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INDOOR AIR QUALITY

ASSESSMENT STRATEGY

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ANNEX 1

DETAILED OBSERVATIONS FOR POLLUTANT SOURCES

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SUMMARY

This paper describes a three-staged approach to the determination and assessment of indoor air quality problems, starting with a series of observations and inspections to be made during a building walk-through, progressing to a series of simple measurements, and finally, if necessary, terminating with complex measurements of indoor air quality parameters. Hopefully, by following it, the reader will be able to properly diagnose the true cause of air quality complaints in the least costly and least time consuming manner possible. It is only by determining the true cause(s) of complaint that the most cost-effective retrofit and problem avoidance strategies may be planned.

INTRODUCTION

The techniques of preliminary assessment are simply different ways of gathering information about the building. Useful information about potential air quality problems can be obtained from:

- study of building floor plans, if available
- details of renovations
- records of complaints about air quality in the building
- inspection of some or all areas of the building
- inspection of the mechanical systems
- discussions or informal interviews with building occupants
- details of operating procedure and usage for the building

CARBON DIOXIDE AND VENTILATION

Detailed Procedures

Since the occupants are almost certainly the only source of carbon dioxide, and concentrations in the building are determined by ventilation effectiveness, this part of the investigation focusses on the distribution of people in the building, air movement and operation of the mechanical systems, as well as on details of complaints.

The floor plans and details of renovations will indicate potential problem areas, such as:

- open office space converted to closed offices
- places where structural alterations have resulted in space usage of a type different from that indicated in the plans (such as transformation of office space into a waiting room)

Potential problem areas may also be signalled by complaints about lack of ventilation, lack of oxygen, stagnant air, stuffiness and symptoms such as headaches and fatigue.

Areas identified as potentially problematic should be inspected, and the occupants should be interviewed. Information on building usage and mechanical system operation are also required. The checklists below indicate the details needed.

Checklist for observations:

- what are the occupant densities in locations where renovations have been carried out?

- are there thermostats in the closed offices created from an open office area?
- what are the peak and average densities in rooms with transient occupancy?
- are the air supply (diffusers) all operational?
- is the exhaust operating properly?
- have the occupants introduced fans to promote air circulation?
- is there system intervention such as blockage of ventilation grilles?
- what types of screens are used as dividers in open office areas?
- how many screens are used?
- where are the supply air diffusers and exhaust relative to the screens?
- in the complaint areas, do all the occupants complain, or only one or two?

Checklist for mechanical systems:

- what type of mechanical systems are used in the building?
- how many separate systems are there, and which floors do they serve?
- how does the fresh air intake rate vary with the seasons?

Checklist for complaints and occupant interviews:

- in areas where renovations have been carried out, is the population density higher than before the renovations?
- does the air seem fresh?
- is the air moving?
- are there drafts?
- is it too hot or too cold?
- does the ventilation system seem to be working properly?
- what symptoms are experienced?
- what time of day does the air seem the worst?
- what day of the week does the air seem the worst?
- is the air quality problem seasonal?

Assessment

The observations made and answers obtained during the inspection can be used to assess the likelihood of carbon dioxide revealing ventilation problems in any of the investigated areas. Problems are likely if:
- rooms with transient occupancy have high peak and average occupancies (the rooms are full, and quite frequently)
- renovations have resulted in higher population densities
- closed offices in space that was originally open do not contain thermostats
- screens in an open office area extend down to the floor, and both diffusers and exhaust are above the screen tops (air may

INDOOR AIR QUALITY ASSESSMENT STRATEGY

INTRODUCTION

Investigation of indoor air quality has been developed by the Building Performance Division of Public Works Canada to include the following three stages: preliminary assessment, simple measurements and complex measurements. These stages are used for all of the performance categories in environmental science within the Building Performance Division. The stages as they apply to air quality are described below. Their relationships with and impacts on other performance parameters are indicated.

In order for acceptable indoor air quality to exist from an objective physical or chemical point of view as well as from the subjective point of view of the building occupant, four factors must be achieved:

a) major pollution sources must either be eliminated or ventilated at source;
b) the air handling systems must circulate reasonable quantities of fresh and filtered air;
c) the space must be used in such a manner that the inherent capabilities of the air handling systems are not defeated; and
d) other environmental stressors (physical or otherwise) must be eliminated so that their effects are not confused with the effects of indoor air pollution.

In other words, it is not sufficient to ventilate the building according to the standard if strong air pollution sources are allowed to exist; nor is it acceptable merely to ventilate if the inherent capabilities of the mechanical systems are allowed to be defeated by office design and layout.

Similarly, no retrofit or operational strategy is likely to provide a cost effective remedy if the right problem is not addressed. For example, there is no benefit at all to increasing fresh air rates or hours of operation if the real source of an indoor air quality complaint lies with mould growth in the humidifier system.

Furthermore, successful diagnosis of air quality problems depends not only on keeping a broad viewpoint on "classical" problem causes (strong sources, insufficient fresh air rates, or ineffective ventilation), but on paying attention to other related factors such as thermal comfort, illumination, acoustics and other stressors.

The indoor air quality assessment strategy developed here aims to provide information for the identification of easy, low cost, energy effective solutions first. It also provides a framework for the acquisition of the most useful information for the least effort and cost.

STAGE I - PRELIMINARY ASSESSMENT

The preliminary assessment consists of collection of information which could be helpful in identifying pollutants, in locating pollutant sources, and in defining the nature and severity of the problems experienced. Information can be obtained from building plans or records of complaints, from inspection of different areas of the building, and from interviews with occupants, managers and others. No measurements involving instruments are made at this stage. The information collected will enable the person conducting the investigation to choose appropriate locations for later testing with instruments.

The preliminary assessment provides the greatest single chance of finding the true cause of an indoor air quality problem. Information gathering techniques normally employed at this stage include four steps: occupant response sampling, pollutant source identification, general mechanical systems observation, and ventilation efficiency determination. These are expounded upon below.

Step 1: Occupant Response Sampling - This should normally be the first and most important source of information. Sources include interviews, questionnaires, records of complaint and union-management meetings. It is impossible to measure and to observe all things at all times. Occupant feedback can greatly reduce the investigative effort required. Although the subjective judgement of the occupants may often be in error concerning the true cause of an indoor air quality problem, their judgement can be an extremely important source of information concerning if, where and when an indoor air quality problem exists.

Step 2: Pollutant Source Identification - The second most important way to gather information is by observing possible air pollution sources during a building walkthrough. Visual observation, the sense of smell, sensitivity to other breathing or eye discomfort as well as common sense should provide the greatest clues as to whether each of these source types could be a significant air pollution source for the building under investigation. Common sources which may be visually identified and associated air pollutants include:

garages (combustion byproducts),
loading docks (combustion byproducts),
kitchens (combustion byproducts),
open sumps (radon and moulds),
laboratories (depends entirely on the functions carried out

circulate above the screens only)
- diffusers and exhaust are both in the ceiling (short circuiting is possible)
- either a diffuser or the exhaust has been blocked off and is inoperative

The symptoms associated with exposure to carbon dioxide are non-specific, and, therefore, not useful for diagnosis. These include headache and fatigue. However, complaints about the environment can be more useful. If complaints of stagnant or stale air, lack of air movement, no fresh air etc. occur in areas where there is evidence (see paragraph above) of ventilation problems, then carbon dioxide could be the cause.

The variation of symptoms and complaints with time may also provide useful evidence. Carbon dioxide concentrations tend to be highest at the end of the working day, and if an occupant is suffering from carbon dioxide exposure, that person should feel worst in the late afternoon. The problem is likely to be worse is seasons where the fresh air intake is at a minimum.

In contrast to some other pollutants, problems with carbon dioxide can be very local. For example, due to some combination of furniture arrangement and ventilation, one workstation on a floor may receive no air while other workstations are adequately served.

CARBON MONOXIDE / COMBUSTION BYPRODUCTS

Detailed Procedures

The plans, or discussions with the building operator, will reveal the presence of possible problem locations such as:

- internal loading docks;
- internal parking garages;
- kitchens with gas-fired stoves;
- furnace rooms for a gas-fired central heating system;
- occupied areas close to any of the above;
- air intakes close to a street carrying heavy traffic or to other exhausts.

