Canada, 1983).

Unlike gas furnaces, the gas stove is designed to provide an open flame, usually on four surface burners and within an oven chamber. Exhaust from combustion thus enters freely into indoor air, and may include high concentrations of carbon monoxide, nitrogen oxides, sulphur dioxide, formaldehyde, and respirable particulates. Stoves with no exhaust vent above the burner area will give rise to the highest room pollutant levels. The concentration of carbon monoxide in kitchens has been measured to rise well above acceptable outdoor standards during stove operation, and some studies have shown that this is most likely to occur when house air exchange rates are less than one air change per hour (Hollowell and Traynor, 1978).

Even fumes from pilot light combustion may be sufficient to trigger symptoms in persons who are particularly sensitive to gas and its combustion products. Full replacement of gas stoves, with electric ones, has been used as a standard prescription in cases of natural gas sensitivity.

Portable Kerosene Heaters

The mechanism for producing indoor air pollution is the same in portable unvented kerosene or gas heaters, as it is in gas stoves. That is, combustion products are vented directly into living areas. The levels of pollutants that are achievable with unvented portable heaters, however, appear to be higher than those produced by unvented gas stoves. High concentrations of carbon monoxide, carbon dioxide, nitrogen oxides, formaldehyde, and respirable particulates have been reported (B.M. Small (1983), p. 106, G. W. Traynor et al (1982)).

Wood Stoves and Fireplaces

Wood stoves suffer from the same three mechanisms of leakage as were listed for oil and gas furnaces - from the front during access or while draft is being established, from the body if there are leaks, and from the back during backdrafting, chimney blockage, or due to faulty installation. It is common, however, to find some wood stoves with removable burner plates on the top of the combustion chamber.

It is not surprising, therefore, that measurements of some wood stoves indicated suspended particulate levels three times higher during woodburning, than when the stoves were not operating. Elevated indoor levels of benzo-a-pyrene, a known and potent carcinogen, have been measured and attributed to woodburning in both stoves and fireplaces (Mueller Associates (1981), Roche Associes (1983), B.M. Small (1983), p. 109).

Problems arising from the use of wood stoves may be more severe than those from gas or oil furnaces, because the exhaust typically contains considerably higher quantities of certain pollutants. Hydrocarbon output from a wood-burning stove may reach levels 700 times that found in the exhaust from an oil-burning furnace, and carbon monoxide levels may reach 300 times that of an oil-burning furnace.

Many reports have been received, by this author, of health effects from wood smoke which filters into a home from outside. This phenomenon will be discussed in section 2.6 'Infiltration of Exterior Pollutants'.

Solution: **Aerodynamic separation of combustion devices**

Problem Addressed: In some homes, furnace chimneys may backdraft under some circumstances, introducing dangerous concentrations of carbon monoxide and other combustion gases. This may occur when other devices exhaust air from the home while the furnace is starting up (e.g. clothes dryer, kitchen exhaust fan, fireplace, etc.). (Refer to introduction in preceding pages for further detail.)

Principles Employed: Fix a condition so that less pollution is produced and/or direct the pollutants away from people.

Description of Solution: The furnace is isolated from the air of the home, as much as possible, by introducing outside air directly to the furnace, or to a sealed furnace room. The goal is to ensure that the furnace will be able to draw an adequate amount of combustion air at all times, and that other devices within the home cannot reverse the pressures, or draw air down the chimney. It is difficult, however, to seal a furnace room effectively, due mainly to the ducting entering and exiting the room.

Application: Applicable to all homes with combustion furnaces.

Implementation: A qualified furnace technician should be consulted so that no conditions are created that would impair the operation of the furnace (e.g. freezing of controls). The furnace room will require some heat.

Materials List: An intake duct and damper are required. Caution must be taken to ensure that any intake device cannot fail in the closed mode.

Advantages: Reduces risk of accident due to overexposure to combustion products, including carbon monoxide. Reduces responsibility of homeowner to understand and manually regulate pressures within the home, to avoid backdrafting conditions (although some precautions, such as keeping the furnace room door closed, are still necessary).

Disadvantages: May increase total air infiltration.

Cost: May vary according to type of furnace, accessibility to outside walls, and whether additional enclosure must be constructed.

Installations: Extensively used in Saskatchewan.

Effectiveness: Canada Mortgage and Housing Corporation is continuing research into conditions that induce furnace backdrafting.

Source: Readers are referred to the report "Hazardous Heating and Ventilating Conditions", prepared by Hatch Associates Ltd. for Canada Mortgage and Housing Corporation. (T.J. Robinson, 1984).

Solution: **2.5.2 Ensure adequate combustion air for furnaces**

Problem Addressed: Air demands for different furnace types in Canada vary considerably. Some types may require more air than is afforded by tight homes, or conventional homes with other exhaust devices operating simultaneously.

Combustion appliances generally require air both for combustion itself and for dilution. The barometric damper on oil furnaces, and draft hood on gas furnaces, are located downstream of the furnace heat exchanger and take no part in the combustion or the heat exchange process. However, the bypass or draft diverter flow forms the major air requirement of the furnace, up to 3 times the air required for combustion.

New gas-fired combustion systems, now available on the market, eliminate the dilution device and forcibly exhaust the combustion products. These devices have low air demand and are more suited to tight homes than conventional oil or gas furnaces.

Principles Employed: Fix a condition so that less pollution is produced; direct pollutants away from people.

Description of Solution: A.C.S. Hayden (1984) recommends that various steps be taken to ensure either reduced air requirements of the furnace, or increased air supply. (see Implementation, below.)

Application: At the same time as any attempt to tighten the building envelope of a home.

Implementation: Hayden (1984) makes the following recommendations to ensure adequate air supply to, and/or safe operation of, domestic combustion appliances:

1. Close up the fireplace. (Fireplaces have significantly higher air requirements compared to conventional furnaces, sometimes three times the average air change rate of a tight home.)
2. Replace the fireplace with a small airtight woodstove.
3. If 1 and 2 are impossible, supply outside air to the fireplace and use well-sealed glass doors to isolate the fireplace from the house.
4. Seriously consider the purchase of a high efficiency (ID fan or condensing) furnace, that has no dilution air requirement.
5. For conventional furnaces, to supply furnace air for warm air systems, connect from the outside to the cold air return, then have an opening in the warm air plenum to supply the furnace. The connection to the cold air return could have a damper, actuated by the thermostat, so that it is open only when the furnace is running.
6. An alternative is to release outside air in the room near the burner. This is particularly suitable for hot water heating systems.
7. Connect the burner directly to the outside (only on those appliances which have been approved for this type of installation). Never connect the dilution device directly to the outside.
8. Do not use unvented space heaters in tight housing.

2.5.2 Ensure adequate combustion air for furnaces (continued)

9. Be cautious in the use of convection ranges that exhaust to the outside. Consider an outside air source. This may be required in tight homes with gas heating systems.
10. Consider an outside air source for clothes dryers in tight housing.
11. Install a spillage switch on the draft hood of existing conventional gas furnaces.
12. Consider the use of carbon monoxide detectors in homes, similar to smoke detectors now in use.

Advantages: Insures against hazardous conditions which could lead to carbon monoxide poisoning and death.

Disadvantages: Some time and investment may be required to implement the solutions described.

Cost: No estimates made as yet.

Effectiveness: No studies have been reported, to this author, which quantify the effectiveness of the measures described.

Source: A.C.S. Hayden (1984)

Solution: **2.5.3 Chimney backdraft check & supplementary air supply**

Problem Addressed: In some homes, backdrafting, with resulting spillage of combustion products into the home, can take place under certain weather conditions and/or when other exhaust devices in the home are operating simultaneously. If backdrafting exists, cold air is being supplied which both dilutes the products of combustion and washes them away from the combustion appliance. During partial spillage, a cold air supply flow may be very small, or non-existent, possibly resulting in reingestion of combustion products and a very rapid rise in carbon monoxide production (see discussion p. 54).

If carbon monoxide concentrations are sufficiently high, the conditions could prove fatal to occupants of the home. Even if carbon monoxide does not reach hazardous levels, however, there is still the potential of serious health effects, particularly for chemically sensitive individuals.

Principles Employed: Direct the pollutants away from people; fix a condition so that less pollution is produced.

Description of Solution: A check procedure described below is followed by the homeowner, to determine whether backdrafting conditions are possible in the home. If the test is positive (i.e. backdrafting occurred), additional air intakes are provided (e.g. opening a basement window near the furnace) to prevent a backdraft failure condition. The procedure is presently under study; readers are invited to contact Canada Mortgage and Housing Corporation, Research Division, Ottawa K1A 0P7 to inquire about updates.

Application: This method can be applied in any home heated by a combustion-type furnace.

Implementation: P. Russell and T.J. Robinson (1984) describe the following procedure. It requires no special equipment and can be carried out by the average householder:

1. Check that the wind is below 10 kph and the temperature difference between the inside and outside falls within the prescribed ranges (between 5 and 20 Centigrade degrees for appliances with continuously operating pilot lights, and between 15 and 30 Centigrade degrees for appliances with electronic ignition.

2. Seal all air intakes, close all windows and exterior doors.

3. Turn down thermostats, including gas water heaters.

4. Turn on all exhaust fans (e.g. range hood, clothes dryer, bathroom fan, central vacuum, central exhaust fan, etc.)

5. Check for a draft in the furnace exhaust flue, above the hood or barometric damper, using a candle held next to a small hole in the flue. If there is a draft, the candle flame will be drawn towards the hole.

6. Light a fire in the fireplace.

2.5.3 Chimney backdraft check & supplementary air supply (continued)

7. Check for spillage of smoke in the fireplace.

8. Recheck the draft in the furnace flue.

9. Return house to original state. CAREFULLY CHECK THAT INTAKES ARE RE-OPENED.

If the draft of either the furnace or the fireplace was inadequate or reversed, additional fresh air is required to replace air drawn out by other exhaust devices and for combustion in the furnace. As a temporary measure, a basement window must be opened near the furnace, and adjusted to the point that the backdraft condition is no longer possible.

Materials List: Candle and lighter or match.

Advantages: No expense to determine whether a risk of backdraft exists.

Disadvantages: The procedure is not infallible, as it cannot properly simulate all weather conditions.

Cost: The procedure itself costs nothing. Providing ventilation may entail some cost, since opening a basement window is only a temporary measure. A qualified furnace installer can retrofit a proper air supply, to the latest installation codes.

Installations: S. Moffatt (1984) reports on the study which employed the above test procedure in 39 Canadian homes. Of the 39 homes, 16 failed the test (i.e. backdrafting occurred). A failure was registered when the furnace was unable to establish a draft in its chimney within three minutes of firing. Four houses failed solely on account of operating exhaust fans. One failed when, in addition to operation of the fans, the furnace fan was also running. Eleven failed when a fire was also lit in the fireplace.

Effectiveness: The studies have not extended yet to the point of evaluating the relative effectiveness of alternative solutions to the backdrafting problem.

Source:

P. Russell and T.J. Robinson (1984).
S. Moffatt (1984)
T.J. Robinson (1984)

Solution: 2.5.4 **Replace gas range with electric**

Problem Addressed: Emission of combustion products by a gas stove.

Principles Employed: Substitute low-pollution for high-pollution surroundings.

Description of Solution: The gas range in a home is removed and an electric range substituted. (Ventilation is installed above the electric range if it was not already present. Backdraft checks are performed to insure that acceptable exhaust of combustion products from the furnace (and possibly water heater) is maintained.)

Application: In any home in which there is either sufficient concern about risk, or where there is known risk to householders from the combustion products of a gas stove, and where ventilation alone is not considered to be sufficient protection. For example, persons who have become hypersensitive to various indoor chemical exposures, at low concentrations, are often advised by physicians to remove a gas range entirely.

Since overhead ventilation fans are not 100% effective, persons at particular risk to carbon monoxide or nitrogen dioxide exposure (e.g. those with heart disease or existing respiratory ailments, and pregnant women) might be advised to consider complete removal rather than increased ventilation of a gas stove.

A physician's advice should be sought as to the degree of risk, if any, that may be involved with gas stove exposure in any individual case.

Implementation: As described above. Ventilation for either a gas stove or electric stove may be informally tested by the householder by observing the path of visible clouds of water vapour above a pot of boiling water cooking on a stovetop burner. Often, vapours from pots on front burners will circulate first to the room, rather than to the vent opening. The vapour path can also be deflected away from the vent, as the householder moves back and forth in front of the stove. If a cooktop is enclosed at the sides and back, rather than open to the room, cooking gases can be more easily captured and removed by vents.

