PROGRESS TOWARDS NATIONAL INDOOR AIR QUALITY GOALS FOR VOLATILE ORGANIC COMPOUNDS

REPORT TO THE AIR QUALITY PANEL OF
THE NATIONAL HEALTH AND MEDICAL RESEARCH COUNCIL

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EXECUTIVE SUMMARY

Volatile organic compounds (VOCs) are defined as all organic compounds exhibiting boiling points between 50°C and 260°C and excluding pesticides and polynuclear aromatic hydrocarbons. Low boiling compounds such as formaldehyde are not included in this definition. Concentrations of VOCs in the indoor air of buildings have been measured mostly during the last 10 years using adsorption sampling techniques in order to collect sufficient sample for analysis. These techniques have become better understood during this period and several inadequacies have been identified when used for sampling low VOC concentrations. These include interference by compounds introduced by the adsorbents, non-quantitative collection/recovery techniques and reaction/degradation of collected compounds. Consequently the precision of concentration measurements at low concentrations is usually poor. Recently developed canister collection techniques should largely overcome these inadequacies in future measurements.

While several hundred VOCs have been detected in the indoor air of buildings, measured concentrations have been published only for 111 compounds. These measurements have been made exclusively in overseas buildings. As no data has been published for Australian buildings (and few unpublished measurements exist), no assessment can be directly made of occupant exposures in Australia. It is assumed that the compounds for which measurements have been made are the more abundant compounds, although together they may constitute only a small proportion of total VOC (TVOC) concentrations. Measurement of the concentrations of compounds for which no quantitative data exists is needed for assessment of their health significance to occupants.

For some VOCs many concentration measurements have been made for a large number of buildings in several countries, while for other VOCs limited quantitative data exists. Also substantially more measurements have been made in dwellings than in public buildings. Concentration measurements by different investigations show reasonable consistency in view of the sampling difficulties described earlier and despite being made under different conditions in several countries. These measurements were pooled to derive the average concentration of each VOC (or TVOC) within each building classification (dwelling, office, school, hospital) and category (established, new, "complaint"). The distribution of concentrations was assumed to be lognormal (as reported in several studies) and a common geometric standard deviation of 3.0 was assumed for all compounds. Under these assumptions geometric mean, 90 percentile (90 PC) and 98 percentile (98 PC) concentrations were derived for each compound and TVOC.

Analysis of derived concentrations showed that:

(a) indoor air concentrations of VOCs were generally several times greater than outdoor concentrations, and many were more than an order of magnitude greater;

(b) the geometric mean concentration of each VOC (except ethanol) in the indoor air of established buildings was below 50 $\mu g/m^3$ with most compounds below 5 $\mu g/m^3$. Thirty compounds exceeded 5 $\mu g/m^3$ and were considered the "major" VOCs in indoor air. Geometric mean TVOC concentrations in established dwellings were 1100 $\mu g/m^3$;

(c) VOC concentrations in dwellings were generally greater than those in public buildings but no explanation for this difference was available;

(d) VOC concentrations in new buildings (< 3 months old) were much greater than those in established buildings although the geometric mean concentration of individual compounds was generally less than 100 $\mu g/m^3$. However the geometric mean, 90 PC and 98 PC concentrations of TVOCs in new dwellings were 4500, 18,000 and 40,000 $\mu g/m^3$ respectively;

(e) VOC concentrations have been measured in only a small number of "complaint" buildings and may be elevated relative to those in established buildings, although not clearly so, and further investigations are needed before such conclusions can be drawn.

Many potential sources of VOCs in indoor air can be identified. Several indoor air studies have identified major sources specific to certain circumstances (e.g. isoparaffinic hydrocarbons from wet process photocopiers, car exhaust compounds from attached garages, chloroform from use of chlorinated tap water, tobacco smoke compounds from smoking indoors). However it appears probable that VOCs in indoor air arise from multiple sources which can be generally described as household/consumer products, construction materials, building contents and occupant activities. The relative significance of each of these is unknown. Methods to control these sources have not been widely investigated, but examples are increased ventilation, building "bake-out" and use of air purifiers. Current development and standardization of procedures to measure source VOC emission characteristics and to model the impact of sources on indoor air concentrations will assist in source control in future buildings.

Individual VOCs may occur in indoor air at concentrations causing the detection of odours by some occupants but irritation from individual compounds is not predicted from documented irritation thresholds. It is not possible, due to the lack of information on the interactive effects

of mixtures, to predict from odour and irritation thresholds whether mixtures of VOCs at the concentrations found in buildings will lead to odour and irritation. Recent studies have exposed human subjects to a specific mixture of 22 VOCs at aggregate VOC concentrations of 7400 and 33,000 $\mu g/m^3$, concentrations that have been shown to occur in a small proportion of established buildings and a large proportion of new buildings (as described in (b) and (d) above). Critical review of these studies has led to conclusions that:

(a) the mixture of VOCs employed was not representative of the mixture normally encountered in buildings as it contained unrealistically high concentrations of several compounds. In particular one compound (n-butylacetate at 2470 and 11,000 $\mu g/m^3$) was present above its odour threshold (30-2800 $\mu g/m^3$) and offered subjects a perceptible clue to environmental conditions;

(b) neurobehavioural impairment was observed in 62 "sick building syndrome" symptomatic subjects but not in 66 healthy subjects. Although a functional mechanism cannot be entirely ruled out in the former subjects, it must be considered that susceptible individuals might be less able to concentrate on the tests because of discomfort or anxiety caused by perception of odours during exposures;

(c) the irritant potential of VOCs may be an important determinant of their relevance to the "sick building syndrome" (SBS), although a causal relationship between VOCs and SBS has yet to be proven, a factor acknowledged by Molhave, the main researcher in this area, but often overlooked by reviewers;

(d) whilst the experimental exposure of human subjects has demonstrated effects on perceived air quality, odour and mucosal irritation, these studies require replication with more realistic VOC mixtures and a wider range of subjects;

(e) the association between TVOC exposure and subjectively assessed or objectively measured symptoms is neither strong nor consistent and the dose-response relationship remains to be established.

Seventeen VOCs for which indoor air concentrations have been measured have been evaluated as to their carcinogenicity by the International Agency for Research on Cancer (IARC). Only one of these compounds, benzene, has been classified as definitely carcinogenic to humans. Several quantitative risk assessments (QRAs) have been conducted to determine the risk of leukaemia at low benzene exposures. Due to several major deficiencies in the data and the models used in the benzene QRA, the risk estimates have an uncertainty of several orders of

magnitude. Because of this and the lack of exposure data in Australian buildings, it is considered premature to calculate leukaemia risk estimates for benzene exposure in indoor air. A similar conclusion is drawn for other VOCs that are suspected carcinogens since carcinogenic risk estimates for these would be based on poorer quality epidemiological data than benzene.

In summary, it is considered that no health-based quantitative indoor air quality goals for VOCs can be derived from presently available knowledge of perception of air quality, mucosal irritation, neurobehavioural impairment or carcinogenicity.

At present no overseas authorities have recommended health-based VOC guidelines for indoor air. However some researchers and organizations have recommended VOC indoor air quality guidelines at levels that are achievable based on current knowledge of indoor air concentrations. For example, Seifert (1990) suggested a target guideline of 300 $\mu g/m^3$ for TVOC and 10-30 $\mu g/m^3$ for individual VOCs. However it is impossible to take this approach in Australia in the absence of exposure assessments in Australian buildings.

The Working Party makes the following recommendations:

Recommendation 1. No quantitative indoor air quality goals for VOCs should be developed until there is more knowledge available regarding exposure levels and a better understanding of their health significance in Australian conditions.

Recommendation 2. Research should be carried out to fully characterise the types and concentrations of VOCs present in Australian buildings using standardised measurement techniques.

Recommendation 3. The VOC concentrations in buildings with occupant complaints should be measured in conjunction with epidemiological studies utilising objective health outcomes.

Recommendation 4. The effects of TVOC exposure on subjective and objective reactions of occupants should be further investigated under controlled experimental conditions with compound mixtures which are similar to those encountered in Australian buildings.

PROGRESS TOWARDS NATIONAL INDOOR AIR QUALITY GOALS FOR VOLATILE ORGANIC COMPOUNDS

1. INTRODUCTION

There has been concern for many years over the effect of outdoor air pollutants on human health and well-being and regulations have been enforced to meet this concern. For example, in Victoria the "State Environment Protection Policy (The Air Environment)" was declared in 1981 in order to preserve the "beneficial uses" of the ambient air, one of these uses being the protection of the health and well-being of humans and other forms of life. This Act specifies ambient Air Quality Objectives for a large range of chemical compounds, organic and inorganic, in order to indicate the state of air quality or to protect the health of people. Revision of these Objectives have recently been recommended by Streeton (1990).

In contrast, concern over the effect of indoor air pollutants on human health and well-being has arisen only in recent years. Significant considerations to this concern are that people spend between 70 to 90% of their time indoors, that there are many sources of indoor air pollutants and that inhalation of indoor air as opposed to outdoor air has been shown to be the major determinant of human exposure to these pollutants (Samet *et al.* 1987, 1988).

In response to this situation the National Health and Medical Research Council (NHMRC 1989) decided to establish interim goals for indoor air by adopting outdoor air quality goals and to commission research to develop national indoor air quality goals. Priority for the latter was given to volatile organic compounds and particulates in indoor air, and working parties were established to advise Council on these areas. This report describes the findings of the Working Party on volatile organic compounds (VOCs).

2. TERMS OF REFERENCE

The aim of the project was to develop and formulate options for the NHMRC Air Quality Committee (AQC) in the development of national indoor air quality goals for VOCs for the protection of public health. Under the general direction of the AQC the Working Party was to:

(a) undertake an extensive review of the literature,

(b) collate and analyse existing health related data,

(c) survey relevant national, State and industrial agencies and professional bodies, and

(d) formulate options for the AQC.

The Working Party met with the Joint Steering Group of the AQC (Mr L. Ferrari, Mr L. Heiskanen, Mr K. Steer) prior to project commencement (October 1990) and determined that:

(a) indoor was defined as the non-industrial areas of dwellings, offices, schools and hospitals,

(b) the definition for VOCs would be similar to that provided by the World Health Organisation (1989), i.e. all compounds within the boiling point range of 50°C to 260°C unless specifically excluded,

(c) formaldehyde was excluded not only because of its low boiling point (–21°C) but because an indoor air goal was already established,

(d) although classified as a very volatile organic compound (VVOC) due to its low boiling point (41°C), dichloromethane was included in the investigation since it is a widely used solvent and is classified as possibly carcinogenic to humans (IARC 1985),

(e) pesticide compounds were excluded from specific investigation although the Working Party acknowledged the need for concern over pesticide levels in indoor air and undertook to record any studies found describing this matter,

(f) odour was to be excluded from consideration of health significance.

The Working Party also held a workshop and a meeting (November 1990) with Prof. J. Samet, University of New Mexico, and Prof. J. Spengler, Harvard University, both authorities on indoor air quality, in which general issues and approaches to the project were discussed.

A detailed project plan was subsequently developed as follows:

(a) production of an information resource on VOCs in indoor air which would specifically include:
- reliability of VOC measurements
- compounds detected
- measured concentrations of compounds in different building types, both overseas and in Australia (the latter by survey)
- sources of VOCs in indoor air

(b) consideration of issues such as
- assessment of the health significance of exposure to very low concentrations
- multiplicity of sources and VOCs involved
- differences between buildings in Australia and those overseas

(c) evaluation of the health significance of indoor air exposure to a model carcinogen, selected from measured compounds determined in (a)

(d) critical review of studies reporting irritancy and neurobehavioural impairment from exposure to "total" VOCs (TVOCs).

3. METHODS

3.1 Literature Search

An extensive and up-to-date literature search was carried out. This was ensured by searching:

(a) proceedings of 14 major international conferences on indoor air quality that occurred between 1978 to 1990, including Indoor Air '90 (Canada Mortgage and Housing Corporation 1990),

(b) two CD-ROMs : CCINFO (Canadian Centre for Occupational Health and Safety, August 1990), searching the CISILO database, and OSH-ROM (Occupational Safety and Health, September 1990, Silver Platter Information Inc.), searching the data bases NIOSHTIC, HSELINE and CISDOC, and

(c) two on-line data bases as follows:

(i) Medline, 1977 to October 1990, searching on the basis of construction materials/interior design/building types/indoor microclimate/air pollutants/ environmental, and excluding radiation, asbestos, nitrogen oxides, sulfur dioxide and air microbiology.

(ii) Toxline, 1981 to November 1990, similar search strategy to above using textword searching.

3.2 Survey of Overseas Activities

Sixteen overseas organizations were contacted for information about work-in-progress on the assessment of VOC concentrations in indoor air and related health effects or the setting of indoor air goals for VOCs. These organizations are presented in Appendix I.

3.3 Survey of Measurements in Australia

In order to assess the levels of VOCs in indoor air of Australian buildings, a postal survey was carried out of 67 organizations from all States and Territories who may have made such measurements. The survey was also advertised in the newsletters of five professional bodies: Australian Institute of Occupational Hygenists, Clean Air Society, Thoracic Society of Australia and New Zealand, Royal Australian Chemical Institute and Australasian College of

Occupational Medicine. This resulted in two other organizations joining the survey bringing the survey total to 69. The survey letter and report form are presented in Appendix II together with a list of the organizations surveyed. Survey forms were reissued to non-responders two weeks after the initial closing date.

4. SURVEY RESULTS

4.1 Overseas Survey

Nine of the 16 organizations surveyed replied, as summarised below:

(a) Dr J. Daisey (California): provided Indoor Environment Program 1989 Annual Report, Indoor Air Quality Bibliography 1986-1990 and two recent reports on VOC emissions;

(b) Dr M. Berry/Dr J. Lewtas (USA): provided Preceedings of 5th International Conference on Indoor Air Quality and Climate, Toronto, 1990.

(c) Mr W.D. Kelley (USA): no information available.

(d) Dr D. Halton (Canada): information only available from provincial ministries (list supplied);

(e) Dr D. Crump (UK): provided unpublished paper on VOC concentrations during painting operations and their reduction using an air purifier; also information that the Building Research Establishment has a project to measure formaldehyde and C_6–C_{18} hydrocarbons in 120 homes in the UK (report expected late 1991);

(f) Dr H. Illing (UK): suggested examination of each compound individually due to wide variation in effects, and use of information summarised in "Toxicity Reviews" series of publications; provided copies of reviews "in press" – cumene, cyclohexane and xylenes; also provided pre-publication paper on toxic risk assessment;

(g) Dr L. Molhave (Denmark): has published most findings and there is an EEC database on VOCs;

(h) Prof. B. Seifert (Germany): provided two recently published reports; and

(i) Dr H. Knoppel (Italy): reported that the European Community has developed a small test chamber procedure to characterise VOCs emitted from indoor materials (similar to new ASTM standard test), which may be useful to control emissions in the future if EC Directives are introduced (but no action in this direction as yet). No discussion has been given to indoor air goals for VOCs (except formaldehyde).

4.2 Australian VOC Measurements

58 of the 69 organizations surveyed provided a response, a response rate of 83%. Most respondees had not measured VOC concentrations in indoor air. Measurements that were supplied were generally single point measurements at one location within a building and cannot provide reliable estimates of general exposure. Each of these cases is summarised below.

Case A. In a hospital recovery ward with no occupant complaints, a concentration of 240 $\mu g/m^3$ (0.3 ppm) of Halothane (1-chloro-1-bromo-2,2,2 trifluoroethane) was measured in 1986 and was considered to originate from the exhaled breath of surgery patients. Note that the occupational exposure limits recommended for Halothane are 410,000 $\mu g/m^3$ (ACGIH 1986) or 410 $\mu g/m^3$ (National Occupational Health and Safety Commission 1990), the latter limit being lower to prevent concomitant exposure to nitrous oxide by operating theatre staff.

Case B. Office (computer room) of multi-storey building which experienced a recurring odor on Monday mornings but not on Monday morning of measurements; measurement of total VOC levels (total FID signal in n-decane equivalents) at three locations were 550, 680 and 120 $\mu g/m^3$ (average 450 $\mu g/m^3$); predominant compounds were branched hydrocarbons.