These should be inspected, and information obtained as indicated on the checklists below:

Checklist for a loading dock:

- is there an outer door which is closed after a truck's arrival?

- are truck drivers asked to turn off their motors while docked?
- how many trucks use the dock during an average week?
- what is the average time each truck stays?
- are any doors to other parts of the building normally kept closed?
- is the reception office separate from the loading dock?
- do the reception office and dock area have proper ventilation?
- is the ventilation running properly, or has it been turned off or has it been blocked?

Checklist for a parking garage:

- is it open to outdoor air, or enclosed with a ventilation system operating?
- if ventilated, how is the ventilation system controlled?
- are there any obstructions in the exhaust or fresh air?
- is the garage only used by people who work in the building, or is it open to the public also?
- are there carbon monoxide sensors in the garage which controL ventilation? If so, have they been recently calibrated? Do they appear to be responsive to changing CO levels?
- what is the frequency of recalibration of the sensors?
- how do people get from the garage to their place of work?
- is special ventilation provided for the person working in the checkout booth?

Checklist for kitchens with gas stoves:

- are there special exhausts to remove combustion gases produced by the stoves?
- how are these exhausts controlled?

Checklist for furnace rooms for gas-fired central heating units:

- is there any evidence of leakage of combustion gases from the furnace into the furnace room or nearby areas?

Checklist for fresh air intakes:

- where are the intakes in the building envelope?
- if the intakes are below third floor level, are they above a busy street, or above the entrance to either the loading dock or the parking garage?

Checklist for complaints and occupant interviews:

- are there complaints of ill-health from occupants?
- are there complaints of symptoms such as headache, fatigue, dizziness and nausea?
- what locations in the building are these complaints associated with?
- are there complaints of odours attributed to auto exhaust,

within the laboratory),
printing shops (volatile organic compounds),
large photocopiers (volatile organic compounds, ozone),
humidifiers (moulds and fungi),
new furnishings (formaldehyde and volatile organic compounds),
new paint, carpet glue etc. (volatile organic compounds),
outdoor air (a variety of pollutants),
smokers (a great number of irritating and carcinogenic substances).

Wherever strong sources exist, ventilation systems should be checked in order to ensure that they are performing in a reasonably satisfactory manner. Since the building ventilation system only dilutes, separate ventilation with exhaust to outside may be required for a strong source.

Step 3: General Mechanical Systems Observation - If the previous two steps have not indicated a good reason for an air quality problem to exist, then the general condition and operation of the mechanical systems should be observed. This should include the determination of:

general type (ie VAV, constant velocity etc),
fresh air rates
- constant,
- economizer cycle,
controls; type, mode of operation, general strengths and weaknesses, general condition and state of upkeep,
details of operation ie
- hours of operation,
- strategy for operation of separate ventilation systems,
- complaint response procedures,
general condition and cleanliness of filters, humidifiers, cooling towers, air handling components,
garage ventilation
- method,
- hours of operation,
- control,
- condition.

Step 4: Ventilation efficiency determination - the way space is used will often have a dramatic effect on the way the ventilation systems will perform. This has now been recognized by ASHRAE in the draft ventilation and air quality standard, 62-81R. Several clues are available to help the observer determine where local problem spots may exist so that they may be investigated in more depth later. These include:

great numbers of fans or heaters,
high density use of tall open office screens which seal to the floor,
evidence of occupant system intervention (ie taping of

diffusers),
high densities of heat producing equipment, and
supplies which can easily short circuit to air returns.

It is while conducting the preliminary analysis that a problem may often be dealt with in an inexpensive and effective manner.

Annex 1 - Detailed Observations - describes what pollutant sources and ventilation conditions to look for in a building and how to assess potential problem causes.

STAGE II - SIMPLE MEASUREMENTS

The simple measurement techniques are designed for non-specialists with a minimum of training, for example, a building operator or property manager who has received complaints about air quality in a building for which he or she is responsible.

The measurements should be easy and quick to perform. It is expected that the data collected will prove or disprove the presence of hazardous levels of air pollutants in most cases. In situations where no clear answer is obtained, it may be necessary to progress to Stage III and use complex measurement techniques to resolve matters.

It must be realized, however, that the "state of the art" is such that physical measurement of air chemistry parameters cannot ever be used to certify that no air quality problem exists. Chances are that either the measurement was taken at the wrong time, or the wrong thing was measured or existing standards are simply not adequate to determine if one or a combination of air contaminants constitutes a significant health or comfort risk.

The techniques described here are all used by PWC Building Performance Division during building investigations.

Instruments giving immediate analogue or digital readout are available to measure:
carbon dioxide,
carbon monoxide,
respirable suspended particulates,
temperature and humidity.

A chemical kit is used to measure formaldehyde. Air is sampled for several hours, then the user carries out the analysis.

Measurements for some pollutants fall between Stages II and III, in that the methods of sample collection are simple, but the analyses are complex. The samples normally require to be sent to

diesel fumes, the kitchen, the furnace room or the central heating?
- where do the people making these complaints work?
- what time of day are the symptoms or odours worst?
- what day of the week or month of the year are the symptoms or odours worst?
- are there more than the average number of smokers in the building, or in one part of it?
- are there complaints about tobacco smoke odours or smokers, or requests for no-smoking areas to be set up?
- is there much absenteeism?

Assessment

The results of observations and answers to questions can be used as follows to assess the likelihood of a pollution problem due to carbon monoxide existing at any of the investigated locations. Usually two or more conditions must be fulfilled before a problem is likely:

- loading dock: a problem may exist if trucks' motors are kept on while the trucks are in the loading dock, and the motors are enclosed within the dock so that the carbon monoxide cannot escape easily, and there are trucks present in the loading dock for more than two hours each day. If these three conditions are fulfilled, the receptionist/commissionaire is at risk if the reception office is part of the dock area and not ventilated. Also, carbon monoxide may migrate to office areas if the dock area is not separated from them by a closed door.

- parking garage: if the garage is open and above ground, there should be no problem. If it is enclosed and ventilated, the potential for problems exists if the system is not operating as designed, i.e. if operation is controlled by carbon monoxide sensors which have not been calibrated for a year, or ventilation is switched off except at peak hours (but people do move cars in and out during the daytime), or the exhaust louvers are blocked off to stop the garage getting too cold in winter etc. The checkout booth should have its own air supply if the garage is enclosed.

- kitchens with gas stoves: if the stoves are fitted with overhead exhausts which operate whenever the stoves are being used, there should be no problem.

- fresh air intakes: if the intakes are above the third floor and not close to the exhaust of either the same or the next building, there should be no problem. Intakes at first or second floor level may conduct carbon monoxide into the building if the street carries a lot of vehicular traffic, or if they are located close to a parking garage entrance or a frequently used loading dock.

- complaints and occupant interviews: the information here is more difficult to assess, because the symptoms of carbon monoxide poisoning (headaches, dizziness, nausea and fatigue) are non-specific, that is, they can arise from a number of different causes. In an office building these other causes include allergy, illness such as influenza, effects of other pollutants, other physical stressors such as poor lighting, and mental stress due to lack of job satisfaction or work-related personal conflicts. Thus complaints of the symptoms listed should not be taken as evidence of a carbon monoxide problem unless there is also another problem indicator, such as the presence nearby of a probable source (an assessment made in one of the preceding paragraphs of this section), the presence in the area of many smokers, or complaints of exhaust or furnace room odours.

FORMALDEHYDE

Detailed Procedures

Records of construction or renovation of the building will indicate whether urea formaldehyde foam insulation (UFFI) has been installed in the building envelope. If it has, the amount used should be determined, and information on whether sealants were used to contain it should be obtained. UFFI is a potentially strong source of formaldehyde.

Records should also indicate which parts of the building have bee renovated (structural alterations, painting, replacement of ceiling tiles or carpets) in the past month. These areas should be inspected, and the occupants interviewed.