Caution: for persons who have become hypersensitive to various odours, it is advisable to install strong ventilation even above an electric stove. Even an electric stove may cause problems for such persons, and when either gas or electricity is used, cooking odours themselves can trigger adverse symptoms.

Materials List: One electric stove. One exhaust fan.

2.5.4 Replace gas range with electric (continued)

Advantages: Removal of all possibility of combustion products mixing with breathing air in the kitchen.

Disadvantages: Expense. Some people also favour the cooking characteristics of a gas range, over an electric one.

Cost: A new electric range can vary in price between several hundred and several thousand dollars, depending on the particular make and model.

Installations: T. Randolph (1962) cites case histories of people in the United States who have changed from gas to electric cooking for health reasons. To this author's knowledge, the number of people who have done so, in the last ten years, probably numbers in the many hundreds, in North America, most of whom did it at their physician's urging.

Effectiveness: Individual case reports, brought to this author's attention at conferences and cited in the references below, indicate that physicians and householders involved feel that the technique is highly beneficial for those who are specifically sensitive to the combustion products of gas stoves. No formal studies have been done on individual cases of removal, to this author's knowledge, which would help to quantify the effectiveness of the method.

Source: The reader is referred to the following references, for further information on the role of gas stoves in illness, and on levels of pollutants associated with gas stoves:

T.G. Randolph (1982)
J.R. Girman et al (1982)
G.W. Traynor et al (1981, 1982)
C.D. Hollowell et al (1976)
E.T. Brookman and A. Birenzvige (1980)
K.J. Stevenson et al (1979)
J.S.M. Boleij et al (1982)
R.J. Jaeger et al (1981)
K.J. Helsing et al (1982)
M.D. Keller et al (1979)
H.D. Kerr et al (1979)
T.D. Sterling and D. Kobayashi (1981)
R. Melia et al (1979,1980)

2.6 INFILTRATION OF EXTERIOR POLLUTANTS

Many literature reports have commented on the fact that indoor pollutant levels are typically higher than outdoor pollutant levels. Generally there is less available air flow, per unit of pollutant source flow, within a home, than there is outside. Pollutants outside get diluted more quickly than those inside.

In some cases, however, infiltration of exterior pollutants constitutes one of the major complaint areas reported by householders who perceive that some of their adverse health symptoms are triggered by pollutants. (see Section 2 following). This discussion will explore the circumstances under which infiltration of exterior pollutants can present a significant indoor air quality problem affecting health.

Two major classes of infiltration will be reviewed. The first involves infiltration of pollutants from the outside air. The second involves infiltration of gases from soil adjacent to, or beneath, a home. In the first type, three facts are important:

a. Pollutants may occasionally travel on outside air in a confined mass, diluting much less rapidly than many people commonly assume.

b. Some people react to low levels of many pollutants.

c. Some people have very specific pollutant sensitivities, so that even very minute levels of a particular pollutant may be the primary trigger of their symptoms.

An example of a pollutant which may not dilute rapidly enough to avoid causing problems is wood smoke. Many people will recognize the image of a home on a still morning, with fireplace smoke rising from the chimney, spilling downwards on one side of the home, and moving slowly away from the home in a visible cloud, often toward a neighbouring home.

They will also recognize the image of an automobile exhaust cloud on a cold winter day (made visible by moisture condensation). Many people will deliberately skirt around a dense exhaust cloud in the winter, but will walk unsuspectingly through the same cloud in the summertime. As with a cloud of wood smoke, an exhaust cloud may drift toward, and infiltrate into, a nearby home. Most people are familiar with the smell and taste of the occasional exhaust cloud that infiltrates into an idling car. The same happens with a home.

A considerable amount of dilution has already taken place, even in such confined clouds of pollutants. The levels may still be sufficient, however, to cause symptoms in many individuals who are more chemically susceptible than the general population. Pollutants which may not cause immediate symptoms, for example, low levels of carbon monoxide, may also present a risk to certain groups of people, such as pregnant women, the elderly, the very young, and others with heart disease or respiratory deficiencies.

Some of the pollutants which have been reported to cause problems, and which may represent a combination of mechanisms 'a' and 'b' above, include:

- o wood smoke;
- o other chimney exhaust (e.g. gas or oil furnace);
- o automobile exhaust; and/or
- o pesticide sprays.

Some householders may also be particularly sensitive to trace odours and particles that are very greatly diluted. Indoor concentrations may be significantly less than those outdoors, but the nature of their sensitivity is that almost any contact at all may precipitate problems. In such people the mechanism is sometimes allergy but, where trace chemical odours are involved, other physical processes, that are less well understood, may be responsible.

Typical examples of pollutants in this category include:

- o the smell of cut grass, or new mown hay;
- o tree, grass and weed pollens; and/or
- o mould spores.

This kind of problem may be aggravated by the introduction of allergens, through automatic air exchange devices, when inadequate filtration is installed. Some householders will keep their home tightly sealed during the heaviest morning pollination hours, during grass or ragweed season. Others will keep the house tightly sealed during the early hours of evening darkness, when mould spore populations, general moisture levels, and various plant smells may present a problem for them.

Very specific pollutants, from distant sources, have also been reported to present a problem for some householders, as they infiltrate from outside, even at trace levels. The survey in Section 2, following, for example, cites one householder who had difficulty with the smell of a pulp mill.

Others known to this author can readily recognize smells from various different urban centres, as the wind shifts from one direction to another. Not all of these exposures, however, are associated with symptoms, and often a householder becomes familiar with one particular wind direction that is perceived to cause more problems than others, even if odours from other directions are stronger.

Another major category of infiltration problems involves multiple family dwellings, in which indoor air from one unit may enter other units: under hall doorways; through cracks in the walls; or through inlet holes, which allow piping and wiring to enter each unit. (Plumbing, electrical wiring, and communications wiring often run through special shafts called 'chases' which may be vertically continuous the full height of a high-rise building, and subject to strong pressure gradients. In some buildings, cracks at the junction between walls and floors and ceilings allow considerable leakage. Depending on pressures within the building, air may also enter a room from the wall or ceiling cavity, through outlet boxes, around baseboard heaters, or through light fixtures.)

Infiltration from the hallway to an apartment can be caused by stack effects within a multi-storey building. In the winter, when there is a considerable difference between outside and inside temperatures, there is often a flow of air upward within a building, fed by infiltration from the outside at the lower floors, and discharged by exfiltration from the inside, at higher floors. Thus, air from apartments at lower levels may enter the hallway, travel upward in a building, and then enter upper level apartments via the hallway. Similarly, air from lower levels may rise through pipe and wire chases, and may enter upper level apartments through holes.

This author has also been advised by tenants that, in some buildings, exhaust ventilation systems designed to remove cooking odours sometimes allow spillage of air from one apartment to another, particularly during off-peak hours, when fan settings may have been reduced in order to save energy.

In a multiple family dwelling, the householder who reports problems is typically bothered by consumer products and activities that they have already discontinued in their own apartment, such as perfume use, tobacco smoking, use of volatile cleaners, deodorizers, paints, and pesticides.

A second class of pollutants, that of infiltration of soil gases, is known to introduce radioactive radon gas into homes. This risk does not appear to be widely known among homeowners, and is not associated, by any homeowners polled by this author, with any immediate adverse effects. Possible carcinogenic effects of radon and radon daughter products are discussed in Appendix A "Factors Affecting Vulnerability to Indoor Air Pollution", under 'The General Population".

There are also other constituents of soil gases, though there are few studies dealing with them in any detail. It is possible that moisture, low levels of a number of different gases, and possibly mould spores, viruses and bacteria, in addition to radon gas, may be entering homes through basement cracks, floor drains, and open holes such as for sump pumps.

A full technical discussion of the penetration of radon gas may be found on pp. 14-17 of Indoor Air Pollution and Housing Technology, and the reader is referred there for full references (B.M. Small (1983)).

The primary points of entry into the home for radon are:

- cracks between basement slab floors and basement walls
- air flow into the basement around loose-fitting pipes and drains
- other openings to the soil, e.g. sump holes

- cracks in basement walls and in mortar between concrete blocks in block walls
- from certain building materials, e.g. concrete and brick
- air circulating within weeping tiles connected to floor drains, and air circulating from storm sewers back through dry traps in floor drains
- from rock beds used for heat storage
- from tap water flow into sinks, baths, showers etc.

The flow of radon into the home may be enhanced by increased wind pressure, decreased barometric pressure, or negative pressure within the basement of a home due to exhausts (e.g. chimney or fan) or stack effects. Radon flux from soil is typically an order of magnitude greater than that from concrete building materials. There is a wide geographical variation in the amount of radon emission from soil and building materials. Since all areas may be subject to the infiltration of other soil gas pollutants, the prevention of soil gas flows is desirable in all buildings.

Solution: **Reduction of radon concentrations by ventilation**

Problem Addressed: Accumulation of radon and radon daughter products in poorly ventilated homes, through influx via soil gases or from building materials.

Principles Employed: Dilute a pollutant with clean air.

Description of Solution: N. Jonassen and J.P. McLaughlin (1982) state that simple ventilation, with radon-free or radon-poor air, is the most effective means of reducing radon and radon daughter levels within a home, though perhaps not the most economical, since there is an energy penalty.

Application: In areas where the air exchange rates required (see implementation below) do not entail excessive energy cost.

Implementation: For commonly encountered air-exchange rates, the radon concentration will be inversely proportional to the air exchange rate. Jonassen and McLaughlin state that, in practice, this means that it is possible, even in the case of a high influx of radon, to keep the radon concentration reasonably low, by using ventilation rates in the order of 0.5 to 2 ach. The air exchange must be arranged so that fresh air is drawn from above grade.

Materials List: Exhaust fan or other means to force air change.

Advantages: Reduces radon and radon daughter concentrations to reasonably low levels.

Disadvantages: Requires rates of ventilation in excess of those considered desirable for tight, energy-conserving homes. Note also that central exhaust leading to negative basement pressures may actually induce further ventilation with soil gases, and therefore increase radon influx. Care must be taken to ensure that fresh air enters above grade.

Cost: Depends on ventilation rate. Cost is primarily that of heating intake air.

Installations: None cited in the reference reviewed.

Effectiveness: Jonassen and McLaughlin state that, if the air in a room is replaced once each hour (1 ach), with air free of radon and radon daughters, the radon concentration is lowered to 0.75% of the unventilated value, and the daughter concentrations to even lower levels.

Source: N. Jonassen and J.P. McLaughlin (1982)

Solution: **2.6.2 Radon control by subslab ventilation**

Problem Addressed: Infiltration of radon gas with associated radioactive decay and health risk.

Principles Employed: Direct the pollutants away from people.

Description of Solution: Sachs and Hernandez (1984) suggest that active ventilation of the gravel or stone bed underlying the basement slab, and the soil or drainage bed around the perimeter of the foundation, can reduce radon concentrations more than 90%.

Application: Particularly helpful in homes where there are high radon concentrations, due to local soil or rock conditions. Sachs indicates that, in homes with unusually high radon concentrations and influx rates, it is not feasible to lower radon concentrations by general ventilation of the home, without incurring a huge and expensive energy penalty.

Implementation: A small centrigual fan is used to vent the subslab space, by attaching it to a sealed box over a sump, or other hole in the basement slab. The air drawn by the fan is exhausted to the outside through a dryer vent pipe.

Materials List: Small exhaust fan and lengths of ducting.

Advantages: Removes radon at the source.

Disadvantages: May not influence infiltration through wall cracks.

Cost: An exhaust fan may cost about $40, and the electricity to run it, about $50 per year at 5 cents/kwh. A new access hole through a concrete slab may cost $100 or more.

Installations: Sachs cites a number of installations in the reference described below.

Effectiveness: The cases cited by Sachs demonstrated a greater than 90% reduction in radon concentrations with this method.

Source: H.M. Sachs and T.L. Fernandez (1984)

Solution: 2.6.3 **Reduction of radon exposure through filtration**

Problem Addressed: Infiltration of radon gas primarily from soil or building material, and subsequent radioactive decay into radon daughter products.

Principles Employed: Remove pollutants from air.

Description of Solution: Several researchers have described experiments involving filtration (with mechanical, electrical and charcoal filters), and circulation, of air to effect removal of radon daughters from indoor air.

Advantages and Disadvantages
There appears to be some conflict, in the literature, as to whether, or when, filtration helps to reduce the bronchial dose of radioactivity. The reader is therefore referred to the source documents for further information.

