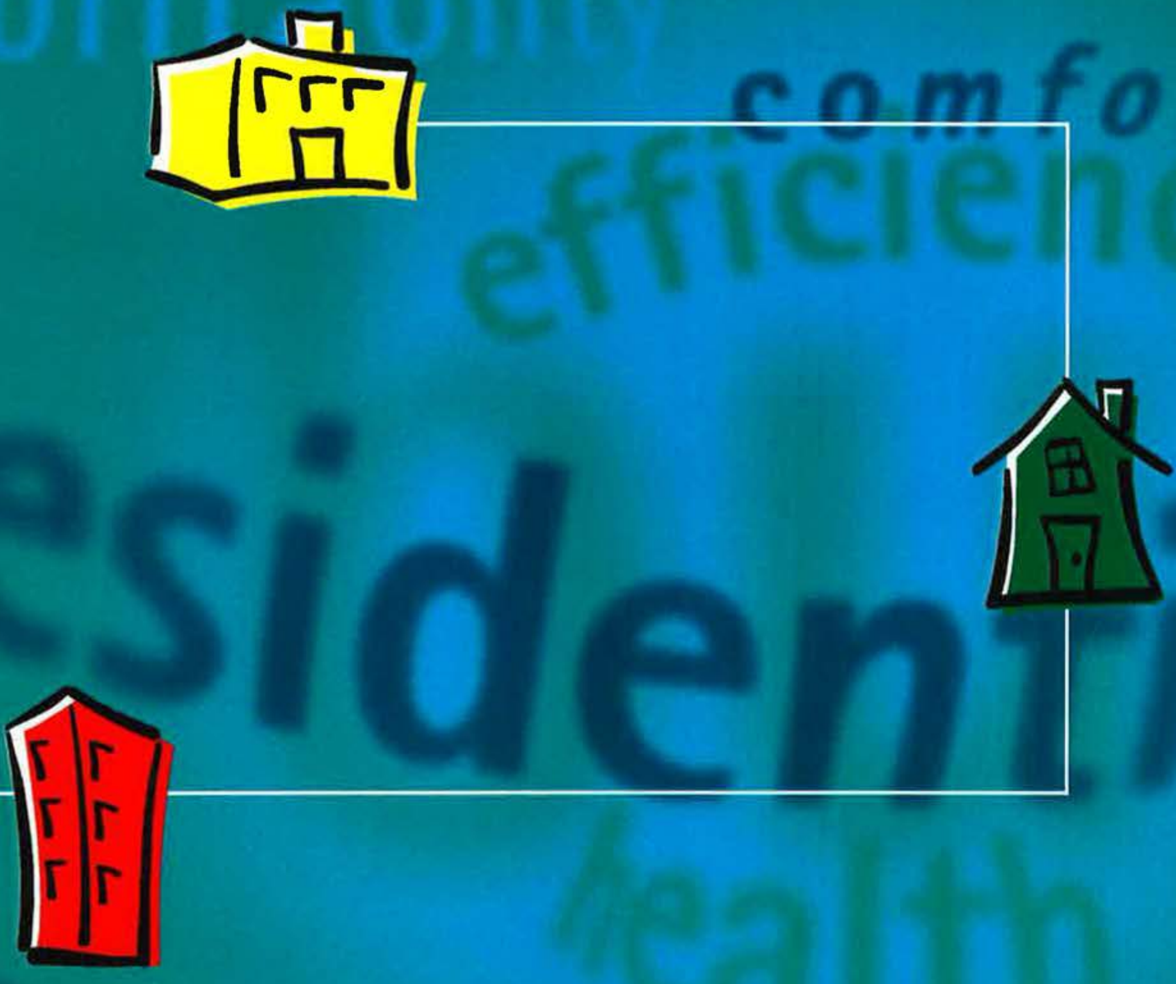
Indoor Air Quality and Natural Gas Equipment: A Look at the Issues



Sheltair Scientific Ltd.

A Discussion Paper for Gas Technology Canada

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GTC Program #1 - HVAC and Appliances
Development of an IAQ Issues Document

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CONTENTS

Part 1: An Introduction to the Issues

Background on this Project

This report completes the first phase of a Gas Technology Canada (GTC) research project that will attempt to identify research priorities related to indoor air quality (IAQ) and natural gas-fired equipment.

The project commenced in August, 1995, and will be completed by March 1996. The first phase has included:

- a comprehensive literature review,
- an overview of some of the key issues to be examined,
- a description of air emissions and related health standards, and
- an explanation of how different categories of equipment can contribute to air quality problems and solutions.

The results of this Phase 1 research are presented in this report. The report is being circulated to stakeholders within the gas industry. It is hoped that by sharing this information at this time it will be possible to obtain helpful input and commentary on research priorities.

The remaining work includes:

- Phase 2 A Survey of Industry Knowledge and Opinion (including a Fax Questionnaire and telephone interviews); and,
- Phase 3 A Final Project Report, which will include a Summary of Research Priorities and Possibilities

Reasons for New Research into IAQ Issues

Natural gas has a well-deserved reputation as an environmentally-friendly and clean fuel. In comparison to most other fossil fuels, it burns with minimal environmental emissions or odours, and the frequency of serious health and safety incidents is very low. However an attitude of complacency is probably unwise. Three reasons justify for new & continued research into indoor air quality issues:

1. Growing public concern

Increasing public awareness about the hazards of environmental pollution have created a new emphasis on the less dramatic, longer term implications of air pollution risks. Media coverage of sick buildings, chemical sensitivities and immune system deficiencies are fueling a trend towards greater concern over perceived public risk.

2. Technical Changes in Building Construction and Operation

Building construction material and methods are rapidly changing, as is gas-fired HVAC equipment. The performance & interaction of these new technologies is complicated and difficult to predict without field research, monitoring and testing.

3. New Knowledge of Health Impacts from Combustion Pollutants and Biological Contaminants

Increasing evidence exists for concern over long term exposure to low levels of nitrogen oxides indoors. Also of concern is the exposure to biological pollutants that can results from high humidities or standing water indoors . High humidities can be a byproduct of combustion gas spillage; standing water can be found in HVAC equipment auxiliaries such as coils and humidifiers. Potential health impacts include allergic responses to moulds and other biological growths, and other types of illness, including a correlation between Sudden Infant Death Syndrome and mould growth in houses.

Potential Benefits for the Gas Industry

An effective research plan on IAQ issues may be of direct benefit to the Canadian gas industry in a number of ways. Research can help to:

1. clarify the nature of any health and safety risks and, by so doing, protect the industry's reputation for providing healthy, safe and environmentally responsible technology ;
2. explore market and technological potential for new natural gas equipment;
3. identify or validate technical and procedural solutions to existing problems; and,
4. identify proactive measures that may help to avoid IAQ problems in the future.

How this Report was Prepared

So far our investigations have been guided by two questions:

1. what is the current and near term status of gas equipment and system design? and,

2. what IAQ issues might be associated with natural gas equipment and systems?

To avoid losing sight of the forest for the trees, we began our investigations by creating a matrix of IAQ issues and natural gas equipment. (See the following page.) The matrix helped us to scope and guide an extensive literature search. To date our search has included:

- conventional print and library resources across North America and Europe, and
- electronic network and CD-ROM information resources, including:
    - ⇒ CISTI
    - ⇒ CMHC
    - ⇒ Air Infiltration Review
    - ⇒ The U.S. Gas Research Institute
    - ⇒ U.S. Occupational Safety & Health Administration
    - ⇒ U.S. Department of Energy National Laboratories

We have now completed the search, reviewed the information, and are now seeking additional input from stakeholders.

Matrix of IAQ & Gas Equipment Issues

Services	*Product Categories*	Combustion Contaminants											Biologicals	Gas Leakag
		VOCs	NOx	CO2	CO	H2O	HCHO	Aldehydes	Aliphatic hydrocarbons	Polycyclic Aromatic Hydrocarbons	Man Made Mineral Fibres	Particulates		
Heating	Atmospherically Vented Forced Air Furnaces & Boilers	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	9	1, 6	2	3
	Direct Vent Forced Air Furnaces & Boilers	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	9	4, 6	-	3
	Sealed & Pulse Combustion Forced Air Furnaces &	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	9	4, 6	-	3
	Gas-fired Heat Pump	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	9	1, 6	5	3
	Gas Fireplaces	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	-	4, 6	-	3
	Integrated DHW/Space Heating	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	9	1, 6	2	3
	Humidifier accessory	-	-	-	-	-	-	-	-	-	-	-	5	-
	Power Venting kits	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	-	4, 6	-	-
Space Cooling	Gas Fired Absorption Chillers	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	-	1, 6	5	3
	Dessicant Cooling	6	6	6	6	6	6	6	6	6	-	6	5	3
	Gas-fired Heat Pump	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	9	1, 6	5	3
Domestic Hot Water	Naturally Aspirated DHW Heaters	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	1, 6	-	1, 6	2	3
	Direct Vent DHW Heaters	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	-	4, 6	-	3
	DHW Demand Heaters	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	-	4, 6	-	3
Ventilation & A/C	Indirect Fired Rooftop Makeup Air Heaters	6, 7	6, 7	6, 7	6, 7	6, 7	6, 7	6, 7	6, 7	6, 7	9	6, 7	-	-
	Direct Fired Rooftop Makeup Air Heaters	8	8	8	8	8	8	8	8	8	9	8	-	-
	Rooftop Package A/C & Gas Heaters	6,7	6,7	6,7	6,7	6,7	6,7	6,7	6,7	6,7	9	6,7	5	-
Cooking	Unvented Gas Ovens & Ranges	8	8	8	8	8	8	8	8	8	-	8	2	3
	Sealed Combustion Gas Ranges	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	4, 6	-	4, 6	-	3

Notes:

1 Heat exchanger & vent leaks, backdrafting & spillage, induction of outdoor air.
2 Increased indoor humidity, induction of outdoor air.
3 Supply piping leaks.
4 Plastic vent pipe cracking & leakage.
5 Potential for standing water or moist conditions provides growth medium.
6 Potential reentrainment of combustion products into ventilation intakes.
7 Heat exchanger leaks.
8 Introduction of combustion products directly to indoor air.
9 Equipment acoustic lining possible source.