Records or inspection will reveal places in the building (such as storerooms) where there is extensive use of unsealed plywood or particleboard. If these materials have been installed then sealed, the method of sealing should be established. Normally two coats of polyurethane varnish or vapour barrier paint are necessary for adequate protection. If sealing is absent or inadequate, people who work in these areas should also be interviewed.

Cleaning and maintenance procedures (such as washing walls and carpets, or applying furniture polish) can also lead to release of formaldehyde into the air. Complaints should be checked to see if their timing coincides with activities of this type. Weak sources are also capable of absorbing formaldehyde, and later re-emitting it. For this reason the dependence of symptoms on time of day, day of the week and season should be determined.

Assessment

Symptoms of formaldehyde exposure include difficulty in breathing, eye, nose and throat irritation, headaches, coughing, fatigue, nausea and skin rashes. As these symptoms also occur with exposure to some other organic compounds, they are not in themselves diagnostic of pollution due to formaldehyde.

Because many of the sources are building and furnishing materials, the emission rate should be fairly constant. Thus, if ventilation is turned off each night and at weekends, symptoms will be worst in the mornings, and particularly bad on Mondays. If the timing of symptoms correlates with cleaning activities, this is reasonable evidence that cleaning materials are responsible. However, chemicals other than formaldehyde in the cleaning materials could also be responsible. Formaldehyde presents a rather different picture from some other air pollutants, such as carbon monoxide, for which most sources are strong and readily identifiable. The only formaldehyde sources which are likely to be identified during the preliminary assessment are improperly sealed UFFI and large amounts of unsealed particleboard or plywood. Neither of these is actually likely to occur in an office building. It is much more probable that an office will contain a myriad of weak sources such as those described at the start of this Section. These are more difficult to identify. Thus it is possible that the preliminary assessment will not provide evidence for a formaldehyde problem.

PARTICULATES

Detailed Procedures

An inspection (or walkthrough) should be carried out of areas recently renovated, of the mechanical rooms, and of areas where there have been complaints. The checklists below indicate the type of information which is needed to assess the likelihood of particulate contamination.

Checklist for observations:

- is there dust on horizontal surfaces?
- are there dirt marks around diffusers or air exhausts?
- do many people smoke in the complaint areas?

Checklist for building operating procedure:

- are there obstructions (such as birds' nests) in the air intake which could lead to particulates entering ventilation air?
- are the ventilation ducts insulated on the inside?
- when were the ventilation ducts last cleaned?
- are particulate filters used in the building?
- if particulate filters are used, are they located in the fresh air intake, in the recirculated air stream, or in the supply air stream?
- how often are the filters changed?
- are the manufacturer's recommendations on filter changes followed?
- are spray humidifiers used in winter?
- if so, are there hard water deposits on the equipment?
- how are hard water deposits removed from the humidification equipment?
- how frequently are hard water deposits removed from the humidification equipment?

Checklist for complaints and occupant interviews:

- are there complaints about dust in any area?
- does dust come out of the diffusers at any time?
- do people in the building frequently suffer from symptoms such as dry throat or nose, coughing or sneezing?
- do people suffer from respiratory allergies while in the building?
- are the problems seasonal?
- what time of day are the symptoms worst?
- what day of the week are the symptoms worst?
- are there requests for provision of no-smoking areas?
- are there complaints about smoking odours?
- are there complaints of any other odours? if so, what are these odours like?
- are large amounts of paper stored anywhere in the building?
- is there frequent movement of paper in any area?

Assessment

The most likely sources of particulates inside an office building are:
- renovations
- outdoor air
- the ventilation ducts

special laboratories for analysis. These pollutants include:

- asbestos,
- radon,
- microbials,
- volatile organic compounds (VOC).

Asbestos, radon and microbials are covered under Stage II, and VOC under Stage III.

Annex 2 - Simple Measurements, contains lists of sources, permissible exposure limits, typical office levels and health effects for each of the above pollutants (except VOC). In addition, appropriate measurement instruments, sources of supply, approximate costs, principles of operation, accuracies and ranges are given. This information was created during the generation of the PWC test kits.

The interpretation of carbon dioxide data is discussed in Annex 3. Even though carbon dioxide is never normally a pollutant of concern, it has been proven to be invaluable as an indicator of effective ventilation rates whether in a building as a whole or in an individual area.

The measurement of carbon monoxide serves as a good indicator of the presence of combustion byproducts such as car exhaust migrating up from parking garages.

The measurement of particulates (dust) can indicate the effectiveness of the air filtering system as well as the presence of strong sources such as paper cutting, and handling. A digital meter is available which counts numbers of respirable particulates (particles small enough to be inhaled right into the lungs), but it is expensive.

Formaldehyde is included because it has a large number of sources, and it is of concern to many people. As an alternative to the kit, badges requiring a day's exposure may be used, but these need to be sent away for analysis.

Asbestos should not be monitored unless inspection of building plans or the walkthrough has indicated its presence. If a federal building is being inspected, the PWC inventory of asbestos should be consulted (PWC has surveyed all its buildings for asbestos).

Radon is not often found in office buildings, and should not be measured unless the building walkthrough has shown some reason for concern. The sampler used is a charcoal canister. It need simply be placed in location for several days and then sent to a laboratory for analysis.

Thermal comfort measurement equipment has been included with the test kits because analysis of questionnaire data has shown a high correlation between the sensations that the air is too warm or that it is not moving, and air quality discomfort.

Microbials include fungi (slime, mould and spores), bacteria and viruses. Viruses cannot live long outside their hosts, and bacteria require water for survival. Thus fungi are the microbials of most concern in indoor air. The measurement method used here is specific for fungi.

The Building Performance Division of Public Works Canada has prepared a test kit which incorporates equipment for carrying out several of the simple measurement procedures indicated above. This kit is available to the Public Works Canada regions. The accompanying Test Kit User Manual contains detailed instructions, including a checklist for building inspection (based on the information in Annex 1), choice of sampling locations, use and maintenance of the instruments, and simple assessment of data. Thus it may not be necessary for a regional technician to have any formal training in the indoor air quality field to perform a building investigation. To assist in interpretion of data, and to offer guidance should further tests be required, an indoor air quality advisory service is being offered.

STAGE III - COMPLEX MEASUREMENTS

The complex measurement techniques are more time-consuming and expensive to conduct than simple measurement techniques. They are usually used after Stage I and II evaluations have failed to resolve a situation. There are, however, often advantages to offset the extra time and expense that the use of complex instrumentation involves. These advantages usually fall into one or more of the categories listed below:

- improved sensitivity, which means one can measure smaller quantities. This is important as office buildings normally contain small quantities of a variety of chemicals, rather than large concentrations of a single pollutant. This can result in concentrations which are below the lower detection limit of simple instrumentation designed to operate in an industrial environment;
- improved accuracy, which means one can have more confidence in the results obtained;
- time resolution, which means one can obtain a pollutant concentration profile over a period of time, such as eight or twenty four hours. Simple measurement techniques generally yield either a concentration at one point in time, or the average over a given time period;
- more information, such as identification and quantification of individual airborne chemicals rather than generation of a single number representing the effect of many chemicals

- humidifier deposits in areas with hard water
- storage and movement of large amounts of paper
- paper-shredding activities
- smoking

The evidence pointing to each of these sources is indicated below. As in the case of some other air pollutants, symptoms arising from exposure to particulates are non-specific, and should not be used to identify sources in the absence of physical evidence for their existence.

- renovations which involve structural changes will almost certainly cause a particulate problem. However, since the particles tend to be large, the problem should not extend far beyond the space being altered (unless particles are carried by the ventilation system), nor should it persist for long after the renovations are completed;
- outdoor air is unlikely to be the cause of particulate problems if there is a filter system installed in the air intake, and this system is properly maintained. However, if there is no filter system, and loose material of any type is observed around the intake, then outdoor air may be implicated. Allergies which appear in the pollen season are also probably caused by outside air (pollen should be removed by the filter unit);
- dirt around the diffusers indicates that particulates are being introduced into the area by the ventilation system. These particulates may originate in the ventilation ducts if the building is old, or the ducts have never been cleaned, or there is insulation on the inside surface of the ducts;
- chalky deposits around diffusers may be hard water minerals coming from humidification equipment. Observation of hard water deposits on humidifier vanes, complaints of dusty or cement- or plaster-like odours when the humidifiers are operating or after they have been cleaned would provide additional evidence. Obviously the problem will be most severe in winter for this source;
- if the storage and movement of large quantities of paper, or paper-shredding, represent a source, that fact should be obvious from observation and discussions with the people who handle the paper.
- smoking can be the source of a particulate problem if there are a large number of smokers in the area, or if smokers use more than a pack each day at work, or if air circulation is poor in an area where people smoke regularly, or if the non-smokers are situated between the smokers and the air exhaust. Usually complaints of the type indicated above are a good indicator for smoking as a source.