Jonassen and McLaughlin (1982) indicate that filtration will change the radiological properties of the air, that is, the relative proportions of daughter products that are airborne, plated out on the walls, or trapped by filters. Their experiments show, however, that the changes depend strongly upon the aerosol condition of the air.

If the aerosol production rate is low, filtration will keep the aerosol concentration low and thus increase the fraction of the daughter products that are in the unattached state. This in turn will cause a high degree of plate out, and hence a lower equilibrium factor than can be explained by filtration alone.

Jonassen cautions that the effect of filtration on the dose delivered to the respiratory tract depends upon the dose model used. According to the model by Harley and Pasternak cited by Jonassen, filtration at low aerosol production rates, and high unattached fractions, will give rise to high dose levels, almost independently of the filtration rate. At higher aerosol production rates, the dose will decrease with increasing filtration rates.

Source:

J.P. McLaughlin and N. Jonassen (1980)
N. Jonassen (1981, 1982, and 1984)
N. Jonassen and J.P. McLaughlin (1982)
Hildingson, O. et al (1984)
J.C.H. Miles et al (1980)
Sandia National Labs (1982)
W.C. Hinds et al (1983)

Solution: **2.6.4 Move to a new location, to avoid outdoor pollutants**

Problem Addressed: Infiltration of exterior pollutants

(e.g.
- nitrogen oxides and carbon monoxide from ambient air
- pollution in a city
- infiltration of herbicide or pesticide spray in suburban or rural areas)

Principles Employed: Separate pollutants from persons, by moving one or the other

Description of Solution: Move household to a new home, in a location that does not suffer the same exterior air pollution.

Application: When exterior air pollutants are demonstrated to be a major factor in householder illness, and either:

a) sufficient reduction of exterior infiltration is not possible,

(e.g. either the householder is so sensitive, or exterior pollution so prevalent, that even if infiltration is reduced to a minimum by sealing, filtering, etc., it still contributes to illness); or

b) reduction of exterior infiltration does not sufficiently lower the householder's total exposure to those exterior pollutants, to decrease adverse health effects to a tolerable level

(e.g. householder is well while within the dwelling, but exposures while outside, going to work, etc. continue to cause intolerable health effects).

Implementation: Householders considering relocation to avoid exterior pollutants often do considerable research to determine potential areas that may have a more suitable environment. Visiting potential areas, and determining on site whether pollutant levels are sufficient to cause adverse health effects, is a must.

If householder sensitivity is sufficiently high to require relocation because of exterior pollution, it is also possible that the householder may react adversely to some common interior pollutants. Care should be taken in selecting or building a new home, to avoid high levels of interior pollution. Trading exterior pollution for interior pollution is not likely to be effective in reducing illness, unless the sensitivity of the householder is highly specific (e.g. certain types of pollen), and there is little or no sensitivity to interior factors.

2.6.4 Move to new location (continued)

Advantages: Reduced total pollutant load on householders affected may be sufficient to reduce adverse health effects, and in some cases to lower overall sensitivity to pollutants and other environmental factors.

Disadvantages: Some locations involve tradeoffs between problems. For example, moving out of an urban area may reduce smog exposure, but could also increase exposure to biological factors such as pollen and outdoor mould. Some rural areas may involve periodic spraying of fields and exposure from pesticide drift.

Relocation may require lifestyle changes (e.g. country vs. city living) or other major changes, such as type and location of employment and schooling.

Cost: Varies depending on location and types of dwellings.

Installations: This author is aware of several cases in Canada and the United States, his own family included, where medical treatment, reduction of indoor pollutants, and reduction of infiltration were not sufficient to reduce adverse health effects to tolerable levels.

Effectiveness: Relocation in an area of generally lower ambient air pollution, of the city smog type, appears to have been of significant benefit in some, but by no means all, such cases.

Source: The following organizations have had experience in advising people who are considering relocation to avoid exterior air pollution:

Human Ecology Foundation of Canada, #465 Highway 8, Dundas, Ont. L9H 4V9
Human Ecology Action League, P.O. Box 1369, Evanston, IL 60204-1369
Technology & Health Foundation, R.R.#1, Goodwood, Ont. L0C 1A0

2.7 CONSUMER PRODUCTS AND ACTIVITIES

Numerous reports in the scientific literature cite consumer products and activities as sources of indoor air pollution (see Indoor Air Pollution and Housing Technology, pp. 36, 58, 115, 126). These can produce a range of pollutant concentrations from those which are barely detectable by instrumentation (e.g. detergent odours and mild perfumes) to high local concentrations which may represent significant hazards if inhaled (e.g. solvents in hair spray).

The reader is referred to Indoor Air Pollution and Housing Technology for full references. This report will review various circumstances in which consumer products and activities give rise to pollutants which can produce adverse health effects in some people.

Household Cleaning Chemicals & Furniture Finishes

One common category of consumer product which can increase indoor pollutant levels is that of cleaning chemicals, detergents, deodorizers, and furniture finishes. Such compounds may give off chlorine compounds, ammonia, various organic solvents, alcohol, naphtha, formaldehyde and other compounds, all of which can cause adverse health effects in high concentrations, and all of which can trigger adverse health effects in sensitized individuals at low concentrations.

Typical examples include:

- laundry detergent with perfume added to give it a 'fresh scent'
- fabric softener with perfume added to make it 'smell like spring'
- laundry starches containing formaldehyde or pentachlorophenol
- cleaning agents with 'strong-acting' and/or strong-smelling ingredients such as chlorine, ammonia, or perfume
- furniture and floor oils and polishes with volatile solvents
- specialty cleaners for aluminum, copper, chrome or silver, containing volatile solvents
- room deodorizers, spray, wick or solid types, often containing naphthalene, paradichlorobenzene, paraformaldehyde, formaldehyde, alcohol, or 1,1,1 trichloroethane

Some of the more highly perfumed cleaners leave an odour in a room for a considerable time. Smells from laundry detergents and fabric softeners may pervade the home to the point that a person with a good nose can recognize the smell of another person's home on their clothes when they are away from home. This involves trace levels of perfume, but they are sufficiently strong to evoke adverse physical reactions in particularly sensitive individuals. Every fabric washed in perfumed detergent and tumbled in a dryer with a fabric softener tissue becomes, in turn, a source of the pollutant, presenting a considerable area for emission.

Pest and Weed Control Products

Pesticides of various kinds have been reported to be particularly troublesome for chemically susceptible persons. These may include:

- mildew proofing for carpets and fabrics, containing pentachlorophenol, aromatic hydrocarbon solvents, methylene chloride or formaldehyde
- moth crystals
- no pest strips
- sprays or powders for infestation of crawling insects, e.g. ants, cockroaches
- garden pesticide sprays
- houseplant insecticide sprays
- weed killer spray for lawn application

Recent reports also indicate that some classes of pesticides may combine with ambient levels of nitrogen dioxide in the home, to produce thin layers of potent carcinogenic compounds on various household surfaces.

Personal Care Products

Another common category is personal care products, which may include the following:

- perfumed hand soaps, bath potions and hair-cleaning products
- personal deodorants, after-shave and perfumes
- shoe polishes containing volatile solvents
- certain makeup preparations containing solvents, perfumes and fine powders

Personal Clothing

Many modern clothing items are major sources of indoor pollution, particularly when they are new. Special chemical treatments for appearance, anti-wrinkle properties, etc. may affect particularly sensitive persons, even when they are being worn by someone else. Modern leather treatments can be particularly offensive, and persons reporting problems also report being able to notice immediately, by smell, when someone with a new leather coat enters a room.

Dry-cleaning is a source of various organic pollutants such as tetrachloroethylene, which can be detected in lung measurements on people who are exposed to it.

Tobacco-Smoking

Tobacco smoking has been documented extensively as a major indoor air pollutant. The reader is referred to p. 36 of Indoor Air Pollution and Housing Technology for full references. About 1200 different compounds have been identified in tobacco smoke, including potent carcinogens, heavy metals, and various irritating and sensitizing chemicals.

The households responding to the survey discussed in Section 2 of this report do not report tobacco smoking as a problem, except by infiltration from other apartments in multiple unit dwellings. This may represent the fact that those approached represent an unusually sensitive population who have responded to their illness by ensuring that no smoking is allowed in the home under any circumstances.

A more typical situation is one in which there are one or more smokers in a home. This situation can create problems both for the smoker and for others in the home who may be particularly sensitive to tobacco smoke, or to the adverse effects of elevated carbon monoxide concentrations.

Three types of situations may be described:

a. direct contact in the same room: As with the drifting of of wood smoke or automobile exhaust outside, a person may have contact with concentrated sidestream smoke if he or she is close to, or 'downstream' from, a smoker in the same room, and receives the smoke before it has a chance to substantially dilute with room air.

b. circulation from other rooms: Occupants may have more indirect exposure to tobacco smoke after it has been diluted with room air in one room, and circulated through a central heating or cooling system to other rooms. The smoke is more dilute than in the case above, but still may be sufficiently strong to affect persons who are allergically sensitive.

c. residues from previous smoking: Some persons are sufficiently sensitive that residues and odours of tobacco smoke on carpets, furnishings or clothing may trigger adverse reactions. Many people will recognize this phenomenon as the smell that lingers in a home for several days after a party in which more than the usual number of household smokers were present.

Hobby or Home Business Activities

Many hobby activities or home business activities will give rise to indoor air pollution problems. These may include:

- woodworking or metalworking;
- ceramics, pottery;
- furniture refinishing;
- painting;
- drawing or other artwork involving spray finishes;
- electronics involving soldering;
- mechanical work involving grease and oil;
- photographic work involving developing chemicals;
- indoor gardening involving pesticides, moulds, etc.;
- writing, involving electric typewriters or word processors;
- sewing involving new fabrics and finishes;
- modelling, with volatile glues and paints;
- various child playing activities, including use of volatile marker pens; and
- computer work.

The list is virtually endless, because of the wide variety of activities that may take place in the home. Often little or no ventilation may be provided for activities that involve highly volatile products.

Sometimes the activity will take place in other buildings or outside, but the pollutant will be brought into the home on hands or clothes. Examples include: smells; mould and dust from farm work; fuel, grease and oil from automotive or tractor repair; animal dander, dusts and moulds from small farming operations; pesticides from gardening; auto exhaust odours from driving; smoke odours from attending events with high concentrations of tobacco smoke; or from outdoor camping; etc.

Pets

Pets in the home are common causes of allergic problems, and their dander, feathers, hair, and associated products, such as anti-flea preparations, kitty litter, and the like, may properly be termed as indoor pollutants.

Some people become sensitive only to the point that close contact with a pet may bring about symptoms. Others are sufficiently sensitive that merely stepping into a house with pets may trigger immediate and severe health effects. A house that has previously harboured cats or dogs may require a period of months of regular cleaning before residual hairs and dander are reduced to levels low enough to be acceptable to persons with severe allergies.

Solution: **2.7.1 Maintenance with Low-Emission Products**

Problem Addressed: Accumulation of low-level odours and other pollutants, from cleaning and other household products (e.g. scented waxes, perfumed detergents, deodorizers, volatile cleaning agents, etc.)

Principles Employed: Substitute low-pollution for high-pollution surroundings.

Description of Solution: The householder may choose cleaning and other household maintenance products that do not add odours or unnecessary chemicals to the home, e.g. do not contain perfumes or other fragrances, or volatile solvents.

Application: This method is particularly important for those people who have become highly sensitive to a wide variety of low-level chemical exposures. The importance to larger risk groups (e.g. pregnant women, young children, elderly people, etc.) has not been scientifically demonstrated, nor has the degree of risk been demonstrated with respect to the general population.

Persons wishing to generally lower indoor pollutant levels, for example in energy-efficient homes, may consider avoiding what could be called 'unnecessary' additional chemicals, such as deodorizers and perfume-added cleaners, in favour of less-perfumed alternative products and cleaning methods which remove conditions that otherwise cause undesirable odours (e.g. clean the garbage bin rather than spraying it with deodorizer).

Raab (1983) cautions that some products also contain odour modifiers which alter perception of unpleasant odours from product constituents. Some dangerous household chemicals do not have strong odours (e.g. methylene chloride). Householders are advised to read labels carefully.

Implementation: To this author's knowledge, no lists of less-perfumed products have been generated. The consumer can be aware of package labelling, and can also use his or her own sense of smell as a guide. Many householders with a chemical susceptibility problem have found that 'old-fashioned' alternative cleaners, such as baking soda, have numerous applications in the home, and do not cause symptoms for the sensitive. Raab (1983) also suggests that warm water and soap, or just water, can successfully accomplish many cleaning tasks.