A Brief Retrospective into the IAQ Issue

The Hatch Report

Historically, much of the research into IAQ and natural gas has focused on carbon monoxide. In Canada, a bench mark study was completed by CMHC in 1983, which attempted to calculate and evaluate the degree of risk associated with combustion equipment in housing. The research, referred to as the Hatch Report[1], is worth summarizing briefly since it provides a basis for much of what has occurred since.

The Hatch Report produced statistics on the incidence of CO poisoning episodes across the country. The statistics were based upon surveys of public and private utilities, universities, and other research organizations, as well as interviews with recognized experts. Due to poor record keeping in some jurisdictions, the data also included many newspaper reports. The data revealed reports of 293 episodes of carbon monoxide poisoning from indoor air, resulting in 145 deaths, over the ten years prior to 1983. Actual occurrences were expected to by higher, due to missing data.

The major contributing factors to the deaths identified in the Hatch Report were summarized:

1. Equipment problems due to poor maintenance, damage and defects.
2. Collapsed, blocked, dislodged or damaged chimneys, vents and flues.
3. Downdrafting of furnace gases in chimneys, vents and flues due to excess exhaust, inadequate air supply, and airtightness of the house envelope.
4. Improper installation of equipment, chimneys, vents and flues. Lack of understanding of combustion equipment operation and the potential problems associated with improper operation.

The Hatch report contains summaries of each poisoning incident. A careful review of these summary descriptions has lead to a number of other insights into the nature of CO poisoning incidents in Canada.

- Most of the investigations were not well documented - the investigators rarely completed any kind of comprehensive diagnosis or follow-up testing.
- In a majority of those incidents that were well described, it appears that the problem occurred as a result of multiple failures. For example, a faulty burner in combination with a plugged vent resulted in combustion gas

[1] Hatch and Associates, *Hazards of Combustion Equipment in Housing*, 1983, for CMHC

spillage to the indoors. Sometimes one problem would lead to another, in a series of cause and effect chains.

- In a surprisingly high number of cases (about 25%) house depressurisation was a factor contributing to the spillage problem.

Statistics Canada also reviewed data on mortality attributed to fuel fired equipment. Their data tended to corroborate the Hatch Report. Based on death certificate surveys, 238 deaths were attributed to indoor exposure to combustion products between 1973 to 1981. The Statistics Canada data revealed that in 15% of these deaths, natural gas fired equipment was implicated. This compares well to those deaths attributed to other fuels - 33% from propane, and 52% from other fuels, including oil, coal, kerosene and wood.

The Campaign to End Vent Backdrafting

Partly as a result of the Hatch Report findings, CMHC in cooperation with HRAI, CGA, Consumers Gas, Esso, and others, undertook extensive research into pressure-induced spillage and backdrafting hazards. The investigations continued over the period from 1984 to 1988, and included surveys of existing houses, delivery of pilot training courses, testing of all kinds of appliances in the field and lab, and computer simulations of chimney performance. The research was successful in a number of areas, producing:

- new procedures for testing houses and measuring depressurization from exhaust systems;
- new safety inspection procedures;
- new courses for trades;
- new appliance test procedures (test bench and on site);
- improved appliance design specifications;
- improved warning devices and fail-safe technology; and,
- new technology for creating balanced household ventilation systems.

Much of this information has now been incorporated into Canadian building codes and standards. Course materials have been expanded, and appliance designs have been improved. However the impact of these changes is not well understood since very little follow-up research has occurred to evaluate the degree of risk now faced by homeowners.

Surveys by CMHC and others have typically indicated that somewhere between 15% and 30% of the housing stock is susceptible to house depressurisation in excess of 5 Pascals - the commonly accepted maximum for safe operation of natural draft flues. The high percentage of potentially vulnerable houses has raised concern within some organizations. CMHC has recently issued a new fact sheet on combustion spillage; some utilities have created bill stuffers to alert their customers, and Demand Side Management programs have adopted elaborate policies to avoid creating or exacerbating spillage problems through draftproofing and central exhaust ventilation. A number of housing programs have banned any type of natural draft appliance.

Despite this precautionary activity, our literature search has not revealed any new information on the extent of risk. Little follow-up work has been done to assess the impact of these programs, nor has any program been reviewed targeted specifically at identifying and remedying existing problems.

A Growing Concern with Pollutants other than CO

While the bulk of IAQ research to date has been directed at reducing CO poisoning incidents, it has become increasingly clear to the industry that other combustion pollutants may represent a greater health risk. CO is not normally present in significant quantities from a well tuned gas appliance. In those buildings where spillage is occurring on a regular basis, it is likely that over time the exposure risk is related to less toxic pollutants.

There is growing evidence that long term exposure to low concentrations of combustion pollutants - particularly NOx and particulates - has chronic health implications. Epidemiological evidence suggests that some individuals may become more prone to respiratory infections, and that others may be more prone to environmental hypersensitivity due to chronic low-level exposures. These possibilities are discussed in more detail in Part 2 of this report.

As our understanding of the nature of the risk improves, it may turn out that the degree of health risk currently present in some buildings is unacceptable.

Is the Health and Safety Risk Increasing or Decreasing?

Whether or not the risk is acceptable at present, it is still important to identify whether the problem is getting better or worse. This is a tricky judgment, because a number of trends are present that may impact in opposite directions. These trends are summarized in Figure 1.1.

Figure 1.1 Factors Affecting the Health and Safety Hazards from IAQ

Increasing the risk	Decreasing the risk
• New buildings and retrofits of older buildings are making them more airtight	• New furnaces are increasing more resistant to spillage or backdrafting
• health impacts from chronic low-level NOx exposures are more serious than we previously believed	• New appliance emissions test procedures have been developed
• atmospherically vented Water heaters, boilers and furnaces (in some areas) are still being used and are becoming larger in many installations	• CO alarms are better, more affordable and standardized
• High powered exhaust fans (including HRVs) are much more common	• Fail safe devices exist on some appliances, and are performing better
• Natural gas fireplaces are increasingly common, but their resistance to spillage and contamination is not well researched	• Codes now require testing of systems during installation, or use of balanced ventilation
• Increasingly complex mechanical exhaust & ventilation systems have greater demands for skills and experience in design, installation and maintenance.	• Many HVAC contractors are better trained in how to test house systems and look for combustion gas leaks

It is not feasible to discuss each of these trends within this report. We encourage readers to make their own judgments about the shape of things to come.

Key Concepts and Concerns

Much of the remainder of this report deals with combustion contaminants and equipment performance. Before reviewing this material we suggest that you consider three key concepts:

- **buildings tend to operate as complex systems**

- **indoor pollutant concentrations tend to vary widely, and,**

- **risk assessment must consider both the severity of the health hazard and the probability of occurrence.**

These three principles help to set a context for much of the material that follows. They emphasize the importance of considering the interaction of all the components of the building before setting research priorities. Each concept is discussed below.

1. Buildings Tend to Operate as Complex Systems
Buildings are complex systems of many interacting components. This was poorly understood in the 80s, and many people suffered as a result. The unanticipated impact of energy conservation measures lead to poor indoor air quality in houses and offices. Initially it was convenient to blame other people's technology for these new problems. Now it is clear that no technology stands alone. Each device is only one of many components that must operate together to create a safe indoor environment. This means that it is important everyone involved - from manufacturer to builder to contractor - understand the features and limitations of specific natural gas-fired equipment.

2. Indoor Pollutant Concentrations can be influenced by Many Factors
The indoor concentration of any given pollutant cannot easily be estimated. Concentration is a function of how many different building components interact, in response to local climatic conditions and the activities of occupants. Figure 1.2 summarize seven key factors, any one of which can turn a minor incident into an unacceptable IAQ problem.

Figure 1.2 Key Factors Affecting Pollutant Concentrations

Indoor Air Pollution Sources	Sources can include unvented combustion appliances, vent leakage, spillage and backdrafting by combustion equipment, interior finishes and building materials, and fumes released by consumer products such as cleaning aerosols and fluids. There is a growing body of knowledge characterizing the nature and rates of emissions, particularly of natural gas appliances however, research on emission rates from many construction and furniture materials and consumer products is recent, not well known by or a form that is difficult to use by designers.
Ventilation and Infiltration Rates	The rate at which air is exchanged between the indoors and outdoors is a key determinant of concentrations of pollutants indoors. Houses typically experience between 0.3 and 1.5 air changes per hour; at lower air change rates, indoor concentrations of pollutants are often several times higher than those outdoors.
Outdoor Air Quality	Ventilation using outdoor air is only successful if the air is less contaminated than the indoor air. In many industrial and urban areas this is not always the case. A related issue is the location of outdoor air intakes relative to contaminant sources such as combustion vents, parking garages and traffic, building exhausts and standing water; entrainment of polluted air into ventilation air streams has been found to be at fault in many problem buildings.
Building Volume	The greater the volume of the building, the longer the residence time of the air for a given ventilation and infiltration rate. This affects both the concentration and the duration of occupant exposure to indoor pollutants

Air Circulation and Pressure Differentials	Air circulation in a building is a significant factor in occupant exposure, particularly for spot sources of pollutants. Greater air circulation increases dispersion of pollutants. This tends to decrease peak exposure concentrations, but exposes more occupants to lower average levels. Factors that affect air circulation include the use of fans and other HVAC equipment, and opening and closing of doors by occupants. Operation of mechanical exhaust equipment affects pressure differentials as well, and thereby affect the pollutant emission rates from any spillage combustion appliance.
Reactions between Pollutants and Indoor Materials	Many air pollutants are highly chemically reactive with each other as well as with materials commonly used indoors, both for construction and in furnishings. Gypsum wallboard, carpets, and furniture foams adsorb (and desorb) many pollutants, affecting their concentration in indoor air. Much research is now directed at understanding an quantifying these effects, but current understanding is mostly based in the research and academic worlds and building designers are only slowly becoming aware for these issues..
Mechanical Filtration and Treatment	Filtration or treatment of air to remove pollutants is often used to reduce occupant exposure. Strategies range from simple mechanical furnace filters, through special high efficiency fabric or electrostatic filters and charcoal cartridges. The impact of filtration and treatment varies from next to nothing to almost 100% removal efficiency.

Risk Assessment: the Probability of Occurrence and the Severity of the Health Impact

Research into IAQ issues can be directed into risk assessment or risk management. This report is structured to aid in both risk assessment and risk management.

Risk assessment focuses on two questions, each of which must be carefully considered:

1. what is the magnitude and probability of exposure to pollutants produced from the combustion process? and,
2. what is the likelihood that an adverse health effect would be produced by such an exposure?