Case C. In response to noxious odour problems in the ladies toilet of an office building, VOC compounds were identified from a toilet air sample and found to be similar to those in air sampled from nearby sewer line into which large quantities of food were discharged by the building canteen. 27 compounds were identified (but not quantified) including xylenes, limonene, higher n-alkanes, organic acids and esters.

Case D. Air was sampled at the air inlet to a laboratory and within the laboratory. 15 VOCs were found in the inlet air and 55 in the laboratory air (including most of the inlet air compounds but at higher concentrations). Compounds included aromatics, n-alkanes, branched alkanes, organic acids and others, but were not quantified.

Cases E&F. Air sampled in two office buildings in 1986 showed the presence of toluene in one case and methylamine in the other.

Cases G.... Measurement of concentrations of 25 VOCs in 18 office buildings were submitted in comments to the NHMRC and are presented in Appendix VII.

5. VOC CONCENTRATIONS IN INDOOR AIR

5.1 Reliability of VOC Measurements

The measurement of VOC concentrations in indoor and ambient air has required analytical techniques with significantly greater sensitivity than those employed in occupational situations since:

(a) the concentrations involved in indoor or ambient air are orders of magnitude lower (e.g. $\mu g/m^3$ cf mg/m^3), and

(b) large numbers of compounds with diverse chemical characteristics must be measured.

VOC measurement methods have progressively improved to overcome these difficulties and in some cases short-comings of previously used techniques have been found, casting doubts on the reliability of measurements, aspects of which will be discussed in this section.

5.1.1 Sample collection techniques

Important sampling considerations are the duration of sampling, whether sample collection is by personal (breathing zone) or static (fixed) location of the sampling device, and whether the device uses a passive or active sampling method. Short-term (< 1 hour) sampling is useful for measuring episodes of high concentrations of compounds and would be appropriate for assessing acute health effects. However such sampling requires prior knowledge of peak occurrence which is generally unavailable, and a very detailed sampling scheme. Long-term sampling (1/2 - 7 days) provides a time-averaged measurement of concentration useful for assessing chronic health effects, and is the procedure generally employed in indoor air sampling. Ideally, longitudinal sampling of indoor air for several months is needed to determine chronic exposure levels but this has been rarely done.

In occupational sampling, personal sampling generally results in higher measured concentrations than static sampling, especially where sources are associated with personal activities. Similar effects have been demonstrated where indoor air measurements have been made during common activities e.g. household cleaning, washing, painting or paint removal (Girman *et al.* 1987, Wallace *et al.* 1987a). However sampling location may be less important when VOC sources are diverse and continuous, although this aspect has received little attention and both approaches have been used in indoor air studies.

Both passive and active sampling methods have been used in indoor air studies and, while active sampling is generally problem-free, significant underestimation of indoor air concentrations can arise from passive sampling due to the effect of air velocity on the diffusion collection process. Diffusion collection occurs according to Fick's first law of diffusion which requires that the gas concentration at the start of the diffusion path be identical to the ambient concentration of the compound. However under low air velocity conditions, boundary layer effects at the sampler inlet can lead to localised depletion of the compound and thereby reduced gas collection. Lewis *et al.* (1985) measured the collection rates of several VOCs at different air velocities with a badge type passive sampling device. They found that the collection rates at a linear face velocity of 5 cm/sec (R_5) were 64% of collection rates at 50 cm/sec (R_{50}). They showed this reduction was consistent with boundary layer theory and calculated that face velocities should exceed 15 cm/sec for sampling rates to exceed 0.8 R_{50}. However Matthews *et al.* (1987) showed that median air velocities in domestic environments ranged from 1–15 cm/sec, indicating that a static passive sampler of the type described by Lewis *et al.* could underestimate exposure by up to 35%. In contrast, Lewis *et al.* predicted that if the passive sampler was worn by occupants then sampling rates would be $R_{50} \pm 5\%$. They recommended that static passive sampling of indoor air should use a fan to ensure adequate air flow.

Similar effects of air velocity on passive sampling have been reported for Dupont Badge samplers using activated charcoal (Sheldon *et al.* 1985), while De Bortoli *et al.* (1987) reported no difference in sampling rates at 0.1 cm/sec and 50 cm/sec for Palmes tube type passive samplers (3 mm diameter, 25 mm path). This difference in behaviour is consistent with a model proposed by Matthews *et al.* (1987) for the boundary layer thickness i of tube-type passive samplers in which i can be maintained small by comparison with the diffusion path by judicious selection of tube diameter, so that velocity effects are minimised.

One further disadvantage with passive samplers is that quantitative collection relies on occurrence of relatively constant compound concentrations. Short, intermittent peak exposures may not be quantitatively collected (Standards Association of Australia 1987). This factor will depend on the sampling rate of the specific sampler design relative to the rate of concentration change. For example Lewis *et al.* (1985) showed that VOC concentrations fluctuating from 1 to 10 to 100 ppb over a one-hour period were successfully measured by a rapid collection badge-type sampler, but different performance can be expected from other sampler designs.

5.1.2 Adsorbent effects

Since VOC concentrations in ambient and indoor air are very small, sample collection techniques have generally used adsorbents to capture and concentrate the compounds which are

subsequently desorbed for analysis. Activated carbon and polymeric resins (in particular Tenax) are the adsorbents predominantly used and these exhibit quite different behaviours and require different analytical techniques.

Activated carbon has non-polar surfaces and sampling is unaffected by humidities below 80% (Lewis *et al.* 1985). It collects organics by chemisorption so that virtually all organic compounds are efficiently collected including very volatile compounds such as vinyl chloride and low molecular weight alkanes. However this adsorption is thermally irreversible and solvent extraction techniques (usually with carbon disulphide) are required for efficient desorption. This limits the analytical detection limit by gas chromatography (GC) since generally only 1 μL of the total of 1 mL of desorption solvent (i.e. 1/1000 th of the air sample) will be injected into the GC. Assuming a GC/mass spectometry (MS) detection limit of 0.1–0.5 ng per compound and an air sample volume of 20 L, it is estimated that a detection limit of 5-25 $\mu g/m^3$ will apply for such analysis. This is comparable to or greater than the VOC concentrations often encountered in ambient and indoor air, although such limitation can be compensated for by sampling much larger air volumes.

A further difficulty with activated carbon sampling arises from the solvent desorption process due to contaminants present in the solvent and non-quantitative release of compounds. For example, it has been reported that benzene and $C_6 - C_7$ hydrocarbons are not quantitatively collected and that C_1 to C_5 compounds are lost due to their volatilities (De Bortoli *et al.* 1987). Also background contamination of charcoal monitors with VOCs has been found to be significant with some commercial products (Table 1) limiting their potential for sampling at low concentrations (e.g. for an air concentration of 1 $\mu g/m^3$ and a 100 L air sample, a compound mass of 100 ng is collected, which is of the same magnitude as some contaminant levels in Table 1).

Polymeric resins have been the most widely used adsorbents for VOC collection from indoor air, especially Tenax GC which has been extensively tested. Polymeric resins exhibit thermally reversible adsorption so that the complete sample can be thermally desorbed and injected into the GC/MS resulting in detection limits generally 200 times or more than those capable with activated carbon (Sheldon *et al.* 1985). Tenax GC (2, 6-diphenyl-p-phenylene oxide) has the highest temperature stability of the polymeric resins so that it can desorb compounds up to boiling points of 300°C cf 240-265°C for Chromosorb resins and 180-240°C for Porapak resins. However while it exhibits high collection efficiencies for many VOCs, it exhibits low collection efficiencies for more volatile or polar compounds.

Due to the reversible nature of adsorption on polymeric resins, there exists for each compound/polymeric adsorbent system a minimum volume of air called the breakthrough volume (V_B) that can be passed through the adsorbent after which the compound starts to elute from it and collection efficiency decreases. V_B will vary with flow rate, temperature and the number and concentration of compounds in the air sample and estimated values for Tenax GC are presented in Table 2. It is seen that at the sampling volumes of 20 L/g generally used in indoor sampling, the more volatile (< 80°C boiling point) or polar (ethanol, propanol, acetone, methylethyl ketone, acetic acid) compounds will not be quantitatively collected. This limitation could be overcome by using other porous polymers (Namiesnik *et al.* 1981, Rothweiler *et al.* 1990) which provide better collection of the more volatile compounds, or by using adsorbent mixtures (Krost *et al.* 1982, Miller 1983, Hodgson and Girman 1989) although these approaches have not been widely used in VOC surveys of indoor air.

Tenax GC has been reported to quantitatively desorb VOCs up to n-pentadecane (b. pt. 290-300°C) (De Bortoli *et al.* 1987). However several studies have found that quantitative analysis is hindered by:

(a) introduction of artifacts such as benzaldelyde and 1-phenylethanone which are formed when Tenax is heated (Walling *et al.* 1986);

(b) presence of background VOCs on blank samplers, possibly introduced by passive collection during handling and storage, as shown by Table 3 (Sheldon *et al.* 1985, Walling 1984, Walling *et al.* 1986). To overcome this difficulty Riggin (1985) recommended that blank 1.5 g Tenax cartridges should release less than 10 ng of each compound and that for any compound of interest the blank content should be less than 25% of the quantity expected to be collected; and

(c) reactivity or degradation of VOCs during the adsorption/desorption process. Walling *et al* (1986) reported poor desorption recoveries of two haloalkanes (bromotrichloromethane (b.pt. 104°C) and pentachloroethane (b.pt. 162°C)) which were spiked onto Tenax cartridges, and the appearance of other compounds which were probably decomposition products of the unrecovered compounds. Unexplained loss of other compounds (benzene, alkylated benzenes, trichloroethylene) was also reported (Walling *et al.* 1986). Crist and Mitchell (1986) investigated the Tenax collection and analysis of seven VOC gas standards at low ppb levels and found positive quantitation biases for benzene (10-25%), toluene (30-60%), bromobenzene (13%), chloroform (5-50%) and dichloromethane (5-30%), negative bias for carbon tetrachloride (30-70%) and a complete loss of chlorobenzene.

It is clear that considerable problems have been found in recent years with adsorbent sampling techniques. This has led to the development of a vessel collection technique in which air is pumped into a 6L stainless steel canister the interior of which is specially polished ("SUMMA" process) to passivate it and allow storage of VOCs for up to 30 days without significant loss (McClenny *et al.* 1986, Lewis and Wallace 1989). The procedure is quoted to be accurate to ± 1 $\mu g/m^3$ at concentrations of 15 $\mu g/m^3$ or less and has been shown to provide very good agreement with Tenax collection. Its disadvantages are that the air samples have to pass through a filter/pump/valve combination which may lead to losses or contamination, the possibility of air leaks and the limited sample volume. However Sheldon *et al.* (1990) reported that this technique provided quantitative recovery of 25 VVOCs and VOCs, with poor performance only for acetaldehyde. Since the technique is a recent development it has not been used in reported VOC indoor air surveys but is being developed as an ASTM Standard Method (as are Tenax and mixed sorbent sampling) and offers promise for more reliable air sampling in the future.

5.1.3 Measurement accuracy and precision

The accuracy and precision of the analytical method are generally considered very high. For example, McClenny and Pleil (1984) verified this with replicate flame ionization detection (FID) measurements at 4 ppb for a 16 compound mixture, which exhibited an average standard deviation (SD) of 3.8%. They also found that with 5 point calibration runs in the region 0-50 ppb relative errors were less than ±11%. Generally the higher molecular weight compounds exhibited greater SDs and relative errors. However due to the errors involved in sampling procedures as discussed earlier (e.g. sample volume, compound breakthrough, adsorbent artifacts, background compounds and compound reactivity) it is expected that measurements of VOCs in indoor air will exhibit much higher imprecision.

Crist and Mitchell (1986) found high imprecision for seven compounds investigated at standardised concentrations and concluded that the measurement precision for field samples using Tenax adsorbent was of the order of ±30%. Riggin (1985) estimated that 'repeatability' was ±25% and that under ideal conditions overall recoveries (trapping and desorption) of >75% could be achieved for many compounds. Krost *et al.* (1982) reported that the relative standard deviation for triplicate field measurements with an active sampling Tenax-based method ranged from ±10% to ±40% for nine different compounds. Lewis and Wallace (1989) reported relative standard deviations (RSD) of 25 to 35% for 20 VOCs in the 10 to 100 $\mu g/m^3$ range, except for benzene for which RSD was 45%. Seifert (1988) reported that analysis of calibrated gas mixtures of benzene and xylene (10-30 $\mu g/m^3$) and toluene (1-3 $\mu g/m^3$) by German standard methods exhibited repeatability within one laboratory of 20-130% and reproducibility between 23 different laboratories of 70-500%.

It is apparent from these measurements that despite the inherent precision and accuracy of GC/MS analysis, the limitations of sampling and preparation procedures will cause substantial imprecision in indoor air measurements. A conservative estimate of precision of ±50% is suggested for assessing indoor air monitoring results with added attention being given to specific compounds for which sampling problems (low breakthrough volumes, artifact/contaminant formation, desorption loss) are known to exist (although this knowledge may be inadequate for many compounds).

5.2 Compounds Detected

A large number of VOCs have been detected, but not quantified, in indoor air. Jarke *et al.* (1981) identified 249 organic compounds in the indoor air of 36 dwellings. Berglund *et al.* (1986) reported that more than 300 VOCs had been detected in non-industrial indoor air. Many of these compounds are also detected in ambient air (Harkov *et al.* 1983, Shah and Singh 1988). Since more than 2000 chemicals in commercial use have been detected in ambient air (Kelly 1990) it is feasible that these could also be detected in indoor air. Hence it is important to consider the difference in compound concentrations between indoor/outdoor locations. Most studies have shown that for any location there are more VOCs present (detectable) indoors and most occur in indoor air at considerably higher concentrations than outdoors. The results of these studies are summarised in Table 4. It is seen that the indoor/outdoor ratio varies considerably but generally is much in excess of unity and that for many compounds the indoor concentrations exceed the outdoor concentrations by an order of magnitude or more. This indicates that the sources of the compounds and greatest human exposure to them occur within the buildings.

5.3 Indoor Concentrations

While a very large number of VOCs have been detected in indoor air, concentrations have been measured only for some compounds, and for each compound the number of measurements and their usefulness for assessing occupant exposure varies considerably. No assessment of population exposure and resulting environmental health significance can be made unless concentrations have been measured. Hence only compounds for which measurements have been made will be considered in this section. It is probable that these are the compounds that occur at highest concentrations, although in combination they may comprise a minor proportion of the total VOC concentration in indoor air (Hodgson *et al.* 1990) indicating the need for a more complete assessment of the compound concentrations.

McCann *et al.* (1987) pointed out the need to estimate the distribution of compound concentrations for risk assessment so that the population exposed to high concentrations is considered. Estimations of the concentration distributions for VOCs in indoor air have been made by a World Health Organisation working group (WHO 1989, Stolwijk 1990) using the averaged results from four large surveys of VOC concentrations. However it was considered that these estimates are limited since (a) the surveys included only dwellings, and (b) it had been assumed that all VOCs followed a distribution (approximately lognormal) which was averaged from those of benzene and trichloroethylene. The 50 percentile (median), 90 percentile and arithmetic mean concentrations that were estimated for 69 VOCs are presented in Table 5. Also shown are averaged measurements from a USEPA sponsored data base of the indoor air concentrations (both published and unpublished) of 35 VOCs in US dwellings (Shah & Singh 1988). Differences exist in the source of data for these estimates and the procedures used to derive them. WHO estimates are derived from large studies in both the US and three European countries and, as described above, rely on assumed distributions of concentrations to estimate 90 percentile concentrations. The USEPA data are for the US only and were derived from direct analysis of available data without assuming a specific distribution. Comparison of median concentrations shows that the USEPA indoor concentrations are generally lower than WHO estimates. An explanation for this difference would require consideration of differences in sources and their characteristics and the ventilation levels in the buildings studied, factors which are unknown. Considerably more buildings have been surveyed in recent years and these have included public buildings as well as dwellings. Hence a further derivation of average VOC concentrations and their distributions has been undertaken for the present investigation.