Materials List: See 'Implementation' above.

Advantages: Lower overall pollutant levels. Less potential for interaction among pollutants.

2.7.1 Maintenance with Low-Emission Products (continued)

Disadvantages: Less perfumed products do not cover up other odours in the home, and the householder may feel more obligation to address these at the source.

Cost: Often less-perfumed cleaners and reduced use of deodorizers, etc., represent a cost savings to the householder.

Installations: There have been no studies, to this author's knowledge, of the use of this method of reducing indoor pollution levels. The author is aware of a number of individuals in Canada, however, who have employed this technique, on the advice of their physician.

Effectiveness: There have been no formal studies, to this author's knowledge, to confirm the effectiveness of this method in reducing illness. Numerous case reports have been presented at conferences, and privately to this author, which claim that a number of people have benefitted from the method.

Source: A review of the role of low-level pollutant sources, in building illness, is included in the report "Chemical Susceptibility and Urea-Formaldehyde Foam Insulation" by this author. Inquire: Small and Associates, Publishers, R.R.#1, Goodwood, Ontario L0C 1A0.

Source references for this topic include:

W.J. Rea et al (1978)
A.V. Zamm (1980)
K. Raab (1983)

Solution: **2.7.2 Reduction or Elimination of Smoking**

Problem Addressed: Tobacco smoke is a major source of pollutants in residences, and it has well-documented adverse health effects on both smokers and non-smokers.

Principles Employed: Fix a condition so that less pollution is produced.

Description of Solution: Stop smoking altogether, reduce smoking, or stop smoking indoors.

Application: Can reduce pollutant levels in any home where tobacco smoking is presently practiced.

Implementation: Declare the home a smoke-free zone.

Materials List: A discreet 'No Smoking' sign as a reminder.

Advantages: Eliminates pollutants at the source. Extends life expectancy, and/or reduces risk of early morbidity and mortality, of all the occupants of a home.

Disadvantages: Quitting is often difficult for the smoker.

Cost: Elimination of smoking within the home can represent a significant cost savings for the householder and for society, in terms of savings on smoking materials, reduced cleaning costs, reduced medical costs, and reduction in time and productivity lost due to illness.

Installations: Various studies listed below address the extent of pollution in homes where tobacco smoking is practiced, versus that in non-smoking homes.

Effectiveness: The same reference list demonstrates, by comparison, the effectiveness of eliminating smoking in the home.

Source: The following references may be of assistance to the reader in assessing the value of this technique:

F.J. Offerman et al (1982)
G. Holzer et al (1976)
J.L. Repace (1981, 1982 and 1983)
J.L. Repace and A.H. Lowrey (1980 and 1982)
B.M. Small (1983)
J.D. Spengler and K. Sexton (1983)
K.D. Brunnemann and D. Hoffmann (1978)
D.T. Wigle (1982)
K.J. Helsing (1982)
M.D. Lebowitz et al (1982)
P. E. McNall (1975)
J.R. White and H.F. Froeb (1980)
National Research Council (U.S.) (1982)
G. Stehlik et al (1982)
W.S. Cain and B.P. Leaderer (1982)
T.D. Sterling et al (1982)

Solution: **2.7.3 Vented or separated storage of chemical products**

Problem Addressed: Low level leakage of emissions from various consumer chemical products over time.

Principles Employed: Direct the pollutants away from people; separate pollutants from persons.

Description of Solution: Raab (1983) suggests storage of household chemicals in a special enclosed area, separate from the living space if possible, and preferably ventilated.

Application: All households might benefit from secure (locked) ventilated storage of chemical products. In addition to the reduction of risk from pollutant emissions, such action would reduce the risk of accidental poisonings.

Implementation: There are various options, the most desirable being a locked cupboard in a separate building, such as an unattached garage or garden tool storage cupboard. Existing closets can be adapted for such storage, particularly if there is a means of adding continuous ventilation.

Raab (1983) suggests that the existence of the special storage facility might raise householder awareness of possible hazard, and by adding a factor of inconvenience, coincidentally reduce the level of use of volatile consumer products.

Materials List: Depends on type of installation.

Advantages: Removes pollutants at the source.

Disadvantages: Storage exterior to the home may not be suitable for products requiring special conditions (e.g. should not be frozen). Unvented cupboards may accumulate pollutants to dangerous concentrations and may present a hazard to a householder when opened.

Cost: Depends on the installation. Where garage storage is already available, the cost is zero or minimal.

Installations: Silver (1978) cites a number of cases in which those consumer products, that could cause an indoor pollution problem in a home, were assembled in one spot, for subsequent removal or external storage.

Effectiveness: No studies were found, by this author, which quantify the effectiveness of this method.

2.7.3 Vented or separated storage of chemical products (continued)

Source: Readers are referred to the following references for further discussion of the problems and techniques described above:

K. Raab (1983 and 1984)
B.M. Small (1983)
F. Silver (1978)

Solution: **2.7.4 Ventilation and isolation of hobby activities**

Problem Addressed: Raab (1983) estimates that one in four Canadians may be exposed to hazards as a result of hobbies, or work in the field of arts and crafts.

Principles Employed: Separate pollutants from persons; direct the pollutants away from people.

Description of Solution: Assign one room in the home for use as a special studio for hobby or craft activity, and make modifications to ensure adequate ventilation and isolation of the air in that room from the remainder of the home, during hobby activities.

Application: In any household where hobby activities involve chemical hazards.

Implementation: Provide adequate ventilation, by installing an exhaust fan or a window fan, and appropriate intake air opening (e.g. by another window). Close off any return air duct that would circulate air from this room into the rest of the home. Protect supply and return ducts from collecting any solid materials from the hobby activity, particularly in the summer when the furnace fan may not be operating. Settled particles could later be blown throughout the home.

For particularly toxic materials or activities, a special vent hood should be constructed, to remove all pollutants immediately above the working area, and exhaust them outside, to a location that will be sufficiently dispersed to reduce hazards to others.

Store any volatile materials in special vented cupboards within the hobby room, or if the room is also used for other purposes, in a remote storage area.

Materials List: Window fan or exhaust fan. Return air ducts may be closed off temporarily with aluminum foil or cardboard, and masking tape.

Advantages: Eliminate pollutants close to the source.

Disadvantages: Cost, time and effort.

Cost: A large window fan may cost about $35. Additional construction will vary depending on the particular installation.

Installations: None cited in reference reviewed.

2.7.4 Ventilation and isolation of hobby activities (continued)

Effectiveness: No studies have reached this author's attention, which would quantify the health benefit from these techniques.

Source: Readers are referred to the following report for further discussion of the techniques described above:

K. Raab (1983)
Lung Association, undated
M. McCann (1979)
Canada Safety Council (1983)
Centre for Occupational Hazards (1983)

Solution: **2.7.5 Strong ventilation during renovation activities**

Problem Addressed: Dust and odours from old and new building materials during renovation projects within the home.

Principles Employed: Direct the pollutants away from people.

Description of Solution: Raab (1983) recommends special ventilation during any renovation project, at a rate of at least 10 air changes per hour in the renovation area. An electric window fan, and an air inlet of a similar size, are recommended.

Application: During any renovation project in any home, but particularly in those homes where known risk factors for illness from pollutants are present. Activities involving stripping, sanding or painting, or breaking apart plaster or drywall, can produce considerable amounts of gaseous and particulate pollution.

Implementation: Raab recommends creating a draft through the renovation area, with a window fan exhausting air on one side, while an equivalent air intake area on the other side introduces fresh air. A vacuum cleaner can also be run continuously during sanding and other operations producing high levels of particulates.

Materials List: Electric fan. Vacuum cleaner.

Advantages: Removal of pollutants at the source, before they spread.

Disadvantages: No major disadvantage other than time and effort.

Cost: Most households already have access to the materials listed.

Installations: Central roof exhaust fans, window ventilation, and a central vacuum system have been used extensively during construction of the Sunnyhill Research Centre, an experimental low-pollution building in Goodwood, Ontario.

Effectiveness: No studies have been done, to this author's knowledge, to quantify the benefits of ventilation, nor the ventilation requirements for specific renovation tasks. Personal reports, to this author, have indicated that ventilation seems to help some people.

Source: K. Raab (1983)

Solution: 2.7.6 **Reduce or eliminate pesticide use within the home**

Problem Addressed: Exposures to certain pesticides, even at low concentrations, can trigger illness in some people, and represents an unknown level of risk in others. Recent evidence indicates that many people harbour measurable concentrations of pesticide in their blood (J. Laseter, 1984).

Principles Employed: Substitute low-pollution for high-pollution surroundings.

Description of Solution: Remove all pesticide containers from the living space of the home. Discard or store safely (see section on ventilated storage of consumer products). Raab (1983) suggests that that householder should identify pests of concern and restrict their access to food. The householder may consult the literature on alternatives to chemical pesticides, and experiment with such methods (see 'Source' below).

Application: In homes where householders have known risk factors regarding indoor chemical exposures, (e.g. an existing hypersensitivity to pesticides and other trace contaminants) and in other homes, where consumers may wish to reduce (unknown) levels of risk, associated with the use of pesticides indoors.

Implementation: Detailed alternative pest control methods are described in other references. Integrated pest management methods (involving control of conditions giving rise to pests, as well as elimination of pests that do arise) should also be investigated by the homeowner, to determine methods that are suitable to the particular local environment.

Materials List: Depends on alternative methods chosen.

Advantages: Reduction of pollutants at the source. Integrated pest management methods including hygienic kitchen practices may represent significant cost savings over periodic pesticiding.

Disadvantages: May require more time and effort.

Cost: Varies with different methods. Integrated management could represent a cost savings.

2.7.6 Reduce or eliminate pesticide use within the home (cont.)

Effectiveness: No studies have been performed, to this author's knowledge, which would quantify possible benefits of reduced pesticide exposure from household sources.

Source: Readers are referred to K. Raab (1983) for further discussion of the techniques described above, and to J.C. Reinert (1984) for further information on pesticides in the indoor environment.

2.8 Plumbing Systems and Tap Water

Plumbing systems can represent a source of pollution when there is leakage of gas from sewer lines or septic tanks. This can occur under various conditions:

- corroded vents and stacks (more common in older buildings);
- improperly sealed cleanout covers;
- open traps in floor drains, due to evaporation or lack of trap seal primer lines; and
- open traps on upper floors, due to unusual atmospheric pressure changes (e.g. storms), bad plumbing design, or clogged vents.

Buildings, under negative pressure due to exhaust fans or combustion devices, or areas within buildings under negative pressure due to stack effects, may be more prone than others to infiltration of sewer gases, through small leaks in piping or at cleanouts.

Sewer gases may contain methane and many other components that could, in sufficient concentrations, adversely affect health for the general population, as well as for the sensitive. Local plumbing codes are designed to protect people from sewer gases, but cases have appeared in which vents and stacks, in older houses, have corroded and become unsafe.

The other major area of complaint, and/or potential hazard involving plumbing, has been the introduction of gases and microbiological agents into the indoor environment, from tap water. These may include sulphur compounds, from natural constituents in well water in certain areas, chlorine and other compounds in treated water supplies, and compounds introduced for local water treatment, such as softening or iron removal. Legionella bacteria have also been reported growing in the hot water systems in some hospitals and hotels, especially in shower heads, and this could conceivably be present in some homes as well (I. Kallings et al, 1984).

To date, the personal reports this author has received have all been from persons known to be chemically sensitive, who perceive that certain symptoms may be related to exposures to the tap water, for example, while showering or bathing. The considerable surface area of the human skin makes it possible that dilute chemical exposures over a large area can represent a significant total dosage. (It is well known that some people may also be sensitive to various treatment, or other, chemicals in water, when ingested.)

Tap water, particularly that derived from wells, has also been investigated as a possible source of radon emissions into indoor air. (B.M. Small, 1983, pp. 14-17)

Solution: **2.8.1 Plumbing inspection and upgrading**

Problem Addressed: Leakage of sewer gases into the home through corroded stack vents, open traps, badly sealed cleanout covers, etc. in the plumbing waste system.

Principles Employed: Seal the pollutants from the people.

Description of Solution: Periodic inspection of a home plumbing waste system, to determine whether there are sewer gas leaks.

Application: Regular inspection by the homeowner could eliminate most problems before they become serious. Such inspection should definitely be performed whenever it is suspected that illness could be related to the home environment.

Implementation: Consult the local plumbing inspector, for advice as to methods and technology available. Homeowners have also been able to identify problems by visual inspection, by smell, and by detecting slight changes of temperature on a moistened finger held next to the plumbing joint suspected of leaking. Sheets or strips of single-ply tissue are also excellent draft sensors.