Combined, these offer a means of determining the relative importance of issues and thus the potential for success of strategies to reduce risk. The section entitled *Air Contaminants of Concern* introduces categories of pollutants, and provides details on acceptable levels of exposure. It provides a summary of background material to aid in risk assessment.

Risk management, on the other hand, focuses exclusively on the probability of occurrence, and involves exploring cost-effective alternatives to reduce population exposure to indoor pollutant hazards, and an estimation of the probability of exposure to those hazards. The next section, *Modes of Indoor Air Pollution by Natural Gas Equipment*, discusses indoor air quality concerns for individual classes of equipment, and the known incidence of problems.

Public Perception of Risk

Public perceptions of indoor air quality problems must be addressed, even if the risk is judged to be low. The public does not typically make a rational risk assessment, being limited both in the information available on the severity of the hazard, and on the likelihood of exposure. Without sufficient communications on risk assessment, the risk management strategies may be totally inappropriate. One example is the city of Chicago requirement to install carbon monoxide sensors in all new construction. This was prompted by public fear concerning carbon monoxide exposure, and not risk assessment. In the absence of a clear assessment, the success of their strategy is difficult to judge, (although in the short term the city's policy has exacerbated public confusion, through the widespread false alarms).

Modes of Indoor Air Pollution by Natural Gas Equipment

Overview of failure mechanisms

There are many means by which indoor air can be polluted, directly or indirectly, by natural gas equipment. Problems typically occur as a result of interaction between:

- ⇒ equipment condition,
- ⇒ ventilation rates,
- ⇒ building envelope airtightness, and,
- ⇒ the operation of other HVAC equipment.

Four general categories of indoor air contamination mechanisms are listed below, in order (we believe) of decreasing concern:

1. Operation of unvented natural gas appliances indoors without adequate ventilation (examples include ovens, cooking ranges, and barbecues).
2. Spillage and leakage from flues and vents, due to excessive building depressurisation, vent or equipment damage, or faulty design, installation, operation and maintenance of mechanical equipment. Failures are typically intermittent, and while peak indoor levels of contaminants (in the living spaces) are typically lower than those from unvented appliances, time-averaged exposures may be greater.
3. Induction of polluted outdoor air into the indoor space. This is typically a problem with poorly placed flue outlets or ventilation air intakes, and in areas where the outdoor air is heavily polluted.
4. Biological contamination from badly maintained gas equipment accessories (such as humidifiers and air conditioning coils) or unvented combustion products from cooking ranges or ovens, that provide the moisture necessary for growth of bacteria, molds and fungi.

Pollutant Emission Rates of Natural Gas Equipment

For an idea of emissions rates by natural gas equipment, the following summary Table 1.3 has been compiled. The data has been extracted from the field and laboratory research projects listed in the Bibliography. Emission rates by oil furnaces and fireplaces are included for comparison purposes.

Table 1.3: Pollutant Emissions Rates of Natural Gas Equipment

Emission Factors of Indoor Air Pollutant Concentrations by Fuel Fired Equipment

	Combustion Oxides				Organic Chemicals		
	Carbon Monoxide	Carbon Dioxide	Nitrogen Dioxide	Sulphur Dioxide	Formaldehyde	Hydrocarbons	Total Particulates
Natural Gas Equipment							
Atmospheric Vented Forced Air Furnaces							
Tuned Average	2.6	38.4	2.36		0.062		
Standard Deviation	0.8	6.6	1.2		0.048		
Untuned Average	66.8	39.7	4.86		0.217		
Standard Deviation	1.2	6.6	1.94		0.141		
Gas Stoves							
Ranges	67.1		14.8				
Burner Pilots	117.1		7.8				
Oven Pilots	340.8		13.6				
Single Burners	121.4		15.3				
Ovens	196.7		10.3				
Unvented Gas Fired Space Heaters	87.4		10.2				
Oil Fired Equipment							
Atmospheric Vented Forced Air Furnace							
Tuned Average	30.0	66.0	100.0	220.0		3	30
Wood Fired Equipment							
Fireplace							
High Burn Average	1000.0		150.0	120.0		2000	1000

Several difficulties were encountered in compiling Table 1.3. First, reports from different sources are inconsistent, with varying emission rates reported by different researchers and organizations; there is no currently widespread standard procedure for emission rate measurement. Second, as in the air pollutant guidelines listed earlier in this document, there are no agreed standard units of measure for reporting of emission rates, with units varying from "parts per million per cubic foot air-free" to "micrograms per kilocalorie after dilution".

Outdoor Air Pollution

Natural gas equipment often plays a role in the induction of pollutants from the outdoors. There are two main issues of concern:

- Combustion air supply, and
- Re-entrainment of combustion products into ventilation air supplies.

Indoor air quality is inextricably linked with outdoor air quality. The most common means of ventilation is the mechanical supply of outdoor air to dilute indoor pollutants, and infiltration and exfiltration ranges from 1/3 to over two air changes per hour in most single family dwellings. Local exhausts and operation of atmospherically vented combustion appliances remove indoor air which is replaced by outdoor air, and if the outdoor air introduced into a building is contaminated, those pollutants will be experienced by the occupants. This is of particular concern in heavily polluted industrial areas and locales close to other pollutant sources such as busy roads, and for buildings with attached parking garages. These can include:

- sulphur oxides and acids
- nitrogen oxides and acids
- heavy metals, such as lead
- particulates, including asbestos fibres, soot, and others
- ozone
- photochemical smog
- hydrogen sulfide (often from pulp mills and refining operations)
- a wide variety of hydrocarbons
- volatile organic chemicals (VOCs)

The relationship between high levels of outdoor air pollution and health impacts is well established, and in fact was the basis for the initial concerns with indoor air pollution. Outdoor air pollutant levels are seldom constant, but typically follow regular diurnal, weekly and often annual cycles that depend on source activity and local weather conditions. The effect of outdoor air pollution is greatest when there is a high rate of air exchange between the outside and

Contamination of Ventilation Air Supplies by Combustion Products
Another concern is the introduction of outdoor air polluted by combustion products vented from the building in question, due to the poor placement of flue outlets relative to ventilation air intakes. Poorly placed vent and flue outlets, or ventilation and combustion air intakes, can result in the reentrainment of combustion products into the ventilation air supply.

The Canadian Natural Gas Installation Code, CAN/CG-B149.1-M95, requires termination of a combustion vent more than six feet from any mechanical air supply inlet of a building, high enough above the building to avoid positive pressures at the vent termination, and at least two feet (three feet for chimneys) higher than any portion of the building within ten feet horizontally. Unfortunately, two situations can result in re-entrainment of combustion products into a ventilation air supply: location of a ventilation air intake in the same downwind wake region as a combustion vent or chimney (which often extend more than ten feet from the building), or location of an appliance vent upwind and near to a ventilation air supply. Few studies have been performed to establish the extent of re-entrainment problems in North American buildings; conservative engineers routinely ensure greater separation of ventilation air intakes and vent terminations than the minimums required by Code.

Backdrafting and Spillage

Backdrafting and spillage are two related indoor air quality concerns with all atmospherically vented combustion equipment, including that fired by natural gas. Direct vent and induced draft equipment, which have no draft hood or other openings to the indoor air, do not present this hazard.

Backdrafting is the continuous flow of air down the vent, in the opposite direction to the intended flow of combustion gasses, resulting in air flow into the building. It is caused by a lower pressure at the draft hood or the appliance within the building than at the vent exit, which induces air flow in the opposite direction than intended.

Backdrafting has two main causes:

1. Overloading of the vent.
2. Lower pressure at the draft hood than at the vent outlet.

Spillage is the flow of combustion products to the indoors through the draft hood or the combustion device itself, that occurs under a backdrafting condition, or during the transition between upward and downward flow in the vent. It typically occurs as the burner first fires, before the thermally induced flow of combustion gasses up the vent fully develops, or when there is a continuous backdraft occurring.

indoors. Table 1.4 lists National Air Quality Objectives as published by Environment Canada.

Combustion Air Supply
Natural gas fired equipment requires combustion air to function properly, and atmospherically vented equipment requires a greater amount of outdoor air to be introduced into the building to provide this air. Approximately ten times the volume of combustion air per unit of gas is required for natural gas combustion, producing more than eleven times the volume of flue gasses (since the flue gases are hotter).

Combustion air for atmospherically vented equipment is usually a combination of air drawn through a dedicated combustion air supply and indoor air that has infiltrated through the building envelope. The relative amount of combustion air from either source changes over time for any given building depending on wind and internal pressures, and from building to building depending on design, construction, and operating conditions. The pressure regimes within buildings that determine this mix are complex interactions of outdoor wind and temperature conditions, indoor temperature, building construction, mechanical equipment operation, and occupant behavior.

Sections 7.2, 7.3, 7.4 and 7.5 of the Canadian Natural Gas Installation code require and regulate the installation of a combustion air supply for furnaces, boilers and water heaters. For atmospheric equipment, this is typically an opening or duct through the envelope of the building that terminates close to the burner of the fuel fired equipment, with the size dictated by the fuel requirements of the appliance. Equipment with a poorly functioning combustion air supply, or that does not have a dedicated ducted air supply, draws most of its' combustion and excess air from the building and vents it to the outdoors; this is replaced by infiltration into the building through the random locations in the envelope.

In post-occupancy surveys of 40 single family dwellings conducted by Sheltair, it has been found that combustion air supplies for atmospherically vented equipment were sealed or blocked, too restrictive to supply the required air, or were never installed in the first place, in approximately one out of ten installations inspected.

In these cases, additional infiltration through walls, windows, doors and other envelope components must make up the difference. Operation of the fuel fired equipment depressurizes the building, and inflow of potentially polluted outdoor air is induced through random locations in the building envelope. In areas with high ambient pollution levels, this can seriously degrade indoor air quality.

Overloading of a vent system can be caused by:

- Inadequately sized, blocked or restricted vents.
- Vent system poorly designed, installed or maintained.

The Sheltair-Scanada consortium conducted a survey of 606 Canadian single family dwellings in cities across Canada in 1986 / 87 for CMHC. The study involved installation of custom spillage monitors on the draft hoods of gas, oil and wood fired equipment in 937 houses, over two to three months of the heating season.

