Indoor air quality investigations
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combustion fumes
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carbon monoxide
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VOCs
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IAT INVESTIGATIONS

A division of

indoor air technologies inc.

Indoor air quality investigations

Example Findings

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TITLE

Indoor air quality investigation example findings

SUMMARY

People spend some 95 percent of their time indoors, at home, the office, in schools, shopping malls, roadway vehicles, airports and aircraft, . . .

Since the 1980s, indoor air quality investigations have found school classrooms are often poorly ventilated; portable classrooms, like finished basements, humidifiers and air conditioners, can be sources of microbial growth; aircraft, like office buildings in sub-zero weather, have low humidity environments on flights of over an hour, and like school classrooms, the potential for human contagion spread; and low-level air intakes whether in downtown offices or suburban homes can be sources of combustion fume.ingestion.

This document provides examples of indoor air quality investigation findings in comparison to norms and criteria. The range of examples is not exhaustive. Rather, it is intended to illustrate the techniques and potential for problem identification and hence resolution. Indoor air quality problem solving is not always straightforward. It requires best available measurement tools, knowledge of what, where and when to measure, and finally an ability to interpret findings and their etiology.

WE HOPE THAT THE INFORMATION WILL BE HELPFUL TO ALL WHO READ IT, INCLUDING:

- Property managers (offices, malls, hotels, restaurants)
- School boards, teachers and parents
- Airline crews and manufacturers
- Homeowners

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1.0 Introduction

In 1990, Canada hosted the 5th International Conference on Indoor Air Quality and Climate, Indoor Air'90. More than 1400 scientists, practitioners and policy makers attended that conference to present and discuss indoor air quality health and engineering research findings, and policy issues (Figure 1).[1]

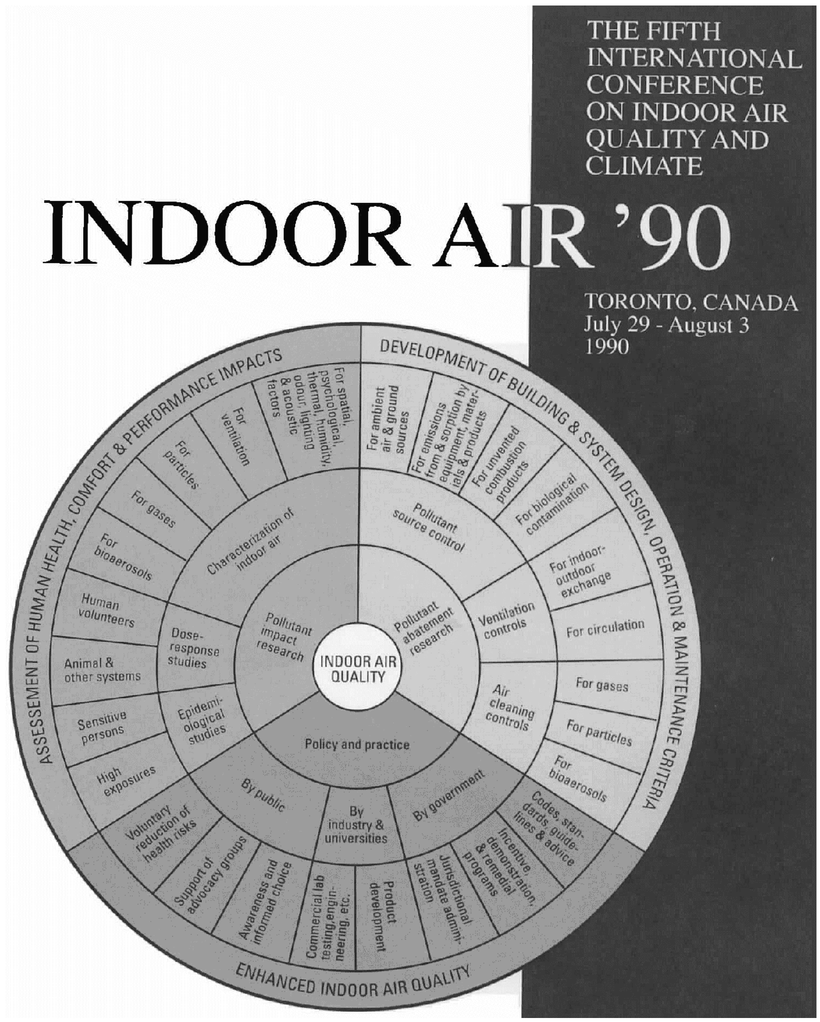

Figure 1Global IAQ Perspective, 1990

[1] Proceedings, The Fifth International Conference on Indoor Air Quality and Climate, Indoor Air '90, Toronto, DS Walkinshaw, President, 5 volumes, over 500 papers, 1990

Over the last decade these initiatives have led to an improved understanding of the indoor environment. For example surveys in residences have shown the relative importance of a number of IAQ factors which might affect respiratory illness (Table 1).

Table 1 Residential IAQ sources of respiratory illness

Source	Odds ratio from various surveys	95% Confidence Interval of the survey	Health effects
Home Dampness	1.82	1.13-2.92	Cough
	1.63	1.46-1.83	Bronchitis
	1.26; 1.48	0.75-2.18; 1.34-1.64	Wheeze
	1.28; 1.22	0.75-2.18; 1.09-1.37	Asthma
Smoking in home	1.93	0.82-4.58	Cough
	1.21	1.08-1.36	Bronchitis
	1.8; 1.24	0.93-3.49; 1.12-1.37	Wheeze
	1.76; 1.20	0.79-3.93; 1.12-1.37	Asthma
Humidifier	1.56	1.38-1.75	Bronchitis
	1.47	1.32-1.63	Wheeze
	1.39	1.23-1.57	Asthma
Air Cleaner	1.35	1.13-1.60	Bronchitis
	1.37	1.18-1.60	Wheeze
	1.47	1.24-1.75	Asthma
Air Conditioner	1.28	1.12-1.47	Bronchitis
	1.14	1.02-1.28	Wheeze
	1.1	0.97-1.26	Asthma
Gas vs. Electric stove	2.2	1.0-4.8	Respir. symp.
	0.99	0.85-1.14	Bronchitis
	1.02; 0.84; 0.54; 0.72	0.90-1.15; 0.64-1.09; 0.12-2.54; 0.25-2.05	Wheeze
	1.02; 0.5; 0.64	0.88-1.19; 0.11-2.34; 0.27-1.5	Asthma
Furry pets	0.99	0.88-1.13	Bronchitis

Source	Odds ratio from various surveys	95% Confidence Interval of the survey	Health effects
	1.01	0.90-1.13	Wheeze
	0.99	0.88-1.13	Asthma

Normal and optimal values for key indoor air quality parameters, and effective measures for their enhancement have been developed. *These parameters and their effects are neither independent nor uniquely interdependent. As well, other parameters are also at play, including ambient air quality and individual response.* For example, any one of: (a) elevated TVOC concentration, (b) elevated RSP count or (c) low relative humidity, will elicit respiratory system and eye irritation. Hence, human environmental perceptions must be validated by environmental measurement so that the appropriate action is undertaken. Such environmental measurement may in turn require further measurement for source validation. These findings are discussed in more detail in the sections which follow.

There is a wide range of individual environmental sensitivities. For example, the general population odour and pungency (irritation) threshold for formaldehyde ranges between 0.05 and 1 ppm. While for most compounds, irritation (pungency) thresholds are higher than odour thresholds, a hypersensitive person can react to formaldehyde at concentrations as low as 0.01 ppm, well below the odour threshold. On the other hand, anosmics (persons lacking a functional sense of smell), while they do detect compound pungency, do so at much higher concentrations than normosmics (persons with normal olfaction).

Health Services Canada Exposure Guidelines for Residential Indoor Air Quality take into account groups at special risk (e.g., asthmatics, chemically sensitive, the very young, the old) by including a safety margin over the lowest 'no-observed-effect'.[1] For example, the nitrogen dioxide short term nitrogen dioxide exposure criterion (0.25 ppm = 480 $\mu g/m^3$ for 1 h average) is 50 percent of the lowest respiratory effects level in clinical exposure studies of asthmatic and normal subjects. The long term exposure criterion for nitrogen dioxide (0.05 ppm = 100 $\mu g/m^3$) is 50 percent of the lowest level for observed increase in respiratory illness. Nevertheless, the possibility that the guidelines may not protect the most hypersensitive persons is acknowledged.

Compound pungency and other acute response guidelines have been developed for only a few compounds - e.g., formaldehyde. However, it has been observed that pungency effects of individual compounds tend to be additive, with lower molecular weight compounds somewhat more 'sharp' and higher molecular weight compounds more 'dull' or 'pastel'. This, observation coupled with the need

[1] HWC, "Exposure Guidelines for Residential Indoor Air Quality," Health and Welfare Canada, April 1987 (revised July 1989).

to address the complexity of IAQ mixtures, has led to the development of TVOC norms and guidelines for building environments.

While health based standards exist for a number of individual compounds, they do not exist for many typical groups of compounds. Such groups range from vehicular exhaust to toxic fungi to TVOCs. Furthermore, most health based standards do not address pungency and non-etiologically specific responses such as headaches and fatigue, for a general population. Hence, IAQ guidelines have evolved.

Appropriate mitigation measures, once the origin of the problem is identified, are not always obvious. For example, ventilation introduces outdoor-sourced pollutants while diluting indoor-sourced pollutants, and increasing or decreasing relative humidity depending upon ambient conditions. Temperature, relative humidity, circulation and ventilation each affect material offgasing rate. Hence, a ‘solution’ of opening windows or increasing the mechanical system ventilation rate, for example, may introduce a new problem while resolving an old one. Mitigation measures, once thought through and implemented, should be followed up by post-mitigation measurement.