Installation of trap seal primers (small water lines which automatically supply small amounts of water to basement drain traps) can prevent evaporation of trap seal water. Inspection and manual filling of open traps, on a regular basis, will also avoid gas leakage through traps.

Installations: To date, this author is only aware of one case in which leaky stack vent plumbing played a role in building illness. In this case, corrosion of copper stack vents had occurred in an attic area, and the extent of damage was immediately visible. Close inspection revealed pipe walls that crumbled when pressed. Other cases have been reported, however, in which sewer gases, properly vented through the main stack, were reentering the home from the outside, through a window, under certain weather conditions. Rerouting the stack to a better location could be a solution, if it is acceptable under local plumbing regulations.

Effectiveness: No studies have been done, to this author's knowledge, to quantify the health benefits of repairing leaking waste plumbing. Personal reports, to this author, in the case cited above, indicated that taking action improved the health problem.

3. GENERAL PRINCIPLES OF LOW-POLLUTION DESIGN

This report, and the August 1983 report, "Indoor Air Pollution and Housing Technology" (B.M. Small, 1983), reviewed a number of solutions for addressing or preventing specific indoor air quality problems. These solutions can be categorized into a small number of different types, each representing some basic principle for avoiding indoor air pollution:

A. Fix a condition so that less pollution is produced

e.g.:
- o fix exterior drainage, to avoid mould inside
- o unplug blocked chimney & install chimney liner

B. Separating pollutants from persons, by moving one or the other

e.g.:
- o remove hazardous materials
- o move to a different home

C. Substitute low-pollution for high-pollution surroundings

e.g.:
- o change type of heating system
- o use less polluting furnishings

D. Direct the pollutants away from people

e.g.:
- o vent a gas stove to the exterior

E. Remove pollutants from air

e.g.:
- o use an air filter to clean the air

F. Seal off or treat sources, to reduce pollutant output

e.g.:
- o use a sealant on particleboard
- o caulk or tape cracks in the building envelope

G. Seal off people from the pollutant source

e.g.:
- o isolate sensitive people in a 'clean room'
- o protect sensitive individuals with a gas mask

H. Dilute a pollutant with clean air

e.g.:
- o increase fresh air ventilation

The following is a quick checklist of questions using the above principles:

- **CAN YOU FIX OR TREAT THE SOURCE OF POLLUTION?**
- **CAN YOU MOVE IT AWAY?**
- **CAN YOU MOVE THE PEOPLE AWAY?**
- **CAN YOU FIND SOMETHING THAT POLLUTES LESS?**
- **CAN YOU VENT IT?**
- **CAN YOU CLEAN UP AFTER IT?**
- **CAN YOU SEAL IT OFF FROM PEOPLE?**
- **CAN YOU ISOLATE PEOPLE FROM IT?**
- **CAN YOU DILUTE IT?**

4. THE DESIGN POPULATION

Proper design, of any kind of building, includes consideration of the 'design population', that is, the people who will use the building. Their characteristics will determine the kinds of features that are needed.

Each factor in the design of a home is affected by the nature of the design population. For example, the number of stairs and the level of lighting, in a home for the elderly, may differ from that in a single family dwelling. A kitchen, for a single person in a small apartment, may be different than one for a large family. Bathroom size and facilities, for a person who uses a wheelchair, will be different than for a person without a physical handicap.

Whenever there may be a wide variation in the characteristics of the persons using a dwelling, the design has to accommodate these variations, or allow special adaptations to address them. Handrails on stairs, for example, must be useful for both children and adults, and especially for the elderly. An entire discipline, ergonomics, has grown up around designing things to suit the needs and characteristics of the users.

Indoor air quality is one performance measure among the many that can be used to assess residential design. How clean must air be? It must be clean enough to satisfy the needs of the user. While some residential dwellings are specialized to particular users (e.g. homes for the elderly), most residences are not. Can new homes be designed in such a way as to accommodate the full range of vulnerability to pollutants?

Appendix A of this report describes a number of factors that make some people more vulnerable than others to indoor pollutants. It is interesting to note that some of the factors described affect all of us, at some point of our lives (e.g. being very young, very old, having a viral illness, etc.). A number of other factors do not affect everyone, but do touch a large number of people for some part of their lives (e.g. pregnancy, respiratory illness, heart ailments and allergy). Still other factors, such as genetic conditions, may affect just a small number of people (e.g. serum anti-trypsin deficiency).

The information presented in Appendix A indicates that those in our society who may be more vulnerable to pollutants do not form a small, easily identifiable and fixed group of 'hypersusceptible' individuals, as is commonly thought. Rather, the many factors affecting vulnerability vary over time, and may affect people in almost any walk of life. It makes it more likely that many houses, rather than few, will play host, at some time, to family members or visitors who have greater susceptibility than most to pollutants.

It was suggested, during discussion at the 3rd International Conference on Indoor Air Quality and Climate in Stockholm, Sweden, in August 1984, that while separate, specialized housing for hypersensitive individuals may be required in some cases, it would be more desirable, from a social standpoint, if housing for the general public could accommodate a wide range of vulnerability to pollution.

This underscores the need to generate design and construction methods which can ensure, at reasonable cost, a clean enough indoor atmosphere to accommodate the many different people that any one dwelling may house. This would also provide a safety factor, for the entire population, against long-term effects of pollutant exposures, which are not now well understood.

APPENDIX A: FACTORS AFFECTING VULNERABILITY TO INDOOR AIR POLLUTION

TABLE OF CONTENTS

INTRODUCTION

It will likely be many years, even decades, before the scientific and medical communities can fully quantify the extent of risk from exposure to common indoor pollution levels. It is clear, at this time however, that some people experience discomfort or illness in environments that have no immediate effect on many others.

In most cases, long term effects of low level exposures are presently unknown and difficult to study. As in the past, we can expect that, over time, some substances will be found to be less dangerous than presently assumed, and others will be found to be more hazardous. The key characteristic of our present situation is the large number of unknowns.

In the face of unknowns, we must ask whether there are ways to reduce potential risks at a reasonable price. Where design and construction methods allow us to build houses, economically, that do not expose occupants to indoor air pollutants, we can avoid uncertainty at little cost. This is more likely to be possible in new housing, since alternative materials can be chosen without abandoning the investment in a previous choice, as is the case with existing houses.

When alternative methods, designed to achieve low indoor air pollution, involve extra investment, we are faced with a difficult choice. Do the unknown risks justify the costs? In such cases, we must rely on a combination of existing evidence and personal choice. Some householders may wish to pay a premium to avoid pollutants which may, or may not, turn out to be harmful. When people with good health and high tolerance for pollutants are the only persons in the environment, the costs may appear less justified than when higher-risk individuals are involved.

This Appendix documents some of the existing literature on the relative vulnerability of different population groups. It describes some of the factors that scientists feel may make one person more sensitive than the next to indoor chemical exposures.

The following sections have been included in this report to give the designer and researcher some understanding of the differences within the Canadian population. The information may also provide a rationale for continuing their efforts to find economical means of reducing, or avoiding, indoor air pollution in Canadian homes.

1. DIFFERENCES IN VULNERABILITY

W.C. Cooper (1973) stressed that it is accepted, in occupational medicine, that individuals differ widely in their vulnerability to toxic agents and other environmental stresses. Some individuals show effects at concentrations which do not affect the majority while, at the other end of the spectrum, there are individuals who appear unusually resistant. Also, those showing sensitivity to low concentrations do not necessarily exhibit the same signs that are characteristic of toxic-level exposures.

High-risk populations include the people who may be the first to experience morbidity and mortality, if pollutant levels in society increase. Sometimes their reactions to the environment can signal potential longer-term problems for the rest of the population.

E.J. Calabrese (1978a and 1978b) emphasizes that it is an illusion to assume that a threshold for chemical exposure exists in the highly diverse human population. That is, it is difficult to determine any chemical dose below which either no person, or only a few persons, may react adversely. He notes that it also cannot be assumed that separate threshold levels exist for so-called normal people and for high-risk groups. Within each high risk group there are multiple variations, and ultimately each individual has a unique threshold.

Various researchers have identified groups of people who are at more risk from exposure to various pollutants (Calabrese (1978), Plumlee et al (1979), Wright et al (1979), Utidjian (1979)). The composite listing below summarizes the populations described in the literature:

- the developing fetus;
- pregnant women;
- the very young;
- the very old;
- smokers;
- people with allergies, or acquired immunologic sensitivity;
- people with existing respiratory disease;
- people with existing cardiovascular disease;
- people with other specific diseases;
- people with certain nutritional deficiencies;
- people taking certain drugs, or consuming large amounts of alcohol;
- people with certain genetic variations or abnormalities; and
- people who are especially exposed to high levels of chemicals.

For any population exposed to pollutants, it is more likely that victims, if there are any, will come from high-risk groups. But it is, at the same time, true that some people with no known risk characteristics may also be affected (B.M. Small, 1982).

The following subsections will discuss each category in more detail. The reader should be cautioned that the scientific literature is only beginning to address the response of many of these groups to pollutants.

2. THE PREGNANT WOMAN AND THE DEVELOPING FETUS

Calabrese (1978a) states that pregnant women may be more vulnerable, than the general population, to a number of different pollutants:

- Their increased dietary requirement for calcium and iron, if not fully satisfied, can increase risk from exposure to cadmium and lead, both found in tobacco smoke;

- During pregnancy, there is an excessive endogenous production of carbon monoxide, making a pregnant female more susceptible to the effects of inhaled carbon monoxide (significant concentrations of carbon monoxide have been found in kitchens during the operation of gas cooking appliances, and in rooms with kerosene heaters); and

- Hormonal alterations may predispose pregnant women to higher risk from exposure to organophosphate insecticides.

J. Rice (1979) notes that there is accumulating evidence which indicates that the pregnant female is at higher risk to at least some carcinogens, than are nonpregnant adults of comparable age.

Toxicological studies, of foreign substances which pass through the placenta, have shown that there are distinct physiological differences between the developing fetus and adults in animal studies, with regard to the capacity of the liver to metabolize foreign substances. One theory for this is that metabolizing enzymes are absent, or have negligible activity. The ability to metabolize foreign compounds increases postnatally.

Limited research, relating to the rate of metabolism of various compounds by the human fetal liver, support the animal studies. Calabrese cites studies which estimated that the metabolism of different compounds, in the fetal liver, was about 35 to 40% of that of an adult's liver. He concludes that fetuses may be more vulnerable to the toxic effects of these more slowly metabolized compounds than adults. He notes that, if a compound passing the placenta is a carcinogen, the reduced capacity to metabolize such a compound becomes a potentially serious problem.

Rice (1979) concludes, on the basis of a number of studies, that the fetus, the infant, and the pregnant female are all individuals in transitory states of heightened risk of carcinogenesis. He notes that transplacental and early postnatal exposures, to many different kinds of carcinogenic substances, have been shown, in rodents, to result in more severe carcinogenic effects than are elicited in adults by comparable treatment. In rodents, at the time of maximal risk, certain organ systems may be as much as two decimal orders of magnitude more vulnerable in the fetus than in the adult.

Studies of nonhuman primates have also confirmed that, in these animals, the fetus is quantitatively at greater risk from nonhormonal, direct-acting carcinogens than adults. Experience with diethylstilbestrol exposure in humans confirms the significance of prenatal exposure to carcinogens for humans.

Fetuses and newborns up to two or three months of age also lack full development of certain enzyme detoxification systems which, in adults, would aid in excreting toxic compounds such as PCB's (Calabrese, (1978a)). Gluconuric acid conjugation is an important system for detoxification and excretion of phenoliclike compounds. This system is deficient in fetuses and neonates, as it is in cats, which are known to be hypersusceptible to phenoliclike compounds. It is strongly suspected that fetuses and neonates are also predisposed to the toxic effects of phenolic compounds. Residential exposure to phenolic compounds may arise from tobacco smoke, building materials, plastics, and various other products incorporating phenolic resins (Small, (1983)).