Of the surveyed houses, sixty-five percent showed evidence of short or long term combustion gas spillage. Evidence of prolonged spillage was found in ten percent of the gas heated houses. Only one quarter of the homes surveyed showed no evidence of spillage or backdrafting problems.

A follow-up study of sixteen natural gas houses with identified spillage problems was conducted, with on-site inspection and testing. The study included houses with gas and oil fired furnaces, boilers and domestic water heaters; it was found that domestic water heaters were possibly more prone to spillage than hot air furnaces or boilers, though experimental design may bias this finding[1].

Identified failure mechanisms causing spillage, with the potential to affect indoor air quality, included:

- insufficient vent height.
- use of corrugated chimney liners, which reduced flue cross-sectional area and increased flow resistance.
- inappropriate use of rain caps that obstructed flue exits.
- excessively long or improperly installed flue connectors.

Lower pressure at the draft hood than at the vent outlet can be caused by many factors, including:

- improperly located, inadequately sized, and blocked or restricted combustion air supplies.
- a tightly sealed building envelope.
- house depressurization by exhaust fans, fireplace operation, built-in vacuum operation, etc.

[1]Statistics quoted below are for the natural gas supplied houses only, unless stated otherwise. Note that the proportions quoted from this study do not add up to 100%, since several contributory factors were usually implicated.

Inadequate, blocked or poorly maintained combustion air supplies, or tight building envelopes were identified as contributory factors to spillage or backdrafting in eight of the houses (50%) examined. (Houses were classified as "tight" if they had an equivalent leakage area of ~4 sq.cm/ sq.m of floor area or less.)

In 75% of the problem houses, depressurisation over the recommended limits of 4 -7 Pa by exhaust fan, clothes dryer, fireplace, or built-in vacuum operation was found to be the major contributory factor. (A tight envelope was also implicated in several of these cases).
Vent blockage, restriction or leakage was identified as a contributory factor in 35% of the houses studied. Damage, defects, poor maintenance or fuel problems were noted in 35% of the homes; insufficient vent height in relation to surrounding buildings or vegetation was a contributory factor in two (11%).

Poorly executed conversions from oil-fired were particularly prone to contamination problems. Improper installation or retrofit of equipment, vents and flues was a problem in 35% of the houses.
The results of the Scanada / Sheltair study and that by Hatch Associates increased concern within CMHC about the interaction of atmospheric vent systems and exhaust systems, particularly in tightly sealed houses such as those built to the R-2000 standards. These concerns resulted in the introduction of the "R-2000 Make-up Air Guidelines", which present a variety of strategies to ensure that excessive house depressurisation does not occur. The primary strategies are to provide systems that will supply sufficient outside air to compensate for exhaust flows, or to eliminate the use of atmospherically vented heating and domestic hot water equipment entirely.

Systems recommended by the Guide to provide make-up air range from the provision of a simple passive inlet duct equipped with a motorized damper (least recommended approach, applicable mainly for dryers only), to dedicated make-up air supply fans, complete with heaters and positive shut-off dampers, interlinked with exhaust fan operation.

Vent System Leakage

The same study identified no instances of vent system leakage or cracked heat exchangers in atmospherically vented natural gas equipment, and only one instance in of a cracked heat exchanger in an oil furnace. However, the Hatch report identified blocked or damaged vents and chimneys in 31% of carbon monoxide poisonings in Canada from 1973 to 1981; damaged heat exchangers, equipment defects and problems in 46%; and improper installation, lack of understanding or poor maintenance in 24%. Any of these categories could include leakage of the vent system or the heat exchanger.

Recent problems have emerged with failure of plastic vent pipe of high efficiency (Category III) natural gas equipment such as furnaces, boilers or combination space/water heating systems. Formation of sulfuric acid or combined sulfuric, nitric and hydrochloric acid within the piping have been found to contribute to vent failure and the release of combustion products to indoor air. This has lead to research efforts by the Canadian and United States Gas Research Institutes, and Underwriters Laboratory to identify solutions.

Unvented Appliances

Unvented natural gas stoves & ovens are major sources of combustion products to indoor air. Unvented natural gas space heaters are not allowed to be installed in residential or institutional buildings in Canada by the Natural Gas Installation Code CAN/CGA-B149.1-M95, which requires vented appliances in all non-industrial occupancies. However, anecdotal evidence suggests that unvented heating appliances are still being misused indoors in many areas.

As can be seen from Table 1.2 emissions from stoves and ranges are of concern. Surveys have shown that gas stoves and ovens are often improperly used as space heaters (especially in lower income homes), which has heightened concern over this type of equipment.
Many studies have found nitrogen oxide and carbon monoxide concentrations are immediately elevated upon use of a gas range or oven, and can reach hazardous levels quickly in normally leaky (>1.0 ACH) and more airtight energy efficient houses. The characteristic concentration pattern is an initial spike of carbon monoxide and nitrogen oxide, with a slow decline over a period of up to five hours until indoor levels approach those outdoors. Carbon monoxide levels have been observed to reach over 35 ppm, and nitrogen oxide levels over 0.56 ppm in prolonged burner use (two hours) in relatively airtight houses, which exceeds both ASHRAE and Health and Welfare Canada guidelines. This is comparable to the 9 - 25 ppm levels of carbon monoxide found in public assemblies that allow smoking. Nitrogen oxide levels tend to decrease more rapidly than carbon monoxide due to adsorption by and chemical reactions with indoor materials and furnishings.

Houses equipped with gas cooking appliances have been found to have average indoor carbon monoxide, nitric acid and nitrogen oxide levels consistently higher than those found outdoors and similar to smoking households and public occupancies; this has been attributed both to burner and oven use, and the presence of pilot lights for ignition. Both pollutant emissions and energy efficiency concerns have led many appliance manufacturers to introduce electronic ignition devices that eliminate pilot lights in the past decade.

Considerable research has been performed by the US Gas Research Institute on factors affecting nitrogen oxide emissions from conventional gas ranges and ovens, but initial studies were ambiguous and often had conflicting results because of the lack of standardized testing protocols. Major conclusions include:

- nitrogen oxides emissions factors are independent of burner position, but carbon monoxide emissions are tend to be higher from rear burners as compared to front burners, typically because secondary air is less available at the back of the range, resulting in less complete combustion.
- Carbon monoxide and nitrogen oxide emissions are not greatly affected by fuel composition.
- Nitrogen oxide emissions are significantly affected by fuel input rate, with yellow flame conditions having increased CO and NO_2 and decreased NO emissions compared to blue-flame conditions.
- Grate material and height had no significant effect on emissions.
- Studies of emissions from burners with and without pans have conflicting results.

A standard testing procedure was developed by Battelle for the U.S. Gas Research Institute, to examine the effect of conventional burner design on emissions. Their report indicated:

- Cast iron burner caps, lower port loadings, higher primary aeration and lower secondary aeration resulted in lower NO_2 emissions. While it was concluded that the thermal and physical characteristics of the burner cap had a significant effect on NO_2 emissions, the study did not isolate the effect of mass, thermal conductivity, and thermal mass.
- Gas composition, burner cap size, turndown ratio and the relative positions of burner cap and aeration pans had no effect on NO_2 emissions.

There has been considerable research on design of low-NOx emission burners and ranges over the past decade. A 1991 study that used the Battelle protocol of 20 conventional and advanced burner and stoves, including an advance vented appliance and several from Europe and Japan, indicated:

- Low input burners had lower NO_2 emissions than high input burners; NO_2 emissions increased with firing from minimum stable flame conditions to the maximum.
- Increased primary aeration decreased NO_2 emissions.
- Reduced secondary air decreased NO_2 emissions from open flame burners, but increased them from sealed top burners.

- Sealed top blue flame burners had greater NO_2 emissions (138%) than open top burners.
- NO_2 emissions from heavy mass burners were much lower than low mass burners.
- Infrared burners produced much lower NO_x emissions (9%) than open blue flame burners.

The infrared burners were composed of ceramic tile sealed under a flat glass cooktop, and a forced draft pre-mix jet impingement ceramic tile burner under a perforated glass-ceramic plate. One of the project's objectives was to develop a low-emission, fully vented cooking appliance that would meet indoor air quality guidelines, and it was technically successful in doing so, but no field evaluation was performed because no manufacturer was found to participate. The Canadian Gas Research Institute also developed a sealed combustion gas range, in which some interest was expressed by a Canadian manufacturer.

Growth Promotion of Biological Pollutants

Three mechanisms have been identified by which natural gas equipment and accessories can promote the growth of biological agents that can affect indoor air quality, such as fungi, bacteria and moulds. These are:

1. increased exposure to outdoor bacteria and fungi carried indoors by combustion and excess air required by atmospherically vented equipment;
2. increased indoor relative humidity produced by unvented combustion of natural gas; and,
3. standing water, either in drain pans of gas equipment accessories such as humidifiers and cooling coils; or as a result of condensation from high indoor humidity.

Relatively little research has been performed on the promotion of biological agents by natural gas equipment, largely due to the complexity and expense of identifying the wide variety of potential agents in a large enough sample to be statistically meaningful.

An Overview of Prime Air Contaminants

This section introduces the categories of air contaminants of concern, and the acceptable exposure levels. Part 2 of this report provides details on each contaminant.

Contaminants have been broken down into two categories which are distinctly different in the details of occupant exposure:

- **Combustion Contaminants,** which are directly produced by combustion appliances, including
  - ⇒ CO2
  - ⇒ CO
  - ⇒ Water Vapour
  - ⇒ Aldehydes
  - ⇒ Nitrogen Oxides (NOx)
  - ⇒ Organic compounds
- **Biological Pollutants,** which are a byproduct of high humidities and other conditions created by combustion contaminants, including
  - ⇒ Moulds
  - ⇒ Fungi
  - ⇒ Viruses
  - ⇒ Bacteria

Standard Combustion Emissions

Carbon dioxide and water vapour are produced as a inevitable result of the chemical combination of carbon and oxygen.

Carbon monoxide, and organic compounds such as aldehydes and aromatic hydrocarbon emissions are results of incomplete combustion due to imperfect mixing of the fuel and combustion air.

Other emissions, such as nitrogen oxides and other volatile organics, are products of combustion at high temperatures in air, which supplies the necessary nitrogen.

Sulphur dioxide emissions result from the combination of trace sulphur in the fuel and atmospheric oxygen during combustion.