2.0 IAQ data collection

Carbon dioxide (CO_2), carbon monoxide (CO), temperature (T) and relative humidity (RH) data are measured with various monitors including several which log, for example a Metrosonics device.[1]

Carbon monoxide, nitric oxide, nitrogen dioxide and sulphur dioxide concentrations are measured with a monitor/logger.[1]

Respirable suspended particle (RSP) count density is measured using a monitor which records concentrations within several particle diameter ranges.[2]

Air flow directions, pressure differences and velocities are identified and measured using smoke pencils and a micromanometer.[3] [4]

Mold propagule aerosols are collected with a portable pump and media and later analyzed by a mycologist. [5] Surface samples are taken with cue tips. [6] Paper, wood and drywall material moisture

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1 Metrosonics AQ-5000 and AQ-513 IAQ monitors/loggers with digital read out. The infrared carbon dioxide sensor is calibrated periodically at 0 and 1066 ppm. The capacitive humidity sensor is calibrated at the factory. The bead type thermistor temperature sensor is calibrated at the factory. The electrochemical carbon monoxide sensor is calibrated at 0 and 54 ppm. The electrochemical CO sensor is calibrated at 0 and 54 ppm. The electrochemical NO sensor is calibrated at 0 and 25.7 ppm. The electrochemical NO_2 sensor is calibrated at 0 and 5.2 ppm. The electrochemical SO_2 sensor is calibrated at 0 and 5.92 ppm Figures prepared using data collected by the AQ5000 are reported as "Filename AQ...". Figures prepared using data collected by the AQ-513 are reported as "Filename 512...".

2 MET ONE model 237B, laser particle counter, +/-5% at $2x10^6$ particles/ft^3; resolution 1 cpm; size fractions: 0.3 to 0.5 µm, >0.5 to 1.0 µm, >1.0 to 5.0 µm, and >5.0 µm.

3 Draeger smoke pencils. Flow directions, circulation velocities.

4 Air Neotronics MP20S micromanometer, air gap capacitor. Differential pressures +/- 0.1 Pascal, velocities (Pitot tube).

5 Biotest RCS sampler drawing air into it at a sampling separation volume of 40 L/min, from up to 40 cm away, using an impeller rotating at 4096 rpm. Particles are impacted by centrifugal force onto a plastic strip normally containing a Rose-Bengal-Agar culture medium suited for molds and yeasts. Sampling (normally for 4 minutes) is at the rate of 40 L/min +/- 2%.

Agar strips are incubated for approximately five to 10 days at 24 C. Unique colonies are identified and counted by genera microscopically. The number of colonies per cu meter content is measured with a real time capacitance sensor.[1]

Volatile organic compounds (VOCs) are collected on three part sorbent tubes at 250 cc/m. The compounds on the sorbents are thermally desorbed, identified and their concentrations estimated using gas chromatography/mass spectroscopy (GC/MS). [2]

Radon is logged over a several day period. Two devices are employed. One has a visual display and is normally used.[3]

(CFU/m^3) in the air are calculated as 6.25 x the number of colonies on the strip.

In the case of colony speciation, representative genera are transferred from the agar strips to CZAPEK Agar and malt extract. These cultures are incubated at 24 C until growth reaches adequate size for identification by species (approximately 10 more days).

[6] Precision Dynamics culture C.A.T.S., PDC-100 amies modified medium.

[1] Electrophysics CT1000 capacitance moisture meter. Range 0-40%. Accuracy +/- 1 %.

[2] Air is sampled at 250 cc/min (normally for 20 min) through an 18 cm long thermal desorption tube packed with Carbotrap C, Carbotrap B and Carboseive S-III.

VOC's collected by the sorbents are released thermally under a flow of helium using a Tekmar 3000 Desorber Accessory kit attached to an HP purge and trap concentrator, and injected into a Supelco Vocol bonded phase capillary column (60 m long, 0.25 mm ID) for analysis using an HP G1800A GCD GC/MS.

The mass spectrum of each detected VOC is searched using the Wiley 138K mass spectral library and the total ion chromatogram plotted. Total VOC concentration is calculated using the area of the total ion chromatogram calibrated against cyclohexane. The cyclohexane standard is prepared as follows: the same desorption tube used for sampling is reconditioned. The sampling inlet end of the tube is then attached to a glass tube packed with a small amount of glass wool onto which 10 µl of a 1 mg/ml cyclohexane in methanol standard was deposited (total of 10 µg cyclohexane). The sampling outlet end of the tube is connected to a pump with a flow rate of 250 cc/min. for the same time as the sampling time. Thus the 10 µg cyclohexane is drawn through the desorption tube under the same conditions used for sampling.

Individual VOC concentrations are estimated from their areas in the total ion chromatogram as a percent of the TVOC concentration.

[3] Radon Alarm continuous radon gas read out (pCi/L)

3.0 Fungi

Outdoors, fungal growth flourishes in soil and decaying leaves. Indoors, it grows in damp susceptible building materials (e.g., paper, wood, textiles) and in stagnant water (e.g., floor drains, humidifiers). Mold emissions include propagules (e.g., spores) and gases (microbial volatile organic compounds (MVOCs)). Outdoors, fungal aerosol isolates generally include the genera *Cladosporium*, *Alternaria*, *Aureobasidium*. These fungi normally grow on decaying leaves and constitute the principal phylloplane mycoflora. Soil fungi normally contain the genera *Penicillium* and *Aspergillus*.

Fungi require moisture or damp materials to grow. Cellulose materials in relative humidity as low as 65 percent and 7 ^{o}C can develop moisture contents capable of supporting fungal growth (e.g., > 18%). This is a particular concern in perimeter wall cavities behind insulation, particularly in below grade areas where soil moisture enters via concrete capillary action and near surface diffusion. Crawl spaces with dirt floors are year around sources of fungal emissions entering the living space via heating ducts leaks and air currents (e.g., case study of house with mold problem, Table 3). Fungi are a maintenance problem in air conditioning condensate collection systems, in elevator sumps (e.g., office building investigation case study, Table 4), and in air handling unit insulation downstream of air conditioners and humidifiers.

In the case of hidden mold growth (e.g., in stud walls behind the insulation), only a few spores will enter the living space. However, MVOCs will be drawn or forced in by stack effect and wind pressures. MVOCs and spores will accumulate in fleecy materials so exposure can arise from skin contact as well as respiration.

Hydrophilic molds grow in chronically wet and high moisture content materials and soil such as found in crawl spaces, cold rooms, on basement floors and behind insulation. Some molds (the most xerophylic) can grow on materials exposed to environments with relative humidity as low as 65 percent and 7 degrees C. To prevent fungal decay in wood the maximum moisture content by weight is around 30 percent and in gypsum board 0.6 percent.

Relative humidity levels supporting mold growth in summertime are most likely to occur in basement insulation, carpets, and sub-floors. Wet soil aggravates the situation, as concrete acts like a sponge drawing in moisture by capillary action and then disseminating it into the air through near surface diffusion. Newly cast concrete itself provides a source of moisture for 7-10 years. Common sources of indoor humidity are listed in the 2.

Table 2 Some Common Dwelling Humidity Sources

Source		**Moisture generated (litres per day)**
interior activities of a family of four (bathing, respiration, perspiration, cooking)		7-23
basement	typical Canadian	2.5
	damp	10
	flooded	223
crawl space	ground cover (plastic)	3 - 4.5
	uncovered soil	45
new construction		3-8
seasonal (fall) material desorption		0-3,200 (litres per year)
seasonal outdoor high humidity		30 to 120
house plants (5-7)		1.3
unvented clothes dryer (family of 4)		5
firewood		5
air conditioner - 1 ton (not drained to outside)		13
50 m^2 swimming pool		334

In contrast with fungi, bacteria generally require full aqueous immersion in order to replicate effectively. Thus a sewer back-up in a basement poses only a short time bacterial exposure risk but can introduce new and toxic mold species (e.g. *Stachybotrys atra* or *S.chartarum*) which amplify in moist materials in stud wall cavities, for instance.

Many fungal health effects are species rather than genera specific. Thus, it is important to identify species in exposure studies. Possible health effects include:

! Allergic respiratory disease

An allergic reaction is one in which the immune system over-reacts. Reactions such as hay fever (nasal congestion, runny nose, sneezing, conjunctivitis and lachrymation) or asthma (wheeze, chest tightness, and shortness of breath) can occur within a few minutes of exposure.

Examples include house dust mite allergy and allergic responses by atopic individuals to *Aspergillus*, *Cladosporium*, and *Penicillium* leading to rhinitis (with hay fever symptoms, and/or asthma. About 15-20 percent of the population is diagnosed as allergic to molds as indicated by their reaction to injection under the skin of the common phylloplane fungi *Cladosporium cladosporioides*, *Cladosporium herbarum*, and *Alternaria alternara*. Allergic reactions may also occur for other molds for which no tests are routinely conducted.

A rare allergy affecting both atopic and non-atopic individuals, *extrinsic alveolitis* or *hypersensitivity pneumonitis* (HP), can result from exposure to a high concentration of dust with organic matter and a range of microorganisms, from the bacterium *Bacillus* to the dry rot fungi *Serpula*. HP is a condition in which the gas exchange tissue of the lung becomes inflamed and from which permanent lung damage can result. HP effects include acute pneumonia-like fever, cough, chest tightness, and lung infiltration: chronic cough, shortness of breath and infiltration of the lungs occur on repeated exposure to the agent. Normally HP is an occupational hazard in agriculture but it has been reported in individuals exposed in the home.

! Atopic allergic/contact dermatitis

This is rare. It may occur from contact with strongly irritant molds such as *Stachybotrys atra*. It may also occur in atopic individuals by contact with molds such as *Alternaria*, *Cladosporium* and *Aspirgillus*. Surface dust findings in the office area of an individual reporting skin irritation are provided in Table 5.

! Endotoxic/mycotoxic effects

Various fungal mycotoxins, such as tricothecenes and sterigmatocystin, are immunosuppressive. Some strongly inhibit the pulmonary macrophages which remove particulate matter (including bacteria and fungal spores) from the lower respiratory tract.
For example, exposure to aflatoxin from corn contaminated with *Aspergillus flavus/parasiticus* can result in liver cancer, and toxin in the blood from *Stachybotrus atra* can affect heart tissue and the immune system. *Stachybotrys atra* (or *S. chartarum*) has a black or black-green appearance. It grows only on wet substrate such as heavily wetted gypsum board or in a stagnant floor drain. *S. atra* can produce very toxic metabolites which are toxic to ingestion (elevated temperature, rhinitis and in severe cases atopic shock leading to death). *S. atra*, as noted earlier, can also irritate the skin (dermatitis) and mucosa (cough, phlegm, itching of nose, throat and eyes). *Penicillium aurantiogriseum* can produce toxins affecting the kidneys and nervous system. It is golden yellow grey in colour and is found in materials

and fabrics undergoing degradation. *P. aurantiogriseum* usually produces an unpleasant smell suggesting soil.