Symptoms of particulate exposure include dry eyes, nose and throat, and effects of dust irritation such as coughing, sneezing and respiratory allergies.

RADON

Detailed Procedures

The building plans and discussions with the building operator will indicate some areas which need to be inspected. These include:

- regularly-used shower facilities;
- basement or sub-basement areas without flooring;
- rooms with sump pumps in them;
- areas where walls or floors incorporate unsealed stone, cement or brick.

In addition, a walkthrough of the parts of the building below ground level will reveal cracks in the foundations, and standing water.

During or after the inspection, the following questions need to be answered:

- is there ventilation in these areas?
- are there people who spend a significant part of the day working in any of these areas?
- are there complaints of odours in these areas, or nearby?

Assessment

There is a real possibility of problems with radon at a location if the following three conditions are met:

- the location has a potential strong source of radon, such as soil or groundwater (in a sub-basement or crawl-space, or exposed through cracks in walls or floors below ground level, or open pipes), unsealed concrete or stone, or frequently-used showers;
- ventilation in that part of the building is minimal or absent, or there are odours (which are a useful indication of whether existing ventilation is operating properly);
- people work in these areas, or nearby.

together. This is useful if the individual chemicals have markedly different toxicities;
- results are obtained in a form more appropriate for comparison with standards;
- there is no simple measurement procedure available.

The complex measurement procedures normally need to be carried out by people with specialized technical expertise and equipment. As a result, it is anticipated that consultants will often be required to perform these tests.

For those interested on conducting more in-depth measurements, Annex 4 - Complex Measurements contains discussions of means of measuring:

carbon dioxide,
combustion products,
particulates,
pollution migration / ventilation performance,
thermal comfort,
volatile organic compounds.

ANNEX 1

DETAILED OBSERVATIONS FOR POLLUTANT SOURCES

VOLATILE ORGANIC COMPOUNDS

Detailed Procedures

While an average office building will contain many different chemicals which offgas from building materials, furnishings and office aids, concentrations of volatile organic compounds (VOC) are likely to be low unless there are major sources and/or poor ventilation. Potential major sources include:

- wet-process photocopiers
- printshops
- chemical laboratories (including photographic darkrooms and conservation laboratories in museums and art galleries)
- storage areas for chemicals such as pesticides and waste solvents
- cleaning and maintenance activities (including painting, recarpeting and structural changes)

Building records, maintenance schedules and interviews with managers should be used to obtain basic information about the building and the location of potential sources. These areas should be inspected and people who work there interviewed. The checklists below indicate the information needed for each source.

Checklist for the building:

- is the building less than a year old?
- has any area been renovated or redecorated within the past month?
- do any of the cleaning or maintenance activities involve use of large amounts of chemicals?
- is the ventilation system shut down overnight and at weekends? If so, how long before the occupants arrive is it restarted in the morning?

Checklist for wet-process photocopiers (copiers that use liquid toner and dispersant):

- is extra ventilation or a separate ventilation system supplied for the areas where these machines are used?
- how many copies are made on each machine in a week?
- how long does each bottle of toner/dispersant last, and what is the bottle volume?
- are there frequent solvent odours near the machines?

Checklist for printshops:

- is extra ventilation or a separate ventilation system supplied for these rooms?
- how frequently are the rollers cleaned with solvent?
- how are waste rags or paper used during cleaning disposed of?

- are there frequent solvent odours in the rooms?

Checklist for chemical laboratories:

- is extra ventilation or a separate ventilation system supplied for these rooms?
- does the ventilation system exhaust directly to outdoors?
- are fume hoods provided for procedures involving heavy use of chemicals that evaporate easily?
- are chemicals that evaporate easily used frequently?
- are there frequent chemical odours in the rooms?

Checklist for chemical storage areas:
- do the chemicals stored here evaporate easily?
- are such volatile chemicals stored in containers which leak, or have loose lids?
- are there frequent chemical odours in these areas?

Checklist for cleaning and maintenance:

- are liquid products used these activities?
- are products used which dry out or cure while releasing solvent?
- are products of these types are used in occupied areas during working hours?
- if use takes place when occupants are not present, is the ventilation system operating (as it would during the day)?

Checklist for complaints and occupant interviews:
- is there much absenteeism?
- if symptoms occur on a regular basis, what time of day are they worst?
- what day of the week are the symptoms worst?
- during what season of the year are the symptoms worst?
- are there frequent complaints of odours?
- do complaints appear to coincide with or follow any cleaning or maintenance activity?

Assessment

A problem due to VOC is only likely if three conditions are fulfilled:

- large amounts of chemicals, or substances containing chemicals, are being used (for example during painting, recarpeting, extensive cleaning, heavy use of wet-process photocopiers or printers)

- the chemicals involved are volatile enough to evaporate quickly, and are given the opportunity to do so (for example, paint drying, cleaning solvent evaporating from equipment such as print rollers or rags used to apply the solvent, chemicals stored in open containers)

- ventilation is inadequate to deal with the situation. Low ventilation may be adequate in storage areas providing chemicals are not too volatile, and containers are tightly sealed. However, darkrooms, printshops and laboratories usually require special ventilation facilities, and wet-process photocopiers may do also if usage is heavy. Cleaning and decorating activities can result in emission of large quantities of chemicals over short periods of time. For this reason, such activities are often carried out during non-working hours. It is important that ventilation systems are operated at daytime levels during these activities, both to protect the people performing them, and to remove VOC before they are adsorbed onto furnishings. Re-emission of adsorbed VOC can cause odours and occupant discomfort later.

The symptoms that people experience when exposed to VOC include coughing, sore throat, faintness, nausea, fatigue, headaches, watery eyes, blurred vision, nervous stomach, skin irritation and allergies. These are non-specific, and are not usually sufficient to identify individual chemicals. For this reason, the nature of the symptoms is less useful than information about when and where they are most severe. If the VOC responsible are are produced as a result of daily work activities, concentrations tend to build up during the day, and symptoms will be worst in late afternoon. If the VOC are emitted from the furnishings, and the ventilation is turned off overnight, problems will be worst in the mornings, particularly Monday mornings. Similarly, overnight cleaning or maintenance activities are likely to affect people more at the start of the day.

MICROBIALS

Detailed Procedures

Biological contamination is only likely to occur when suitable wet or damp breeding grounds are found associated with the air handling system or with occupied areas. It is essential to inspect the mechanical rooms thoroughly, and to check any shower facilities in the building.

Checklist for humidifiers:

- what type of humidification system is used?
- if a spray type is used, are biocides used?
- if a spray type is used, how regularly are the pans cleaned?

- is there any sign of fungal growth anywhere in the humidifier unit?
- are there mouldy odours?
- is there any sign of mould in the ducts connected to the unit?

Checklist for air-conditioning systems:

- is there slime on the cooling coils or in the condensate trays?
- are the trays cleaned regularly?
- is there mould in the ducts?
- are there mouldy odours?
- does the spray from the cooling tower discharge fall over an air intake, or towards an occupied area of the building?

Checklist for shower facilities:

- is the ventilation system for the facility working as designed?
- at what temperature is the hot water maintained?
- are there signs of mould growth on the shower heads, on the shower curtains or on the walls of the shower stalls?
- are there mouldy odours?
- how often are the shower facilities used?

Checklist for complaints and occupant interviews:

- do occupants suffer from respiratory allergies while in the building?
- do occupants suffer from skin allergies?
- what time of day are the symptoms worst?
- what day of the week are the symptoms worst?
- are the symptoms seasonal?
- are the symptoms associated with one area of the building, or do they occur in all areas?
- are there damp patches on the walls or ceilings?
- is the any sign of mould on the air supply diffusers or exhaust louvers?
- are there mouldy odours?