Organic Compounds

Indoor organic compounds include a wide array of chemical compounds, in four main classes:

Aldehydes

hydrocarbons that include a hydroxyl (-OH) group at the end carbon of the hydrocarbon chain. Examples include formaldehyde, acetaldehyde

Aliphatic hydrocarbons

consist of straight chain, branched chain and cyclic saturated systems, i.e., with a ring of five carbon atoms bound in a ring with a carbon, hydrogen attached to each. Examples include butane, isobutane, propane, cyclopentane and petroleum distillate solvents.

Aromatic hydrocarbons

hydrocarbons consisting of benzene ring arrangements, i.e., six carbons attached in a ring with a single carbon or hydrogen attached to each. Examples include benzene and polycyclic aromatic hydrocarbons (PAHs) such as toluene and the xylenes; typically liquids at room temperature. Some of these compounds are solvents, and are found in many consumer and building products. Benzene is present in many hydrocarbon fuels, including trace amounts in natural gas; PAHs are produced in combustion of hydrocarbons.

Halogenated hydrocarbons

hydrocarbons bonded with one or more halogens, such as chlorine. Examples include tetrachloroethylene, trichloroethane and trichloroethylene; typically liquid at room temperatures. Many of these compounds are excellent solvents, and are found in many consumer and building products; they have not been found to be typically a product of gas combustion except under unusual circumstances.

Over 800 organic compounds have been identified in indoor air; sources include buildings materials such as plywood, foam insulation, furniture, finishes such as paints, and many others, as well as combustion gasses. While the main sources of indoor organic compounds are seen to be offgassing of furnishings and construction material , unvented combustion and combustion gas leakage are significant contributors in some cases.

Organic compounds of concern resulting from combustion include formaldehyde, acrolein, benzene, polycyclic aromatic hydrocarbons, and others. The health effects of many of these are poorly understood, particularly in complex mixtures typically found in much indoor air. Synergistic and additive effects are suspected, and under some investigation. In particular, chronic exposure to low levels is not well characterized at this time.

It has been found that aliphatic and aromatic hydrocarbons are predominant in indoor air, with halogenated hydrocarbons less represented, particularly in new buildings. Total VOC exposures in indoor air in new buildings will range ten times greater than that found in older building. Many new building materials have high glue and solvent content which can offgas for considerable periods after installation.

Typical Concentration Ranges for Volatile Organic Compounds

New Buildings:
0.50 to 19 mg/m3

Existing Buildings:
0.01 to 1.7 mg/m3

Outdoors:
<0.16 mg/m3

Water Vapour

While water vapour is not itself toxic or known to be unhealthy over a wide range of exposures, it is an essential component to the growth of many biological contaminants and enhances the effects of many other combustion pollutants such as nitrogen and sulphur oxides. Water is an unavoidable product of hydrocarbon combustion, and unvented combustion by natural gas space heaters and kitchen ranges can contribute significantly to indoor humidity.

Standing water resulting from condensation can be found in poorly maintained gas appliance accessories such as air conditioning coils and humidifiers. This hazard is more fully discussed in the following section on biological pollutants.

Biological Pollutants

Biological pollutants in indoor air can include allergens such as pollens and animal dander, funguses, molds, and pathogens such as Legionella. The common factor of many of these contaminants, particularly the latter, is the presence of standing of water or consistently high humidity levels, warm temperatures, and the presence of a growth medium (dust and carbon are excellent foods for many of these agents).

The mix of hazardous biological agents in any given indoor circumstance is a unique and dependent on the particular growth and dispersion factors present. Discussion of specific effects of individual agents is beyond the scope of this report, but range from mild allergenic symptoms such as sneezing and immune system suppression by pollens, to respiratory and pulmonary infections from fungus and molds, and death from pneumonia and other complex mechanisms of legionella.

Water vapour resulting from unvented natural gas combustion, and leakage of combustion gasses into the indoor air, can increase indoor humidity levels that aid the growth of biological agents. As well, accessories of gas equipment, such as humidifiers and air conditioning coils, can act as reservoirs, amplifiers and disseminators of microorganisms, spores and bacteria. Entrainment of outdoor sources of moisture laden exhaust or cooling tower spray into ventilation air has been implicated in several outbreaks of both Legionellosis and Pontiac fever.

Untreated water in air conditioning systems and cooling towers have been identified as prime sources of Legionella pneumophila, aspergilla fumigatus, penicillium and others.

Several combustion products of natural gas equipment, such as nitrogen and sulphur oxides, have been shown to increase susceptibility to respiratory and bacterial infection.

With greater sealing of, and reduced ventilation in, buildings as concern rises for energy conservation, indoor concentrations of unhealthy biological agents have probably risen. Hospitals are of particular concern, due to the danger to vulnerable patients to increased exposure to pathogens.

The wide variety of biological agents found in indoor air, and difficulty in detection, has prevented most regulatory agencies from establishing indoor air limits and concentrations.

Indoor Air Concentration Recommendations, Limits and Standards

Many different exposure limits and standards are in use for different circumstances in different jurisdictions worldwide. In North America, regulation of air concentration limits has been driven largely by occupational health and safety and outdoor air pollution legislation, and only recently by increased concern with long term exposures to levels typically found in indoor environments. Table 1.4, at the end of this section, presents a summary of *Air Quality Standards & Guidelines for Contaminant Concentration* for indoor air, outdoor air, and industrial applications drawn from a variety of sources in North America and Europe.

A Few Words of Caution about Using IAQ Limits

Guidelines and limits for IAQ are notoriously difficult to interpret. Below we have outlined some of the most important

Exposures can vary within the same household

Typical exposures to combustion gasses in indoor circumstances often follow a characteristic pattern of short exposures (several minutes to an hour) to relatively high concentrations in a limited area, with an hours-long decay to lower average background levels throughout the building, to which all occupants are chronically exposed. An example of this pattern is that of a kitchen range used for cooking, where the cook often experiences to high levels of many different combustion products while preparing the meal, and the other occupants are exposed to lower average levels as the pollutants disperse through the building and are diluted.

This pattern of exposure presents difficulties in assessing the hazards of exposure to indoor air pollutants. Occupants may be affected both by short exposures to relatively high levels of pollutants approaching those found in industrial circumstances, as well as long term exposures to low concentrations that may have subtle health effects. The majority of the research on the health effects of most pollutants has been performed for the high concentrations and healthy workers that may be found in industry, and dose/response relations are often difficult to extrapolate to the lower short term exposures typically seen indoors.

Although Outdoor Air research has Historically Established Limits, but Indoor Air Exposures and Composition can be Much Different.

Concern with outdoor air pollution has led to research on chronic exposures to low average concentrations over long periods, typically a year in duration. However, little research has been performed comparing the pattern of exposures to outdoor air pollution to that indoors. Further, indoor air are typically complex mixtures of pollutants, which makes the definition of the effect of any single contaminant difficult to determine, due to additive and synergistic effects within mixtures, and the confounding effects of other pollutants. This is particularly a concern with many epidemiological studies that form the basis for most outdoor air pollutant standards, which typically do not characterize the pollutant mixtures or other important factors in any great detail.

As well, the amount of time people spend indoors in the course of a year is typically much greater than that spent outdoors, particularly in severe climates such as Canada's. This increases the relative importance of indoor air pollution as compared to outdoor air.

Occupants sensitivity and health can vary greatly

Finally, occupants of buildings span a wide range of health. Occupants of buildings include children, the elderly, those with pre-existing poor health, and the environmentally hypersensitive. These groups are at greater risk from many indoor air pollutants. Typical clinical studies are done with healthy, young male individuals as subjects; extrapolation of results to more diverse populations can be misleading in predicting effects upon people at higher risk.

Background on Terms and Assumptions used in Table 1.4

Occupational and outdoor air standards can inform guidelines for indoor air quality, but are typically higher than is advisable for general use in buildings. One rule of thumb often used by governments agencies and other regulatory organizations, in the absence of definitive research, is to set indoor air pollutant concentrations at one tenth of the occupational standards. It should be noted that indoor air concentration guidelines or standards of a given pollutant are often not determined by our limited understanding of hazard and risk, but by what is achievable or detectable.

Industrial Health and Safety Guidelines and Limits: the American Conference of Governmental Industrial Hygienists (ACGIH)

Industrial health and safety guidelines and limits have been established in the United States by the American Conference of Governmental Industrial Hygienists (ACGIH), who established recommended "Threshold Limit Values" ("TLVs") for industrial application. The ACGIH Threshold Limit Values are "... intended for use in the practice of industrial hygiene as guidelines or recommendations in the control of potential health hazards *and for no other use.*" (Emphasis added.) They are *not* applicable to infants, the sick or elderly or others with chronic health concerns, and are composed largely of time weighted averaged ("TWA") exposures over the course of an 8 hour workday, or short-term exposures ("STE"; typically time weighted average exposure over 15 minutes) in the workplace. The ACGIH standards were influenced heavily by industry, and are widely perceived as being extremely conservative (i.e., higher than acceptable for long-term exposures), but have been influential in establishing indoor concentration guidelines in both the United States and Canada.

Industrial Health and Safety Guidelines and Limits: the U.S. National Institute of Occupational Safety and Health (NIOSH)

The U.S. National Institute of Occupational Safety and Health (NIOSH) has also developed Recommended Exposure Limits ("REL's"). NIOSH claims that their Recommended Exposure Limits are more applicable to indoor air quality situations. However, REL use for indoor air is currently in dispute from both sides of the debate.

Outdoor Air Standards: National Ambient Air Quality Standards (NAAQS)

Outdoor air pollution standards have been derived largely from risk assessments performed by the U.S. Environmental Protection Agency to establish National Ambient Air Quality Standards ("NAAQS"), and other national regulatory bodies. The NAAQS standards are based on average exposures over the course of one year.

Indoor Air Quality Standards & Recommendations

ASHRAE Standard 62-1989, "Ventilation for Indoor Air Quality" & Health & Welfare Canada's "Exposure Guidelines for Residential Indoor Air Quality"

There are few guidelines for indoor air exposure limits, the most notable being ASHRAE Standard 62-1989, "Ventilation for Indoor Air Quality", and the "Exposure Guidelines for Residential Indoor Air Quality" by Health and Welfare Canada. Both are being incorporated into new provincial codes and standards; the B.C. Workman's Compensation Board draft standards currently under debate (November 1995) are an example of current directions of future legislation and regulation in Canada.