! Microbial volatile organic compounds (MVOCs)
Odorous VOCs are produced during the growth of a wide range of bacteria and fungi, forming complex molecules of alcohols, aldehydes, esters, hydrocarbons, and aromatics. Earthy odours of mixtures of compounds such as 1,10 dimethyl-trans-9-decalol (geosmin), 1-isopropyl-3-methoxy-pyrazine and 2-methyl-iso-borneol are clear markers. Health effects evidence is anecdotal. Effects reported include nausea, malaise, stuffiness and wheeziness. Table 8 presents MVOCs identified in a case study of hidden mold.

! Infection
Examples include: Inhalation of *Aspergillus fumigatus*, *A. flavus* and *A. terrus* can cause invasive lung disease (*aspergillosis*) with pneumonia-like symptoms. Many molds can cause invasive (systemic) diseases in immune-compromised individuals or via wounds. Examples include *A. fumigatus* and *Pseudomonas aeruginosa*. .

The objective is to have no mold aerosols present in occupied areas from indoor growth and minimal outdoor entry. Since mold spores are generally greater than 1 µm in diameter, a medium efficiency filter in the AHU will prevent most outdoor spore entry.

Health Canada states that in residences, due to varying individual sensitivity, extraordinary measures may be required to prevent allergic symptoms and exposure limits and does not recommend any acceptable level of exposure.[1]

Health Canada does set guidelines for fungal exposure limits in offices:[2]

! Significant numbers of pathogenic fungi should not be present (e.g., *Aspergillus fumigatus, Histoplasma, and Cryptococcus*). Bird or bat droppings in or near intakes could contain these pathogens and should be removed.

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1 Health Canada,"Exposure guidelines for residential indoor air quality", A report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health. April 1987 (revised 1989), Environmental Health Directorate, Health Canada, Ottawa.

2 Health Canada, "Indoor air quality in office buildings: a technical guide", A report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health. 93-EHD-96 (revised 1995), Environmental Health Directorate, Health Canada, Ottawa.

- ! The persistent presence of significant numbers of toxigenic fungi (e.g., *Stachybotrus chartarum, toxigenic Aspergillus, Penicillium and Fusarium* species) requires action.
- ! The presence of one or more fungal species as a significant percentage of an indoor sample and not found in a concurrent outdoor sample requires action.

- ! The normal fungal count in federal buildings is 40 CFU/m^3 for *Cladosporium, Alternaria*, and non-sporulating basidiomycetes.

- ! More than 50 CFU/m^3 of a single species other than *Cladosporium or Alternaria* is cause for concern.

- ! Up to 150 CFU/m^3 is acceptable if there is a mixture of species reflective of outdoor samples. More than that suggests dirty or inefficient air filters.

- ! Up to 500 CFU/m^3 is acceptable in summer if the species are primarily phylloplane (leaf fungi). More than that suggests failure of the filters or contamination of the building.

- ! The visible presence of fungi in humidifiers and on ducts, moldy ceiling tiles, or other surfaces requires remedial action regardless of the airborne spore load.

- ! There are certain kinds of fungal contamination not readily detectable by the standard sampling methods. If unexplained symptoms persist, dust samples should be collected and analysed.

Table 3 Case study of fungal spore dissemination from a crawl space, March 11, 1995

4 min. (0.16 m^3) sample	Sample start time h:m	Location	Colonies CFU/m^3	Species in order of colony count
1	17:11	Basement bedroom	175	*Penicillium aurantiogriseum, Penicillium brevicompactum, Penicillium* species, *Cladosporium*, non-sporulating isolates
2	17:16	Crawl space air vents in furnace room and laundry room.	> too numerous to count	*Penicillia, Aspergilli, Stachybotrus atra*

4 min. (0.16 m^3) sample	**Sample start time h:m**	**Location**	**Colonies CFU/m^3**	**Species in order of colony count**
3	17:20	Kitchen, living room	31	*Penicillium brevicompactum, Penicillium aurantiogriseum*

Table 4 Case study of fungal CFU aerosols (identified contaminated sump pit in elevator shaft)

GENERA AND SPECIES **characteristics** **- some known sources**	**CONCENTRATIONS** **Colony forming units (CFU) on media strip exposed to 160 L air**					
	under-ground garage	Elevator. shaft	Floor elect. box	office	out-doors	**Acceptable CFU (Note 1)**
	26Jan98					
Phylloplane non-toxigenic fungi originating on leaves, generally outdoors Office Norm = 6 CFU total in 160 L air						
Cladosporium cladosporioides						<80
Alternaria alternata		1			1	<80
Ulocladium chartarum	69	30	11			<80
Total Phylloplane species	69	31	11	0	1	<80
Fungi originating in soil and other materials						
Aspergillus fumigatus pathogen -bird, bat feces, leaves			1			pathogen
Aspergillus niger degrader of organics such as soil, plant litter, dried seeds		1				<8
Aspergillus sydowii			28			<8
Chaetomium globosum -very wet wood-soft rot						8
Erotium herbariorum moderate xerophile carpet & wallboard					2	8
Penicillium viridicatum wallboard	6	5	4			toxic
Non-sporulating isolates-(damp conditions-wood rot), indicate presence of *basidiomycetes*: white			5			8
brown		2				8
clamp connections					2	8
green	1					8
Yeast	18	1	1			8
Total non-phylloplane CFU	25	9	39	0	4	<25
Total CFU/m^3	588	250	313	0	31	< 150 or <500 Note 3

Notes:
1. See text for more details.
2. Shading indicates follow up was recommended.
3. Office criteria is 150 CFU/m^3 if species similar to coincident outdoor sample and 500 CFU/m^3 if primarily phylloplane (leaf) fungi.

Table 5 Case study of fungal species in surface dust (occupant had skin irritation)

GENERA AND SPECIES characteristics - some known sources	SWABS, March 11, 1998				Propagules: toxigenic (√), pathogenic VOCs: toxigenic	Most frequent molds in Cdn. house dust (% of samples)
	Hall cabinets 1,2 near Office		Hall cabinet 3 near Office	Desk in Office		
	+ boxes					
Phylloplane non-toxigenic fungi originating on leaves, generally outdoors						
Cladosporium cladosporioides						67%
Cladosporium herbarum		1				
Alternaria alternata						57%
Ulocladium chartarum				1		
Total Phylloplane species	0	1	0	1		
Fungi originating in soil and other materials						
Aspergillus niger common degrader of organics such as soil, plant litter, dried seeds		11	1			53%
Mucor species						31%
Paecilomyces variotti wet wallboard		1			Pathogen VOCs cytotoxic √	
Penicillium bilai wide range of substrates				1		
Penicillium chrysogenum - food products	1	1				
Penicillium viridicatum wallboard	2			3	√	39%
Penicillium species						80%
Rhizopus spp.						73%
Trichoderma harzianum hydrophilic soft rot fungus, destroys cellulose in wood	2				√	
Trichoderma viride						25%
Ulocladium botrytis						22%
Non-sporulating isolates- (damp conditions-wood rot), indicates *basidiomycetes*	1 (white)					
Yeast	1			4		
Total non-phylloplane CFU	7	13	1	8		
Total CFU on swab	7	14	1	9		

4.0 Volatile organic compounds

Volatile organic compounds (VOCs) are frequent air pollutants in non-industrial environments. These gases are produced by building materials, solvents, cleaners, paints, combustion, fungi, and humans (especially when exercising or under stress). Finishes and glued wood products are the main formaldehyde sources. Material emission rates generally increase with temperature and relative humidity. Example findings are provided in Table 8.

VOCs emissions can be reduced with time by ventilation and removed from the air by sorption (e.g., with carbon). Formaldehyde may also be removed by damp wiping surfaces and steam cleaning carpets. Fleecy materials (carpets, curtains, upholstery) sorb VOCs when rooms are at high concentrations (e.g., during painting or use of an open fireplace) and later re-emit them (desorb) when the space is at a lower concentration.

Some possible health effects of volatile organic compounds at typical total indoor air concentrations (TVOC normally less than 1 mg/m^3 and individual compound concentrations normally less than 50 $\mu g/m^3$ or two orders of magnitude below industrial standards[1]) are:

Acute effects
These are reversible, ending after the exposure stops. Such effects are unlikely if TVOC is less than 0.2 to 0.6 mg/m^3, and likely if TVOC is greater than 3 mg/m^3. Formaldehyde is an exception with effects felt by some at concentrations greater than 0.05 ppm (0.06 mg/m^3). Effects include:

! odour
  - e.g., formaldehyde has a pungent odour

! stinging, itching, tingling of tissues
  - mucosal irritation: eye, nose, mouth, upper and lower respiratory system
  - trigeminal nerve reaction: exposed skin

! headache, drowsiness, changed performance, confusion, fatigue
  - neurotoxic effects

! inflammation: running eyes or nose, cough, changes in breathing pattern, increased mucosal secretion, increased blood flow to exposed skin
  - metabolic, microbiologic or immune system reaction

Chronic effects
These are caused by absorbed or metabolized VOCs, normally at exposures higher than ACGIH TLVs. Examples are:

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[1] ACGIH, "1998 TLVs and BEIs", American Conference of Governmental Industrial Hygienists, Cincinnati.

- neurotoxicity: e.g., n-hexane and some ketones
- ocular toxicity: e.g., methanol
- hepatotoxicity: e.g., chloroform
- genotoxic effects
- immune system effects
- cancer: e.g., benzene, dichlorobenzene, formaldehyde

While there are criteria for individual compounds, there are no concentration criteria for VOC mixtures. However, research has shown that for a TVOC mixture typical of office buildings, effects are unlikely for concentrations below 0.3 mg/m^3. For mixtures having concentrations above 3 mg/m^3, effects are likely. Canadian investigations have found that the normal TVOC concentration in non-industrial office buildings is 0.5 mg/m^3. In this light, a maximum TVOC concentration target of 0.5 mg/m^3 is currently being used.

With respect to individual compounds, ASHRAE recommends that industrial criteria for individual compounds, as a starting point, be divided by ten, with no guarantees that this will be sufficiently low to avoid all problems.[1]

There is no acceptable 8 hour industrial exposure specified for formaldehyde (HCHO) since it is a known carcinogen (nasal). However, Health Canada has specified an acceptable long term residential exposure target of 0.05 ppm and an action level of 0.1 ppm.[2] These criteria are currently being used for offices as well.