Calabrese (1978a) also cites a number of studies indicating that children are at considerably greater risk from the effects of radiation than adults, and that fetuses are at even higher risk. This may have particular significance in the consideration of radon gas exposure in residences. He also cites the following list of substances which have shown teratogenic effects (can induce defects in the developing fetus):

- aluminum
- benzene
- cadmium
- carbaryl
- carbon tetrachloride
- chromium compounds
- copper
- 4-dimethylaminoazobenzene
- 2,3-dinitrophenol
- fluorine
- formaldehyde
- lead
- malathion
- mercury
- nickel
- nitrogen oxides
- paraquat
- parathion
- polychlorinated biphenyls
- selenium

Of these, the compounds that have been reported to be present in the residential indoor environment (usually in low concentrations) are (Small, (1983):

o aluminum	(some aerosol sprays)
o benzene	(building materials, maintenance products, tobacco smoke, paint and varnish, putty, fillers, stains & finishes)
o cadmium	(cigarette smoke)
o chromium compounds	(aerosol pigments)
o fluorine	(cigarette smoke)
o formaldehyde	(building materials, cigarette smoke)
o lead	(cigarette smoke)
o malathion	(pesticides)
o mercury	(certain house paints)
o nitrogen oxides	(gas stoves, kerosene heaters)
o polychlorinated biphenyls	(pre-1970's fluorescent light ballasts and some other household products)

3. INFANTS

L.A. Plumlee (1979) notes that neonates, up to the age of about two or three months, have immature enzyme detoxification systems, and that infants and children don't reach mature levels of immunoglobulin A until they reach the ages of 10 and 12. He also cautions that infants may be at greater risk, because of increased absorption of pollutants, as a function of their age.

J. Rice (1979) cites several studies on newborn animals, which indicate that early postnatal life should be considered as a period of generally enhanced susceptibility.

E.J. Calabrese (1978, p. 30) reviews a number of studies on the rate of absorption of heavy metals as a function of age. These indicate that absorption rates are significantly higher in the very young, as compared with any other age group. His review of radiation studies also indicates that lower doses of ionizing radiation are required to double the incidence of cancer in children, compared to adults. There is also some evidence of considerable variation in vulnerability to radiation among children.

4. THE ELDERLY

It is a generally accepted fact that vulnerability to many factors increases with age. Statistics Canada (1981, p. 109) reports that the frequency of health problems shows a definite relationship to increasing age. While overall, 54% of the population surveyed reported at least one health problem, some 85% of the population over 65 years of age reported at least one problem. In this age category, the average number of problems reported, among those reporting problems, was three, compared to two per person reporting problems among the 15-64 age group. There were just over 2 million people age 65 and over in Canada in 1978/79, when the Health Survey was conducted.

Calabrese (1978b) states that cell-mediated immunity decreases with age, and that the elderly may be at higher risk than younger people, from exposure to environmental carcinogens:

> "At all ages, the thymus is necessary for the normal differentiation and maturation of thymus-derived (T) cells. Cell-mediated immunity, in turn, requires T cells. After birth, the size of the thymus decreases with increasing age. Cell-mediated immunity also decreases with age. Many investigators think that these events are causally related to the increased incidence of infections, autoimmune disease, and cancer that accompanies aging. Since certain environmental carcinogens, such as a variety of hydrocarbons, depress humoral and cell-mediated immune reactivity, the aged are subject to an even greater likelihood of environmental cancers."

Calabrese (1978b) also noted an increased susceptibility of the elderly to the effects of respiratory irritants, such as sulfur dioxide. Considerable concentrations of sulfur dioxide can be associated with the use of portable kerosene heaters, particularly if consumers do not use the proper grade of kerosene intended for use with such heaters. (Consumer's Reports, 1982).

Plumlee (1979) cautions that retention of pollutants, such as fluoride, might be more common in individuals over the age of 50. He notes, as well, that as we age, our immune system becomes less functional, leaving us at greater risk from carcinogens and respiratory irritants.

5. PEOPLE WITH RESPIRATORY DISEASE

G. von Nieding and H.M. Wagner (1979) reported effects of NO2 exposure on human subjects with chronic, nonspecific lung diseases. They showed that inhalation of NO2, at concentrations down to 1.5 ppm, for periods of 5 minutes to one hour, resulted in a significant increase of airway resistance. No significant effects were observed at lower concentrations, for the same time exposure. Although no measurements were taken over extended periods of time, at lower concentrations (conditions more representative of indoor residential exposures), this kind of result does indicate some susceptibility, of persons with existing lung disease, to added exposure to irritants.

Not all researchers agree on the range of exposures that will trigger adverse effects in persons with existing respiratory disease. For example, in a single-blinded study of a group of 20 asthmatics in France, J. Orehek, J.P. Massari et al (1976) demonstrated that one-hour exposures, to levels of nitrogen dioxide as low as 0.1 ppm, adversely affected 13 of the subjects (in contrast with the work of von Nieding and Wagner, who observed no significant effects at the same level). In the affected persons, the effect of a known bronchoconstrictive agent was enhanced. Several of those responding also demonstrated a moderate bronchial obstruction. The degree of enhancement of bronchial sensitivity was variable among the reponding group.

Orehek and Massari suggest that the incidence and severity of asthmatic attacks would be higher in areas with a polluted atmosphere, at least for some very sensitive subjects. They also speculate that indoor exposure to nitrogen dioxide produced, by gas heaters and gas stoves, may be more detrimental, for many asthmatics, than outdoor exposure.

F. Silverman (1979) notes that asthmatics appear to be more susceptible to the effects of air pollutants than nonasthmatics. Her experimental studies showed that acute exposures to ozone, at the 0.25 ppm level, can produce adverse reactions in some asthmatics. The Canada Health Survey (Statistics Canada, 1981) notes that some 547,000 people in Canada had asthma in 1978/79.

R. Yoshida et al (1974, p.5) conclude that outdoor air pollution, including nitrogen oxides, can aggravate bronchial asthma, by inducing hypersecretion from the secretory glands of the bronchial mucosa, as well as bronchial spasticity. Their animal experiments are reported to show that nitrogen dioxide causes histamine release in lung tissues and thereby facilitates sensitization with other antigens. They suggest that children with bronchial asthma, in polluted areas, should be quarantined from air-polluting substances.

Calabrese (1978a) reviews the literature on nitrogen dioxide effects, and the literature on high risk groups. He concludes that those with cardiopulmonary disease are clearly at increased risk from increased NO_2 exposure.

L.M. Reid (1979) states that exposure to industrial irritants, or to an inclement environment, may be serious, for children with bronchiolitis or cystic fibrosis, for children who have had asthma, and for children who have developed localized hyperlucency in the radiograph after infection.

J.D. Hackney (1974) includes carbon monoxide exposure among the hazards for persons with existing respiratory disease. He states that the hazard from carbon monoxide may be increased by conditions in which oxygenation of the blood is less efficient than normal, leading to lower arterial oxygen saturation. Examples include newborn infants with respiratory distress, or persons with pulmonary emphysema.

Enhanced susceptibility of various groups to sulfur dioxide exposure, has been demonstrated in a number of studies. B.W. Carnow (1970) (as reported by Calabrese, 1978b) showed a relationship between the level of sulfur dioxide and person-days of illness, for persons over 55 with severe bronchitis. Calabrese also notes that several British epidemiological studies of children have revealed a direct correlation between the degree of particulate and sulfur dioxide air pollution and the frequency of respiratory disease. The Canada Health Survey reported that there were some 562,000 people with bronchitis and/or emphysema in Canada, in 1978/79.

Some studies have related indoor air pollution exposures to effects on lung function in children. This kind of relationship would reinforce the advisability of considering at least those with already existing respiratory illness as being at higher risk than normal, from such pollutant exposure.

A study of 8000 children in 6 American cities, found a significant association between gas cooking stoves and history of illness and decreased lung function in children (F.E. Speizer et al, (1980)). Changes were small, but significant. The authors felt that even a minor decrease in lung function in children might lead to them not reaching their full adult lung size, and that such persons might be more inclined to experience rapid decline in pulmonary function in adult life.

The findings of J. Melia et al (1977), in a similar study in Britain, also indicated higher rates of respiratory disease in children living in households with gas cooking stoves, than in those living in households with electric cooking stoves.

B. Burrows, R.J. Knudson and M.D. Lebowitz (1977) present data consistent with the hypothesis that pediatric respiratory illness represents an important risk factor for the development of obstructive airway diseases in adult life. They suggest that these childhood respiratory illnesses cause the adult lung to be unusually susceptible to the adverse effects of a variety of bronchial irritants and infectious agents.

Data on the presence of nitrogen dioxide and sulfur dioxide in residential air, and their health effects, have been reviewed in a previous study and will not be repeated here in further detail. (B.M. Small, 1983, pp. 18-25). Several studies reviewed therein (C.D. Hollowell and G.W. Traynor, (1978), R. Yoshida et al (1974)) indicate that levels of nitrogen dioxide encountered indoors, due to unvented gas cooking appliances, are often high enough to present a risk.

6. PEOPLE WITH HEART DISEASE

J.D. Hackney (1974) cites increased hazard from carbon monoxide exposure by conditions which compromise the oxygen supply to tissues. Persons with coronary or cerebral vascular disease, in which blood flow is limited, particularly to the heart or the brain, are at higher risk than the normal population. In such cases, small amounts of COHb could have disproportionately severe effects on higher cerebral function (cerebral activity, vigilance and functional capability). Cerebrovascular arteriosclerosis is prevalent among older age groups. Hackney also suggests that persons with anemia, or chronic respiratory diseases, are at greater risk of effects from CO exposure, than are normal people.

M. Utidjian (1979) notes that consideration, by the U.S. National Institute for Occupational Health and Safety (NIOSH), to lower allowable exposure levels to carbon monoxide and methylene chloride (which degrades to carbon monoxide in humans) was based, at least in part, on the acknowledgment that persons with either incipient or overt ischemic heart disease were at greater risk. He notes that the NIOSH Criteria Document, at the time of proposing a lowering of the 50 ppm CO standard to 35 ppm, also acknowledged that the new standard might not be fully protective of the ischemic heart disease subject, and that known sufferers should be advised that they may be at increased risk from occupational exposure to carbon monoxide. The Canada Health Survey (Statistics Canada, 1981) reported some 837,000 persons with heart disease in Canada, in 1978/79.

Carbon monoxide is considered, by some researchers (e.g. E.J. Calabrese (1978), R.D. Stewart (1976)), to exhibit 'nonthreshold' effects. That is, every molecule of CO in the body displaces a molecule of oxygen, diminishing the oxygen-carrying capacity of the blood. The body can adapt to this reduced capacity by increasing cardiac output, or alteration of blood flow to various organs. This adaptational response has been measured at levels as low as 2 to 3 percent COHb in the blood. In patients with coronary artery disease, there is a significant diminution of the normal adaptational response. Detectable adverse effects have been measured on such susceptible individuals at levels as low as 2.8 percent COHb.

R.K. Severs (in N.M. Trieff, (1980), p. 143) confirms that those segments of the population, most susceptible to the adverse effects associated with atmospheric carbon monoxide, can be predicted, on a physiological basis, to include those people most sensitive to decreased oxygen supply. These include individuals with: some types of anemia; cardiovascular disease; abnormal metabolic states such as thyrotoxicosis or fever; chronic pulmonary disease; and the developing fetus.

H.E. Griffin (1974, p. xxi) states that the effects of carbon monoxide stem from its propensity to interfere with oxygen transport in the body, by displacing oxygen from hemoglobin and other proteins. This propensity is so constant that an equation can be developed to describe the relationship between the concentration of inspired carbon monoxide and the resultant blood carboxyhemoglobin at equilibrium. The most sensitive measures that detect the effects of carboxyhemoglobin concentrations fall into three categories:

a. Effects on vigilance: Carboxyhemoglobin concentrations, in the range of 3% to 5%, may degrade the ability to detect small unpredictable environmental changes.

b. Effects on exercise: Concentrations as low as 5% will decrease maximal oxygen consumption, during exercise, in healthy young males.

c. Exacerbation of symptoms, in patients with cardiovascular disease: Patients with exertional angina pectoris develop chest pain earlier, in the course of exercise, at COHb concentrations of 2.5% to 3.0% than at 1%. Further, COHb concentrations of 3% have hastened the onset of leg pain, during exercise in patients with peripheral arteriosclerosis. (The COHb concentration at equilibrium, associated with exposures to CO at 35 ppm, is about 5%.)

J.D. Hackney (1974) quotes a correlation table for CO exposure and equilibrium COHb concentrations in the blood:

inspired CO (ppm)	%COHb
0	0.36
5	1.11
10	1.85
15	2.57
20	3.29
30	4.69
40	6.05
50	7.36

The National Research Council (U.S.) (1969, pp. 4-6) concludes that mental performance can be impaired by blood COHb concentrations as low as 2%, probably due to the interference with oxygen delivery to the brain. It notes that people appear to be able to tolerate some increase of CO concentrations in ambient air, but at the cost of some reserve capacity for oxygenation. To some extent, the body adapts, but in a manner that imposes a continuing burden on physical reserves. Because of their reduced reserves prior to CO exposure, susceptible populations may include pregnant women, persons with diseases such as emphysema, and people with peripheral or coronary vascular disease.