Most indoor air surveys of VOCs have reported concentrations as different types of averages and have not reported the distribution of concentrations. Consequently it was assumed that concentration distributions were lognormal for all compounds and a single geometric standard deviation (GSD) was adopted for data analysis. The distributions for benzene and trichlorethylene that were adopted by the WHO (1989) were analysed and found to be approximately lognormal with GSD ~ 1.6. However the 25, 50 and 75 percentile concentrations for 13 compounds (boiling points from 74°C to 195°C) provided by the USEPA database were found to be lognormally distributed with GSDs of approximately 3 (Table 6). Also TVOC measurements in 10 offices (Morey and Jenkins 1989) were found to exhibit a lognormal distribution with a GSD of 2.8 and Wallace *et al.* (1990) reported that tests for log-normality were not rejected for 42 of 54 distributions of TVOC concentrations in dwellings with GSDs ranging from 2.0 to 3.5. Consequently a GSD of 3.0 was adopted for analysis of data in this investigation.

Data analysis employed all available studies of VOC concentrations in indoor air to derive a single average concentration for each VOC. The studies involved and some details of their designs are presented in Table 7. In some studies static passive sampling was used to collect VOCs. In others using active sampling, air volumes were collected which exceeded the reported breakthrough volumes of some of the more volatile VOCs. For these cases it is expected that the VOC concentrations would be underestimated as discussed earlier. However omission of such data from the derivation of averages usually had little influence, either due to the low number of data points involved in such cases or the similarity of the concentrations measured to those from other studies. In some cases such omission could have led to lower derived averages. Consequently all data was included in derivations but some derived data was highlighted as a possible underestimate since it was derived mainly from studies employing poor sampling strategies such as those described above.

Average and 90 or 98 percentile concentrations for each compound were derived from data provided by several studies using the following procedure:

(a) measurements from each study were classified according to whether they represented non-industrial areas of dwellings (D), offices (O), schools (S) or hospitals (H) with additional sub-categories in each of these for separating results for "established" (greater than 3 months old), "new" (less than 3 months old) or "complaint" (by occupant report) buildings. Nursing homes were also included under H, and since one study evaluated a number of mobile dwellings (MD) these were treated as a further sub-category.

(b) the following results were compiled from each study (if available) – number of buildings, number of measurements, maximum concentration, arithmetic mean concentration, geometric mean concentration, median concentration, and 90 percentile concentration (no studies provided 98 percentile concentrations).

(c) if the study provided a geometric mean (GM) it was always used in averaging; if not, but an arithmetic mean (AM) was provided, this was used to estimate a GM by assuming data to be distributed lognormally and using the following equations provided by Tancrede *et al.* (1987):

$$GM = (AM / \sqrt{1 + CV^2}) \quad (1)$$

$$\log_e GSD = \sqrt{\log_e (1 + CV^2)} \quad (2)$$

where CV is the coefficient of variation.

Assuming GSD = 3.0, as described earlier, it can be calculated from (2) that CV = 1.53 and thus from (1) that

$$GM = AM/1.83 \qquad (3)$$

(d) if the study did not provide values for GM or AM but did provide a median, then the median was taken as an estimate of GM; this appeared reasonable based on a limited number of examples where both median and GM were provided:

Median	GM
16	12
15	14
6	6
13	12
6	7
5	6
12	10
24	32

(e) using the GM_i results assembled by the above procedures and the number of measurements N_i for each study i, the weight averaged GM (WAGM) for each compound was derived from

$$\log_e WAGM = \frac{\Sigma N_i \log_e GM_i}{\Sigma N_i}$$

(f) WAGM was used to derive the 90 percentile concentration (90 PC) from

$$\log_e 90\,PC = \log_e WAGM + 1.28 \log_e GSD$$

$$= \log_e WAGM + 1.41$$

Similarly the 98 percentile concentration (98 PC) was derived from

$$\log_e 98\,PC = \log_e WAGM + 2.05 \log_e GSD$$

$$= \log_e WAGM + 2.25$$

(g) an average maximum concentration (AMC) was derived from the maximum concentrations (MC_i) reported in some studies from

$$\log_e AMC = \frac{\Sigma \log_e MC_i}{n}$$

where n is the number of studies.

(h) a weight averaged arithmetic mean (WAAM) was derived from the arithmetic mean reported by some studies (AM_i) using

$$WAAM = \frac{\Sigma N_i AM_i}{\Sigma N_i}$$

Note that AMC and WAAM were derived only from directly reported data and are thus based on fewer studies or measurements than WAGM and 90 PC/98 PC values. An example of the above derivation procedure for benzene concentrations in established dwellings is presented in Appendix III.

Full Results of derived concentrations for all compounds are presented in Appendix IV and analysis of these forms the basis of the following discussion. It is seen.that concentrations have been determined for 111 organic compounds, including six very volatile organic compounds (boiling point < 50°C). This is only a small proportion of the number of organic compounds detected in indoor air (Berglund *et al.* 1986), and while it is believed they are the compounds occurring at highest concentrations, determination of the concentrations of the other compounds is needed for assessment of their health significance.

5.3.1 Major compounds

WAGM values were derived for 81 VOCs in established dwellings. Sixty-two (77%) of these VOCs exhibited WAGM concentrations below 5 $\mu g/m^3$ and only one (ethanol) exceeded 50 $\mu g/m^3$ (Table 8). The 19 VOCs (23%) occurring at WAGM concentrations above 5 $\mu g/m^3$ will be considered the "major" compounds in indoor air. These were also the compounds exhibiting high elevation of indoor concentrations above those outdoors (Table 4). These compounds and their derived WAGM and 90 PC concentrations for dwellings are presented in Table 9 with comparison to median and 90 PC results derived by WHO (1989). Note that limonene, toluene, m,p-xylene and dichloromethane appear as the more abundant VOCs in both derivations. The WHO (1989) also identified 3-methylpentane, 2-methylpentane, 3-methylhexane, cyclohexane and methylcyclohexane as more abundant compounds, largely based on the study of Le Bret *et*

al. (1986). This study provided low median (2-4 $\mu g/m^3$) but large maximum (50-500 $\mu g/m^3$) concentrations for these compounds and the different finding in the present investigation probably results from different derivation procedures.

Additional VOCs are shown to be major indoor air compounds in the present derivation, in particular acetone, 1,1,1-trichloroethane, camphene, 1,2-dichloroethylene, benzene, ethyl acetate and p-dichlorobenzene. Acetone, 1,1,1-trichloroethane, benzene and p-dichlorobenzene were also major compounds in the USEPA indoor air database, the latter showing agreement with the present derivation with the exception of methylethylketone (MEK) which was one of the most abundant VOCs in the USEPA database. This discrepancy may be due to the high reliance of the present derivation for MEK on measurements by Krause *et al.* (1987) who used a static passive sampler which probably underestimated actual concentrations. Consequently MEK was included in the present list of major compounds.

Comparative data for VOC concentrations in dwellings relative to those in offices, schools or hospitals were available for 36 compounds. For most of these compounds the concentrations in the public buildings were less than those in dwellings, often by more than 50% (Appendix IV). Comparative values of WAGM were available for 84 established dwelling-public building combinations and the differences between each data pair were evaluated for statistical significance (using an approximate t-test which assumed GSD = 3.0 and at a 5% significance level). It was found that dwelling concentrations were significantly lower than public building concentrations in 61 cases, no different in 13 cases and significantly greater in 10 cases. Causes of these differences are unknown. It is notable that data for dwellings are derived from a large number of measurements in a large number of buildings, while data for public buildings are derived from fewer measurements and usually several buildings, but the significance of this factor is unknown. Those compounds for which WAGM concentrations were at least 20% higher in public buildings than in dwellings are summarised in Table 10 and are seen to occur mainly in offices. Five of these compounds are additional to those in Table 9 and exceed a WAGM concentration of 5 $\mu g/m^3$ and are thus also considered as major compounds in indoor air.

Also Wang (1975) determined the concentrations of several bioeffluents in a mechanically ventilated 2400 m^3 lecture theatre containing 225-389 people. No comparative measurements appear to have been made in dwellings. Six of these compounds exceeded a WAGM of 5 $\mu g/m^3$ and are also considered major compounds, albeit for this specific situation. Five of these were VOCs not measured in other surveys – diethyl ketone, phenol, acetic acid, butyric acid and methanol – and when combined with the other compounds described earlier provide a total of 30 "major" VOCs in indoor air. These VOCs and their derived concentrations are presented

in Table 11 in addition to odor thresholds, irritation levels, ambient air guidelines and occupational exposure standards, aspects which will be discussed in Section 7.

5.3.2 VOC concentrations in new buildings

Occupant complaints of poor indoor air quality have arisen when new buildings are first occupied (Hodgson *et al.* 1989) and it is known that VOC concentrations in indoor air are much higher during the first few months after construction (Berglund *et al.* 1982). Consequently new buildings (less than 3 months old) were treated as a separate sub-category in this investigation to allow comparison with established buildings.

For many VOCs for which comparative data were available, indoor air concentrations were considerably greater in new buildings, often by an order of magnitude or more, as shown in Table 12. These compounds are assumed to originate from new building materials and furnishings, and it is notable that approximately one-half of the compounds were also major compounds found in established buildings. TVOC concentrations were also higher in new buildings with very high values (> 15,000 $\mu g/m^3$) in some cases (Table 12). It is expected that these concentrations will decline significantly in the first few months after construction. For example Wallace *et al.* (1987) determined that the concentration decays of several VOCs in three new public buildings had half-lives of 2 to 8 weeks depending on compound volatility.

It is seen from Table 12 that the WAGM concentrations of individual VOCs in new buildings are typically less than 100 $\mu g/m^3$ while 90 PC and 98 PC concentrations are of the order of several hundred $\mu g/m^3$. Concentrations of m,p-xylene, α-pinene, n-decane and 2-propanol were higher but these measurements all result from one study (Molhave and Moller 1979). This study involved Danish "factory-constructed" dwellings which may not be representative of normally constructed buildings.

Seven of the VOCs that were elevated in new buildings were not classified as major compounds in Table 11. In addition 2-ethoxyethylacetate exhibited a WAGM concentration of 5 $\mu g/m^3$ in a new building but no comparative measurement had been made in an established building. These may also be considered as major indoor VOCs, although specific to new (or renovated) buildings. These compounds and their derived concentrations as well as information on odour, irritation and environmental/occupational guidelines are presented in Table 13.

Several compounds were not elevated in new c.f. established buildings, possibly reflecting the different nature of their sources. These compounds were: (a) tetrachloroethylene, which occurred at lower concentrations in new buildings, consistent with its major probable indoor air

source from residues on dry-cleaned clothing (Tichenor *et al.* 1988), (b) toluene, (c) n-butyl acetate, (d) benzene, (e) n-heptane, and (f) n-hexane.

5.3.3 VOC concentrations in complaint buildings

Since it has been suggested that occupant complaints of poor air quality and even the "sick building syndrome" may be associated with elevated VOC concentrations in indoor air (Molhave 1986, Bayer and Black 1988, Andersen 1985, Zweers *et al.* 1990, Norback *et al.* 1990), VOC measurements in such buildings were analysed separately. Buildings were considered as complaint buildings in this analysis if studies reported that occupant complaints had occurred but generally the nature and incidence of such complaints had not been investigated.

Concentrations of individual compounds had been measured only in office and school buildings where complaints had arisen and derived WAGM concentrations for these were compared to those for established buildings. Concentration ratios are presented in Table 14 and show that many VOC concentrations were not elevated in complaints buildings while in several cases they were. These results must be considered tentative since they are based on very limited investigation. For example results for 8 of the 10 compounds with elevated concentrations came mostly from one office building investigated by Bayer and Black (1988). Comparative results for total VOC (TVOC) concentrations in complaint buildings have a somewhat better data basis, being derived from 438 measurements in 66 buildings. These values are also presented in Table 14 and are elevated relative those for established buildings in the cases of public buildings but not dwellings. However since TVOCs have been defined in several different ways (see Section 5.3.4), the significance of an observed TVOC elevation in complaint buildings is also difficult to interpret. Further, recent studies have provided conflicting findings on the influence of TVOC concentrations on the incidence occupant complaints (Norback *et al.* 1990, De Bortoli *et al.* 1990).

Due to these difficulties it is considered that at present no conclusion can be drawn from site measurements as to the influence of specific VOCs or TVOCs on the occurrence of occupant complaints of poor air quality or sick building syndrome. Further studies in this area are needed before conclusions can be reached. Investigations of subjective and objective effects on human subjects when exposed to a controlled VOC mixture have been carried out as a further means of studying the influence of VOC exposure on building occupants and these will be discussed in Section 7.

5.3.4 Total VOC concentrations in indoor air

While it has been found that indoor air can contain a large number of VOCs which are individually at very low concentrations (generally < 5-50 $\mu g/m^3$), it has also been found that the total VOC (TVOC) concentration in indoor air is considerably greater (generally thousands $\mu g/m^3$) and this has been postulated to be a cause of occupant complaint (Molhave 1990). However while many studies have estimated TVOC concentrations in indoor air, the methods by which these have been estimated vary greatly, limiting the direct comparison of data from different studies or the assessment of concentrations leading to health complaints.

Generally TVOC concentrations are estimated from:

(a) an integrated flame ionization detector (FID) signal generated with or without chromatographic separation and calibrated as equivalents of specific compounds (e.g. methane, toluene) or groups of compounds. In the absence of chromatographic separation this method will estimate additional organic compounds (very- and semi-volatiles as well as VOCs, although not formaldehyde) depending on the sample collection procedure. However since the FID response is approximately proportional to the number of carbon atoms present in the sample with reduced or no response to carbon atoms bound to oxygen, nitrogen or halogens, the total organics present may be underestimated depending on the nature of the compounds present.

(b) summation of the concentrations of certain (generally prevalent) compounds, usually approximately 20 compounds specifically monitored or present in greatest concentrations and measured by mass spectrometric (MS) detection. This must always underestimate the actual TVOC concentration and may underestimate greatly if the most prevalent compounds were not monitored; and

(c) summation of all compound concentrations measured by MS detection and including an estimate for non-identified compounds assuming a specific calibration factor.

In order to overcome this difficulty Seifert (1990) has suggested that a definition of TVOC be adopted in future measurements for the purpose of establishing a target guideline value for indoor air, as follows:

TVOC means the sum of individual VOCs (as defined by the WHO, i.e. VOCs with a boiling point range from 50-100°C to 240-260°C and sampled by adsorption on a solid sorbent) separated and quantified by a gas chromatographic technique. To obtain the sum, the VOCs

belonging to each of the following chemical classes are ranked according to their measured concentrations: alkanes, aromatic hydrocarbons, terpenes, halocarbons, esters, carbonyl compounds (excluding formaldehyde) and "other". The concentrations of the first ten VOCs in each class are then summed up and should contribute no more than the following to the TVOC concentrations:

alkanes	100	$\mu g/m^3$
aromatic hydrocarbons	50	"
terpenes	30	"
halocarbons	30	"
esters	20	"
carbonyl compounds	20	"
other	50	"
TVOC target guideline	300	$\mu g/m^3$

Additionally no single compound should exceed 50% of the concentration limit allotted to its class or 10% of the guideline TVOC (i.e. guidelines for single compounds would range from 10–30 $\mu g/m^3$).

Seifert stressed that the guideline values were not based on toxicological considerations but reflected what could be achieved based on current knowledge. He also stressed that they were intended to represent normal conditions and that under special circumstances such as after renovations, TVOC concentrations 50 and 10 times higher (i.e. 15,000 and 3,000 $\mu g/m^3$) after 1 and 6 weeks respectively, should be acceptable. Molhave (1990) has suggested that no occupant discomfort or irritation should be expected with a TVOC guideline of 200 $\mu g/m^3$, measured by summation of GC/FID peaks (procedure (a)). While these two guidelines values appear numerically similar they are based on widely different measurement procedures preventing their direct comparison. It is likely that TVOC concentration estimated by procedure (a) will overestimate relative to the Seifert definition since very volatile organic compounds captured by some adsorbents may significantly increase the FID response (Rothweiler *et al.* 1990) and all compounds are considered (provided they provide an FID response). TVOC concentration estimated from procedure (b) is likely to be a significant underestimate since it considers fewer compounds than considered in Seifert's definition. In some situations it has been found that the 20 compounds found at highest concentrations comprise less than 5% by mass of the total VOCs present (J. Girman, Health and Welfare Agency, State of California, private communication). The authors consider that procedure (c) will provide the best TVOC estimates (especially when combined with canister collection of samples) and that estimates by

Seifert's definition will be lower to an extent depending on the number and types of compounds present in greatest abundance.