A summary of TVOC and HCHO target maxima are listed in Table 6. Norms are provided in Table 7.

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1 ASHRAE 62-1989, "Ventilation for acceptable indoor air quality", American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 1989.

2 Health Canada, "Exposure guidelines for residential indoor air quality", A report of the Federal-Provincial Advisory Committee on Environmental and Occupational health. April 1987, (revised July 1989), Environmental Health Directorate, Health Canada, Ottawa.

Table 6 VOC targets for non-industrial environments:

formaldehyde (HCHO)	action level < 0.1 ppm, target < 0.05 ppm
others	TLV/10
TVOC	target <0.5 mg/m^3

Table 7 VOC norms for non-industrial environments

	Canadian [1]			World [2]	
	20th %	50th %	80th %	GM	90th %
TVOC (mg/m3)					
Office established	0.27	0.5	1.62	0.18	0.74
Office established (with LPP)	0.15	0.64	2.6		
Office new				4.15	17
Residences established	0.5	0.79	2.06	1.13	4.63
Residences new				4.5	18.4
HCHO (ppm)					
Office established		<0.05 ppm			
Residences		avg 0.036 ppm			
UFFI Residences		avg 0.054 ppm			

Notes:
LPP = liquid process photocopier. Such photocopiers use large quantities of liquid dispersant.
UFFI = urea formaldehyde foam insulation

1 Tsuchiya et al, Volatile organic compounds in Canadian indoor air, 5th International Jacques Cartier Conference, Montreal, 1992 (National Research Council Canada, Ottawa).

2 Brown et al., Concentrations of volatile organic compounds in indoor air - a review, Indoor Air, Munksgaard, V 4, N2, 1994, 123-134.

Table 8 Case study of MVOC exposure (occupant had allergy symptoms. Fungi was hidden in a pipe chase and aerosols in living space were normal)

COMPOUNDS IDENTIFIED -some possible sources	**CONCENTRATIONS ($\mu g/m^3$)**									
	Den	**MBR**	**Den**	**M BR**	**Comparisons**					
	13 Nov. MVOCs entering via plumbing chase		**5 Dec. plumbing chase sealed**		**Recent IAT investigations**		**Canada 1992** [1]		**World 1994** [2]	
					> 6 month old	**<6 month old**	**50th %**	**80th %**	**GM**	**90th %**
AROMATIC HYDROCARBONS										
benzene C6H6 adhesives, solvents, paints, fuels		16	2	4	1.3-4	3.6-53	3.5	10	8	34
toluene C7H8 human, adhesives, solvents, paints, fuels, furniture lacquer, carpet		96	8	6	2.1-37	152-1961	3.5	12	37	150
1,1,2,2 tetrachloroethene				4	1.3		3.6	26	7	28
ethyl benzene fuels, lacquered furniture finish						45-285			5	22
4-phenyl cyclohexene (4-PC) carpet										
propyl benzene						123				
1-ethyl-2-methyl benzene						137			8	33
1-ethyl-3-methyl benzene			2	2		155-212			8	33
1,3,5-trimethyl benzene carpet/glue						108-194				
1,2,4-trimethyl benzene carpet/glue				2		336-397				
1,2,3-trimethyl benzene carpet/glue					42.5	71-188				
m,o,p-xylenes fuels, adhesives, lacquers, paints, solvents		9	6	3	2.5	154-1168	6.8	17	24	96
TERPENES										
α-pinene										

COMPOUNDS IDENTIFIED -some possible sources	**CONCENTRATIONS ($\mu g/m^3$)**									
	Den	**MBR**	**Den**	**M BR**	**Comparisons**					
	13 Nov. MVOCs entering via plumbing chase		**5 Dec. plumbing chase sealed**		**Recent IAT investigations**		**Canada 1992** [1]		**World 1994** [2]	
					> 6 month old	**<6 month old**	**50th %**	**80th %**	**GM**	**90th %**
camphene									14	55
limonene(C10H10) cleaners		7			11-537	4-32	18	43	21	85
terpenes(C10H16) mold										
ALCOHOLS										
ethanol fungi, human		1189				5	14		120	490
methanol human, mold		42							29	118
2-butanol glued wood, mold		59								
2-butoxyethanol furniture lacquer (water based, acrylic), carpet, mold					315-1132		3.5			
2-ethylhexanol PVC flooring, mold in fibreglass							3.5			
geosmin (1,10-dimethyl-trans-9-decalol) mold in HVAC unit										
phenol human, mold									9	36
KETONES										
acetone human, mold, glued wood		28	11	13	2-4.6	20-168	21		32	130
2-butanone caulking, mold, human		20			31	52-242				
diethyl ketone									6	26
methyl ethyl ketone									4	16
ALDEHYDES										

COMPOUNDS IDENTIFIED -some possible sources	**CONCENTRATIONS ($\mu g/m^3$)**									
	Den	**MBR**	**Den**	**M BR**	**Comparisons**					
	13 Nov. MVOCs entering via plumbing chase		**5 Dec. plumbing chase sealed**		**Recent IAT investigations**		**Canada 1992** [1]		**World 1994** [2]	
					> 6 month old	**<6 month old**	**50th %**	**80th %**	**GM**	**90th %**
formaldehyde, HCHO adhesives (glued wood), UFFI	0.03 ppm	0.08 ppm		0.04 ppm Jan 5'98			< 0.05 ppm	0.05 to 0.15 ppm		
acetaldehyde (ethanal) CH3.CHO human, adhesives (glued wood)		46								
benzaldehyde C7H6O mold										
C5-C7 aldehydes mold										
HALOGENATED COMPOUNDS										
chloroform							1.9	15	10	40
1,4 dichlorobenzene air fresheners, mothballs							3.1	15	8	32
1,1,1 trichloroethane							0.8		24	96
BRANCHED CYCLOALKANES										
2-methyl butane gaseous fuels, aerosols		41			2-43	8-143				
hexamethyl-cyclotrisiloxane carpet treatment, furniture lacquer					3-5.4					
methyl cyclohexane						491				
2,2,4 trimethylhexane					166					
2,2,6 trimethyloctane						286				
butyl cyclohexane						101				
cyclohexane						18-336				
2-methyl pentane adhesives, solvents, paint		40	4	6	2.8	73-718				
3-methyl pentane adhesives, solvents, paint		33				73-648				

COMPOUNDS IDENTIFIED -some possible sources	CONCENTRATIONS (µg/m³)									
	Den	MBR	Den	M BR	Comparisons					
	13 Nov. MVOCs entering via plumbing chase		5 Dec. plumbing chase sealed		Recent IAT investigations		Canada 1992 [1]		World 1994 [2]	
					> 6 month old	<6 month old	50th %	80th %	GM	90th %
methyl cyclopentane carpet rubber underpad		78				58-314				
2-methyl hexane						67-291				
3-methyl hexane						77-375				
2,3,5,8 tetramethyldecane					129					
2,5 dimethyldodecane										
2,2,3,4 tetramethylpentane					303					
2,2,4,6,6 pentamethylheptane					73					
2-methyloctadecane										
n-ALKANES										
n-pentane solvents, paints, adhesives					1.7-14	6-64				
n-hexane lubricating oil, adhesives, solvents, paint		301			1.8-4	175-1177			5	19
n-heptane liquid fuels						63-661				
n-octane liquid fuels					63	38				
n-nonane liquid fuels, LPP, carpet (glue)					123					
n-decane (C10H22) LPP, liquid fuels, carpet (glue)						92-888	21		5	20
n-undecane carpet (glue), LPP										
n-hexadecane					143					
TVOC Residence-established.	<50	2200	50	70			624	2320	1130	4630
TVOC Residence-new									4500	18400

COMPOUNDS IDENTIFIED -some possible sources		**CONCENTRATIONS ($\mu g/m^3$)**									
		Den	**MBR**	**Den**	**M BR**	**Comparisons**					
		13 Nov. MVOCs entering via plumbing chase		**5 Dec. plumbing chase sealed**		**Recent IAT investigations**		**Canada 1992** [1]		**World 1994** [2]	
						> 6 month old	**<6 month old**	**50th %**	**80th %**	**GM**	**90th %**
	Office-established					400-3000		500-640	1600-2600	180	740
	Office-new						2500-14600			4150	17000

1 Tsuchiya et al, Volatile organic compounds in Canadian indoor air, 5th International Jacques Cartier Conference, Montreal, 1992 (National research Council Canada, Ottawa).
2 Brown et al., Concentrations of volatile organic compounds in indoor air - a review, Indoor Air, Munksgaard, V 4, N2, 1994, 123-134.

Notes:
1. Problem compound levels are shaded
2. 20th % -= 20 percent of buildings have a lower concentration
3. GM= geometric mean
4. IAT = Indoor Air Technologies
5. UFFI = urea formaldehyde foam insulation

5.0 Carbon dioxide

Carbon dioxide is produced by combustion and by human metabolism. Humans produce carbon dioxide at rates that depend upon activity level. *Thus, ventilation rates per person can be measured indirectly from indoor equilibrium and outdoor carbon dioxide concentration differences.* This method of calculating ventilation rate is more precise on a per person basis than measuring rates of ventilation air supply and dividing by occupancy because:

- it accounts for actual as opposed to design occupancy.
- it accounts for absences.
- it provides ventilation rate in the area measured rather than average rate.
- it includes infiltration ventilation air.
- measurement of AHU make-up air flows is often difficult.

Human activity levels are typically 1.2 mets (22.1 BTU/h/ft^2) when doing office work sedentary house activities. This correlates with a carbon dioxide production rate of 0.3 L/min/p. During house cleaning or flight attendant type duties, the activity level might be 2 mets. This corresponds to a carbon dioxide production of 0.6 L/min/p. Sleeping typically equates to 2.5 mets and carbon dioxide production rate of 0.2 L/min/p.

Ventilation is the exchange of indoor air with outdoor air. Ventilation dilutes indoor air-sourced contaminant concentrations (human, material, equipment, cleaners). High ventilation rates are required in new buildings until material volatile organic compound (VOC) offgasing rates reduce and concentrations reach established building norms or targets. High rates can also be introduced to reduce the spread of human contagion.