ASHRAE Standard 62 is also currently under revision, and has taken the position that, where no indoor air guidelines or standards have been established for a particular contaminant, to use as a first guide levels which are typically one tenth of the threshold limits values of the ACGIH and other bodies. It is assumed that these will not cause widespread complaints in a non-industrial population or occupancy. However, the revised Standard recognizes that "the 1/10 TLV may not provide an environment satisfactory to individuals who are extremely sensitive to an irritant." Environmentally hypersensitive individuals are advised that expert help should be consulted to establish acceptable limits on an individual basis.

Part 2: Quick Reference on Indoor Air Pollutants of Natural Gas Equipment

Introduction to the IAQ Quick Reference

The following pages describe the key indoor air contaminants of concern. Each contaminant is summarized in the following manner:

- Description,
- Acute Effects,
- Chronic Effects,
- Sensitive Populations,
- Interactions with other pollutants.

Note that the acute effects for most of the contaminants are seldom the result of concentrations found indoors in homes or offices. Notable exceptions are carbon monoxide and nitrogen oxides.

Carbon Monoxide

Description

Carbon monoxide is a flammable, colourless and odourless gaseous product of incomplete combustion of any carbonaceous fuel, including natural gas. Its density is slightly less than that of air; it is readily soluble in water and diffuses easily through biological membranes. Its flammability limits in air are 12 - 75% by volume.

Carbon monoxide binds selectively with blood hemoglobin, reducing its ability to transport oxygen to the tissues and inducing oxygen starvation, or hypoxia. Carbon monoxide has over 200 times the binding affinity to hemoglobin than oxygen. The level of the carbon monoxide saturated hemoglobin (carboxyhemoglobin) in the blood is a clinical indicator of reduced oxygen transport capacity.

No studies reviewed indicate other adverse health effects of carbon monoxide exposure, with the possible exception of heart metabolism changes and increased capillary protein permeability in some cases.

One hour average outdoor concentrations in major Canadian cities have been found to range from 0 to 30 ppm; the highest eight hour average reported was ~20 ppm. Indoor concentrations have been found to range from 0,.90 to 87 ppm, averaging 5 ppm in typical circumstances.

From an indoor air quality perspective, the primary natural gas equipment sources are unvented combustion appliances such as ranges and space heaters; and backdrafting or vent leakage from equipment with poorly adjusted or badly maintained burners.

Acute Effects

The effects of carbon monoxide exposure are influenced by the concentration and duration of exposure, as well the health of the individual. The body produces some carbon monoxide itself; normal blood levels are ~0.5% carboxyhemoglobin.

The healthy body compensates for reduced blood oxygen supply by increasing cardiac rate and blood flow to specific organs such as the brain, heart and liver. Individuals with reduced cardiovascular or respiratory ability are less able to respond in this way, and are thus at greater risk. It normally takes the body ~16 hours to return to equilibrium after carbon monoxide exposure.

The acute effects of carbon monoxide are those of hypoxia, or lack oxygen: loss of alertness, impaired vision, changes in blood flow, reduced learning ability and manual dexterity, confusion, drowsiness, headaches, nausea, and at exposures greater than 1800 ppm for one hour, convulsions, coma and death. Hemorrhage of the nerve fiber layer of the retina has been found to be an indicator of subacute CO poisoning,

Chronic Effects
Few effects of either chronic low level or acute carbon monoxide exposure are known at this time. Studies of tunnel workers and submariners have showed no long term general health effects.

Sensitive Populations
Those people with reduced cardiovascular ability, such as fetuses and the elderly, and those with heart or respiratory disease or adjusting to high altitudes, are at greater risk because of their limited ability to respond to lower blood oxygen levels. As well, use of alcohol and other drugs can increase susceptibility.

Interactions with Other Pollutants
There are no known chemical interactions of note with other air pollutants. However, nitrogen oxide also binds with hemoglobin to affect the blood's oxygen carrying capability, so effects of exposure to mixtures of carbon monoxide and nitrogen oxides are additive; the effect of nitrogen oxide exposure is roughly four times those of similar carbon monoxide concentrations.

Carbon Dioxide

Description

Carbon dioxide is a clear, colourless, non-flammable gaseous product of combustion of any carbonaceous fuel, including natural gas, as well as metabolic respiration. It is non-toxic in low and medium concentrations (<12, 600 ppm), but has been reported to cause unconsciousness at 70,000-100,000 ppm (7-10%), possibly due to oxygen displacement.

Carbon dioxide is a normal constituent of ambient air; typical levels in outdoor air range from 300 to 500ppm. Its density is typically approximately 1.5 times that of air; it is readily soluble in water and diffuses easily through biological membranes.

Indoor concentrations of carbon dioxide are used as a general indicator of indoor air quality; ASHRAE Standard 62-1989 recommends that provision of ventilation to an indoor concentration of 1000ppm or less as likely to meet comfort and odour criteria for most occupants.

Outdoor concentrations are typically in the range of 350 to 500 ppm, depending largely on the proximity to sources such as busy roads.
Indoor concentrations have been measured from 450 to 5600 ppm, and typically average ~600 ppm.

Carbon dioxide is the reference greenhouse gas, with a "global Warming Potential" of one, and is one of the main anthropogenic compounds that may result in global climate change.

From an indoor air quality perspective, the primary natural gas equipment sources are unvented combustion appliances such as ranges and space heaters; and poorly adjusted or badly maintained burners.

Acute Effects

The body's response to short-term high level exposure to carbon dioxide is to increase the rate and depth of breathing, and thus blood acidity . Exposure to levels of 500 - 3200 ppm has been associated with subjective symptoms of undue fatigue, increased perception of warmth and unpleasant odours, and headaches; however it is unclear if these may have been caused by other substances. Exposure to levels exceeding 50,000 ppm can result in headaches, dizziness and visual distortion, with some evidence of cardiovascular effects. Extremely high concentrations (70,000-100,000 ppm or 7-10% by volume) have been reported to cause unconsciousness, possibly due to oxygen displacement.

Chronic Effects
Long term exposure (several weeks) has been studied by several researchers in both human and animal studies. The lowest concentration known to produce adverse human health effects (increased blood acidity) is 7000 ppm over the course of several weeks of continuous exposure. The body regulates blood acidity by kidney function, which has been seen to increase with long-term exposure, and by metabolizing of calcium, leading to some bone decalcification.

Sensitive Populations
Research has not identified a specific population that is especially vulnerable to increased carbon dioxide exposure. However, individuals with reduced kidney function, or who suffer from bone calcium deficiencies such as those induced by poor diet or osteocalcholysis are likely to be at increased hazard from long term exposure to high levels of ambient carbon dioxide.

Interactions with other pollutants
No interactions or synergies with other air pollutants have been identified, except possibly for those associated with increased temperature due to global warming.

Nitrogen Oxides

Description
Nitrogen oxides are formed in atmospheric combustion occurring at high temperatures. They include a number of compounds: NO (nitric oxide), NO_2 (nitrogen dioxide), N_2O (nitrous oxide), and others such as OONO, ON(O)O, N_2O_3, N_2O_4, and N_2O_5. Of these, nitrogen dioxide is the most detrimental to human health at concentrations typically found in indoor air, and many studies reference the cumulative effects of an nitrogen oxide mixture in units of total equivalent NO_2. Many of these combustion products are highly reactive and thus short lived in standard atmospheric conditions. Nitric oxide and nitrous oxide are both colourless gases; nitrogen dioxide is reddish-brown and has an acrid odour.

Health effects of nitrogen oxide exposure are dependent on dosage, time of exposure, and the pulmonary health of the individual exposed. Concentrations of nitrogen oxides in indoor air have been measured to range between ~0.015 - 1.5 ppm.

Outdoor concentrations have been found to range from 0 to 0.50 ppm in major Canadian cities for a one hour average; eight hour averages have been found to range from 0 to 0.29 ppm. Pollution control regulation, particularly of car emissions, has resulted in significant improvements in outdoor air ambient concentrations in the past decade.

Indoor concentrations have been found to range from 0.006 ppm to 1.46 ppm, and under typical circumstances (without an indoor combustion source) average ~0.06 ppm. From an indoor air quality perspective, the primary natural gas equipment sources are unvented combustion appliances such as ranges and space heaters; and poorly adjusted or badly maintained burners. Other sources, particularly for induced outdoor air, include internal combustion engine exhausts.

Acute Effects
Brief exposures as low as 0.5 ppm can result respiratory and eye tissue irritation, nasal discharges, increased bronchoconstriction, especially asthmatics and those with impaired lung function. Little human clinical research has been done on exposures below this level, and a "no-adverse-effect" level has not been established. Animal studies at similar short-term exposures indicate inhibited respiration, decreased brain activity, morphological changes in blood vessels and disturbed energy metabolism.
Both NO and NO_2 bind selectively with blood hemoglobin to form methemoglobin. The effect is the same as carbon monoxide: to reducing the

bloods ability to transport oxygen, resulting in hypoxia. However, nitrogen oxides have an effect roughly four times that of similar carbon monoxide concentrations. As a result, NO_x exposure has similar, but more pronounced effects to those noted for hypoxia induced by carbon monoxide.

Concentrations of greater than 1 ppm have been shown to affect all humans exposed. Exposure to levels ranging from 1 - 100 ppm for up to two hours cause increasing airway resistance, and decreased pulmonary function. Exposures of 10 ppm for less than one hour typically causes acute respiratory, nasal and eye irritation as well; levels over ~20 ppm induce pneumonia and bronchitis. Concentrations over 150 ppm cause death due to bronchial damage or pulmonary edema. Nitrogen oxides readily form highly reactive acids, such as nitric acid, in the respiratory tract and other mucous membranes, the probable cause of acute irritation.

Chronic Effects

Effects of nitrogen oxides at typical indoor air levels has been the subject of much epidemiological research. Unfortunately, much is confounded by simultaneous exposure to associated combustion pollutants and the lack of accurate exposure data. An increased prevalence of respiratory illness in adults and children has been associated with average levels of ~0.10 ppm, similar studies show little of no association at mean levels of ~0.05 ppm.
The biological action of nitrogen oxides includes oxidation of unsaturated fatty acids such as those in cell membranes, resulting in highly chemically active free radicals. These affect the physiological functioning of membranes and can alter proteins such as elastin and collagen, key components of lung tissue. There is evidence of the formation of nitrosamines, which are potentially carcinogenic and have been implicated in liver dysfunction. However, the link between these effects and chronic low-level exposure to NOx has not been conclusively established to date.