TVOC estimates were available from most of the studies presented in Table 7 and derived concentrations were determined using procedures described earlier without consideration of differences in samplng strategies or estimation procedures. Derived TVOC concentrations are presented in Table 15. As found with individual VOCs, TVOC concentrations were considerably greater in dwellings than other building types and were elevated in new and complaint building sub-categories. It is seen that numerically the guidelines proposed by Seifert and Molhave are frequently exceeded, particularly in dwellings and those public buildings in which complaints have arisen. In new buildings, Seifert's guidelines of 15,000 and 3000 $\mu g/m^3$ after 1 and 6 weeks respectively are difficult to compare with derived data since the latter were averaged for the first three months after construction and data on specific variations within this period were generally unavailable.

6. MAJOR INDOOR SOURCES OF VOCs

It is clear from the forgoing discussion that a large number of VOCs are normally found in indoor air, although generally at individual compound concentrations below 50 $\mu g/m^3$, and often much below this level. However even at these levels, VOC concentrations in indoor air are considerably greater than in outdoor air and are the main determinants of personal exposures to these compounds even in urban and industrial areas (Wallace 1991). Additionally when buildings are first constructed the number and concentration of VOCs in indoor air are considerably elevated above those in established buildings, further increasing occupant exposures. The major indoor sources of VOCs are expected to be household products, construction materials, building contents and personal activities. However identification of the relative importance of these sources will be necessary if decisions are to be made on appropriate strategies to reduce VOC concentrations in indoor air.

6.1 Source Identification Approaches

Information on major sources of VOCs in indoor air has been generated by three experimental approaches, each with different degrees of success:

(a) following determination of the more abundant VOCs in the indoor air of a specific building, comparative investigation of emissions from samples of potential sources is undertaken;

(b) known sources are placed in a test building under controlled conditions to determine how they influence VOC concentrations in indoor air; and

(c) potential sources are placed in a chamber under specific conditions of temperature, humidity and ventilation and their emission characteristics (type of VOC, emission rate) are measured for comparative assessment or for use in models that predict indoor air concentrations.

Examples of approach (a) are:

(i) Hodgson *et al.* (1989) who found that most VOCs detected in office air had components that were the same as a mixture of C_{10} and C_{11} isoparaffinic hydrocarbons used as solvent in a liquid process photocopier and occasionally a mixture of compounds (and carbon monoxide) from motor vehicle exhausts from a basement garage.

(ii) Gebefuegi and Korte (1990) who traced the presence of motor vehicle exhaust compounds in an office building to the siting of air intakes at the entrance to underground parking.

(iii) Tsuchiya *et al* (1988) and Tsuchiya and Stewart (1990) who found that for 18 out of 28 office buildings the same VOCs were present in the indoor air as were used in a solvent for liquid process photocopiers (as in case (i)). In 8 of these buildings these compounds accounted for greater than 90% of TVOC concentration. TVOC concentrations at photocopier exhausts were 3000-4000 mg/m^3 (compared to 1.4 mg/m^3 for a dry process photocopier). Note that use of liquid process photocopiers in Australia has been rare for several years (Sturrock, Field and Williams, Fairfield, Victoria, private communication).

(iv) Seifert and Abraham (1982) and Lebret *et al.* (1986) who determined that a toluene concentration (1-7 day sample period) of 3800 $\mu g/m^3$ occurred in a kitchen into which freshly printed magazines and newspapers were regularly brought; toluene emission rate from fresh magazines was determined to be 150-400 $\mu g/kg.$ hour.

(v) Gammage *et al.* (1988) who determined that concentrations of gasoline fumes were 4 times higher in houses with attached garages than in those without attached garages.

(vi) LeBret *et al.* (1984) who found that the total concentration of 45 VOCs in houses with non-smokers was 213 $\mu g/m^3$ c.f. 353 $\mu g/m^3$ in houses with smokers (t-test : $p < 0.01$), although Bayer and Black (1987) were not able to make such distinction for concentrations of 10 VOCs in offices; the latter did however find that extra compounds were detectable in the offices of smokers, viz. pyrrolidine, 6-chloro-2H-pyran-2-one, tetrahydrofuranmethanol, 2-methyl-1H-pyrrole and 2-methylpropylcyanate, and that nicotine concentrations were higher (10-18 $\mu g/m^3$) in comparison to offices without smoking (0.1-2 $\mu g/m^3$).

Examples of approach (b) are:

(i) Jackson *et al.* (1988) who operated unvented kerosene heaters in a test house for 6 hours and found that the 11 VOCs present in greatest quantities were unburned kerosene and that radiant/radiant heaters caused considerably greater TVOC concentrations than convective/radiant heaters (820-828 $\mu g/m^3$ c.f. 49-66 $\mu g/m^3$, respectively).

(ii) Tichenor *et al* (1988) who measured tetrachloroethylene concentrations in a test house in which dry-cleaned clothing had been hung in a closed bedroom closet for 7-9 days. Indoor air concentrations ($\mu g/m^3$) were found to be:

location	day 1	day 7
closet	520-2900	125-720
bedroom	60-195	15-85
den	36-79	8-40

(iii) Tancrede and Yanagisawa (1990), McKone (1987) and Andelman *et al.* (1987) who showed that halocarbons present in water supplies (e.g. chloroform in chlorinated drinking water) are efficiently released to indoor air, especially by showers; in simulated shower trials short term concentrations of chloroform and tetrachloroethylene have been measured to be 100,000-200,000 $\mu g/m^3$ and 50,000-250,000 $\mu g/m^3$, respectively.

(iv) Stehlik *et al.* (1982) who measured N-nitrosodimethylamine (NDMA) and N-nitrosodiethylamine (NDEA) concentrations in several closed rooms in which smokers were asked to smoke as much as possible (6 to 40 cigarettes consumed per hour over 1-2 hour period in 22-46 m^3 room). Concentrations measured in the rooms were: NDEA <0.01-0.01 $\mu g/m^3$, NDMA 0.02-0.15 $\mu g/m^3$ and carbon monoxide 8-16 ppm. In experiments where NDMA concentrations were 0.07 $\mu g/m^3$ or greater, the occupants reported that very strong irritation beyond tolerance limits occurred. NDMA concentrations under more realistic conditions (smokers in restraurants and offices) were normally 0.02-0.05 $\mu g/m^3$.

(v) Wooley *et al.* (1990) who measured peak ethanol concentrations up to 2000 $\mu g/m^3$ in an environmental chamber during laundry/dish washing trials with detergents containing 5-9% ethanol.

Approaches (a) and (b) will allow identification and control of VOC sources for the specific situations studied but are of limited value for comparing the relative importance of several sources in order to control emissions in future buildings. These limitations are overcome by approach (c) which provides comparable source emission characteristic data from chamber measurements, although this data must be combined with information on source use patterns, building design and indoor air simulations or model predictions in order to determine their relative impact on indoor air concentrations. Chamber studies which have identified the major VOCs emitted from sources without determining specific emission rates will be discussed here. Source emission rates will be discussed in Section 6.2.

In the United States, NASA has developed a database of sources and emission rates for chamber testing of over 5000 products (such as paints, adhesives, tapes, rubber products, marker pens) that could be used in space vehicles. However since the testing was carried out at 120°C and 12 psi (0.8 atm), the data is of limited use to building situations. Analysis of the NASA database by Ozkaynak *et al.* (1987), Wallace (1991) and Wallace (1989) has shown that the VOCs most commonly emitted from the 5000 products were toluene (1896 products), MEK (1261 products), xylene (1111 products), benzene (400 products), trichloroethylene, 1,1,1-trichloroethane and styrene. It is notable that many of these compounds are "major" indoor air VOCs as listed in Table 11. Similarly, Molhave (1982) found that the VOCs most frequently emitted from 42 building products were (in decreasing order of frequency): toluene, n-decane, 1,2,4-trimethylbenzene, n-undecane, m-xylene, o-xylene, n-propylbenzene, ethylbenzene, n-nonane and 1,3,5-trimethylbenzene. Again, 7 of these 10 VOCs are listed in Table 11.

Several studies have identified the major VOCs present or emitted from specific products commonly used in buildings and a summary of these is presented in Table 16. Note however that VOCs in other products with the same descriptions may vary from those presented. It is seen that most products contain complex mixtures of VOCs and that potential sources for any one compound are widely distributed and may include household products, construction materials, building contents and occupant activities. Hence it is considered that the predominant factors influencing relative VOC concentrations in indoor air will be the VOC emission rates for specific sources and the extent/duration of source usage within buildings, aspects which will now be considered.

6.2 Source Emission Rates

As described earlier, source emission rates can be measured in chambers under environmental conditions similar to those encountered indoors (typically, 23°C, 50% RH and 0.5-1 air change per hour are used). At present a standard method for such measurements with a small chamber is believed to be under development by the American Society for Testing and Materials Committee D22 on "Sampling and Analysis of Atmospheres".

Ideally, source emission rates are determined as follows, although most investigations have employed a range of procedures. The source is placed in a chamber through which clean air is passed. The concentrations of organics in the outlet air are measured over time using a GC with suitable detector allowing determination of the emission rates (ER) of individual VOCs or their totals in units of mass of VOC (μg) per exposed surface area of sample (m^2) per time (hour) i.e. $\mu g/m^2.h$. Since emission rate will vary with time (t) it should be measured repetitively with time and is believed to generally follow a relationship of the form (Sparks *et al.* 1990):

$$ER = R_o e^{-kt}$$

where R_o is the initial emission rate (at t=o) and k is the decay constant. Note that the smaller k, the longer it takes for the source emission to decay and that k will be zero for a steady state source.

R_o and k will completely define the emission characteristics of a product under the conditions of testing. Sparks *et al.* (1990) provide values of R_o and k for total organic emissions from several sources as follows:

Source	R_o $\mu g/m^2.h$	k h^{-1}
dry cleaned clothing	27,000	0.43
wood floor wax	20,000	6.0
wood stain	17,000	0.4
moth crystals	14,000	0
polyurethane (lacquer)	6000	0.25

These show that while wood floor wax has a high R_o value, its k value is also high so that source emission rates will rapidly decrease with time. By comparison moth crystals (probably p-dichlorobenzene) exhibit a k value of zero and will continue to emit volatiles indefinitely at a rate of R_o (until consumed).

Note that R_o and k alone will not define the significance of a source to VOC concentrations in indoor air. The area of source material used relative to building design, ventilation and other factors must be considered, as in indoor air modelling described by Sparks *et al.* (1990). Levin (1989) showed that by assuming the amount of each source used in a 400 m^2 office building, source emission rates could be used to calculate the following contributions of sources to indoor air contaminants:

floor wax (within 10 h of use)	8000	mg/h
floor adhesive (within 10 h of use)	6600	"
moth cake (p-dichlorobenzene)	1400	"
wood stain (within 10 h of use)	1000	"
polyurethane lacquer (within 10 h of use)	900	"
new particleboard or plywood	600-1000	"
dry cleaned clothing (within 1 day)	6	"

It is seen that despite the high value of R_0 for dry cleaned clothing, its relative contribution to TVOC concentrations in the indoor air of a new building would be very small, although this situation could change after emissions from other sources have declined (Tichenor *et al* 1988).

While emission rates of individual VOCs and TVOC have been measured for a large range of sources, values of R_0 and k under standard test conditions have seldom been reported. Generally values of ER have been measured after some time period and in widely different chamber sizes and design. Such measurements are not directly comparable and will be assessed in this investigation for tentative identification of major potential sources. However since products within the same generic classification have been found to exhibit emission rates spanning over three orders of magnitude (Ozkaynak *et al.* 1987), it will be impossible to generalize from such identification that any particular product is a major contributor to VOCs in indoor air.

Source emission rates for individual VOCs are summarised in Appendix V and these will be discussed in Section 6.3. TVOC emission rates for different sources are presented in Table 17. Sources have been categorised as "wet" (household and construction products) and "dry", according to their condition of usage. Wet sources are expected to emit at magnitudes similar to the tabulated rates for short periods (hours to days) immediately after building cleaning or construction operations while dry sources may emit at the tabulated rates for a number of months. It is notable that the emission rates of many "wet" products are extremely high, as would be expected from their physical condition and the presence of organic solvents. Also it is seen that some water-based products (e.g. waxes and adhesives) have high emission rates, reflecting the use of organic constituents in these products (Table 16), although solvent-based products exhibit much higher emission rates.

It is clear from measurements in new buildings that TVOC concentrations are elevated for several weeks to several months after construction and probable sources of these compounds are wet products such as those described in Table 17. By comparison volatile organic emissions in established buildings are expected to arise continuously from dry sources such as building materials and contents, semi-continuously from sources such as volatiles in tap water, cigarette smoke and garage fumes, and intermittently from frequently-used wet household products such as those in Table 17. The relative contribution of these varied sources to indoor air concentrations is unknown. However for high-emission wet products it appears feasible that emission rate characteristics and method of use will influence acute levels of exposure while frequency of use will determine impact on chronic exposures. For example, Auguenot *et al.* (1990) modelled the use of high emission adhesives or waxes in a dwelling and calculated that indoor air concentrations of toluene would exceed the occupational TLV level (375,000 $\mu g/m^3$)

for approximately 24 hours. While such emissions will decrease sharply and exponentially, Tichenor (1987) showed that floor wax in a ventilated chamber would still emit measurable concentrations of several compounds (outlet air concentrations of 10–100 $\mu g/m^3$) even after 48 hours. Further investigation of the emission characteristics of wet household products and their impact on indoor air concentrations of VOCs in established buildings appears warranted based on their high potential to influence occupant exposure.

Source emission rates for dry building products exhibit considerable differences and indicate that some gypsumboards are low emission products while some vinyl and rubber flooring products are high emitters. Carpets, particleboards and painted products exhibit intermediate emission rates. It is clear however that there is considerable variation in emission performance within each product type. While this makes it difficult to generalize about the contribution of any product type to VOC concentrations in indoor air, it also demonstrates that low emission brands are available within each product type.

6.3 Sources of Specific Compounds

It is seen from the previous discussion and data presented in Appendix V that many VOCs have a large range of sources and that the importance of each source to air concentrations is unknown. However some conclusions can be drawn for the sources of some compounds where these sources are few, are easily identified or have been studied in detail.

6.3.1 Benzene

Benzene can be emitted from cigarette smoke, petrol fumes and a range of building and consumer products, and has been investigated in detail by Wallace (1989, 1991) and Wallace *et al.* (1987b, 1989). Two large studies have determined that benzene occurs at a median indoor air concentration of 7 $\mu g/m^3$ in non-smokers' and 11 $\mu g/m^3$ in smokers' homes. Overall it was estimated that approximately 50% of US exposure to benzene originated from tobacco smoke, 25% from car usage and indoor sources and 25% from outdoor sources. Relative exposures in Australia may differ from these estimates. For example, petrol contains 1-2% benzene in the US (Wallace 1989) but up to 5% in Australia, although the latter may be reduced to 1% in the future (Mr R. Bowes, Mobil Aust. P/L, private communication).

6.3.2 Chloroform

While present in some indoor products, the main source of chloroform in indoor air appears to be the use of chlorinated water supplies (particularly in hot showers).

6.3.3 p-Dichlorobenzene

The major sources of p-dichlorobenzene appear to be moth repellants and room deodorizers, although emission at significantly lower rates have been reported from some cleaning and dry building materials (Wallace *et al.* 1987b, Monteith *et al.* 1984).

6.3.4 Tetrachloroethylene

This compound is used by the majority of drycleaners in both the US and Australia. Depending on the type of fabric, drycleaned clothes act as a significant source of tetrachloroethylene emission to indoor air for several days after cleaning (Tichenor *et al.* 1988). It may also be emitted from use of household water, although this has received little investigation (McKone 1987), and from use of some spot cleaning products.

6.3.5 Toluene/Xylenes

These compounds can arise from a wide variety of indoor sources but both have been heavily used in construction materials such as sealants and adhesives and building products that use such materials. Toluene has also been identified as a significant emission from printed matter in homes (Le Bret *et al.* 1984, Seifert and Abraham 1982).

6.3.6 Limonene

Limonene (lemon scent) is used in room fresheners and also as an odorant in wet household products and building materials.