Ventilation has some negative effects. In winter, ventilation reduces indoor relative humidity. Under summer humid weather conditions, ventilation increases indoor relative humidity. Ventilation also introduces outdoor air contaminants. These include mold spores and pollen in summer, and chimney and vehicular exhaust combustion pollutants.

Ventilation air particulate matter may be removed by deposition (e.g., when passing through the building envelope) and filtration (e.g., when passing through an air handling unit (AHU)). Filters must be replaced regularly so that AHU ventilation and circulation rates are maintained. Some contaminant gases can be removed via sorption (e.g., by charcoal). Sorbent filters must be replaced regularly.

There are two forms of ventilation - mechanical and natural. Mechanical ventilation is produced by blowers creating indoor-outdoor pressure differences across the envelope and in ducts leading to and from the outdoors. Mechanical ventilation make-up and exhaust rate imbalances induce vertically uniform pressure differences across the envelope.

Natural ventilation is produced by wind pressures and by indoor/outdoor air density differentials due to temperature differences. For example, in cold weather, the lower half of the building is depressurized relative to outdoors and the upper half is pressurized. This is termed 'stack effect', with pressure differentials created by temperature/air density differences across an insulation layer. Air conditioning produces the reverse situation.

Air movement through the envelope can create or prevent envelope moisture/indoor air fungal problems. In winter, a mechanically depressurized building can be humidified without indoor air moisture accumulation in the envelope. In summer, a pressurized building can be air conditioned without ambient air moisture deposition in the envelope.

The minimum ventilation rate varies with the space.[1] It is 20 CFM/p in offices. In homes it is 15 CFM/p and 0.3 building air changes per hour (ACH). In school classrooms it is 15 CFM/p. Figure 2 shows a carbon dioxide record in a bungalow with six occupants.

Ambient carbon dioxide concentration is normally about 325-350 ppm although it can be higher in downtown areas at street level, and around homes in winter. If there are no combustion sources of carbon dioxide and there are people in the space, the 15 CFM/p ventilation rate requirement typically corresponds to an equilibrium (maximum) carbon dioxide equilibrium concentration of about 1,000 ppm during waking hours, and 700 ppm when sleeping. The 20 CFM/p requirement typically corresponds to a 850 ppm CO_2 concentration at equilibrium.

Some acceptable and normal carbon dioxide concentrations and associated ventilation rates follow.

Acceptable CO_2 concentrations:		
	in smoking lounge	525 ppm maximum as a tracer for ventilation rate ventilation rate (V) = 60 CFM/person minimum
	in cocktail lounges, bars	700 ppm maximum as a tracer for ventilation rate ventilation rate (V) = 30 CFM/person minimum
	in offices, restaurants:	875 ppm maximum as a tracer for ventilation rate ventilation rate (V) = 20 CFM/person minimum
	in homes, classrooms	1000 ppm maximum in the day
	in homes at night	820 ppm maximum at night ventilation rate (V) = 15 CFM/person minimum
Norms:		Offices: < 600-700 ppm, V=30-40 CFM/p Homes: daytime 600-800, V= 25-40 CFM/p nighttime (bedrooms-door open) 600-800 ppm, V=15 CFM/p

1 ASHRAE 62-1989, "Ventilation for acceptable indoor air quality", American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 1989.

Source: Humans, combustion (ETS, vehicular, furnace, stove, fireplace,....)

Acceptable CO_2 concentration

Residences: 1000 ppm maximum as a tracer for IAQ
1000 ppm when occupants awake; 820 ppm when occupants sleeping.; as a tracer for ventilation rate, V= 15 CFM/person when only source is human respiration.

Norms: Homes: daytime 600-800, V= 25-40 CFM/p
nighttime (bedrooms-door open) 600-800 ppm, V=15 CFM/p

Source: Humans, combustion (vehicular, furnace, stove, fireplace,....)

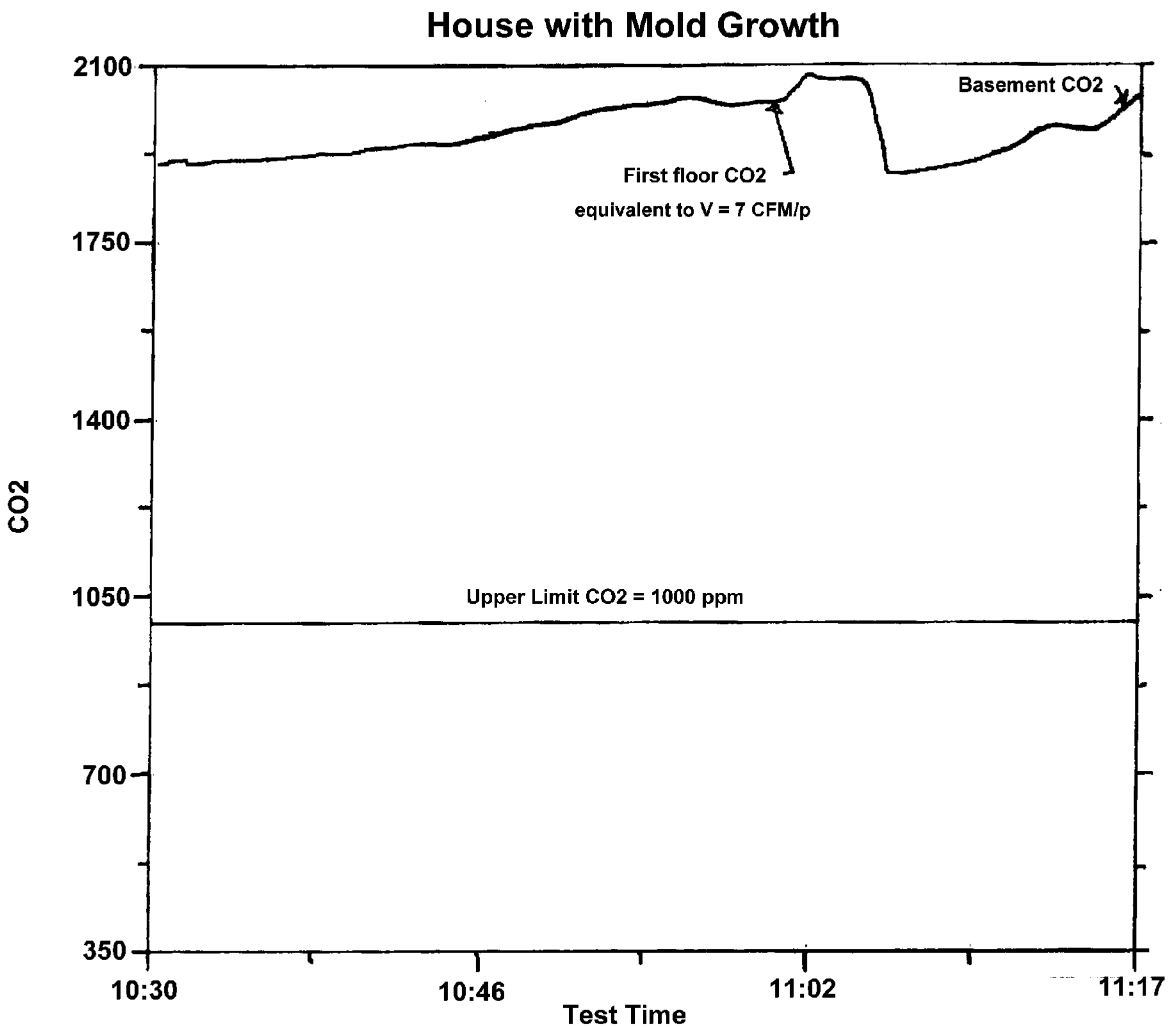

Figure 2 Case study of carbon dioxide level in a house with mold growth throughout

6.0 Circulation

Air circulation within and between rooms, indoors and outdoors, and to and from wall and subfloor cavities is caused by pressure differentials.

These pressure differentials are created by forced air circulation systems, HRVs, exhaust fans (kitchen, bathroom, dryer), chimneys, wind, within room and building/outdoor thermal/air density gradients.

Circulation transports gaseous and particulate contaminants from their sources (e.g.. Mold contaminated wall cavities; a room being painted) to AHUs and furnaces where outdoor (ventilation) air is sometimes added (normally a minimum of 20 percent of supply air in office buildings) to the return air before recirculating.

Some spaces such as copier rooms and washrooms are exhausted directly outdoors without any intended recirculation. Typical air circulation velocities in a room range between 0 fpm (stagnation points) and 300 to 500 fpm (diffusers, portable fans).

Gases also move via diffusion at velocities two orders of magnitude higher. Hence, the stratification of contaminant gases in an office beyond the micro environment of their source is normally independent of the circulation rate. However, circulation does affect gas as well as particulate concentrations in the source micro-environment, and it does transport respirable particulate (including human generated virus and bacterial aerosols) along its streams. Thus, air circulation rates and flow patterns at desks and in meeting rooms can affect the spread of contagion and human VOC micro-environment concentrations.

Circulation between diffusers and returns should be adjusted to create an air velocity in each occupied area of at least 20 fpm. At the same time, air-conditioning drafts must be avoided. Achieving this in open office areas with several occupant spaces sharing one diffuser requires fine tuning of diffuser flow directions, divider screen arrangements and air movement paths between spaces. It is essential that pathways between occupied spaces in open offices near the floor be kept open. As well, room supply and exhaust flows must be balanced so that circulation streams between adjoining rooms are from areas of low pollution (e.g., offices) to ones of higher pollution (e.g., near copiers, washrooms, elevators).

7.0 Temperature

The most common IAQ complaint is being ‘too warm’ or ‘too cold’. In basements, cold floors are often a problem, particularly with vertical gradients between floor and seat height typically between 3 and 7 C near the perimeter. Adding a carpet gives the impression of warmth but in reality adds little insulation value. Figure 3 illustrates the temperature difference between the the basement and first floor found in a case study of a bungalow with a mold problem.

Thermal comfort depends upon activity level, clothing, relative humidity, air circulation, temperature and temperature gradients (near windows, above basement floors). For offices, the seasonal target temperature ranges are:[1]

Winter:	20-23.5 C for 90 percent office worker satisfaction in winter[2] (clothing: heavy slacks, long sleeve shirt, sweater)
Summer:	23-26 C for 90 percent office worker satisfaction in summer[3] (light slacks, short sleeve shirt)
Thermal gradient	< 3 C (0.1 m to 1.7 m above floor)

Ambient conditions dictate the appropriate settings on spring and fall days.