The Council quotes a study in which it was determined that the mortality rate, among hospitalized patients with myocardial infarction, was higher in weeks during which the ambient carbon monoxide level exceeded 10 ppm. Exposure to higher CO concentrations for relatively short periods such as 1 or 2 hours, were considered innocuous, because of the delay time for buildup of COHb in the blood. It was emphasized that it is the blood level, not the concentration breathed at any moment, that counts.

Persons with existing heart disease have been considered a risk group for the purposes of this study. This is because of the potential for harm from high carbon monoxide exposures, which are found indoors in the presence of unvented gas stoves, unvented kerosene heaters, and certain combustion and ventilation conditions for fossil fuel furnaces. For further details concerning indoor carbon monoxide exposures, readers are referred to a previous study report (B.M. Small, (1983).

7. SMOKERS

It is well-known and widely accepted that smoking entails considerable health risk. Smoking is known to be related to many forms of cancer, serious circulatory disorders, chronic bronchitis, emphysema and peptic ulcers. The level of risk is known to vary according to smoking behaviour and the amount smoked. For example, current daily cigarette smokers are at much greater risk of death or illness than either former or occasional smokers. Risk increases with the number of cigarettes smoked per day. When a smoking-related illness does occur, it tends to be very serious, often leading to hospitalization and even death. (Statistics Canada, (1981), pp. 46-48.)

P. Kotin (in M. Wright et al (1979)) notes that genetic factors represent a small proportion of high risk populations, compared with such environmental factors as cigarette smoking and alcohol ingestion. Some corporations consider smoking to be a high risk factor and he notes that this is a determinant in whether a person gets and keeps a job which will involve any level of exposure to pulmonary irritants.

E.J. Calabrese (1978a, p. 135) reviews various literature reports on the effects of smoking on the lung, and summarizes as follows:

> "Cigarette smoking has been experimentally shown to have a paralyzing effect on the cilia of the lung. In addition, it may cause a proliferation of mucous glands, leading to a marked thickening of the mucous blanket so that cilia drown in the mucous blanket. This tends to prolong the period of contact of the irritant with the bronchial wall. Acute inflammatory alterations, secondary to the adhering irritants, may occur, with breakdown of resistance of the bronchial wall and possible invasion of pathogenic bacteria. Thus it is quite clear that smoking interferes with the normal cleansing mechanisms of the lung."

Cigarette smoke is also known to contribute considerably to the body's exposure to carcinogenic hydrocarbons and radioactive elements, as well as numerous heavy metals, including cadmium and lead. R.D. Stewart (1976) indicates that carboxyhemoglobin (COHb) saturation in the blood (displacement of oxygen by carbon monoxide) resulting from tobacco smoking is additive to that resulting from other exogenous carbon monoxide sources, encountered either indoors or outdoors. He cites that, in a U.S. study, a one pack-per-day cigarette smoker in Milwaukee has an approximate COHb saturation of 5.5 percent, when nonsmokers in the same area had a 1.2 percent saturation.

Smokers who average a pack of cigarettes a day, and inhale the smoke, have blood COHb levels of approximately 5%. The National Research Council (U.S.), (1969) concludes that the CO present in cigarette smoke could, independently of other constituents of the smoke, produce some adverse health effects.

Based on both direct health damage from smoking, and added risk of damage from chemical irritants and other pollutants such as carbon monoxide, smokers, in general, may be considered a 'risk' group with respect to long-term exposure to indoor pollutants. The inclusion of tobacco smokers as a risk group may be a contentious issue, because smoking is done by choice. However, the evidence that exposure to tobacco smoke can lead to health impairment, for both smokers and non-smokers, is more incontrovertible than for any other pollutant or risk group.

N.E. Collishaw et al (1984) state that, in 1981, 39% of the Canadian population smoked (roughly 7 million Canadians), and the average number of cigarettes smoked daily was 27.

8. PEOPLE WITH ALLERGIES AND CHEMICAL SUSCEPTIBILITY

H. Savel (1970) observed a number of individuals who exhibited a clinical hypersensitivity to tobacco smoke. All were nonsmokers with strong allergic backgrounds, and all developed immediate upper respiratory discomfort after being exposed even briefly to cigarette smoke. Symptoms appeared typically within 30 minutes to one hour after exposure to cigarette smoke, and persisted for at east 8 to 12 hours. He cites another study which demonstrated that 10% of a sample of noncigarette smoking allergic patients developed respiratory distress after being exposed to cigarette smoke created by other persons in their immediate vicinity. The total number of people with allergies in Canada, reported by the Canada Health Survey in 1978/79, was over 2 million (Statistics Canada, 1981).

Allergy has been cited as a predisposing factor in exposure to substances such as formaldehyde (J. Day, (1981)).

It is beyond the scope of this report to carry out a full investigation of allergy, as this is a complex and controversial area. Many researchers and clinicians acknowledge that people with allergies are more at risk than others, when exposed to various pollutants, particularly chemical irritants and tobacco smoke. However, there have been no large scale studies, found during the course of this investigation, which would suggest just what proportion of the total allergic population is likely to be at risk from pollutant exposures on the order of magnitude of those commonly encountered indoors.

Numerous reports (e.g. W.J. Rea, (1979), B.M. Small (1982)) have also linked allergic conditions with incidence of widespread chemical susceptibility, a condition resembling allergy but not apparently involving the same immune mechanisms. Persons who have become sensitized, to low-level exposures to various pollutants, represent a special vulnerable category. In some cases, a mild sensitivity to one chemical gradually worsens and 'spreads' to other chemicals. In the more severe stages, such persons can be chronically ill and experience debilitating episodes of acute illness, even with minute chemical exposures, at, and even far below, the levels commonly encountered in indoor air.

J. Pepys (1981) notes that the increasing use of chemical agents of many sorts, in the home and elsewhere, poses considerable problems in diagnosis and management of sensitized persons, because of the minuteness of the amounts needed to elicit reactions.

The present treatment method, for persons who have become chemically susceptible, often includes a therapeutic reduction in chemical exposures (Rea et al, 1978). Chances of recovery and reversal of chemical susceptibility are considered to be greater, the sooner the exposure reduction is achieved, and the more prolonged the period of reduction. Some physicians hold the belief that, if chemical exposures can be lowered early in life, for persons who appear to be predisposed to developing hypersusceptibility, the risk of developing such susceptibility is lowered.

In some cases, susceptibility to a wide array of low-level chemical exposures may be a symptom of other ailments. C.O. Truss (1980) reports that many patients, with chronic systemic infection with the yeast candida albicans, develop multiple intolerances to foods and chemicals, making it increasingly difficult for them to live in a normal environment. He notes that many of these intolerances disappear, as the yeast problem is brought under control, through medical and dietary therapy.

9. PEOPLE WITH GENETIC VARIATIONS OR ABNORMALITIES

Occupational medicine has identified a number of genetic conditions which are considered to be risk factors in regard to various industrial chemical exposures. For example, D.J. Kilian (in M. Wright et al (1979)) notes that the chemical industry has used a number of tests to determine which workers potentially fall into specific high risk groups and subgroups:

- serum alpha1-antitrypsin (SAT);
- glucose-6-phosphate dehydrogenase (G-6PD);
- lymphocyte transformation for isocyanate sensitization; or
- sickle cell assay.

C.F. Reinhardt (1978) notes that the number of people involved is small, but significant enough in industry that, in some corporations, such tests are used to screen persons with these risk factors, to avoid their placement in jobs involving chemical exposures which would present a high risk to them.

The reader is cautioned that insufficient data was found, during this study, to determine the number of Canadians in these specific genetic or occupational categories and, in any case, the numbers are assumed to be small compared to other risk factors, such as pregnancy, old age, smoking, heart disease, etc. Nor does the scientific literature shed much light on the significance of the categories with respect to levels of chemical exposure in the home, rather than the workplace.

Serum Anti-Trypsin Deficiency (SAT) The substance alpha1-antitrypsin is the predominant component of total inhibitory trypsin antibody in human serum. It has been associated with incidence of chronic obstructive pulmonary disease, and low values are regarded, industrially, as a signal to avoid general exposure to respiratory irritants. (C.F. Reinhardt, 1978)

The initial mutation may have occurred in Northern Europe, and estimates of this gene deficiency in the heterozygous form (passed on from one parent only) vary from 2% to 5% in persons of Irish, English, German and French-Belgian extraction. Reinhardt states that homozygotes (persons inheriting this trait from both parents) may account for 1% to 10% of cases of emphysema, and that most homozygotes develop symptomatic, chronic lung disease by age 40.

Glucose-6-Phosphate Dehydrogenase (G-6PD) Deficiency This enzyme deficiency is found in somewhere between 6% and 15% of the U.S. black population, and may be the most prevalent example, worldwide, of a human genetic abnormality (Reinhardt, 1978). No specific data was found on the Canadian population during this study. The following table, prepared by Calabrese (1978) for the American population, gives some idea of the incidence of the trait:

Black males - United States		11 %
Caucasian males	- United States	0.1%
	- British	0.1%
	- Greeks	1-2 %
	- Sardinians	1-8 %
	- Indians from India	0.3%
	- Mediterranean Jews	11 %
	- European Jews	1 %
Mongolian:	- Chinese	2-5 %
	- Filipinos	12-13 %

Red blood cells, with deficient G-6PD, lack reduced glutathione and cannot maintain integrity of the cell membrane, when under the stress of chemicals with hemolytic action. Susceptibility extends to many drugs, ranging from sulfonamides to acetaminophen, as well as a variety of industrial amino compounds and nitro compounds which are associated with formation of methemoglobin in the blood.

Industrial screening tests are used to avoid placement of G6PD-deficient workers in situations involving the handling of nitro and amino compounds. Hemoglobin levels are monitored for people who are placed in such jobs, and action taken if hemoglobin levels drop sharply, or show a continuous decline.

Exposure to amino and nitro compounds in the home may arise from the use of unvented gas stoves, and from various building materials and household products (B.M. Small, (1983)).

E.J. Calabrese (1978a) also presents experimental data which support the idea that individuals with G-6-PD-deficiency should be considered at high risk to the hemolytic action of breathable ozone. He predicts that levels on the order of 0.5 ppm. ozone, for three hours duration, can cause acute hemolysis.

G.L. Waldbott (1973, p. 89) notes that ozone can be produced in concentrations of 1 ppm (2000 mcg/m^3) in electrostatic air cleaners which are defective or which need cleaning. The drier the air, the more ozone is produced.

Toluene Diisocyanate (TDI) Sensitivity Certain chemicals, such as TDI, are strong sensitizers. TDI has evoked clinical reactions of susceptibility in industrial workers exposed to the substance. C.F. Reinhardt suggests that an immunologic mechanism is the basis for these reactions.

Sickle Cell Anemia In the sickle cell trait, a mutant hemoglobin structure is found in the affected individual, which results in a distorted or sickle-shaped red blood cell when blood oxygen tension becomes low. In individuals who have received the trait from both parents (homozygous), obvious anemia may result. For heterozygous individuals (receiving the trait from only one parent) the condition is not often clinically serious.

Persons with sickle cell trait and accompanying anemia (hemoglobin less than 14g/100ml) may be restricted from placement in industrial jobs involving exposure to nitro compounds and amino compounds.

The Sickle cell trait is found in about 8% of the black population of the United States and is also found among persons with ethnic background of African, Mediterranean or Middle East origin. (C.F. Reinhardt, 1978, Calabrese, 1978a and 1978b)

10. PEOPLE WITH NUTRITIONAL DEFICIENCIES

Several authors have included groups with nutritional deficiencies among those who are at more risk from pollutant exposures, than the general population.

E.J. Calabrese (1980) notes that, while the science of nutrient-pollutant interaction is relatively young, there is sufficient evidence at the moment to warrant much further investigation. He concludes that, for many people, nutritional status is an important determinant of risk from pollutant exposures. K.R. Mahaffey and J.E. Vanderveen (1979) reported that nutritional status can significantly modify the toxicity of environmental pollutants, including pesticides and heavy metals. The data reviewed indicated that the degree of nutritional deficiency, that alters vulnerability, need not be severe.