6.3.7 Pesticides

Studies have found that pesticide vapours are present in the indoor air of some buildings and may exceed the US National Academy of Science guideline of 5 $\mu g/m^3$ (Wallace 1991). It is believed that this is an interim guideline established to indicate the presence of pesticide residues and is not based on health considerations (Wood Protection Council 1987). Pesticides are classified as slightly volatile organic compounds under the WHO (1989) definition and did not form part of this investigation. However the Working Party undertook to collate references to this subject that arose during searching of literature on VOCs. The references found are summarised in Appendix VI. A more critical search should be performed to evaluate this subject.

6.4 Techniques to Reduce VOC Concentrations

Several techniques to reduce VOC levels in indoor air have been investigated, although not widely so. The following techniques are presented in order of their probable extent of usage, not efficacy. Source control is considered the optimum approach but has greatest relevance for future buildings, while the other techniques are applicable to existing buildings.

(a) Use of increased ventilation. This will dilute the VOCs but not necessarily in direct proportion to the ventilation increase (Girman 1989). Also it may not provide a long term solution if ventilation rates are later reduced to conserve heating and cooling costs. It has been suggested that ventilation be used to "gas off" new buildings by having no recirculation of return air for the first 6 months of occupancy (Berglund *et al.* 1982) but measurements to support the efficacy of this approach have not been published.

(b) Use of building "bake-out". The air temperature of the building is held at 32–40°C for 2 to 3 days under low ventilation conditions. Girman (1989) reported that this does reduce TVOC levels in buildings but to a somewhat variable degree (e.g. 35–94% reduction) and with only modest reduction for the most-abundant individual compounds.

(c) Use of air purifier based on activated carbon or other adsorbents. These can remove VOCs and other contaminants from building air (Daisey and Hodgson 1989) even during high emission operations such as painting (Brown *et al.* 1991) although this control option has only recently gained attention. Laboratory evaluations have shown that with their high adsorption capacities for organic compounds, activated carbon purifiers could be effective for several months. However while they have been used in conjunction with catalytic burners to reduce organic contaminants in submarines and also in the nuclear power industry to capture radioactive gases, study of their effectiveness for reducing VOCs in indoor air has been limited (Godish 1989). It is believed that the use of purifiers (for particulates, tobacco smoke and odours) is allowable as a trade-off for increased ventilation requirements of some areas of public buildings in requirements of the Standards Association of Australia (1991).

(d) Use of source control. This involves identifying and modifying major emittents already present in a building or by limiting use of high emission products in future buildings. This is a new approach and little has been published on its practical application, although Bayer and Black (1988a) demonstrated that an office building using low emission materials exhibited low TVOC concentrations. The approach relies on precise determinaton of the emission characteristics of materials or processes as described

earlier. Environmental chamber methodology for such determination has been developed in recent years (Tichenor 1987, Bayer and Black 1989, Black 1990) and, as stated earlier, it is believed that a standard method is being developed by the American Society for Testing and Materials. Development of these procedures is also occurring in Australia at CSIRO Division of Building, Construction and Engineering (S.K. Brown, personal communication).

7. HEALTH EFFECTS OF EXPOSURE TO VOCs IN INDOOR AIR

7.1 Detected Compounds and Major Compounds

Tables 11 and 13 present the derived concentration distributions of "major " VOCs in indoor air in comparison to reported odour and irritation thresholds, ambient air guidelines, occupational exposure standards and IARC carcinogenicity classification. The WHO (1989) concluded that for VOCs "acute toxic effects on various organs normally occur only at concentrations higher than normally encountered indoors" and for this reason such effects were not considered in this investigation. Odour was not considered a factor in assessing the health significance of exposure to these compounds although it may have significance to occupants' subjective assessment of indoor air quality and will be discussed from this viewpoint. Note that the odour thresholds show considerable variation due to differences in definitions of thresholds, test protocols and the use of purer samples and better sample presentation techniques. These latter two factors were considered to cause the finding of lower thresholds in more recent studies (Ruth 1986).

It is seen that for most major VOCs the derived concentrations are considerably lower than the lowest reported thresholds (LRTs) for odour, often by a factor $10^2 - 10^4$. Only butyric acid has a WAGM concentration exceeding the LRT and this was for a specific building situation of a lecture theatre containing 225-389 people (the VOC source). VOCs with WAGM concentrations within an order of magnitude (35-50%) of LRTs are ethylacetate, acetic acid, and ethanol. Other VOCs with 98 PC concentrations within an order of magnitude (23-65%) of LRTs are ethylbenzene, xylene isomers, toluene, phenol, chloroform and 1,2-dichloroethylene. The response to a mixture of such compounds at concentrations below their odour thresholds is unknown, as it is possible that their odorant effects will act independently, additively, synergistically or counteractively (Ruth 1986).

Many other compounds have been detected in indoor air (Berglund *et al.* 1986) but not quantitated and many of these have LRT values comparable to typical indoor concentrations of VOCs, e.g. acetaldehyde (LRT - 0.2 $\mu g/m^3$), benzaldehyde (0.8 $\mu g/m^3$), phenylacetaldehyde (1.0 $\mu g/m^3$), creosol (1.2 $\mu g/m^3$), 2-methylpropanol (2.7 $\mu g/m^3$), biphenyl (6.2 $\mu g/m^3$), pyridine/i-butylacetate (9.0 $\mu g/m^3$) (Ruth 1986). Also nitrogenous and sulfurous organic compounds have seldom been detected in indoor air, probably because of the specific sampling and analysis procedures required, and yet these exhibit very low LRTs for odour, e.g. dimethyl sulfide (2.5 $\mu g/m^3$), dimethyl disulfide (0.1 $\mu g/m^3$), methylamine (25 $\mu g/m^3$), dimethylamine (85 $\mu g/m^3$), trimethylamine (0.8 $\mu g/m^3$), diethylamine (60 $\mu g/m^3$). A recent study has found the above compounds are emitted from casein-containing self-levelling cement as a result of

microbiological breakdown of casein (Lundholm *et al.* 1990) and that in complaint buildings the total concentration of short-chained organic amines ranged from 8 to 33 $\mu g/m^3$ cf. less than 0.3 $\mu g/m^3$ in control buildings. Building industries in Australia and overseas have been aware of this problem and have ceased using casein in this application in recent years and removed extensive quantities of affected cement (Mr D. Chapman, Fosroc Australia, Victoria, private communication).

It is considered from these observations that it is possible for VOCs in the indoor air of established buildings to be associated with the perception of odours although this is not clearly indicated in the absence of data for indoor concentrations of all VOCs and a greater understanding of odour interaction. Recent studies have reported procedures to quantitate of odour in the indoor air of buildings (Ahlostrom *et al.* 1984, Fanger 1988, Fanger *et al.* 1988) although none have attempted to correlate odours to VOC concentrations. A recent investigation of odours and TVOC concentrations from building materials in chamber experiments found poor correlation between the two and suggested that specific VOCs were responsible for odours (Wolkoff *et al.* 1990).

By contrast the irritation levels for all major VOCs in established buildings are considerably higher than derived indoor concentrations, even the 98 PC concentrations, usually by a factor of $10^3 - 10^5$ except for acetic acid and toluene ($\sim 10^2$). Analysis of Tables 12 and 13 also indicates that irritation is not predicted from individual VOCs even in new buildings for which 98 PC concentrations are somewhat higher. Further, few other organic compounds are known to cause irritation at the low concentrations generally encountered for VOCs in indoor air. For example Ruth (1986) listed the irritation concentrations for 171 compounds and only three of these were below 1000 $\mu g/m^3$ and these have not been detected as indoor air contaminants (Berglund *et al.* 1986). However Molhave (1986, 1990) has investigated the exposure of human subjects to a controlled mixture of 22 VOCs at aggregate concentrations of 7,400 and 33,000 $\mu g/m^3$ and has concluded that sensory irritation may arise from exposure to TVOC concentrations greater than 200 to 3000 $\mu g/m^3$. As shown in Table 15 such TVOC concentrations have commonly occurred in indoor air. Molhave also reported finding that these exposures led to impairment neurobehavioural function and this was further investigated by Otto *et al.* (1990). The significance of these studies will be critically reviewed in Sections 7.2 and 7.3.

Seventeen of the VOCs for which indoor air concentrations were derived have IARC carcinogenicity classifications (Table 8). Carcinogenic potency factors have been reported for these in several studies and have been used to estimate the population risk from indoor air exposure (WHO 1989, Tancrede *et al.* 1987, McCann *et al* 1987). However it was considered

that this estimation should be made after due consideration of the factors involved in deriving carcinogenic potency factors. This derivation and the estimation of population risk will be discussed for benzene since it is the only class 1 carcinogen for which indoor air concentrations have been measured (Section 7.4).

7.2 Irritancy of VOCs

Complaints about indoor air quality may reflect perception of odour (olfactory stimulation) by the nose and/or irritation (trigeminal stimulation) by the eyes, nose and throat. The "Sick Building Syndrome" (SBS) has been described as a complex of eye, nose and throat irritation, mucosal dryness, erythema, mental fatigue and headaches, upper respiratory infections, hoarseness, wheezing and cough, itching, nausea and dizziness (WHO 1983). Thus the irritant potential of VOCs may be an important determinant of their relevance to SBS.

The relevant stimulus response models were outlined by Berglund *et al.* (1986) who noted that facilitation can occur near the sensory threshold. There are large individual differences in sensitivity to detect and perceive VOCs. Indoor air contains a complex pattern of sensory stimuli and there is no simple causal relationship between sensation and stimulus pattern.

Studies of trigeminal irritation in animals have lead to the development of a model of the irritant receptor (Nielsen and Bakbo 1984). Chemically reactive substances that are irritants include sulphur dioxide, ozone, chlorine and organic compounds containing activated C=C double bonds such as acrolein or halogen carbon bonds. The sensory irritation capacity of alkylbenzenes and alcohols in mice is related to the saturated vapour pressure at 37°C.

Studies of the effects of indoor air quality on human health fall into two broad categories. Firstly, there are experimental studies in which small numbers of healthy subjects or individuals with SBS are exposed to controlled levels of VOCs for short periods in stainless steel chambers. Such experiments shed light on the acute toxicity of VOCs. Secondly, epidemiological studies examine symptoms in larger numbers of occupationally exposed subjects. Epidemiological studies provide information about the chronic toxicity of VOCs.

7.2.1 Experimental studies

The experimental designs, subjects, exposures, outcome measures and conclusions of the studies reviewed are summarised in Table 18. Most of the experimental studies have been conducted by Molhave and colleagues at the Institute of Environmental and Occupational Medicine, Aarhus, Denmark. The first few papers report different outcomes for a group of 62

symptomatic subjects (Molhave *et al.* 1986). These subjects were selected from a larger group of 287 persons by specified criteria and cannot be considered representative of general populations, but presumably constitute a susceptible subgroup. Normal asymptomatic subjects and asthmatics have also been studied (Otto *et al.* 1990, Kjaergaard *et al.* 1990, Johnsen *et al.* 1990).

The experiments were mostly controlled exposures following a Latin square design. The mixture of 22 VOCs employed in aggregate concentrations of 7,400 and 33,000 $\mu g/m^3$ is listed in Table 19 (Molhave *et al.* 1986). Note that Molhave and others have generally expressed these concentrations as 5000 and 25,000 $\mu g/m^3$, as measured by a Flame Ionization Detector in toluene equivalents. It would have been difficult to maintain complete double blinding because the malodorous compound n-butylacetate was present in the relatively high concentrations of 2,470 and 11,000 $\mu g/m^3$ respectively (Girman 1989). Although this unblinding might be attenuated by olfactory habituation (Otto *et al.* 1990), the experiments need to be repeated without n-butylacetate. Kjaergaard *et al.* (1987) reported a dose response study with n-decane alone. Other exposures include carbonless copy paper (Camp and Morgan 1984) and rubber floor covering, acid cured lacquered particleboard, wall-papered gypsumboard and nylon carpet with a foam rubber backing (Johnsen *et al.* 1990, Wolkoff *et al.* 1990). Such sources are probably more representative of naturally occurring occupational and domestic exposures.

A wide range of outcome measures have been employed. These include standardised questionnaires about symptoms and odour, perception of mucosal irritation using a linear potentiometer and tests of neurobehavioural performance (see Section 7.3). Molhave and other researchers have attempted to objectively quantify ocular outcomes such as eye blink frequency, tear electrolyte and albumin concentrations, tear film stability by slit lamp examination and conjunctival cytology. Objective upper respiratory tract outcomes include nasal resistance from rhinomanometry (Camp and Morgan 1984) and polymorphs in nasal lavage (Koren *et al.* 1990).

Molhave *et al.* (1984) reported that perceived air quality and odour were related to the square root of TVOC concentration, but that mucosal irritation occurred at both levels without adaptation. However given that only two levels of exposure were utilised, one cannot have a great deal of confidence about the exact nature of the dose response relationships. Kjaergaard *et al.* (1990) subsequently replicated these findings with 14 of the SBS subjects and 21 healthy controls in the same laboratory. The subjects with SBS were more likely to report poor air quality and mucosal irritation than were healthy controls. Otto *et al.* (1990) confirmed that normal subjects experienced discomfort after 75 minutes exposure to 33,000 $\mu g/m^3$ of the VOC mixture. However Wolkoff *et al.* (1990) were unable to demonstrate a significant relationship

between perceived air quality and TVOC concentrations (1100-1900 $\mu g/m^3$) from construction product sources (see above).

With respect to ocular effects, Thygesen *et al.* (1987) found increased median concentrations of sodium, potassium and albumin in tears following exposure to 7,400 $\mu g/m^3$ TVOC. However the statistical test employed lacked power and the postulated dose relationship was not supported by the results published. Kjaergaard *et al.* (1987) reported that n-decane could reduce tear film stability, consistent with complaints of dry eyes. However they were unable to reproduce this finding with the VOC mixture (Kjaergaard *et al.* 1990). Johnsen *et al.* (1990) found reduction of tear film stability and the precorneal lipid layer following exposure to construction product sources (see above) and Wolkoff *et al.* (1990) suggested that lipophilic VOCs might degrease the protective tear film. Examination of conjuctival cytology by Kjaergaard *et al.* (1987, 1990) also yielded conflicting findings. Increased cuboidal epithelial cells were found at 200,000 $\mu g/m^3$ of n-decane, but polymorphs were increased following one regimen of exposure to the VOC mixture, suggesting an inflammatory reaction.

There is limited objective evidence of nasal congestion and inflammation in response to VOCs. Camp and Morgan (1984) reported increased nasal resistance during expiration following exposure to carbonless copy paper. However there was no significant increase in nasal resistance during inspiration, which is more relevant to the normal pattern of breathing. Utilising the Danish mixture of 22 VOCs, Koren *et al.* (1990) found increased polymorphs in nasal lavage 18 hours after a four hour exposure. Multiple one sided t-tests were performed, casting some doubt on the statistical validity of this conclusion. Nonetheless, nasal lavage is a simple technique which could be applied in epidemiological studies.

Harving *et al.* (1991) exposed 11 asthmatic subjects to 3,500 (approx) and 33,000 $\mu g/m^3$ of the 22 compound mixture (Table 19). Whilst FEV_1 decreased to 90.4% of the initial value after 85 minutes exposure to 33,000 $\mu g/m^3$, this was not significantly different to the decline observed after the control session. There was no change in bronchial reactivity to histamine. Although the authors concluded that VOCs are probably bronchial irritants, clearly further research is required to determine the significance of VOC exposure in asthma.

7.2.2 Epidemiological studies

Epidemiological studies of the health effects of VOCs have been hampered by a lack of objective outcomes and inadequate measurement of environmental exposure. One early cross-sectional study of office workers identified sick building syndrome (SBS) from responses to a symptom questionnaire (Finnegan *et al.* 1984). Nasal or eye symptoms, lethargy, dry skin and headache were more prevalent in air conditioned than naturally ventilated buildings.

Franck (1986) examined 169 workers for signs of "office eye syndrome". Subjects completed a questionnaire about ocular symptoms and underwent slit lamp examination for measurement of precorneal tear film stability and lissamine green staining for epithelial damage. The frequency of eye irritation was related to tear film breakup time and the presence of epithelial damage, which are objective features of dry eyes. Unfortunately the normal range for these tests does not appear to be well established.