Assessment

Some general guidelines for assessing the likelihood of microbial contamination in a building are indicated below.
- the presence of slime or mould in a humidifier or air-conditioning system, or of mould in any of the ducts leading into or out of these units indicates a problem
- similarly, mould in ducts or on the surface of diffusers or exhaust louvres in an occupied area is a bad sign
- the spatial distribution of illness or complaints can be useful: if problems are localized, the contamination is most probably in that area; if problems are widespread in the building the contamination is probably in some part of the

mechanical system

- problems are likely to be seasonal, involving humidifiers in winter and central air-conditioning systems in summer. Problems are more likely to occur in summer because of the larger number of micro-organisms in outdoor air
- the degree of contamination will increase if the ventilation is turned off overnight or at weekends. Thus symptoms are likely to be worst in the mornings and especially bad on Mondays
- where there is a mouldy odour, there is probably also mould, although its location may not be immediately obvious
- damp spots on walls may be accompanied by fungal growth in the wall cavity
- problems could occur in shower areas if they are frequently used and the ventilation is inadequate
- the temperature in the hot water tank should be maintained at 75 °C to eliminate legionella bacteria

ANNEX 2

SIMPLE MEASUREMENTS

CONTAMINANT:	Carbon Dioxide (CO_2)
SOURCE(S):	Human Metabolism, Combustion
PERMISSIBLE EXPOSURE LIMITS:	ACGIH 5000 PPM ASHRAE 1000 PPM
TYPICAL OFFICE LEVELS:	600 - 800 PPM
HEALTH EFFECTS:	Headache, dizziness, drowsiness
INSTRUMENTATION:	FUJI ZFP5 ($3,300) Horiba APBA 210 ($4,200) GASTEC RI-411 ($3,400)
SUPPLIER:	Safety Supply Canada Analygas System Ltd., Scarborough Levitt - Safety Ltd.
PRINCIPLE OF OPERATION:	Non Dispersive Infrared (NDIR) Air is sampled and passed through an infrared beam. The CO_2 concentration is measured by the detector and output to the meter in PPM.
RANGE:	0-2000/5000 PPM
ACCURACY:	+/- 5% Full Scale
OTHER INSTRUMENTS/ METHODS:	GASTEC or Drager Detector Tube/Hand Pump ($150) (tubes 10 for $25)

CONTAMINANT:	Carbon Monoxide (CO)
SOURCE(S):	Car and truck exhaust Gas-fired appliances, kerosene heaters
PERMISSIBLE EXPOSURE LIMITS:	ACGIH 50 PPM ASHRAE 9 PPM average over 8 hours
TYPICAL OFFICE LEVELS:	0.5 - 2 PPM
HEALTH EFFECTS:	Headache, Impairment of visual acuity and brain functioning. Death at 1000 PPM.
INSTRUMENTATION:	CO 260 Monitor ($1,125) Industrial Scientific Devices
SUPPLIER:	Safety Supply Canada
PRINCIPLE OF OPERATION:	CO passes through a diffusion medium and is absorbed on a electrocatalytic sensing electrode. This generates an electric current proportional to the gas concentration.
RANGE:	0 - 1000 PPM
ACCURACY:	+/- 1 PPM
OTHER INSTRUMENTS/ METHODS:	GASTEC or Drager Colorimetric Tube/Hand Pump ($150) (tubes 10 for $25)

CONTAMINANT:	Respirable Suspended Particulate (RSP)	
SOURCE(S):	Paper handling & cutting, tobacco smoke, incomplete combustion	
PERMISSIBLE EXPOSURE LIMITS:	ACGIH	5 mg/m^3 (total dust: 10 mg/m^3)
	ASHRAE	75 ug/m^3 (year), 260 ug/m^3) (24 hours) total particulates
TYPICAL OFFICE LEVELS:	30-200 ug/m^3 non-smoking 200-600 ug/m^3 smoking	
HEALTH EFFECTS:	Dependent on chemical and physical nature. Can increase risk of lung cancer.	
INSTRUMENTATION:	MDA-PDC-1 Digital dust Counter ($8,700)	
SUPPLIER:	Safety Supply	
PRINCIPLE OF OPERATION:	Light is scattered by dust particles, converted to pulses and related to counts per minute.	
RANGE:	0.001 - 9.999 mg/m_3	
ACCURACY:	$\pm$ 10%	
OTHER INSTRUMENTS/ METHODS:	Gravimetrically with pump and filter ($1,800 for pump) Piezoelectric mass monitor (TSI model 3500; $7000)	

CONTAMINANT:	Formaldehyde (CH_2O)	
SOURCE(S):	UFFI, off-gassing of building materials (carpets, particle board, fabrics) Cleaning fluids, adhesives	*
PERMISSIBLE EXPOSURE LIMITS:	ACGIH 1 PPM ASHRAE 0.1 PPM	
TYPICAL OFFICE LEVELS:	0.1 PPM	
HEALTH EFFECTS:	Irritation of eyes and upper respiratory passages	
INSTRUMENTATION:	STC Formaldehyde Monitoring Kit (100 samples, $750)	*
SUPPLIER:	Air Technology Labs, Inc. 548 East Mallard Circle, Fresno CA 93710	*
PRINCIPLE OF OPERATION:	Formaldehyde vapours diffuse to a liquid solution in a passive bubbler. Sampling time ranges from 15 to 300 minutes. Tubes are placed in a colorimeter to read % transmittance (colour) and PPM of formaldehyde.	
RANGE:	0.02 to 9.90 PPM	
ACCURACY:	± 25% (meets OSHA requirements)	
OTHER INSTRUMENTS/ METHODS:	7 Day Samplers, $40 each Air Quality Research Inc. 901 Grayson Street Berkeley, CA. 94710	

CONTAMINANT:	Asbestos
SOURCE(S):	Building materials, ceiling tiles, insulation
PERMISSIBLE EXPOSURE LIMITS:	ACGIH 0.5 fibers per cc Amosite 2 fibers per cc Chrysotile
TYPICAL OFFICE LEVELS:	N/A
HEALTH EFFECTS:	Increased risk of lung cancer (Mesothelioma)
INSTRUMENTATION:	Air sampling pump with air filter 37mm cellulose acetate (0.8u pore size)
SUPPLIER:	Millipore (filters) Levett-Safety or Safety Supply (pumps)
PRINCIPLE OF OPERATION:	Air is pulled through the filter at a known rate for 4-6 hours. the sample is then sent to the laboratory for microscopic fibre counting.
RANGE:	0.1 - 60 fibers per cc
ACCURACY:	+/- 20%
OTHER INSTRUMENTS/ METHODS:	Transmission Electron Microscopy

CONTAMINANT:	Radon
SOURCE(S):	Decay product of uranium, rises from the soil and is often trapped in buildings. Building materials; bricks, stone.
PERMISSIBLE EXPOSURE LIMITS: (residential)	Health & Welfare Canada: 20 pCi/L or 0.1 WL ASHRAE (EPA) 4 pCi/L or .02 WL
TYPICAL OFFICE LEVELS:	N/A
HEALTH EFFECTS:	Increased risk of lung cancer
INSTRUMENTATION:	Charcoal Canister ($20) - short term screening device
SUPPLIER:	Alpha Nuclear Co. 1125 Derry Road East Mississauga, Ontario L5T 1P3 (416) 676-1364
PRINCIPLE OF OPERATION:	The activated carbon sampler is exposed to air for several days and traps any radon present. The sampler is sealed and returned to the supplier for analysis.
RANGE:	N/A
ACCURACY:	+/- 20%
OTHER INSTRUMENTS/ METHODS:	Long term (6 months) Alpha etch detectors ($35-$50)

1. Barringer Laboratories
   5735 McAdam Road
   Mississauga, Ontario
   L4Z 1N9
   (416) 890-8566
2. Bubble Technology Inc.
   Highway 17
   Chalk River, Ontario
   K0J 1J0
   (613) 589-2456