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1 ASHRAE Standard 55-1992,”Thermal environmental conditions for human occupancy”, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, July 1992.

2 The Canadian federal government winter time minimum setting is 21 C.

3 The Canadian federal government summer time maximum setting is 24 C.

Winter: 20-23.5 C for 90 percent occupant satisfaction in winter (clothing: heavy slacks, long sleeve shirt, sweater)

Summer: 23-26 C for 90 percent occupant satisfaction in summer (light slacks, short sleeve shirt)

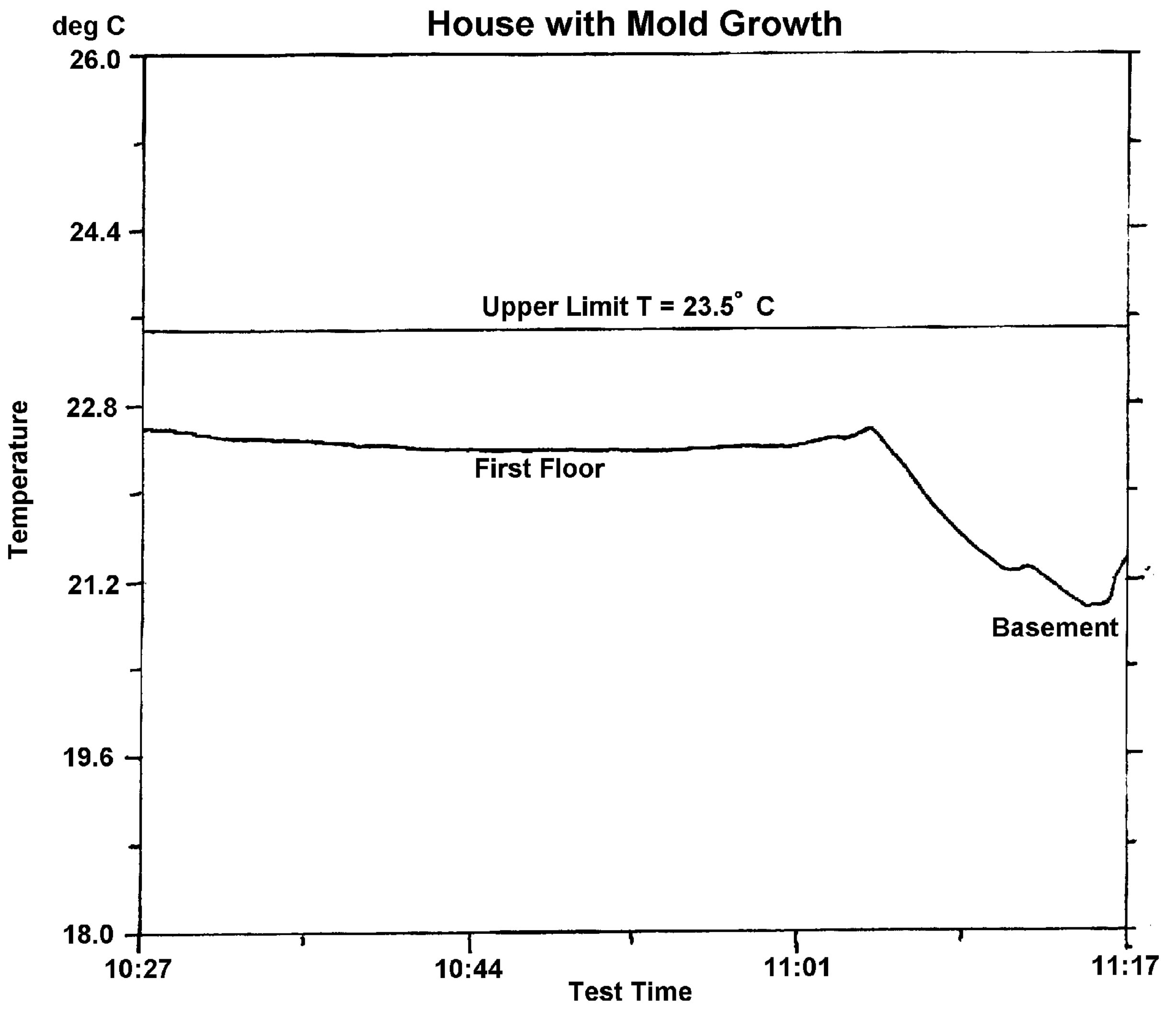

Figure 3 Case study of temperature in a house with mold growth throughout

8.0 Relative humidity

While humidity is generated by human perspiration and breath, the primary source of humidity in office buildings is from ventilation in summer and humidification in winter. In homes, high occupancies and associated cooking and washing activities are a significant source.

Without control measures, indoor relative humidities can reach 100 percent in summer (e.g., in basements) and 10 percent or lower in winter. Mold growth can occur in susceptible materials at relative humidities as low as 65 percent and temperatures as low as 7 C. Such a humidity level can occur in sealed basement insulated wall and subfloor cavities for typical soil temperatures and soil moisture entry rates through concrete, in winter as well as summer. Figure 4 illustrates the relative humidity difference found between the basement and main floor in a case study of a bungalow with a mold problem.

In practice, relative humidity can be maintained above 20 percent in insulated buildings with double glazing in cold weather without window or envelope condensation problems. Even with single glazing, window frosting can still be avoided through targeted air circulation over the window.

In older uninsulated buildings without a continuous vapour barrier, humidification can create condensation with associated structural and finishing failures. In these buildings, therefore, there is often no humidification and relative humidity levels of 10-15% are the norm in cold weather. Exhaust ventilation of a building which overcomes stack effect allows winter time humidification by preventing humid air leakage into the envelope.

Maintenance of relative humidity below 60 percent is generally achievable through air conditioning, sometimes supplemented by basement dehumidification. In Canada, envelope condensation problems due to building air conditioning and dehumidification have not been reported, although some major failures leading to fungal-related air quality have occurred in the southern USA.

Health Canada states that indoor relative humidities between 25 percent and 60 percent, at temperatures between 20 C and 26 C, are judged to be comfortable.[1] However, complaints of low humidity may be more frequent within these bounds when volatile organic compound concentrations are high, since both can cause drying of the eye and respiratory system mucous membranes.

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[1] Health Canada, "Indoor air quality in office buildings: a technical guide", A report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health.93-EHD-96 (revised 1995), Environmental Health Directorate, Health Canada, Ottawa.

ASHRAE recommneds an minimum relative humidity of 30% at 20 C (25% at 27 C).[1]

From a health viewpoint, several species of bacteria and viruses survive best at either low or high humidities. High humidities can lead to the growth of mites and of fungi. Relative humidities between 40% and 50% are deemed optimal to reduce the incidence of upper respiratory infections, and allergic and asthmatic reactions.[2]

Generally, relative humidity targets in Canadian buildings are set to avoid moisture problems and provide comfort at:

Winter	>20 percent during occupied hours
Summer	< 60 percent

1 ASHRAE 55-1992, "Thermal environmental conditions for human occupancy," American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta, 1992

2 Health Canada, "Exposure guidelines for residential indoor air quality", A report of the Federal-Provincial Advisory Committee on Environmental and Occupational health. April 1987 (revised July 1989), Environmental Health Directorate, Health Canada, Ottawa.

Target relative humidity range for comfort:	25<RH<60 percent
Optimal relative humidity range for health:	40<RH<50 percent
	Provided mold growth is not created in envelope

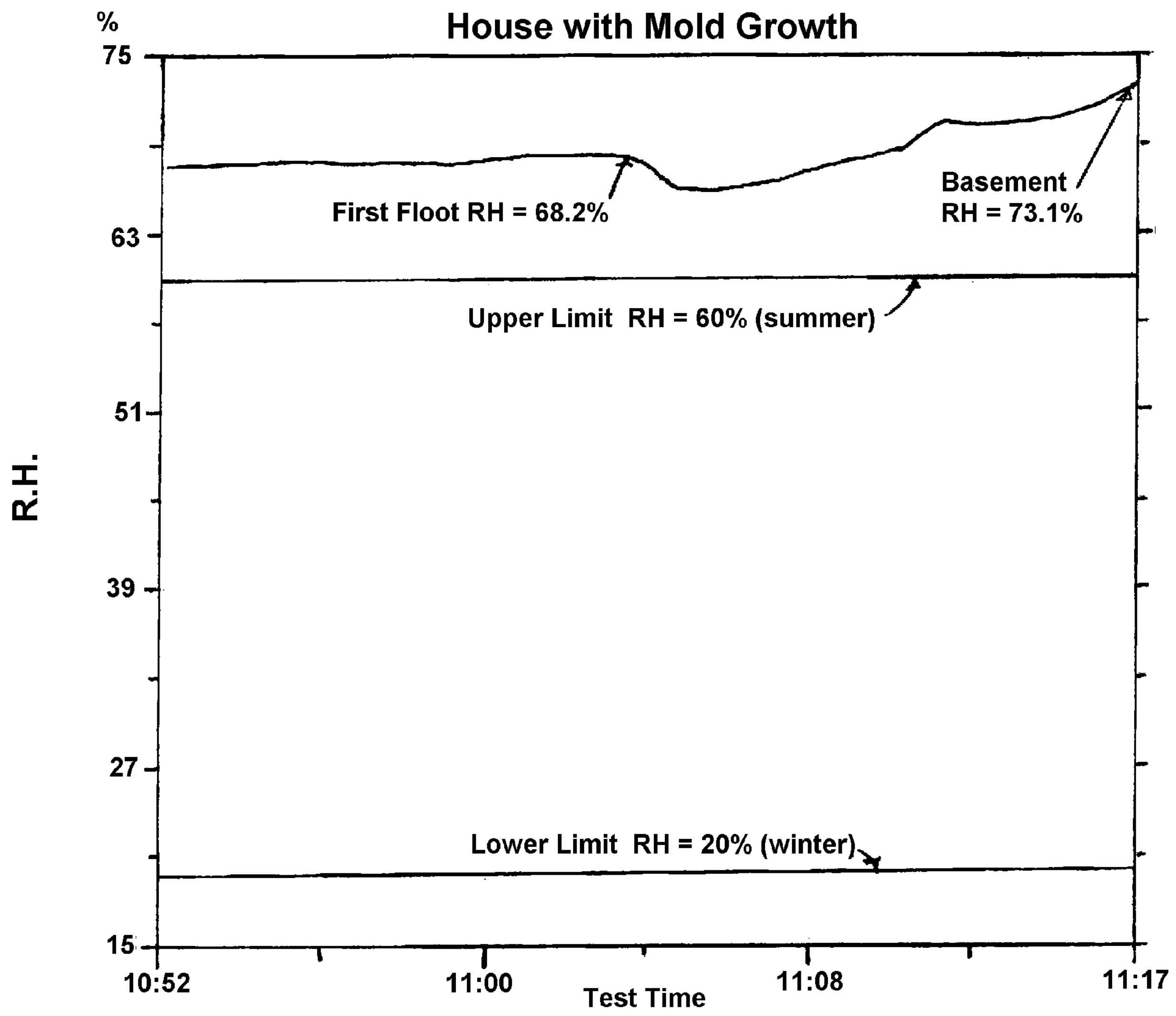

Figure 4 Case study of relative humidity in a house with mold growth throughout

9.0 Carbon monoxide and products of combustion

The complete combustion of fossil fuels produces carbon dioxide, water vapour and nitrogen. Incomplete combustion produces carbon monoxide, oxides of sulphur, and unburned and partially oxidized hydrocarbon gases and particulates (e.g., benzene, toluene, formaldehyde, benzo (a) pyrene). High temperatures produce oxides of nitrogen.