The relationship of symptoms to TVOC concentrations has been examined in a cross-sectional study of office workers (Norback *et al.* 1990a) and a methodologically stronger longitudinal study of teachers (Norback *et al.* 1990). In both studies, multivariate analysis allowed for confounding by psychosocial factors. The number of symptoms reported by office workers could be predicted from TVOC, nonspecific irritability, sick leave, cigarette smoking and psychosocial dissatisfaction. Chronic symptoms in teachers were found to be related to TVOC, wall to wall carpets, nonspecific irritability and psychosocial factors. The incidence of new cases was related to dust levels, cigarette smoking and the psychosocial milieu.

7.2.3 Conclusions

A causal relationship between VOCs and SBS has yet to be proven, which is acknowledged by Molhave (1990), although often overlooked by reviewers of his work. To establish that a given exposure causes a given syndrome or disease requires fulfillment of standard criteria (Hill 1965). The evidence should be derived from strong study designs, the association should be strong and consistent, a dose response relationship should be demonstrated, exposure should occur before disease and finally the association should be biologically plausible. Whilst controlled experiments on human subjects have demonstrated effects on perceived air quality, odour and mucosal irritation, these studies require replication with different mixtures on a wider range of subjects. The mixture of VOCs employed in most controlled exposure experiments are not representative of those VOCs and their concentrations generally encountered in buildings. The association between TVOC and symptoms is not strong or consistent. The dose response relationship remains to be fully characterised. The temporal relationship between natural exposure and chronic symptoms has only been established in one longitudinal study. Finally however, the postulated mechanism is not inconsistent with animal experimentation, such as the mouse bioassay (Wolkoff *et al.* 1990).

The relationship between VOCs and mucosal irritation is also subject to complex interactions and effect modification (Figure 1 from Molhave 1986). Molhave (1986) postulated that TVOC concentrations below 160 $\mu g/m^3$ did not cause irritation, levels between 160 and 2000 $\mu g/m^3$ could possibly be irritant in the presence of other exposures and that concentrations over 2000

$\mu g/m^3$ probably would be irritating. After reviewing some additional largely unpublished literature, Molhave (1990) suggested that the no effect level should be 160 $\mu g/m^3$, discomfort could be expected at 3000 $\mu g/m^3$ and probable neurotoxic effects over 25,000 $\mu g/m^3$.

An alternative approach was taken by Seifert (1990) who suggested that a TVOC guideline of 300 $\mu g/m^3$ represented an achievable target without any toxicological basis (see Section 5.3.4). The numerical coincidence of these levels is purely fortuitous given that these authors refer to different mixtures of VOCs. At the present state of knowledge there is insufficient evidence to determine an indoor air quality guideline for VOCs based on irritancy.

7.3 Neurobehavioural Effects of VOCs

The acute effects of exposure to high concentrations of volatile organic compounds are well established and include generalised central nervous system depression, headache, tiredness and other symptoms. Numerous reports suggest that prolonged (>15 year) occupational exposure to organic solvents results in adverse chronic neurobehavioural effects including intellectual impairment.

The evidence for either acute or chronic effect due to typical exposures to VOCs in indoor air is either weak or negative.

Recent developments in standardised neurobehavioural test batteries and computer administered neurobehavioural testing (Baker *et al* 1985) have made the investigation of these effects more efficient and less prone to observer bias. However, these batteries have been assembled arbitrarily from a wide range of classical neuropsychological tests such as those from the WAIS (Weschler Adult Intelligence Scale) (Weschler 1955) or the Halstead-Reitan set (Lezak 1983). Trials with subjects exposed acutely or chronically to intoxicants or suspected neurotoxins have indicated that several of the tests, such as block design and digit-symbol substitution, are particularly sensitive to decrements in higher mental function. This practical approach has lead to more sensitive batteries but not to a mechanistic understanding of the effects detected.

7.3.1 Effects of occupational exposure

The acute central nervous system depressant effects of organic solvents are well established. Workers exposed to high levels of solvents often complain of headache, intoxication, vertigo, tiredness, paresthesiae and other symptoms. More dramatic intoxication and anaesthesia are observed among solvent abusers. In addition to these acute effects, prolonged exposure to organic solvents used in paints, adhesives, printing inks and other substances is thought to cause adverse central nervous system effects including intellectual impairment. Throughout the

Scandinavian countries such solvent-induced effects are recognised as a compensatable industrial disease, although the diagnostic methods and criteria are controversial.

A number of cross-sectional studies on workers with prolonged exposure to organic solvents have indicated an excess of brain dysfunction (Mikkelson 1980). These findings relate to workers whose employment at the time of testing involved solvent exposure and therefore, the possibility of acute or sub acute effects cannot be ruled out. However, case-control studies based on disability pension registers suggest that chronic effects may be occurring and that these may be permanent (Valciukas *et al.* 1985, Axelson *et al.* 1976, Lindstrom *et al.* 1984, Mikkelson 1980, Olson and Sabroe 1980). A large number of clinical reports, published mainly in the Scandinavian countries, describe cases of mild to severe neurobehavioural dysfunction or psychiatric disorder associated with organic solvent exposure. These will not be cited here as they do not add reliable evidence in favour of solvent-related effects. It is interesting to note that such clinical reports have not appeared elsewhere in the world and have often been met with reservation or scepticism (Grasso *et al* 1984, Spencer and Shaumburg 1985, Waldren 1986) although they have been used to justify compensation payments in all Scandinavian countries.

Few if any of the cross-sectional studies are entirely conclusive on their own because of the possible effects of acute exposure, problems of matching subject and control groups, possible bias and inadequate power in some cases. However, there is a fairly consistent pattern of deficit on certain sensitive neurobehavioural tests such as symbol-digit substitution lending support to the view that the effects are associated with chronic solvent exposure. In addition there have been several reports of neurophysiological effects such as electroencephalogram (EEG) and electromyogram (EMG) changes (Seppalainen 1985) and alterations in sensory threshold (Bove *et al.* 1989). A wide range of test methodologies has been employed in various studies (Anger 1985) although these are now becoming more standardised.

Typical occupational exposures to VOCs in painting, printing and adhesive application are highly variable but typically range from several tens to several hundred milligrams per cubic meter.

7.3.2 Effects of VOCs in indoor air

Molhave *et al.* (1986) exposed 62 subjects who had previously complained of symptoms characteristic of sick building syndrome to mixed volatile organic compounds under laboratory conditions and assessed both their subjective and objective responses. The 22 compound mixture (Table 19) consisted of aliphatic and aromatic hydrocarbons, olefins, ketones, aldehydes, esters and a single halogenated hydrocarbon (1,2 dichloroethane). Exposures were to an aggregate concentration of 7,400 or 33,000 $\mu g/m^3$ or a control atmosphere containing 440

$\mu g/m^3$ as a background contamination of the room in which the tests were conducted. A questionnaire of subjective responses to the exposures revealed a variety of responses to the higher concentrations including mucous membrane irritation, reduced olfactory acuity and perceptions of reduced air quality. Exposure at either concentration was found to result in reduced short term memory as measured by auditory digit span. Similar results were reported for a study carried out by a research group including two of the previous workers (Kjaergaard et al. 1990), although the findings were not conclusive. These findings are surprising as in several other studies acute neurobehavioural effects have not been detected at exposures below several hundred mg/m^3 of hydrocarbons (Johnson 1987). The acute neurobehavioural effects of organic solvents are generally thought to involve a generalised central nervous system depression. If this is true then the acute effects of mixed solvents should be additive. It would be difficult on this basis to explain the apparent neurobehavioural decrement reported in this study. Although a functional mechanism cannot be entirely ruled out it must be considered that susceptible individuals might be less able to concentrate on the tests because of discomfort or anxiety occasioned by the perception of odours during exposures.

Similar, more recent work by Otto, Molhave *et al.* (1990) involved controlled exposure of 66 subjects with no history of chemical sensitivity, to a complex mixture of volatile organic compounds at an aggregate concentration of 33,000 $\mu g/m^3$. Each subject underwent both control and exposure sessions at one week intervals. Learning effects were overcome by using a counterbalanced test regime in which half the subjects underwent exposure sessions first and the other half control sessions first. The subjective response quentionnaire previously used by Molhave *et al.* was used in this study and a variety of neurobehavioural tests were employed. These included the auditory digit span test also employed by Molhave *et al.* plus tests from the computer administered Neurobehavioural Evaluation System (NES) developed by Baker *et al.* (1985). The NES includes a wide range of tests and a subset including motor speed memory, attention and mood scales were utilised. The NES test battery has been widely used in the study of both the acute and chronic effects of organic solvents and other chemicals, and the sensitivity and reproducibility of the tests have been assessed. The study confirmed the subjective responses of subjects to aggregate VOC concentrations of 33,000 $\mu g/m^3$. However, no significant neurobehavioural impairment was observed. This throws further doubt on the findings of impaired short term memory reported by Molhave *et al.* and suggests that any acute neurobehavioural effects due to VOC exposures in typical indoor air would be undetectable by present test techniques.

7.4 Carcinogenicity of VOCs

From Table 8 it can be seen that seventeen compounds have been classified by the International Agency for Research on Cancer (IARC) as to their carcinogenicity (IARC 1987). This

classification system is based on a consideration of mutagenicity, animal carcinogenicity testing and human epidemiological studies.

The IARC classification system is as follows:

Class 1 – Definitely carcinogenic to humans
Class 2A – Probably carcinogenic to humans
Class 2B – Possibly carcinogenic to humans
Class 3 – Insufficient information to classify
Class 4 – Probably not carcinogenic to humans

Of the major VOCs listed in Table 11 one is classified as class 1 (benzene), none is classified as class 2A, and three compounds are classified as class 2B (tetrachloroethylene, chloroform and dichloromethane).

In order to determine the carcinogenic risk to humans from inhaling indoor air contaminated with a known carcinogen, it is necessary to determine:

(a) the type(s) and latent periods of cancer caused by exposure to the contaminant,

(b) the dose-response relationship,

(c) the concentration profile to which people in indoor air environments are exposed, and

(d) the quantitative risk assessment for the contaminant to assess the attributable risk of cancer from indoor air exposure.

To illustrate the procedure required to fully evaluate the carcinogenic potential of an indoor air contaminant a model VOC has been selected from Table 11. It was decided to select benzene since it is the only definite human carcinogen in the list of 30 major VOCs in indoor air.

7.4.1 Benzene

Benzene (C_6H_6) is a colourless, clear liquid with a boiling point of 80.1°C. It is mainly used as a raw material for the production of other aromatic hydrocarbons and it is a constituent of crude oil, petrol and cigarette smoke.

Benzene can be absorbed into the body via inhalation, ingestion and skin contact. About 50% of inhaled benzene is absorbed. Cigarette smoke contains high concentrations of benzene and this may be inhaled via active or passive smoking (Wallace *et al.* 1987a). Overseas, benzene

has also been detected in low concentrations in drinking water and a variety of foods. In Australia, no regular monitoring of drinking water or food for benzene levels is conducted although this is regularly conducted for other substances (NH & MRC, 1986). Ambient air levels have been measured in Sydney as an arithmetic mean of 8 $\mu g/m^3$ (Nelson and Quigley 1982) and in an inner suburb of Melbourne at 7am and 9am as a median of 9 $\mu g/m^3$. (I. Galbally, CSIRO Division of Atmospheric Research, private communication).

The relative contribution of the various routes of exposure has been estimated, but this is based on US data (Wallace 1989). This indicates that inhalation of indoor air is the major contributor to body burden of benzene in both smokers and non-smokers. A more detailed discussion of the relative contribution of different exposure sources is outlined in Section 6.3.1.

Absorbed benzene is distributed into fatty tissues within the body due to its lipophilic nature. Benzene is oxidised by the cytochrome P-450 mixed-function oxidase system to several metabolites (Goldstein *et al.* 1989). The main metabolite is phenol. About 30% of absorbed benzene is exhaled unchanged and metabolites are excreted as water-soluble conjugates in the urine. Elimination follows a 2-compartment model with a half-life for the slower phase of 28 hours.

7.4.2 Health effects of benzene

In high concentrations, benzene has been found to cause central nervous system effects and reduction in all cell types in blood and aplastic anaemia (ACGIH 1990). The haematotoxic effects are thought to be due to a metabolite of benzene rather than benzene itself but the mechanism is uncertain. The sites of action are the stem cells in the bone marrow rather than circulating blood cells. Non-carcinogenic effects of benzene are not further discussed in this report as studies have indicated that these effects do not occur at the low concentrations found in indoor air (WHO 1987).

Benzene has been classified as a class 1 carcinogen since several human epidemiological studies have consistently shown an increased risk of non-lymphocytic leukaemia (IARC 1982). Relative risks for lymphocytic leukaemias and cancers at other sites have not been consistently elevated to statistically significant levels in these studies.

7.4.3 Quantitative risk assessment for benzene and leukaemia

Several quantitiative risk assessments (QRAs) for leukaemia from benzene exposure have been carried out and these are summarised in Table 20. These assessments are based on the findings of human epidemiological studies involving occupational exposure to benzene rather than the results of animal studies. The QRAs are based mainly on data generated by two large cohort

studies (Infante *et al.* 1977, Ott *et al.* 1978) conducted in the USA. Follow-up data from these two studies has also been considered in some QRAs (Rinsky *et al.* 1981, Bond *et al.* 1986). Although several other studies investigating leukaemia and benzene exposure have been published, these have not been used for QRAs because only qualitative measures of benzene exposure were reported (Rushton and Alderson 1981, Vigliani 1976).

From Table 20 it can be seen that most of the risk estimates are expressed as extra deaths from leukaemia due to the stated exposure level. Crump *et al.* (1987) have given no absolute figures as the purpose of their study was to compare results using different models. Albert (1979) and WHO (1987) expressed their results as excess risk of leukaemia death. Unfortunately, insufficient data is given to convert these figures to the number of excess leukaemia deaths expected. Rinsky *et al.* (1987) have expressed their results as odds ratios with 95% confidence intervals. Again, insufficient information is given to convert these figures.

The absolute figures from the rest of the QRAs in Table 20 show similar risk estimates per 1000 exposed for similar dose levels. Swaen and Meijers (1989) report their estimates in terms of excess leukaemia deaths per 1000 total deaths in Holland. It is difficult to compare their findings with the other risk estimates because of this difference. The closeness of the estimates given by White *et al.* (1982), IARC (1982) and Austin *et al.* (1988) is not surprising as they are based on the results of the same studies (with the addition of two small studies by Austin *et al.* 1988), assume a similar dose-response model and use similar exposure levels. Despite this, there are wide ranges, up to an order of magnitude given for these estimates.

QRAs of benzene have been criticised because of several deficiencies in either the quality of data used in the calculations or uncertainties generated by assumptions relating to missing data. Austin *et al.* (1988) concluded that the small number of studies available for a benzene-leukaemia QRA and the small numbers of cases in these studies make the standardised mortality ratios (SMRs) very imprecise. This imprecision is the main reason for the wide range of the QRA estimates. Austin *et al.* (1988) have also criticised these studies because several members of the cohort may have been exposed to very high peak exposures which may be more important than continuous low exposure, even though the cumulative exposures may be similar.

Infante *et al.* (1984) have acknowledged the incomplete nature of quantitative data regarding exposures in their earlier study (Infante *et al* 1977). This has lead to the assumption that subjects were exposed to benzene levels at the recommended standard in operation at the time. Also White *et al.* (1982) based their QRA on deaths in subjects exposed for 5 years or more as most of the cases (5 of 7 leukaemia deaths) occurred in this group. This decision was not based

on any biological rationale, such as the mechanism of benzene carcinogenesis, and its justification is questioned by Austin *et al.* (1988). Brunekeef (1990) has also criticised the QRA of Swaen and Meijers because of the use of negative studies where most of the cohort was not exposed to benzene.

QRAs rely on good dose-response data to determine the shape of the dose-response curve. Because of the small numbers of cases in the cohort studies for benzene, reliable dose-response data has not been available. Also, little is known about the biological mechanism of benzene carcinogenesis (Chandler 1984). These two factors have led to uncertainty in the most appropriate model to use when extrapolating from effects at high exposures to potential effects at low doses. Several models have been proposed to calculate theoretical excesses of cancer risk due to chemical exposures. At the present time insufficient information regarding the biochemical mechanism of benzene-induced leukaemia exists to correctly identify which model is appropriate (ACGIH 1990). Most QRAs have assumed a linear model which tends to overestimate the effect at low doses.