Direct reading ($3,000 - $5,000)

1. Pylon Electronic
   147 Colonnade Rd.
   Ottawa, Ontario
   K2E 7L9
2. Thomson & Nielsen Ltd.
   4019 Carling Avenue
   Phase 1, Suite 202
   Kanata, Ontario
   K2K 2A3
3. EDA Instruments Inc.
   4 Thomcliffe Park Drive
   Toronto, Ontario
   M4H 1H1

CONDITIONS:	Temperature and Humidity	
SOURCE(S):	HVAC and enclosure problems, inappropriate use	
PERMISSIBLE LIMITS:	ACGIH	30°C WBGT*
	ASHRAE	RH 25-65%
		Temp: Winter 20 - 24°C Summer 22 - 26°C
INSTRUMENTATION:	VAISALA HMI-31/HMP-31UT ($1000)	
SUPPLIER:	Hoskins Scientific 1156 Speers Road Oakville, Ontario	
PRINCIPLE OF OPERATION:	Temperature; Platinum Thermistor R.H.: Thin film polymer capacitor	
RANGE:	Temp.: -40° to +80°C R.H.: 0-100% RH	
ACCURACY:	Temp.: ± 0.3°C R.H.: ± 2% RH in 0-80% range ± 3% RH in 80-100% range	
OTHER INSTRUMENTS/ METHODS:	Solomat MPM Series * Aspirated Psychrometers Sling Psychrometers	

*WBGT - Wet Bulb Globe Temperature
(This index is not directly related exclusively to temperature and humidity).

CONTAMINANT: Microbial: Fungi

SOURCE(S):
Outdoor air and soil
Improperly drained or maintained humidifiers
Wet surfaces of HVAC systems
Furnishings and Ceiling Titles damaged by flooding

PERMISSIBLE LIMITS:

ACGIH - 1,000 cfu (colony forming units) per cubic meter of air
1,000,000 fungi per gram of dust
100,000 fungi per ml of stagnant water or slime

AGRICUTURE CANADA - <50 CFU/m^3, 2 species, or
<150 CFU/m^3, 3 species, or
<500 CFU/m^3

TYPICAL OFFICE LEVELS:
under 200 CFU/m^3 summer
under 50 CFU/m^3 winter

HEALTH EFFECT: Allergic reaction to fungi causes shortness of breath, cough, sneeze, itchy eyes, or runny nose.

INSTRUMENTATION: Biotest RCS Centrifugal Air Sampler ($2,300) with Rose Bengal Agar Strips (box of 50, $150)

SUPPLIER:
Gelman Sciences
2535 Deminiac Street
Montreal
Quebec, H4S 1E5

PRINCIPLE OF OPERATION: Fungal spores drawn into the sampler are impacted by centrifugal force onto a strip of nutrient media (agar). After incubation, the number of colonies grown are counted and identified.

ACCURACY: Sampled air volume ± 2%

OTHER INSTRUMENTS/ METHODS: Andersen sampler for viable particles with pump

ANNEX 3

CARBON DIOXIDE AND VENTILATION

Carbon Dioxide and Ventilation

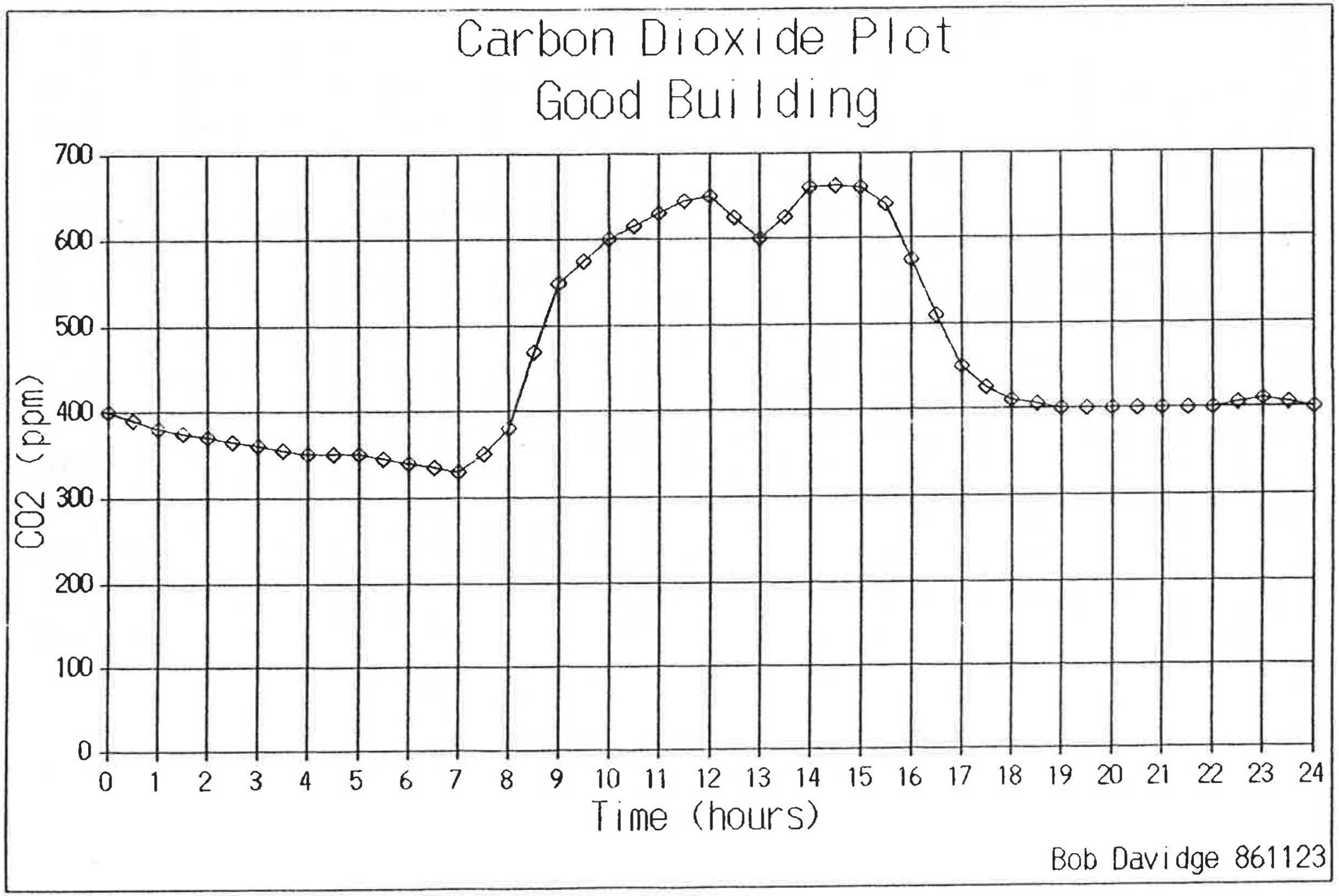
Humans need oxygen to survive, and when the body utilises it, carbon dioxide is produced and exhaled. Since it is a product of metabolism, human tolerance to carbon dioxide is high (the American Conference of Governmental Industrial Hygenists standard is 5000 ppm). It should thus be regarded as an irritating rather than a toxic pollutant. Nevertheless, people complain about poor air quality when the carbon dioxide concentration is considerably less than the standard. This can occur because the concentration of other pollutants increases along with that of carbon dioxide when air circulation is poor, or not enough fresh air is being allowed into the building. For this reason, ASHRAE have recommended a standard of 1000 ppm for office buildings, and have suggested that carbon dioxide concentrations be used as indicators of ventilation effectiveness.