In downtown buildings or buildings with underground parking garages, exposure to combustion fumes from vehicular exhaust is periodically encountered. In suburban homes, exposure to combustion fumes from cigarettes, a fireplace or a vehicle in an attached garage is more likely.
Carbon monoxide is often used as a tracer of combustion fumes. This compound is also produced by human metabolism. Metabolic carbon monoxide typically accounts for about 0.01 to 0.05 ppm indoors.

Normally, indoor concentrations of carbon monoxide are below instrument detection limits in offices and homes where there is no smoking. Example carbon monoxide and carbon dioxide concentrations from a case study of a home with two smokers are provided in Figure 5 Carbon monoxide averages of several ppm have been found in offices in some buildings with underground parking garages. Sealing elevator lobbies leading from the garage, and depressurizing the garage during vehicular activity, will prevent such occurrences.

Carbon monoxide concentrations associated with rush hour traffic of 1 or 2 ppm are common in buildings in downtown areas. Ingestion of fumes from diesel trucks at loading docks is another common problem. Diesel fumes produce strong odours indoors at carbon monoxide levels of less than 1 ppm. Randomly opened windows can be an easily remedied entry point. Locating air intakes on roof tops rather than building walls will help. Decreasing ventilation rates or even closing make-up dampers during rush hours is an obvious solution. This latter approach requires an offsetting ventilation rate increase during other hours, with an assessment of other indoor air quality parameters.

In homes with gas stoves, typical values of NO_2 according to Health Canada as of 1987 were between 30 and 100 $\mu g/m^3$. A more recent study found values in bedrooms of homes with gas stoves averaged 28 $\mu g/m^3$ while bedrooms in homes with electric stoves averaged 19 $\mu g/m^3$.

The health effects of exposure to vehicular combustion product mixtures have not been assessed. The effects of exposure to some of it components has. For example, exposure to carbon monoxide can pose reproductive, anoxia, cardiovascular system and central nervous system risks.
A prospective study of exposure to gas stove combustion products in homes in comparison to homes with electric stoves, which looked at one of the most susceptible group - infants, found no correlation of exposure and respiratory risk.

There are no Federal standards for indoor exposure to combustion product mixtures, from gas stoves, vehicular exhaust, tobacco smoke, etc. However, Health Canada states that the presence of carbon monoxide concentrations of 5 ppm indicates the presence of combustion pollutants that, once located, should be exhausted.[1]

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends that limits of exposure in non-industrial environments not exceed 1/10th threshold limit values (TLV) recommended for industrial environments by the American Conference of Governmental Industrial Hygienists.[2] [3] ASHRAE notes that some people may have problems even if these criteria are met.

The TLV/10, eight hour time weighted average (TWA) concentrations for five combustion contaminants of concern, carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and respirable suspended particulate (RSP) , are:

CO = 2.5 ppm
NO = 2.5 ppm
NO_2 = 0.3 ppm (564 µg/m^3)
SO_2 = 0.2 ppm (526 µg/m^3)
RSP = 0.015 mg/m^3 for particles less than 1 µm in diameter.

In residences, Health Canada recommends the following criteria:[4]

CO =	1 h:	25 ppm
	8 h:	11 ppm
NO_2 =	short term:	0.25 ppm (480 µg/m^3)
	long term:	0.05 ppm (100 µg/m^3)

1 Health Canada, “Indoor air quality in office buildings: a technical guide”, A report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health.93-EHD-96 (revised 1995), Environmental Health Directorate, Health Canada, Ottawa.

2 ASHRAE 62-1989, “Ventilation for Acceptable Indoor Air Quality,” American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc, Atlanta, GA, 1989,26 pp.

3 ACGIH, “ 1998 TLVs and BEIs, Threshold Limit Values For Chemical Substances And Physical Agents, And Biological Exposure Indices,” American Conference of Governmental industrial Hygienists, Cincinnati, OH, 1998,148 pp.

4 Health Services Canada, “Exposure Guidelines for Residential Indoor Air Quality,” Health Services Canada, Ottawa, April 1987, revised July 1989, 23 pp.

SO_2 =	short term:	0.38 ppm (1000 μg/m^3)
	long term:	0.019 ppm (50 μg/m^3)
RSP =	1 h:	100 μg/m^3
	long term:	40 μg/m^3

Acceptable CO concentration in non-industrial work places as a tracer for combustion fumes:	2.5 ppm, 8 h average over 5 day, 40 h work week
Norms:	0.02 to 0.04 ppm in occupied rooms
Sources:	combustion (vehicular, furnace, stove, fireplace,...), tobacco smoke, human respiration

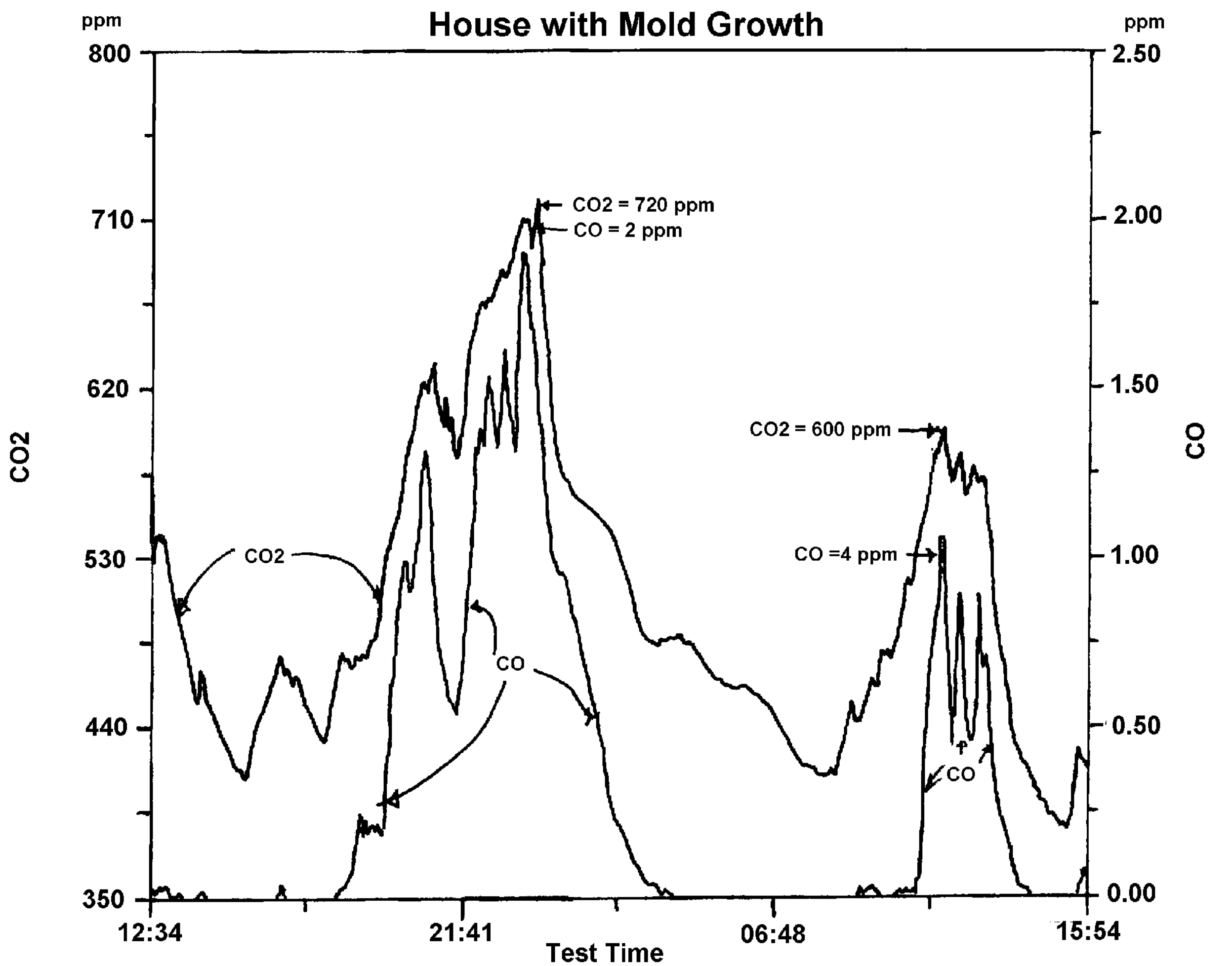

Figure 5 **Case study of carbon monoxide and carbon dioxide concentrations in a house with two smokers**

10.0 Filtration

Sources of respirable suspended particulate (RSP: diameters less than 5 micron meters) include:
- environmental tobacco smoke (300,000 to 500,000 counts per liter (cpl)),
- vacuuming, cooking, dishwasher exhaust (50,000 to 100,000 cpl),
- paper dust (due to occupant paper movement),
- outdoor air (5,000 to 150,000 cpl, depending on wind and temperature conditions, traffic, furnace use),
- human breath (10,000 cpl).