Infante *et al.* (1984) consider that the use of a linear model is appropriate when extrapolating down one order of magnitude (e.g. from 100 ppm to 10 ppm). However, when extrapolations of 4 orders of magnitude are being made to the levels of exposure encountered in indoor air (i.e. 8 $\mu g/m^3$), this will lead to much greater uncertainties in the utility of the assumed linear model. Crump *et al.* (1987) highlighted this problem in their QRA by making a comparison of eight different dose-response models for nine different exposure levels. Differences in extra lifetime risks of leukaemia differed by up to a factor of 37 between different models.

All of these models assume no threshold. Chandler (1984) has criticised the simplicity of this approach as the causal agent for leukaemia is thought to be a metabolite of benzene. This has critical implications for the simplistic assessment of a linear model as benzene follows non-linear kinetics at low doses. Because the mutagenicity of benzene has not been established (IARC 1982) this further suggests that a no-threshold model is inappropriate. Hoel *et al.* (1983) concluded that the assumption of a linear model for chemicals such as benzene may overestimate the carcinogenic risk at low doses by several orders of magnitude.

In summary, the risk estimates outlined in Table 20 have a high degree of uncertainty. Crump *et al.* (1987) concluded that the deficiences in the QRA process for benzene may lead to risk estimates for low dose benzene exposure varying by several orders of magnitude. ACGIH (1990) has acknowledged these difficulties when establishing their threshold limit value (TLV) for benzene. They considered the QRA of Rinsky *et al.* (1987) to be the most reliable. The ACGIH set a TLV at 0.1 ppm (320 $\mu g/m^3$) because the odds ratio at this level approximates the

risk of leukaemia for the general population. This level is well in excess of the level of 8 $\mu g/m^3$ found in indoor air but it must be emphasised that a TLV is set for a working population over a working lifetime.

An additional problem relates to the extrapolation of data from occupational mortality studies in the USA to estimate the risks of leukaemia in the whole Australian community from indoor air contamination. The populations studied had a limited range of age, sex (all male), race (all white) and socio-economic characteristics (Infante *et al.* 1977, Ott *et al.* 1978). Again, more assumptions have to be made about the risks to a population with broader demographic characteristics who may differ in their susceptibility to the effects of benzene.

Non-lymphocytic leukaemias are uncommon tumours in Australia (Giles *et al.* 1987). In 1982 the age-standardised incidence rates for acute myeloid leukaemia were 2.2 per 10^5 person years in males (176 new cases) and 1.6 per 10^5 person years in females (159 new cases). For chronic myeloid leukaemia the corresponding figures were 1.4 per 10^5 person years in males (119 new cases) and 0.7 per 10^5 person years in females (71 new cases).

Stolwijk (1990) conducted a QRA for leukaemia for the USA population, based on expected distribution of benzene concentrations in residential indoor air. He concluded that less than 2% of the total incidence of leukaemia was attributable to indoor exposure to benzene. This figure was based on a risk estimate of 0.1 cases per million people per year per $\mu g/m^3$ exposure but it was not shown how this figure was derived. Because of the uncertainty in the derivation of this risk estimate and the lack of exposure profiles for benzene in Australian buildings, it is inappropriate to use this model to calculate excess leukaemia deaths in Australia.

QRAs for other suspected carcinogens in indoor air have not been considered, but these would be based on poorer quality epidemiological data than benzene (IARC 1987). At the present time it appears premature to undertake a QRA for the Australian population for any carcinogen in indoor air. The lack of exposure data compounds previously discussed uncertainties in undertaking a QRA for leukaemia from benzene exposure. The degree of variation in risk estimates can only be reduced by the availability of better dose-response data from further epidemiologic studies, more information on the carcinogenic mechanisms and more accurate exposure profiles for the general population.

8. REGULATIONS AND GUIDELINES FOR VOCs IN INDOOR AIR

While regulations are enforced in most countries to control exposure to occupational and outdoor air pollutants, their development for indoor environments is seen to be problematic (particularly for dwellings) from the viewpoint of property rights, privacy and the ability to assess and enforce the compliance of large numbers of buildings (Godish 1989). A further complication is determinig which government authority has responsibility for indoor air quality (Spengler and Samet 1991). More effective approaches are considered to exist such as the encouragement of systematic research and education (Besch 1989), the application of emission standards to control product performance and the development of guideline concentrations (or goals) for indoor air pollutants (Seifert 1990). Examples of the first two approaches are the formaldehyde emission standards developed for plywood and particleboard (Sundin 1985), the encouragement of low emission paints in Germany (Plehn 1990) and USEPA actions to reduce VOC emissions from new carpets (Anon 1990). Building and other regulations in some countries provide the opportunity to specify product emission standards. For example, the European Economic Community Directive 89/106 requires that construction materials not threaten the health and hygiene of the occupants or neighbours by "the giving off of toxic gas", and product emission standards may prove useful to assess and control such performance (Dr H. Knoppel, Commission of the European Communities, private communication). In Australia the "Building Code of Australia" (Australian Uniform Building Regulations Co-ordinating Council 1988) specifies that occupied rooms have "adequate" ventilation and air quality and that provision of natural ventilation or mechanical ventilation complying with AS1668.2 (Standards Association of Australia 1991) satisfies this specification

Development of guideline concentrations for indoor air has been attempted using several approaches. One approach has been to suggest the adoption of ambient air guidelines for indoor environments. Spengler and Samet (1991) consider this unsatisfactory since both guidelines need to be based on different social, environmental and economic contexts. Peterson (1984) considered that it was an inadequate approach since many ambient air guidelines were derived from empirical considerations and not toxicology. Specifically the ambient air guideline for non-methane hydrocarbons (160 $\mu g/m^3$) was based on prevention of photochemical smog. Another approach suggested by Sagunski *et al.* (1990) was to develop guidelines by dividing the "lowest observed adverse effect level" from toxicological literature with factors of 1/100 to 1/10,000 depending on the carcinogenic classification of the compound. In this way he derived indoor air quality "requirements" for dichloromethane (40 $\mu g/m^3$), trichloroethylene (30 $\mu g/m^3$), tetrachloroethylene (50 $\mu g/m^3$), toluene (400 $\mu g/m^3$)), xylene (400 $\mu g/m^3$) and styrene (100 $\mu g/m^3$). However the division factors were subjectively selected removing any toxicological basis for the "requirements".

Van der Wiel and Lebret (1989) selected 13 indoor air quality "indicators" for which health-related nationally or internationally accepted maximum allowable concentrations existed and for which indoor air measurements were available. Two of the "indicators" were VOCs for which Dutch maximum allowable concentrations had been published. These were benzene (12 $\mu g/m^3$, averaged over 1 year) and dichloromethane (1700 $\mu g/m^3$, averaged over 24 hours).

Canadian "Exposure Guidelines for Residential Indoor Air Quality" were derived from health considerations (special risk groups, mechanism of action of contaminants) and include only one VOC – acrolein (propenal) – for which a guideline of 50 $\mu g/m^3$ (over a 5 minute period) was recommended (Department of National Health and Welfare 1989). It was also recommended that exposure to chlorinated hydrocarbons present in consumer products be kept to a minimum by ensuring adequate ventilation and observing manufacturer-specified precautions.

The WHO (1989) determined a number of "compounds of concern" in indoor air, including 10 VOCs, and specified a "concentration of concern" for each that was either an ambient air quality guideline or an occupational exposure standard. Risk factors were calculated for carcinogens for unit exposure instead of specifying concentrations of concern. However, the WHO has suggested that attention be focussed on those compounds that contribute in excess of 2% of the total background incidence of the disease concerned (Seuss 1990). For example, the WHO (1989) estimated, using the same risk estimate reported by Stolwijk (1990) and which entailed considerable uncertainty, that this incidence was exceeded for benzene in relation to leukemia in the US when median indoor exposure exceeded 10 $\mu g/m^3$.

Several researchers have recommended that guidelines for TVOC concentrations be adopted to preserve the indoor air quality of buildings but no country is known from published literature or by direct survey (Appendix I) to have yet adopted such a guideline. The recommendations by Molhave (1990) or Seifert (1990) have not been implemented in any country.

Bayer and Papanicolopoulos (1990) and Tucker (1990) reported that the State of Washington has required that all furnishings used in new State office buildings be characterised for their VOC emission behaviour and meet strict emission guidelines such that (a) indoor air concentrations of TVOCs will not exceed 500 $\mu g/m^3$ (based on model predictions), and (b) emissions of IARC category 1, 2A and 2B carcinogens and teratogenic agents must be identified, quantified and eliminated or reduced as much as technologically feasible. Tucker also reported that the USEPA was considering a similar approach to limit TVOC levels in its own buildings. He suggested that the maximum TVOC contribution to the indoor air from any single source should be 500 $\mu g/m^3$ and derived the maximum allowable emission rates for building materials and furnishing in offices as:

floor materials/coatings	600 $\mu g/m^2.h$
wall materials/coatings	400 $\mu g/m^2.h$
movable partitions	400 $\mu g/m^2.h$
office furniture	2500 µg/h.workstation
office machines (central)	250 $\mu g/h.m^3$ of space
office machines (personal)	2500 $\mu g/h.m^3$ of space

9. RECOMMENDATIONS

The Working Party makes the following recommendations:

Recommendation 1. No quantitative indoor air quality goal for VOCs should be developed until more knowledge is available regarding exposure levels and there is a better understanding of their health significance in Australian conditions.

Recommendation 2. Research should be carried out to fully characterise the types and concentrations of VOCs present in Australian buildings using standardised measurement techniques.

Recommendation 3. The VOC concentrations in buildings with occupant complaints should be measured in conjunction with epidemiological studies utilising objective health outcomes.

Recommendation 4. The effects of TVOC exposure on subjective and objective reactions of occupants should be further investigated under controlled experimental conditions with compound mixtures which are similar to those encountered in Australian buildings.

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Table 1. Contamination levels (ng per monitor) on commercially available charcoal pasive monitors (Sheldon *et al.* 1985)

Compound	Dupont		3M		Abcor	
	median	range	median	range	median	range
chloroform	<5	<5-108	15	<5-16	<5	–
1, 2 dichloroethane	<170	–	<170	–	<170	–
1,1,1 trichlorethane	22	<2-68	240	178-292	443	400-760
carbon tetrachloride	6.0	<0.4-14	5.3	4.8-7.4	230	220-1720
bromodichloromethane	<0.8	–	<0.8	–	<0.8	–
trichloroethylene	4.0	<4-45	230	194-305	120	110-430
tetrachloroethylene	24	<0.7-41	15	10-141	44	20-50
benzene	<10	–	<10	–	<10	–
chlorobenzene	<18	–	<18	–	<18	–

Table 2. Breakthrough volumes for organic compounds at ~20°C on Tenax GC (Brown and Purnell 1979, Krost *et al.* 1982, Hodgson and Girman 1989, Riggin 1985)

Compound	B.Pt. °C	V_B (L/g of Tenax)
Alkanes/alkenes		
pentane	36	2.2,<3
hexane	69	16,12,6-12
heptane	98	85,54
octane	125	390
butadiene	-4	not collected
1-heptene	94	>40
Aromatics		
benzene	80	31,39,12-25
toluene	111	190,175
xylenes	138-44	1500
ethylbenzene	136	500
cumene	152	2400
trimethylbenzenes	165-76	8900
styrene	145	1500
methylstyrene	167	6000
Esters		
methyl acetate	57	3
ethyl acetate	71	18,>24
propyl acetate	102	92
isopropyl acetate	90	31
butyl acetate	126	420
ethyl acrylate	100	120
methyl acrylate	80	32,54
methyl methacrylate	100	230
Ethers		
diethyl ether	35	11
bis (chloromethyl) ether	106	330
Chlorinated Compounds		
methyl chloride	-24	4
vinyl chloride	13	0.9
dichloromethane	41	1.5,5,<3
chloroform	61	9,17
carbon tetrachloride	77	31,15,6-12
1,2-dichloroethane	84	27,22
1,1,1-trichloroethane	74	19,11,<3
1,2-dichloroethylene	55	5
trichloroethylene	87	28,36
tetrachloroethylene	121	240,140
1,2-dichloropropane	95	82
chlorobenzene	132	130,340
o-dichlorobenzene	181	620
m-dichlorobenzene	173	920
benzyl chloride	179	1800

Compound	B.Pt. °C	V_B (L/g of Tenax)
Aldehydes		
acetaldelyde	20	1.4
proponal (acrolein)	53	2,7
pentanal	102	3-6
benzaldelyde	179	2500
Ketones		
acetone	56	3,9
butanone (MEK)	80	16,6-12
methylisobutyl ketone	118	130
acetophenone	202	1270
Alcohol		
methanol	65	0.6
ethanol	78	0.9
n,i-propanol	82-97	2,4,10
n,i-butanol	108-118	14,25
n-octanol	180	6900
Acids/Anhydrides		
acetic acid	118	4
n-butyric acid	162	210
acetic anhydride	140	4
maleic anhydride	202	440
Amines/Nitrosamines		
diethylamine	17	1.2
propylamine	48	4
isobutylamine	69	24
pyridine	116	39,135
aniline	184	1100,2700
N-nitrosodimethylamine	151	150
N-nitrosodiethylamine	177	950

Table 3. Background contamination on blank samples of Tenax (1.2-1.5g) cartridges (Sheldon *et al.* 1985, Walling 1984, Walling *et al.* 1986)

Compound	Weight (ng) per cartridge	
	field blanks	laboratory blanks[a]
1,1,1- trichloroethane	6 ± 1 , 11 – 25	4 ± 3
benzene	12 ± 3, 5 – 13	5 ± 1
trichloroethylene	2 ± 1	ND
n butylacetate	1 ± 1	ND
tetrachloroethylene	1 ± 0	ND
ethylbenzene	2 ± 1 , 8	ND
m-xylene	2 ± 1	ND
styrene	9 ± 4	1 ± 1
benzaldehyde	25 – 36	NA
methyl benzene	3 – 30	NA
ethenyl benzene	7 – 8	NA
1- phenylethanone	17	NA

a ND = not detected
NA = measurement not available

Table 4. Ratio of indoor/outdoor concentrations of volatile organic compounds that are frequently detected in indoor air[a]

n-ALKANES		1,1,1-trichloroethane	12±9	AROMATIC HYDROCARBONS	
n-pentane	3±1	1,1-dichloroethylene	13	styrene	8±11
n-hexane	28±41	trichloroethylene	20±31	benzene	7±14
n-heptane	4±2	tetrachloroethylene	9±9	toluene	19±39
n-octane	8±1	p-dichlorobenzene	11±12	ethylbenzene	33±83
n-nonane	14±3	m-dichlorobenzene	0.4	m,p-xylene	23±49
n-decane	95±170			o-xylene	14±31
n-undecane	28±23	ALCOHOLS		n-propylbenzene	4
n-dodecane	43±58	2-propanol	>73	1,3,5-trimethylbenzene	5±1
n-tridecane	>6	n-butanol	5±3	1,2,4-trimethylbenzene	17±9
n-tetradecane	21±20			1-methylethenylbenzene	5
n-pentadecane	>5	ALDEHYDES		naphthalene	4±2
		acetaldehyde	5		
BRANCHED CYCLO-ALKANES		butanol	2	TERPENES	
2-methyl pentane	2	hexanol	>5	camphene	20
2-methyl hexane	2	nonanal	5	α-pinene	24±9
3-methyl hexane	3±1			limonene	96±74
cyclohexane	4	KETONES			
		acetone	59±118	TVOC	9±4
HALOGENATED COMPOUNDS		methylethyl ketone	18±36		
trichlorofluoromethane	10				
1,2-dichloroethane	48±76	ESTERS			
dichloromethane	15±22	ethyl acetate	15		
chloroform	15±23				
carbon tetrachloride	3±2				

a arithmetic mean ± standard deviation of data from Seifert and Abraham (1982), Le Bret *et al.* (1984), De Bortoli *et al.* (1984), Monteith *et al.* (1984), Gammage *et al.* (1986), Wallace *et al.* (1986), Sheldon *et al.* (1988), Gammage *et al.* (1988), Hodgson and Girman (1989), Cohen *et al.* (1989), Chan *et al.* (1990)., Baldwin *et al.* (1990), Rothweiler *et al.* (1990), Wallace *et al.* (1990).