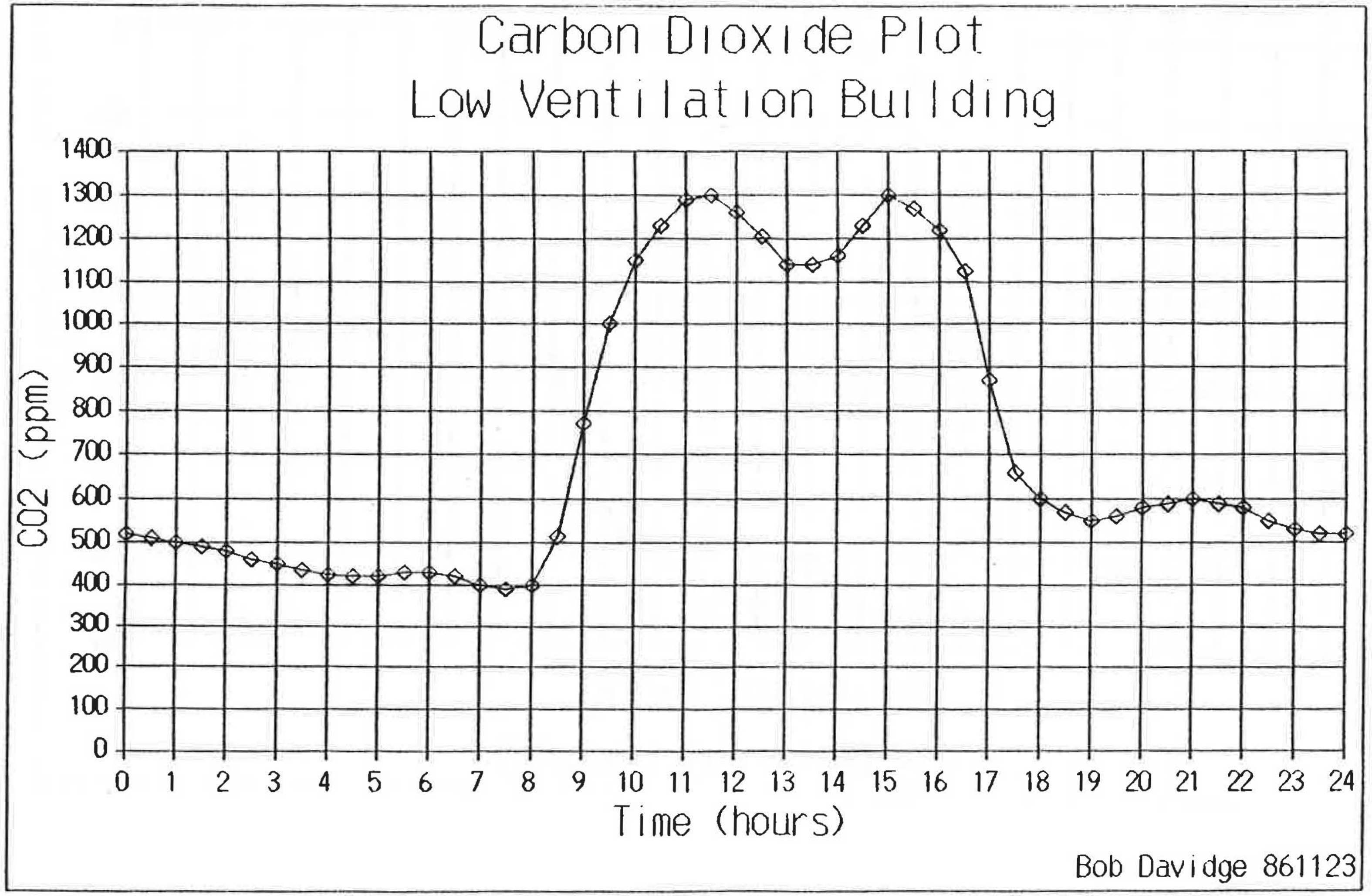
An understanding of the way carbon dioxide concentrations change with time and occupancy during a working day is necessary for proper application of this standard in office buildings. Figures 1 and 2 show two 24-hour traces of carbon dioxide concentrations in office buildings, and the shape is typical. The carbon dioxide concentration increases steeply as people arrive at work and peaks in the middle of the morning. Reduced occupancy causes a dip at lunch time. Usually the maximum concentration occurs in mid afternoon, and a decrease takes place later as people leave work. The steepness of this decrease and the night time minimum concentration achieved depend on whether (or when) the ventilation is slowed (or turned off) at night, and on the building's air leakage rate.

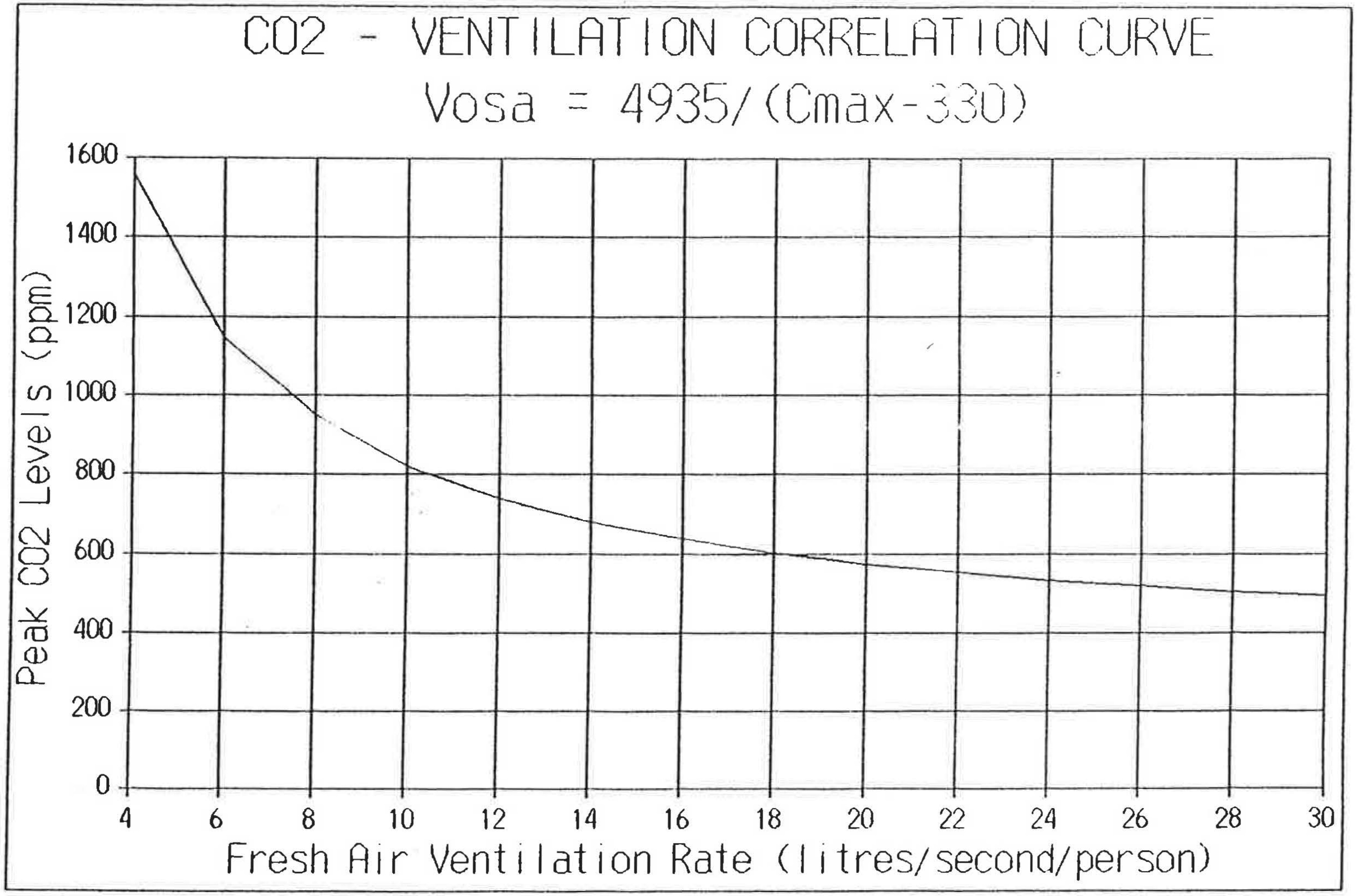
The data given in Figures 1 and 2 can be used to generate approximate fresh air rates for those locations in the buildings.