Sensitive Populations

Those people with reduced cardiovascular ability, such as fetuses and the elderly, and those with heart or respiratory disease or adjusting to high altitudes, are at risk because of their limited ability to respond to lower blood oxygen levels. Similarly, persons with impaired lung function, such as asthmatics and children less than two years old are more susceptible to NOx exposure.

Interactions with other pollutants

Nitrogen oxides are principal reactants in the formation of photochemical smog when exposed to sunlight. Photochemical smog includes such compounds as ozone and peroxyacetylnitrates (PANs), many of which have detrimental health effects. These reactions are not known to occur without exposure to sunlight;

however, no studies have been found to explore these reactions under artificial light frequencies typically found indoors.

Several other interactions are potentially of concern. Exposure to elevated levels of nitrogen oxides can reduce alveolar cleaning, resulting in more prolonged exposure to particulates. Reactions with airborne and mucosal amines result in nitrosamine formation, a possible carcinogen. Reactions with benzo-a-pyrene and pyrelene form mutagenic compounds.

Hypoxia reactions due to exposure to mixtures of nitrogen oxides and carbon monoxide are additive.

Sulphur Oxides

Description

Sulphur oxides are formed by combustion of sulphur, mostly in trace amounts in fossil fuels. They include a number of oxides, of which sulphur dioxide (SO_2) is the greatest concern. Sulphur dioxide is a colourless gas at standard temperature and pressure, with a characteristic pungent odour. At temperatures below 14 F it may be liquid. Much Canadian natural gas is treated to remove sulphur compounds before being shipped to market, however, sulphur is typically a component of safety odourants, such as methyl mercaptan, added to natural gas sold to the consumer.

Sulphur dioxide is a strong irritant to mucous membranes in the lungs, throat and eyes, primarily due to sulphurous acids and sulfate salts formed on contact with moisture. Consequently, adverse health effects of sulphur oxides are typically increase with higher humidity, where acidic droplets are more easily breathed deeply into the lungs.

In a 1979 study, average annual mean outdoor levels of sulphur dioxide in 69 Canadian cities were found to be 0.012 ppm; 90% were found to be less than 0.018 ppm. One hour average concentrations were found to range from 0 to 1.1 ppm; 24 hour averages measured varied between 0 and 0.2 ppm. Indoor concentrations are typically lower than outdoor concentrations by a factor of two (typically ~ 0.06 ppm), in the absence of an indoor source; SO_x is readily adsorbed by many indoor finish materials and furnishings, which tends to reduce indoor air concentrations.

From an indoor air quality perspective, the primary natural gas equipment sources are unvented combustion appliances such as ranges and space heaters; and poorly adjusted or badly maintained burners. The prime source of sulphur dioxides is polluted outdoor air, particularly in areas close to high traffic, or industrial smelting, ore refining or high sulphur coal-fired combustion operations.

Acute Effects

Acute effects of sulphur dioxide exposure do not typically result of the low levels of exposure from indoor air. Clinical studies indicate that airway and nasal (pulmonary) flow resistance of healthy subjects is reversibly increased following short exposures to 1.0 ppm; similar effects in asthmatics have been found with exposures as low as 0.38 ppm. Increased concentrations of SO_x increase these impacts; mouth breathing tends to have larger effects than nose breathing. Exposure to concentrations greater than 20 ppm results in choking and sneezing. Direct effect of acids on epithelial tissue in the lungs is the main mechanism of damage; these are aggravated by the increased permeability of mucous membranes, which makes the subjects more susceptible to intake of toxic gasses, and sulfate cations in the acids are also toxic.

Chronic Effects
Epidemiological studies of SO_x exposure suffer from the same limitations as those conducted for NOx exposure, i.e., confounding factors, and a shortage of representative exposure data. They have however resulted in some insight into health effects of chronic exposure. Chronic impacts are related to long-term changes in lung function due to irritation, which renders the subjects more susceptible to infection and the toxic or carcinogenic effects of other pollutants. Populations exposed to ambient air concentrations greater than 0.12-0-0.15 ppm over 24 hours exhibit excess mortality, especially in the elderly and with pre-existing cardiac and pulmonary conditions, and hospital admissions rise under these conditions. Increased acute and chronic respiratory ailments and cardiopulmonary function have been observed in subjects exposed to mean concentrations of 0.038 ppm for over one year. Exposure to average levels of 0.04 ppm have been seen to induce 100% increase in days of illness of bronchitis patients. Chronic exposure to levels at or below 2 ppm has been seen to induce an increased loss of pulmonary function in smelter workers.
It is suspected that sulphur dioxide is itself a carcinogen or mutagen, and that it may promote the effects of other compounds such as benzo(a)pyrene in development of squamous cell carcinoma. There is also some evidence that it may cause teratogenesis or other reproductive impairment.

Sensitive Populations
People with cardiovascular or pulmonary illness are especially vulnerable to sulphur oxide exposure, as are the elderly and young children. Pregnant woman are advised to avoid high sulphur oxide exposures.

Interactions with other pollutants
Increased humidity tends to increase the effects of sulphur oxides, due to the formation of acidic compounds which are more easily breathed deeply into the lungs. Sulphur oxides and the resulting acids are also strong oxidizing agents of toxic heavy metals and are likely to increase their health effects. Interactions between sulphur oxides and polyaromatic hydrocarbons have been observed, and are thought to play a role in their carcinogenic effects.

Aldehydes

Acute Effects
Formaldehyde is the best understood of the organic compounds resulting from combustion, and its effects are similar to those of most other aldehydes. Formaldehyde is a colourless gas with a pungent odour. It is an important mediator in the normal metabolism of cells. The most significant sources in indoor air, other than combustion, are furnishings and construction materials such as carpets, insulating foams, plywoods and particle boards.

Formaldehyde levels in Canadian homes not insulated with ureaformaldehyde foams (UFFI) have been found to range from 14 to 42 ug/m3. (0.011 - 0.034 ppm); UFFI houses were found to significantly higher, averaging 66 ug/m3. (0.054 ppm). Higher concentrations in UFFI houses has been found to be due to increased airtightness and thus lower infiltration rates, as well as increased source strength. Outdoor levels in Canada are typically 10 ug/m3. (0.008 ppm). Acrolein levels in indoor air range from 2 to 50 ug/m3. (0.001 - 0.02 ppm); smoking environments have been found to range from 0.006 ppm to 0.013 ppm. Measured acetaldehyde concentrations range from 1 to 48 ug/m3. and average 17 $ug/m^{3.}$

Acute Effects
Effects of formaldehyde concentrations exceeding 0.5 ppm for short exposures include irritation of the eyes, nose, and throat. Exposure to acrolein at levels as low as 0.09 ppm have resulted in significant increases of eye irritation, with levels of 0.8 ppm leading to severe irritation. Acetaldehyde is significantly less irritating, with these symptoms appearing only at exposures greater than 25 ppm.

Chronic Effects
Very high exposures (up to 3000 ppm) to either formaldehyde or acetaldehyde, inducing nasal cancer in rats, have lead both to be designated suspected human carcinogens, however, epidemiological studies have to date been inconclusive. Formaldehyde and acetaldehyde have also been found to be weakly mutagenic and genotoxic; acrolein is not currently thought to present a carcinogen hazard.

Aliphatic hydrocarbons

Aliphatic hydrocarbons commonly associated with natural gas include butane, isobutane and propane; these have four or fewer carbon atoms and are gaseous at room temperatures. They are also used as aerosol propellants. These short chain hydrocarbons have no known chronic health effects at concentrations typically encountered indoors, though at extremely high levels displacing oxygen can cause asphyxia, besides the obvious safety risk.

Aliphatic hydrocarbons such as hexane, heptane and octane with longer carbon chains are liquids at room temperature and are commonly found in glues, varnishes and paints and inks where they are commonly used as solvents. Several induce central nervous system depression at very high concentrations, not typically found in non-industrial indoor air. N-hexane has been implicated in nerve damage in industrial workers.

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs), such as benzo(a)pyrene, benzanthracene, chrysene, benzofluoroanthracenes and others, are produced in combustion of hydrocarbons. They are can be found in both vapours and as non-volatile solids, and are easily adsorbed into airborne particulates, which have been found to bear over 100 different PAHs. As a result, their effects are indistinguishable from the effects of fine airborne particle.

Natural gas equipment are secondary sources of PAHs as compared to wood or coal combustion, tobacco smoke, and internal combustion engines. However, cooking using gas ranges (particularly involving charring of the food), unvented appliances and combustion gas leakage are thought to be significant indoor sources.

Little quantitative data was reviewed on PAH levels in indoor air; outdoor levels are known to range from 0.001 to 60 ng/m^3. Identification of specific compounds requires gas or liquid chromatography analysis, which till recently was an expensive and time consuming process. More research is being performed as gas chromatography becomes easier and less expensive.

Epidemiological studies have typically been confounded by the occurrence of other factors. Similarly, no dose-response relationship has currently been established for most PAHs. However, all polycyclic aromatic hydrocarbons are among the most potent known animal carcinogens and are thought to carcinogenic in man.

Interactions with other pollutants
Aliphatic hydrocarbons are precursors of photochemical smog when exposed to sunlight outdoors. It is not currently known if similar reactions occur under artificial light. The health effects of many organic compounds are though to be additive and possibly synergistic, but the complexity of research in this area is daunting.

Soot and Particulates

Description
Airborne particulates are complex mixtures of physically and chemically diverse substances, in both solid and liquid forms, including soot, dust, man-made mineral fibres, animal dander, sulfates and nitrates and others. They vary in size from 0.005 to 100 um; particles less than 10 um are of particular concern because they are easily inhaled deep into the lungs. Particles between 10 and 15 um are typically deposited high in the esophagus or in the nose and mouth. These are of less concern than those that are deposited in the tracheobronchial or pulmonary regions of the lung.

Cigarette smoke is the primary source of indoor airborne particles, with unvented combustion another significant source. Indoor particulates tend to be associated with polycyclic aromatic hydrocarbons, which also result from combustion of hydrocarbons, particularly in sooty flames such as wood fires, coal and badly adjusted natural gas flames. The envelopes of buildings tend to filter large particles from infiltrating outdoor air, so sizes of particles indoors tend to be smaller than is typically encountered outdoors.