For example, some studies indicate that Vitamin A plays a role in protecting epithelial cells from being transformed into a malignant condition, following exposure to a variety of hydrocarbon carcinogens (Calabrese (1980)). There is also evidence that low levels of dietary Vitamin A predispose a variety of animals to experience benzo(a)-pyrene cancer (benzo(a)-pyrene is a predominant carcinogen in cigarette smoke). However, only one epidemiological study has begun to approach the relationship of dietary Vitamin A and respiratory cancer in humans.

It is also notable that early results in this field indicate that various vitamins may have protective effects, while others may enhance health damage from pollutants. For example, pyridoxine (Vitamin B6) enhanced cadmium toxicity in rats.

Calabrese cites evidence which shows that the toxicity and/or carcinogenicity of greater than 30 chemical substances and physical agents can be markedly affected by at least one of the vitamins of the B-complex. These vitamins have been shown to influence the enzymatic detoxification of a number of the chemical substances. He emphasizes that the interactions found include both minimization and enhancement of toxic effects. Those pollutants, which are of significance in the indoor environment, include:

- acetaldehyde (building materials, furnishings)
- ammonia (cleaning products, tobacco smoke)
- benzene (building materials, maintenance products, tobacco smoke, paint and varnish, putty, fillers, stains & finishes)
- benzo(a)pyrene (tobacco smoke)
- carbon monoxide (combustion equipment, tobacco smoke)
- dieldrin (pesticides)
- ethylene glycol (paint, detergents)
- lead (tobacco smoke)
- nitrogen oxides (gas stoves, kerosene heaters, tobacco smoke)
- trichloroethylene (building materials and furnishings, oils & waxes, cleaning compounds, dry cleaning)

With respect to ascorbic acid (Vitamin C), E.J. Calabrese concludes that there are approximately 50 chemical and physical agents that affect ascorbic acid metabolism and/or have their toxicity (and/or carcinogenicity) either diminished or enhanced by ascorbic acid. Ascorbic acid can affect microsomal enzymatic detoxification reactions, the detoxification of both organo-chlorine and phosphate pesticides, the toxicity of more than 10 heavy metals and a similar number of hydrocarbons and common drugs, and the activity of several carcinogens, respiratory tract irritants, and physical agents. He emphasizes that a number of these interactions are in such early stages of investigation that the associations should be considered as hypotheses rather than fact at this stage. He notes:

> "At the present time the knowledge of how ascorbic acid influences pollutant toxicity and/or carcinogenicity is extremely interesting and promising but generally too incomplete upon which to base specific policy directives."

Various interactions have also been determined between minerals and pollutant toxicity. For example, animal experiments have shown that deficiencies in dietary calcium can increase the retention and toxicity of cadmium and lead, both of which are present in many residential indoor environments, via cigarette smoke.

Much of the data quoted by Calabrese and others is preliminary in nature, and it is clear that the nutrient-pollutant interactions are not all in one direction, i.e. various nutrients will enhance the toxicity of pollutants, and others will reduce toxicity. A qualitative conclusion that can be supported from the literature is that nutritional status can influence toxicity of pollutants.

11. ALCOHOL AND DRUGS

The interaction of alcohol or drugs with indoor pollutants represents a further unknown.

Alcohol consumed in excessive amounts, over a period of years, is known to cause permanent damage to a person's liver (Calabrese, 1978a, p. 147). Any disruption to the liver often has generally widespread health consequences, particularly for the detoxification and excretion of foreign substances. It is expected, for example, that the ability to detoxify foreign substances, such as PCB's, may be impaired in alcoholics. He cites other studies which confirm that people with high alcohol consumption are considered to be at higher risk of lead poisoning than others under equivalent exposure.

Statistics Canada (1981, p. 47)) states that there is a strong relationship between heavy drinking and heavy smoking, another risk factor for pollutant exposure. Those people who consume 14 or more drinks per week are significantly more likely to smoke 23 or more cigarettes per day than those who drink more moderately. Some 602,000 people were in this category (14 or more drinks/week plus 23 or more cigarettes per day) in Canada, in 1979. The Canada Health Survey notes that there is some evidence that the combination of heavy smoking and heavy drinking may influence health in an additive, or even a multiplicative fashion.

Calabrese (1978a) also notes that there is a possibility that commonly used drugs (depressants, narcotics, stimulants, etc.) may also interact with pollutants to exacerbate their toxic effects, or in some cases, to stimulate the normal detoxification mechanisms.

12. PEOPLE WITH HIGH OCCUPATIONAL CHEMICAL EXPOSURES

Some people with high occupational chemical exposures can be considered to be at risk from additional exposures encountered at home.

Not all people with such exposures, however, would be at higher risk. P. Infante (in M. Utidjian et al, (1979)) notes that there is a 'healthy worker effect'. He states that industry often selects workers who are initially relatively healthy in comparison to the general population. This phenomenon has been demonstrated by mortality patterns from epidemiologic cohort studies. That is, if total mortality for workers within a period of 10-15 years since onset of employment is compared with mortality experience of an age, sex, race, and calendar time-period adjusted standard population, a deficit in mortality (in the worker population) will be observed.

Infante hypothesizes that this is because the industrial cohort is compared to the general population, which includes people who are relatively less employable due to various illnesses or chronic disabling conditions. He cautions, however, that after 20-25 years since onset of employment, this same kind of group, rather than having a deficit of mortality, has an increased risk of mortality as compared to a standard population, presumably due to occupational exposure.

It is this latter population, the workers exposed over many years to high industrial chemical concentrations, that may prove to be at greater risk from residential exposures than others without such occupational histories.

W.J. Rea et al (1978) confirm that cases have been examined where industrial chemical overexposures have precipitated periods of severe chemical hypersusceptibility, during which the persons affected were intolerant of residential chemical exposures that were previously well tolerated.

13. THE GENERAL POPULATION

There are a number of factors or indoor air quality problems that may prove important for the general population.

While certain risk groups have been identified above, it is clear that all effects from indoor pollutants are not necessarily confined to such clearly demarcated groups. There is still a considerable variation in vulnerability across the remainder of the population, and the scientific literature does not offer any clear thresholds or dividing lines that would allow the separation of additional risk groups. It has been emphasized, in other sections, that individual vulnerability will vary over a person's lifetime. L.A. Plumlee (1979) also notes that every one of us has his or her more susceptible times during the day, because of circadian rhythms.

There are also a number of different pollutant exposures, for which no obvious predisposing factors have been established with any certainty. For example, carbon monoxide concentrations, in sufficient quantity, are highly toxic and could cause death in anyone, not just a person with one of the specific risk characteristics. A recent study found that there were over 300 episodes, involving 200 deaths, from accidental carbon monoxide poisoning in homes in Canada, in the decade from 1973-1983 (T.J. Robinson, 1984). One of the prime causes identified was inadequate exhaustion of combustion products from fuel-burning equipment. Included were 145 deaths, or an average of 14 per annum, due to hazardous heating and ventilating conditions in houses. These were caused by a variety of conditions such as chimney blockage due to a failure to install a chimney liner following conversion to gas heat, and backdrafting due to negative pressures induced by fireplaces and dryer exhausts.

In addition, radon gas exposure, and exposure to various chemical carcinogens, is thought, by some researchers, to be responsible for a random incidence of cancers throughout the general population. For example, O. Axelson and C. Edling (in W.N. Rom & V. Archer (1980)) predict that indoor concentrations of radon will increase as a result of sealing homes, and that the risk of lung cancer might become an important health hazard to the general population. They report levels on the order of 1-10 nCi/m^3 of radon as being common household levels in the mid-1970's, though it does vary considerably, depending on the type of house, the construction material, and the air exchange through ventilation. Their study results suggest that background radiation, from radon and radon daughters, could explain a great deal of lung cancer morbidity, particularly among non-smokers, but perhaps also among smokers, namely if smoking plays its major role as a promoter, rather than being an initiator, of lung cancer.

However, R.G. McGregor et al (1980) and E.G. Letourneau et al (1983 and 1984) measured radon and radon daughters in a total of 14,000 homes in 18 Canadian cities, and retrieved mortality and population data for the geographic areas surveyed in each city. The results of analysis of the relation between lung cancer and radon daughter concentration, smoking habits and socioeconomic indicators for each city showed no detectable association between radon daughter concentrations and lung cancer mortality rates, with or without adjustment for differences in smoking habits between cities.

Dr. McGregor (personal correspondence, 1984) states that the study may not have been sensitive enough to detect small increases in lung cancer incidence due to radon exposure. The results do not support or eliminate a carcinogenic hazard due to chronic domestic exposure to low radon concentrations in Canada, but suggest that any effect of such exposures on lung cancer mortality rates must be very small, in comparison to the effect of smoking. The study design, based on comparison of large population groups, was adequate to detect the smoking/lung cancer association among men, but did not reveal a statistically significant smoking/lung cancer association for women, even though there is abundant evidence from other studies based on analyses of individuals. The Radiation Protection Bureau of Health and Welfare Canada has embarked on an epidemiology case-control study as a more definitive approach to determining whether radon contributes to mortality from lung cancer.

Some of the apparent victims of chemical exposure have had no obvious history of risk factors similar to those already described. W.J. Rea et al (1978) have indicated that cases have been observed in which acute chemical hypersusceptibility has apparently been precipitated by environmental chemical overexposure, where no known susceptibility risk factor, or family history of disease, was present. The same phenomenon has been reported with respect to susceptibility triggered by exposure to urea-formaldehyde foam insulation (B.M. Small, (1982)).

The population as a whole is also susceptible to various infectious diseases, many of them viral in origin. R.L. Riley (in W.N. Rom & V. Archer, (1980)) suggests that respiratory virus infections, tuberculosis, Legionnaire's disease, and a number of other types of infections can be spread throughout buildings, by air recirculation. He concludes that more recirculation of air in tighter houses means less dilution of airborne organisms with outdoor air, and that the consequence is a higher concentration of airborne organisms indoors, and an increased likelihood of airborne infection for those who breathe the air.

E.C. Riley et al (1978) reported, in detail, on the airborne spread of a measles in a U.S. suburban elementary school, and cited the recirculation system in the school as being partially responsible for extensive spread of the measles virus. One measles case produced 28 secondary cases in 14 different classrooms in the school, and by the time the epidemic was over, 60 children had been infected. The authors estimated that this represented all those, out of the total school population of 868, who were susceptible to measles virus.

Although the study yielded no quantitative information that would help estimate risk in residential situations, it can be concluded that reduction of ventilation in homes will only increase the risk of spreading viral infection from one occupant to another.

J. Pfeifer et al (1983) studied the effect, on immunity indicators in children, of long term exposure to formaldehyde. They observed a statistically significantly higher occurrence of abnormal findings in the studied immunity indicators in an exposed group compared to a control group, over a three-month and a three-year period. They recommended, on the basis of their observations, that houses built with prefabricated wood panels, made with urea-formaldehyde glue, were unfit for use for a long-term sojourn of children. A relatively prompt normalization of the findings was seen after elimination of the formaldehyde exposure.

While the effect of pollutants on immunity, and the effect of ventilation on pathogen exposure, will most certainly affect certain risk populations, these also represents risk factors for the general population.

One final effect, of some considerable significance for the general population, is second-hand exposure to tobacco smoke. Tobacco smoking has been reviewed in previous sections as an important risk factor, and smokers have been referred to as experiencing definite adverse health effects, due to indoor air pollution, albeit under personal control. Second-hand tobacco smoke may have the greatest effect on some of the other risk groups already discussed, including people with heart disease, acute respiratory disease, emphysema, asthma and hay fever. These groups represent approximately 21% of the Canadian population (N.E. Collishaw et al, 1984).

B.M. Small (1983) reviews various reports relating to the adverse health effects of second-hand tobacco smoke, i.e. the exposure of the non-smoker living with a smoker. G.S. Bonham and R.W. Wilson (1981) studied the number of restricted activity days and bed-disability days due to acute respiratory conditions among children in smoking homes, compared with those in non-smoking homes, and concluded that cigarette smoking by adults adversely affects the health of children in their families. J.L. Repace (1981) estimated that over 60% of the children under 16 years of age in the United States may be living in homes with one or more smokers. (The corresponding figures for Canada were not investigated during this study, due to time limitations.)

More recent reports (G. Miller, 1984) suggest a possible increase in mortality rate of non-smoking wives whose husbands smoke, compared to non-smoking wives whose husbands did not smoke. While the effects of tobacco smoke in the residential environment may appear to be beyond the interest of housing design, ventilation rates and home design will affect the degree of exposure of both non-smokers and smokers, and therefore could influence the nature, or degree, of adverse health effects resulting from tobacco smoking.

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