In order to do this, several assumptions must be made. Firstly, it must be assumed that at the morning and afternoon peaks, the fresh air taken into the ventilation system is just enough to limit the carbon dioxide concentration to the observed peak values (ie that the curve has peaked out or an equalibrium condition exists). Secondly, given an average carbon dioxide exhalation rate of 0.005 litres per second per person, and an outdoor carbon dioxide concentration of 330 ppm have been assumed. Figure 3 shows the relationship between peak carbon dioxide levels and fresh air rates that may be developed based on these assumptions. This curve is generally applicable to buildings. If any of the assumptions changes such as the activity level of the occupants or the carbon dioxide content of the fresh air, then the graph must be adjusted accordingly.

The following exapmle shows how to use this graph to generate approximate equivalent fresh air rates. The average peak concentrations in Figures 1 and 2 are 650 and 1300 ppm. If these values are looked up on Figure 3, it will be noted that they correspond to fresh air rates of 15.4 and 5.1 L/s respectively. Note how the occupancy changes at lunch time and afternoon end could hide a higher potential peak concentration. If the fresh rate is lower (ie the CO2 peak is higher) this effect of not reaching a full peak will be more pronounced. The calculated fresh air rate using this method should be regarded as a maximum value, especially as the peak CO2 levels approach or exceed 1000ppm.


Carbon Dioxide Plot
Good Building
700
600
500
400
300
200
100
0
CO2 (ppm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (hours)
Bob Davidge 861123


Carbon Dioxide Plot
Low Ventilation Building
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
CO2 (ppm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (hours)
Bob Davidge 861123



CO2 - VENTILATION CORRELATION CURVE
Vosa = 4935/(Cmax-330)
Peak CO2 Levels (ppm)
0
200
400
600
800
1000
1200
1400
1600
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Fresh Air Ventilation Rate (litres/second/person)

ANNEX 4

COMPLEX MEASUREMENTS

INTRODUCTION

This annex contains a series of discussions of means of measuring some common air pollutants. These measurements require skills or equipment which are not normally available except from a specialist in the field.

In cases where a simple method is available for a pollutant, some justification is required for selecting a more complex technique. Some standard reasons are listed earlier in this report, and further information is given below.

One frequently-encountered reason is the need to obtain time-resolved data, or a plot of how pollutant concentration changes with time. Some of the direct-reading instruments used by PWC can be linked to either a strip chart recorder or a datalogger and left in place for several hours to collect data.

CARBON DIOXIDE

The simple instruments used to measure carbon dioxide can be linked to a chart recorder or datalogger to record information over a working day. Alternatively, a Miran infrared analyzer can be used with a chart recorder. Because the analyzer requires calibration at several concentrations of CO as well as a zero calibration, it is more accurate than simpler instruments. The overall error is determined by the specifications of the calibration gases.

The data collected can be used to establish peak carbon dioxide concentrations, which are then used to determine ventilation efficiencies as indicated in Annex 3.

COMBUSTION PRODUCTS

The most important chemicals under this heading are carbon monoxide (CO) and nitrogen oxides (represented as NO_x).

The complex measurement procedure for carbon monoxide involves an infrared analyzer, such as the a Miran 1A, and a chart recorder. The analyzer is slightly more sensitive than the hand-held instrument. A plot of CO concentration against time can be useful in assessing ventilation effectiveness in a loading dock, or during peak hours in a parking garage.

The principal sources of nitrogen oxides are gas-fired space heaters or heating furnaces, and diesel fuel. These are not normally a problem in office buildings. If a problem does occur, it is most easily detected by measuring carbon monoxide, which always occurs with the nitrogen oxides in these situations.

Nitrogen oxides may need to be measured in situations where their corrosive properties are important (i.e. film damage). PWC can measure nitrogen dioxide to parts per billion level with an Ecolyser 2000 series instrument which is portable and battery-operated.

PARTICULATES

The simple method described earlier determines the number of particles in air, rather than the weight. Exposure limits are normally expressed in terms of weight, and it is often necessary to supplement the particle count with a weight measurement. Battery-powered pumps are used to draw air for several hours through a pair of matched-weight filters in a cassette. The top filter collects all the particles. The weight difference between the filters and the volume of air sampled are used to obtain a concentration which can be compared to exposure limit. This technique measures total dust (total suspended particulates). If respirable particulates are to be determined, it is necessary to attach a cyclone to the pump to screen out the heavier particles. Usually PWC measures total particulates with this method, as the quantities found are very small, close to the limit of detection of the weighing balance.

POLLUTION MIGRATION / VENTILATION PERFORMANCE

These are usually investigated by using a tracer gas to mimic movement of the airborne pollutant or the ventilation air through the building.

The tracer gas must be non-toxic, not a normal constituent of air, and easily detected. Sulfur hexafluoride (SF6) has been widely used, and some halons and freons are also suitable. These can all be monitored by gas chromatography. Carbon dioxide can also be used, with an infrared analyzer as monitor, but only in areas empty of people.

The test procedure followed depends on the type of information required. For pollution migration studies, a calculated quantity of the tracer gas is released (seeded) at a site previously identified as a possible pollutant source. This site may be monitored for disappearance of the tracer, and other sites monitored for its appearance and build-up.

For ventilation performance studies, the tracer can be released at a constant rate into the supply air, and its build-up at different workstations followed, or the building may be preseeded and the decay of the tracer may be monitored. A simple mathematical treatment of decay (or build-up) curves can yield air change rates. Use of several tracer gases simultaneously enables one to determine the transfer index for air between workstations, leakage between floors etc.

The absolute accuracy of the concentrations measured depends on the calibration gases used for the GC. However, much useful information can be gained from comparing relative concentrations, which depend on the instrumental precision only and thus contain less error.

THERMAL COMFORT

The Stickon datalogger is a miniature unit which combines mesurement of temperature and relative humidity with datalogging capabilities. It can accumulate data for periods of hours to several months, and the data can then be displayed and manipulated on a personal computer.

If measurements of thermal comfort parameters other than temperature and humidity are required, the Building Performance Division can utilize its Thermal Comfort Test Kit.

VOLATILE ORGANIC COMPOUNDS

There are two problems to deal with when monitoring volatile organic compounds (VOC): indoor air contains a mixture of a large number of VOC. These are present in much smaller quantities than normally found in industrial environments, and they display a range of detector responses. Thus measuring devices developed for industrial environments (for example, Gastec and Draeger tubes) are frequently not sensitive enough to detect VOC in offices, or suffer from interferences if several chemicals are capable of detection simultaneously. Simple methods are available for detecting total VOC (TVOC) (for example, the photoionization detectors produced by Photovac and HNU Systems), but they are not accurate because the different types of VOC are detected with different efficiencies.

PWC collects samples using a battery-operated pump to draw air through a solid adsorbent, such as activated charcoal, which extracts VOC from the air. Two techniques are available for analyzing the samples, gas chromatography (GC) and gas chromatography/mass spectrometry (GC/MS). Both rely on the separation of chemicals with different boiling points which occurs when a mixture of gaseous chemicals travels down a tube of adsorbent (column). Thus, both can separate air pollutants from one another. For compound identification, GC relies on the time of travel down the column (retention time), which is characteristic for each chemical and each column. GC/MS additionally breaks up the chemical in each fraction as it comes off the column, producing a mass spectrum which can be used to produce a more positive identification. This identification procedure is, however, unreliable if the fraction contains more than one chemical having similar boiling points or molecular structures.

Both techniques are much more sensitive than simple methods of detection, and are able to detect low parts per billion concentrations. Quantification requires calibration of the GC detector in both instruments. Unfortunately, calibration must be done for every chemical of interest as the detector response varies widely. Thus, errors again depend on the extensiveness of use of calibration gases. An additional complication occurs if the air samples have been collected on adsorbent and require desorption into the instrument. However, given great care, accuracies of +10% are achievable.

A GC/MS instrument is normally computer controlled, and the recorded data may be manipulated to provide information on groups of chemicals. For example, total hydrocarbon levels can be generated, or, separately, aliphatic hydrocarbons and aromatics hydrocarbons. These two sub-groups have very different toxicities.

The equipment is expensive, the analysis time-consuming, and the results still open to interpretation. However, GC/MS is still the most complete, accurate and sensitive method available for organic compounds.