Indoor concentrations also tend to be higher indoors than out, with levels approaching 20 to 30 ug/m3. Houses with smokers have been seen to have levels approaching 40 ug/m3., however, no studies were reviewed identifying indoor particulate concentrations associated with vented or unvented natural gas combustion.

Acute Effects
Increased hospital admissions have been noted at exposure levels of 250 - 350 ug/m3., with respiratory distress symptoms. This is especially apparent in the elderly, children and people with pre-existing complaints. Increased mortality in vulnerable populations has been observed in long term (one to four days) exposure to levels of 500 ug/m3., associated with high SO_x levels. Children exposed to similar levels tended to have impaired pulmonary capacity for several weeks.

Chronic Effects
Increased respiratory disease and reduced respiratory function are associated with long term (several years) exposure to levels averaging 180 ug/m3. of total suspended particles and 80 ug/m3. fine particles.

Sensitive Populations
People with pre-existing respiratory illness such as asthma or bronchitis and cardiovascular ailments are especially vulnerable to respirable particulate exposure, as are smokers, mouth-breathers and the elderly and young children.

Interactions with other pollutants
As previously mentioned, indoor airborne particulates are often closely associated with adsorbed polycyclic aromatic hydrocarbons, many of which are known carcinogens. As well, particulates are known to reduce the ability of lung and throat tissues to remove other contaminants, and may thus increase their effects. Synergistic effects are suspected, but not well researched.

Biological Pollutants

Su, Rotnitzky, Burge and Spengler performed a thorough microorganism field collection and culture study on 150 houses in Topeka, Kansas in 1992. The sample included houses that were broken into four groups: non-smoking, no gas stove; smoking, gas stove; smoking, no gas stove; and non-smoking, gas stove. As well as field collection of airborne spores and bacteria, a survey of health history and home characteristics was taken for each home. The field samples were then cultured, and the number and type of mold, fungi, bacterial species identified. The researchers then used statistical techniques to identify species that were significantly associated, both with other species populations and health and physical characteristics of the occupants and homes.
The study revealed several species to be correlated with the presence of gas stoves, specifically Alternaria spp., Cladosporidium spp., Epicoccum spp., Aureobasidium spp., and yeasts. These are typically outdoor fungi that grow on dead organic matter with optimal temperatures between 18 and 25 deg.C, and their greater incidence was associated with the presence of a gas stove with greater than 95% probability. The presence of these agents was also significantly associated (P>97%) with increased incidence of children's respiratory illness such as wheezing, asthma and hay fever. The study did not examine the cause of these complaints, which may also have been due to direct effects of combustion product exposure. The authors suggested several possible causes for the correlation of gas ranges and these species: the increased outdoor air required for combustion; possibly greater resistance of these species to higher concentrations of combustion products; or the increased humidity produced by water released in combustion.

The same study also indicated a high correlation (P> 81%) between reservoirs of standing water and higher counts of Fusarium spp., Aspergillus spp., and other and unknown fungi. The fungi in this group all require more water for growth than the others studied. While the report did not detail the type of water reservoirs reported in the survey, it does point out the general principle, well established in indoor air quality remediation engineering, that standing water reservoirs, such as coil drain pans and moisture from cooling towers and humidifiers, should be avoided. Condensation on window sills and other cold envelope areas that results from high indoor humidities can also serve as incubators of these fungal and bacterial species; use of unvented gas ranges and heaters can result in high indoor humidities if not properly ventilated.

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Table 1.4: Survey of Air Quality Standards & Guidelines

	Combustion Oxides				Organic Chemicals								Particulates	
					Aldehydes			Aliphatic Hydrocarbons			Aromatic Hydrocarbons			
	Carbon Monoxide	Carbon Dioxide	Nitrogen Dioxide	Sulphur Dioxide	Formaldehyde	Acetaldehyde	Acrolein	Methane	Butane	Propane	Benzene	Polycyclic Aromatic Hydrocarbons	Respirable Particulates	Total Particulates
Typical Indoor Air Concentration Measurements														
Average	5 ppm	560 ppm	0.056 ppm	0.057 ppm	0.025 ppm	17 ug/cu.m	-	-	-	-	0.03 ppm	-	0.03	-
Range	0.90 - 87 ppm	450 - 5600 ppm	0.006 - 1.46 ppm	-	0.006 - 0.81 ppm	1 - 48 ug/cu.m	0.001 - 0.02 ppm	-	-	-	0.003 - 0.09 ppm	-	0.015 - 0.60 mg/cu.m	-
Indoor Air Quality Standards & Guidelines														
th & Welfare Canada Guidelines for Residential Indoor Air Quality					Σci/Ci<1 (5 min.)									
Acceptable Long Term Exposure Range (8 hour)	11 ppm	3500 ppm	0.05 ppm	0.019 ppm	0.10 ppm	5.0 ppm	0.02 ppm	-	-	-	-	-	-	40 ug/cu.m
Acceptable Short Term Exposure Range (1 hour)	25 ppm	-	0.25 ppm	0.038 ppm				-	-	-	-	-	-	100
ASHRAE Standard 62-1989 Target Guidelines:	3 ppm (alert) 9 ppm (health)	-	100ug/cu.m	80 ug/cu.m	0.1 ppm	-	-	-	-	-	-	-	-	50 ug/cu.m
World Health Organisation Working Group (1984) Consensus:														
Concentration of Limited or No Concern:	2% COHb	<1800 mg/cu.m	0.19 mg/cu.m	0.5 mg/cu.m	0.06 mg/cu.m	-	-	-	-	-	-	-	0.1 mg/cu.m	-
Concentration of Concern:	3% COHb	12,000 mg/cu.m	0.32 mg/cu.m	1.35 mg/cu.m	0.12 mg/cu.m	-	-	-	-	-	No Lower Limit; Carcinogen	-	0.15 mg/cu.m	-
Concentration of Limited or No Concern:	2% COHb	<1008 ppm	0.11 ppm	0.19 ppm	0.05 mg/cu.m	-	-	-	-	-	-	-	0.1 mg/cu.m	-
Concentration of Concern:	3% COHb	6720 mg/cu.m	0.18 ppm	0.513 ppm	0.93 mg/cu.m	-	-	-	-	-	No Lower Limit; Carcinogen	-	0.15 mg/cu.m	-
Occupational Air Quality Standards														
Workman's Compensation Board of B.C.														
Eight hour Limit	25 ppm	-	1 ppm	2 ppm	-	-		-	-	-	-	-	-	-
15 minute Limit	100 ppm	-	-	5 ppm	-	-		-	-	-	-	-	-	-
U.S. Occupational Health & Safety														
8 hour Time Weighted Average	50 ppm	-	-	-	0.75 ppm	200 ppm	-	-	-	-	1 ppm	-	5.0 mg/cu.m	15 mg/cu.m
Short Term Exposure Limit					2 ppm	-	0.1 ppm	-	-	-	5 ppm	-	-	-
Ceiling	5000 ppm	-	5 ppm	5 ppm	-		-	-	-	1000 ppm	-	-		
J.S. National Institute of Occupational Safety and Health (NIOSH)								-						
Recommended Exposure Limit 8 hour Time Weighted Average	35 ppm	5000 ppm	25 ppm (NOx)	2 ppm	0.016 ppm; carcinogen	No Lower Limit; Potential Carcinogen	0.1 ppm	-	800 ppm	1000 ppm	0.1 ppm; carcinogen	-	10 mg/cu.m	10 mg/cu.m
Short Term Exposure Limit	-	30,000 ppm	1 ppm	5 ppm	-	-	0.3 ppm	-	-	-	-	-	-	-
Ceiling	200 ppm	-	-	-	0.10 ppm	-	-	-		-	1 ppm (15 min.)	-	-	-
erican Conference of Governmental Industrial Hygienists (ACGIH)														
Threshold Limit Value / Time Weighted Average	25 ppm	5000 ppm	3 ppm	2 ppm			0.1 ppm	-	800 ppm	Simple Asphyxiant	10 ppm	-	-	10 mg/cu.m
Threshold Limit Value / Short-term Exposure Limits	400 ppm	30,000 ppm	5 ppm	5 ppm			0.3 ppm	-	-		None; Carcinogen	-	-	-
Ceiling	-	-	-	-	0.3 ppm; Potential Carcinogen	25 ppm; Potential Carcinogen	-	-	-	-	-	-	-	-
Outdoor Air Quality Standards														
Environment Canada National Air Quality Objectives														
Maxiumum Desirable Level	5 ppm (avg. 8 hrs); 13 ppm (avg. 1 hr.)	-	0.03 ppm (annual mean)	0.01 ppm (annual mean); 0.06 ppm (avg. 24 r.); 0.17 ppm (avg. 1 hr.)	-	-	-	-	-	-	-	-	-	60 ug/cu.m (annual geom. mean)
Maximum Acceptable Level	13 ppm (avg, 8 hrs); 31 ppm (avg, 1 hr.)	-	0.05 ppm (annual mean); 0.11 ppm (avg, 24 hr.); 0.21 ppm (avg, 1 hr.)	0.02 ppm (annual mean); 0.11 ppm (avg. 24 hr.); 0.34 ppm (avg, 1 hr.)	-	-	-	-	-	-	-	-	-	70 ug/cu.m (annual geom. mean); 120 ug/cu.m (avg., 24 hr)
Maximum Tolerable Level	17 ppm	-	0.16 ppm (avg, 24 hr.); 0.53 ppm (avg, 1 hr.)	0.31 ppm (avg., 24 hr.)	-	-	-	-	-	-	-	-	-	400 ug/cu.m(avg., 24 hr.)
U.S. EPA National Ambient Air Quality Standards														
Average exposure for one year	9 ppm (8 hr exposure)	-	100 ug/cu.m	80 ug/cu.m	-	-	-	-	-	-	-	-	-	50 ug/cu.m
Alert	35 ppm	-	0.055 ppm	-	-	-	-	-	-	-	-	-	-	-
Conversion Factors	1 ppm = 1.15 mg/cu.m	1 ppm = 1.8 mg/cu.m	1 ppm = 1.8 mg/cu.m	1 ppm = 2.64 mg/cu.m	1 ppm = 1.23 mg/cu.m	-	1 ppm = 2.67 mg/cu.m	-	1 ppm = 2.0 mg/cu.m	1 ppm = 1.8 mg/cu.m	1 ppm = 3.2 mg/cu.m	-	-	-