RSP composition might include hydrocarbons, material fibres, micro fungi and water droplet aerosols with viruses and bacteria (human sneezing produces water droplet aerosols in the 1 µm range).

A significant portion of the RSP in nonsmoking buildings enters from the outdoors. Thus, keeping windows closed, reducing ventilation rates and use of high efficiency filters will reduce indoor counts significantly. With good filters (not necessarily HEPA), indoor counts of less than 10,000 cpl are typical. AHU filtration efficiency is a function of its filter efficiency and any air leakage around its filters. A filtration efficiency of 50% on RSP in the 1 µm diameter range is quite good. The removal efficiency by particle size of 12" pleated filters located in a roof top air handling unit of an office building is illustrated in Table 9.

RSP pose respiratory and possibly skin health hazards, with particles less than 2.5 microns reaching the lung alveoli. Historically, health criteria have been based on particle mass for air borne dust, rather than numbers of RSP. This was based on the measurement technology available. The relatively recent availability of laser particle counters has provided a new approach to assessing RSP exposure and filtration efficiency. While no health criteria have been set for particle counts, an RSP target maximum of 10,000 counts per liter (cpl) is sometimes used.

Table 9 **Case study of filtration efficiency in an office building with a roof top intake, 2" pre-filters and 12" pleated filters**

RSP target: < 10,000 cpl
Note:
Microbial aerosols: virus and bacteria water droplet aerosols are ~ 1 micron diameter.

Location	Time 02/26/98	RSP count by size fraction (counts per liter, cpl)				Total RSP count(cpl)
		0.3 to 0.5 µm	>0.5 to 1.0 µm	>1.0 to 5.0 µm	>5.0 µm	
Outdoors, street level	10:57	42,878	15,582	1,630	16	60,106
Outdoors, street level	10:58	22,210	4,506	508	21	27,245
Flr 4 Elevator lobby	11:00	7,850	1,592	1,567	247	11,256
AHU before filter	11:49	17,749	3,470	3,019	336	24,574
AHU after filter	11:53	6,178	466	227	8	6,879
AHU filter efficiency		65%	87%	92%	98%	72%
AHU before filter	11:54	17,699	2,297	2,004	222	22,222
AHU after filter	11:53	6,178	466	227	8	6,879
AHU filter efficiency		65%	80%	89%	96%	69%

11.0 Ozone

Ozone is produced by the action of ultra violet radiation on oxygen and indoors by the electrical arcing of motors, for example. Outdoors, ozone concentrations average 30 µg/m^3 with noon hour peaks as high as 400 µg/m^3. The normal background level is 30-90 µg/m^3.

Indoor concentrations of ozone normally follow outdoor concentrations. They can, therefore, can be reduced by closing windows and reducing mechanical system ventilation rates. In office buildings, poorly maintained photocopiers exhausting indoors are an important localized source of ozone. Any such exhaust vented indoors should be vented through a carbon filter that is regularly replaced. In homes, electronic air cleaners can be a source of ozone. Use of carbon after-filters usually solves this problem.

Ozone is a highly toxic gas that penetrates deep into the respiratory system and irritates the eyes and mucous membranes. It can cause headaches, weaken the immune system making the body susceptible to irritation, and affect lung function. It has a sharp searing odour detectable at concentrations as low as 40-50 µg/m^3. However, it deadens the olfactory function after a short period. This characteristic is sometimes used (inappropriately) to promote the use of ozonators to 'deodorize' buildings. The ASHRAE indoor air criterion for ozone in non-industrial settings is 100 µg/m^3. [1] There is no other federal criterion for non-industrial settings.

The short term Health Canada criteria for residences is 240 µg/m^3 (0.12 ppm)

[1] ASHRAE 62-1989, "Ventilation for acceptable indoor air quality", American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 1989.

12.0 Radon and other soil gases

Soil gases include radon from soil and stone, methane and other VOCs from decaying organic matter, sulphur compounds including hydrogen sulphide and mercaptans from anaerobic reactions in sludge in sewers and elsewhere, and various chemical waste contaminants deposited or leaking into the soil.

Most of these gases are hazardous to health. Some pose an explosion risk. They enter buildings via foundation cracks and openings, drawn in by building stack, wind and HVAC pressures.

Radon is the most widespread of the soil gases, entering most basements. Normal indoor levels in the Ottawa area are between 1 and 2 pCi/L. However, a substantial number tested have been near or above the government action level of 4 pCi/l.[1] The highest average exposure was recorded in a basement in Ottawa at about 20 pCi/l.

The concentration of soil-sourced gas and microbials throughout a building depends upon:

- soil gas concentration around the building foundation
- water table level
- size of foundation openings and cracks
- driving across-the-foundation pressure difference
- availability of underground air
- faulty or missing sewer pipe and sump pit air traps
- building ventilation rate
- air movement patterns within the building

Water elevation affects underground air supply and contaminant movement. Knowing annual fluctuations relative to foundation level is helpful in predicting radon entry, for example.

Across-the-foundation pressure difference is variable, depending *inter alia* upon indoor/outdoor temperature difference, wind condition, building tightness, HVAC and window operation. Higher driving pressures correlate with higher rate of soil gas entry.

Logging radon, an easy gas to monitor, helps calibrate soil gas entry rate variations.

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1 The Canadian Institute of Radiation Safety and the United States Environmental Protection Agency recommend mitigation if average levels reach 4 pCi/l. Health Canada recommends action at 20 pCi/l but in any case that radon be kept as low as practicable. Many US states enforce residential radon mitigation at the time of sale and some have pro-active radon mitigation programs for schools.

Surveying with real time soil gas monitors with photoionization, flame ionization and electro-chemical catalytic sensors can detect compounds such as methane, hydrogen sulphide, gasoline, oil and other vapours and identify entry points of these gases at 'ppm' level concentrations. Sometimes a monitor is calibrated according to mixture lower explosive limit.

Generally PID, FID and catalytic sensors react to a combination of compounds. Identification and quantification of individual compounds must therefore be carried out with GC, MS and other laboratory analyses. For these analyses, gases are collected with sorbent tubes, and in bags and canisters.

If tests demonstrate a health hazard, the Ontario Building code requires that special construction/venting measures be undertaken.[1] A minimum measure is to install and commission a sub slab depressurization system. This will not prevent entry into basements with rubble mound or block foundation walls. A continuously depressurized envelope ECHO System constructed on the interior of the foundation walls and slab is a better solution.[2]

A case study of radon mitigation using the ECHO System is illustrated in Figure 6.

[1] Ministry of Municipal Affairs and Housing, “Ontario Building Code 1997, Section 9.13.7.

[2] The ECHO System consists of specially sealed, ventilated, and moisture protected construction which, in concert with a small blower and pressure monitor, produces a depressurized envelope between the below grade portion of the basement and the occupied space. This traps and expels humidity ad gases before they can enter the occupied space. It also provides interior drainage for any foundation leakage and building ventilation. The ECHO System is approved under the Ontario Building Code.

Acceptable Rn concentration	4 pCi/L average- US EPA, Canadian Institute of Radiation Safety 20 pCi/L - Health Canada
Norm:	1-2 PCi/L
Sources:	Stone, soil, concrete.

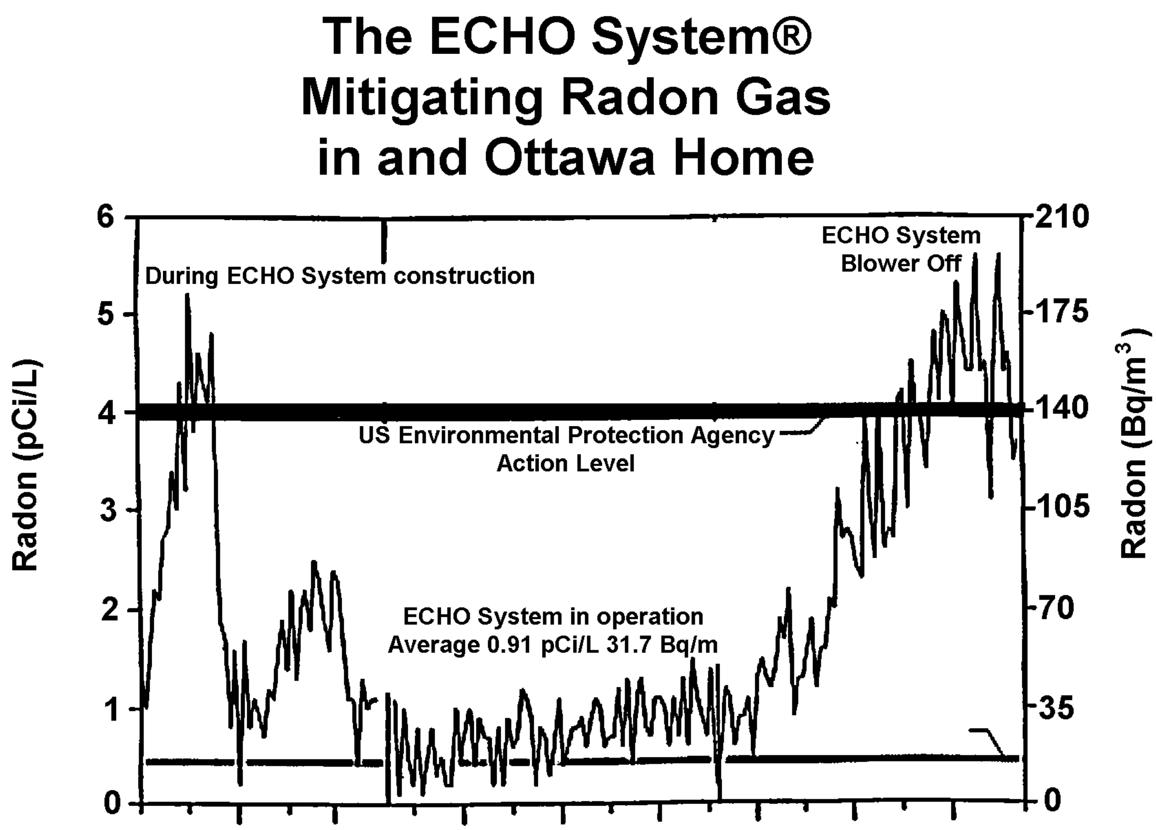

Figure 6 **Case study of radon concentration in a bungalow versus operation of an ECHO System cavity exhaust blower**