Table 5. Estimated VOC concentrations in indoor air (Stolwijk 1990, Shah and Singh 1988)

Compound	WHO Estimated Concentrations ($\mu g/m^3$)			US EPA Database Concentrations ($\mu g/m^3$)		
	median	90 percentile	arithmetic mean[a]	median	75 percentile	arithmetic mean[a]
n ALKANES						
n-hexane	10	20	10	–	–	–
n-heptane	5	15	10	–	–	–
n-octane	5	10	5	2	4	4
n-nonane	5	20	10	4	6	6
n-decane	10	50	20	2	4	5
n-undecane	5	25	10	2	4	5
n-dodecane	5	10	5	–	–	–
n-tridecane	5	10	10	4	11	11
n-tetradecane	2	10	2	5	8	7
n-pentadecane	1	5	1	2	3	2
n-hexadecane	1	5	1	–	–	–
BRANCHED/CYCLO ALKANES						
3-methyl pentane	5	80	5	–	–	–
2-methyl hexane	5	100	5	–	–	–
3-methyl hexane	2	100	–	–	–	–
cyclohexane	10	100	–	3	8	5
methylcyclohexane	10	100	–	–	–	–
dimethylcyclopentane	3	10	–	–	–	–
HALOGENATED COMPOUNDS						
dichloromethane	<10	600	–	–	–	–
chloroform	15	–	–	0.5	3	4
carbon tetrachloride	20	–	–	0	1	3
1,1,1-trichloroethane	5	20	10	12	35	307
trichloroethene	5	20	–	1	5	7
1,1,2,2-tetrachloroethane	–	–	–	0	0	0.1
tetrachloroethylene	5	20	–	5	11	21
chlorobenzene	<0.5	10	1	–	–	–
o-dichlorobenzene	–	–	–	1	15	5
m-dichlorobenzene	<0.5	5	–	2	6	24
p-dichlorobenzene	5	20	–	2	6	24

Table 5 continued

Compound	WHO Estimated Concentrations (µg/m³)			US EPA Database Concentrations (µg/m³)		
	median	90 percentile	arithmetic mean[a]	median	75 percentile	arithmetic mean[a]
1,2,3-trichlorobenzene	1	10	–	)		
1,2,4-trichlorobenzene	1	15	–	) 0.5	0.5	0.6
1,3,5-trichlorobenzene	<0.5	5	–	)		
ALCOHOLS						
ethanol	–	–	–	–	–	–
propanol	–	–	1	–	–	–
n butanol	< 1	3	2	–	–	–
i-butanol	1	5	2	–	–	–
2-ethylhexanol	1	5	–	–	–	–
2-butoxyethanol	–	–	–	0.4	1	2
ALDEHYDES						
(formaldehyde)	25	60	40	52	89	61
(acetaldehyde)	10	30	–	–	–	–
propenal (acrolein)	–	–	–	–	–	–
butanal (crotonaldehyde)	1	5	1	–	–	–
hexanal	1	5	–	–	–	–
benzaldehyde	–	–	–	0	6	7
KETONES						
acetone	–	–	–	20	27	19
methylethyl ketone	5	10	1	21	42	27
4-methyl-2-pentanone	2	–	1	–	–	–
ESTERS/ETHERS						
ethyl acetate	–	–	–	–	–	–
n-butyl acetate	–	–	–	–	–	–
1,4-dioxane	–	–	–	0	0.3	4

Table 5 continued

Compound	WHO Estimated Concentrations ($\mu g/m^3$)			US EPA Database Concentrations ($\mu g/m^3$)		
	median	90 percentile	arithmetic mean[a]	median	75 percentile	arithmetic mean[a]
AROMATIC COMPOUNDS						
benzene	10	20	10	10	21	17
toluene	65	150	80	6	29	28
styrene	1	5	10	1	3	6
o-xylene	5	10	10	5	9	12
mp-xylene	20	40	20	14[b]	25[b]	38[b]
ethylbenzene	10	20	10	5	10	13
n-propyl benzene	2	6	3	–	–	–
i-propylbenzene (cumene)	1	3	1	0	1	1
o-methylethylbenzene	2	5	5	–	–	–
1,2,3-trimethylbenzene	2	5	2	–	–	–
1,2,4-trimethylbenzene	5	20	10	1	4	3
1,3,5-trimethylbenzene	2	5	5	1	5	4
n-butylbenzene	1	10	–	–	–	–
p-methyl isopropyldiethylbenzene	1	10	–	–	–	–
napththalene	2	5	–	–	–	–
TERPENES						
α-pinene	10	20	10	1	3	3
β-pinene	< 1	5	1	–	–	–
limonene	15	70	30	–	–	–
α-terpinene	5	10	5	–	–	–

[a] arithmetic means were provided by the referenced sources but may not represent useful central measures due to the highly skewed nature of the data (see pages 15 to 18)

[b] p isomer only

Table 6. Geometric standard deviations (GSD) for volatile organic compounds in indoor air estimated from US EPA database (Shah and Singh 1988)

Compound	Boiling Point ℃	Number of measurements	Estimated GSD
acetone	56	4	(1.6)[a]
trichloroethane	74	2132	3.4
methyl ethyl ketone	80	4	not lognormal
benzene	80	2128	2.5
cyclohexane	81	4	not lognormal
toluene	111	220	5.1
tetrachlorethylene	121	2195	2.5
octane	126	605	2.0
p-xylene	138	2305	1.9
o-xylene	144	2216	2.1
nonane	151	134	not lognormal
α-pinene	156	623	3.1
1,2,4-trimethyl benzene	170	96	2.8
2-butoxyethanol	171	14	not lognormal
m-dichlorobenzene	172	2121	4.1
p-dichlorobenzene	174	2121	3.9
decane	174	710	2.8
undecane	195	706	2.3
tetradecane	253	119	not lognormal
		mean GSD[b]	2.8

[a] excluded from estimated mean since value is based on few measurements

[b] geometric mean of GSD values weighted for degrees of freedom (n-1) for each value.

Table 7. Studies used to estimate average VOC concentrations in indoor air

Study reference	Building		Sampling details		
	type[a]	number	period	location[b]	type[c]
Bayer & Black (1988)	O	3	2 hr	S	A
Hodgson *et al.* (1989)	O	1	2 hr	S	A
Hodgson & Girman (1989)	S,O	2	2 hr	S	A
De Bortoli *et al.* (1986)	D(O)	15	4-7 d	S	A
Chan *et al.* (1990)	D	18	1.5 hr	S	A
Johansson (1978)	S	2	10 min	S	A
Krause *et al.* (1987)	D	230	14 d	S	P
Seifert & Abraham (1982)	D,O	15	1-7 d	S	P
De Bortoli *et al.* (1990)	O	10	–	S	A
Jungers *et al.* (1987)	O,S,H	3	12 hr	P	A
Sheldon *et al.* (1988)	O	1	12 hr	P	A
Le Bret *et al.* (1986)	D	319	7 d	S	A
Kleist *et al.* (1990)	D	20	7 d	S	A
Cohen *et al.* (1989)	D	35	21 d	S	P
Bayer & Black (1987)	O	3	4 hr	S	A
Wallace *et al.* (1989)	D	752	12 hr	P	A
Wallace *et al.* (1987)	O,S,H	7	12 hr	P	A
Hartwell *et al.* (1984)	D	20	12 hr	P	A
Berglund *et al.* (1982)	S	1	15 min	S	A
Monteith *et al.* (1984)	MD	44	2-3 hr	S	A
Jungers & Sheldon (1987)	O,H	3	12 hr	S	A
Wanner *et al.* (1984)	D,O	57	–	S	A
Yocom *et al.* (1984)	O	1	–	–	–
Gebefuegi *et al.* (1990)	O	1	4 hr	S	A
Wallace (1986)	D	573	12 hr	P	A
Gammage *et al.* (1988)	D	8	30 min	S	A
Molhave & Moller (1979)	D	7	3 hr	S	A
Weber (1984)	O	44	–	–	–
Matsushita *et al.* (1984)	O	8	–	–	–
Nagda *et al.* (1990)	O	1	–	–	–
Stehlik *et al.* (1982)	O	4	2 hr	S	A
Lamb *et al.* (1985)	D	10	–	–	–
Norback *et al.* (1990)	O	11	2 hr	S	A
Zweers *et al.* (1990)	O	4	–	–	–
Fanger *et al.* (1988)	O	20	–	S	A
Molhave (1979)	D	14	1 d	S	A
Molhave (1984)	–	–	–	–	–

Table 7 continued

Study reference	Building		Sampling details		
	type[a]	number	period	location[b]	type[b]
Molhave (1986)	–	–	–	–	–
Syverson *et al.* (1984)	D	7	–	S	A
Walkinshaw *et al.* (1987)	D,O,S,H	8	20 min	S	A
Wolkoff (1987)	O	16	40 min	S	A
Tsuchiya & Stewart (1990)	O,S,H	22	40 min	S	A
Wallace *et al.* (1990)	D	760	12 hr	P	A
Baldwin *et al.* (1990)	O	2	8 hr	S	A
Berglund *et al.* (1990)	O	1	15 min	S	A
Morey *et al.* (1989)	O	15	–	S	A
Wang (1975)	S	1	n.a.	S	A

[a] D = dwelling, O = office, S = school, H = hospital, MD = mobile dwelling
[b] S = static, P = personal
[c] A = active, P = passive

Table 8. Summary of derived WAGM concentrations for VOCs in established dwellings (IARC classification in brackets)

WAGM Concentrations in Dwellings ($\mu g/m^3$)

< 1	< 1	1 – < 5	5 – < 10	20 – < 50
i-amyl alcohol bromodichloromethane n-butanol n-butyl benzene chlorobenzene o-dichlorobenzene (3) m-dichlorobenzene 1,2-dichloroethane (2B) 1,2-dichloropropane (3) diethyl ether dimethylcyclopentane 1,4 dioxane (2B) n-hexadecane 1-methyl naphthalene p-methyl-i-propylbenzene napththalene N-nitrosodiethylamine (2A) N-nitrosodimethylamine (2A) N-nitrosopyrrolidine (2B) β-pinene 1,2,3,5-tetramethylbenzene	1,2,4,5-tetramethylbenzene 1,2,3-trichlorobenzene 1,2,4-trichlorobenzene 1,3,5-trichlorobenzene 1,2,3-trimethylbenzene 4-methyl-2-pentanone	2-ethyl-1-hexanol n-heptane hexanal n-hexane methylcyclohexane methyl cyclopentane o,m,p-methyl ethyl benzene 2,3-methyl hexane 3-methyl pentane n-nonane n-octane n-pentadecane α-pinene n,i-propylbenzene styrene (2B) tetradecane trichloroethylene (3) 1,3,5-trimethylbenzene n-undecane α-terpinene	benzene (1) n-decane p-dichlorobenzene (2B) ethyl acetate ethylbenzene nonanal tetrachloroethylene (2B) 1,2,4-trimethylbenzene o-xylene	acetone limonene toluene 1,1,1-trichloroethane (3)
	1 – < 5			> 50
	butanal 2-butanone i-butanol n-butyl acetate carbon tetrachloride(2B) chloroform(2B) cyclohexane 1,1-dichloroethene n-dodecane ethylene dibromide (2A)		10 – < 20	ethanol
			camphene 1,2 dichloroethylene dichloromethane (2B) m,p-xylene (o,m,p-xylene)	

Table 9. Derived WAGM and 90 PC concentrations for 19 "major" VOCs in dwellings with comparison to WHO (1989) derivations

Compound	Boiling point °C	Derived Concentration ($\mu g/m^3$)		WHO Derived Concentration ($\mu g/m^3$)	
		WAGM	90 PC	median	90 PC
n-decane	174	5	20	10	50
ethylbenzene	136	5	22	10	20
o-xylene	144	6	25	5	10
1,2,4-trimethylbenzene	170	6	23	5	20
nonanal	185	7	27	–	–
tetrachloroethylene	121	7	28	5	20
p-dichlorobenzene	174	8	32	5	20
ethylacetate	77	8*	31*	–	–
benzene	80	8	34	10	20
1,2-dichloroethylene	48-60	11*	47*	–	–
camphene	158	14	55	–	–
dichloromethane	41	17	70	< 10	600
m,p-xylene	138-9	18	73	20	40
limonene	178	21	85	15	70
1,1,1-trichloroethane	74	24	96	5	20
acetone	56	32	131	–	–
toluene	111	37	151	65	150
ethanol	79	120	490	–	–

* may be underestimates due to sampling strategies used

Table 10. VOCs with higher concentrations in public buildings than dwellings

Compound	WAGM Concentrations ($\mu g/m^3$)		
	dwelling	public building	building type[a]
1,2-dichlorethane	0.1	0.4	O
"	0.1	0.2	H
n-butanol	0.7	0.9	S
trichloroethylene	3	4	O
o-xylene	6	8	O
m-methylethylbenzene	2	8	O
1,2,3-trimethylbenzene	0.4	9	O
chloroform	2	10	O
n-hexane	5	12	O
1,2,4-trimethylbenzene	6	13	O

[a] O = office, H = hospital, S = school

Table 11 Derived concentrations for major VOCs in indoor air in comparison with health effects and environmental/occupational exposure guidelines

Compound	B.Pt. °C	Building		Derived Concentrations ($\mu g/m^3$)					Odour Threshold ($\mu g/m^3$)[g]		Irritation Level[h] ($\mu g/m^3$)	Ambient Air Objective ($\mu g/m^3$)		Occupational Exposure Standard[n] ($\mu g/m^3$)	IARC Class[a]
		No.	type[b]	No. of meast	WAGM[c]	90PC[d]	98PC[e]	AMC[f]	low	high		EPAV[i]	WHO[j]		
n-decane	174	852	D	1085	5	20	47	470	–	–	–	–	–	–	–
ethylbenzene	136	1225	D	1867	5	22	51	60	220	870,000	435,000[m]	14,500	–	435,000	–
diethyl ketone	102	1	S	12	6	26	59	–	3,200	49,000	–	23,300	–	705,000	–
o-xylene	144	891	D	1518	6	25	57	50	350[k]	170,000[k]	435,000[k,m]	14,500[l]	–	350,000[k]	–
1,2,4-trimethylbenzene	170	619	D	619	6	23	52	190	140	–	250,000[k]	4,000[k]	–	125,000[k]	–
nonanal	185	15	D	15	7	27	62	80	–	–	–	–	–	–	–
tetrachloroethylene	121	1276	D	1919	7	28	66	65	8,000	470,000	680,000	6,300[l]	5,000	335,000	2B
m-methylethylbenzene	161	3	O	168	8	33	77	30	–	–	–	–	–	–	–
m-methylethylbenzene	161	20	D	20	2	7	16	–	–	–	–	–	–	–	–
p-dichlorobenzene	174	1256	D	1881	8	32	75	160	1,080	180,000	240,000	–	–	450,000	–
n-nonane	151	586	D	592	5	19	43	220	250,000	3.4×10^6	–	–	–	1.05×10^6	–
ethyl acetate	77	248	D	302	8	31	73	110	20	670,000	350,000	22,100[l]	–	1.4×10^6	–
ethyl acetate	77	1	S	12	10	42	97	–	20	670,000	350,000	22,100[l]	–	1.4×10^6	–
benzene	80	1388	D	2171	8	34	80	70	4,500	270,000	9×10^6	100	–	16,000	1
1,2,3-trimethylbenzene	176	3	O	152	9	36	83	70	–	–	250,000[k]	4,000[k]	–	125,000[k]	–
1,2,3-trimethylbenzene	176	569	D	569	0.4	2	4	34	–	–	250,000[k]	4,000[k]	–	125,000[k]	–
phenol	182	1	S	5	9	36	84	–	154	22,000	180,000	36[l]	–	19,000	–
chloroform	61	1	O	20	10	40	93	110	300	1.0×10^6	20×10^6	1,590	–	50,000	2B
chloroform	61	672	D	1315	2	8	18	17	300	1.0×10^6	20×10^6	1,590	–	50,000	2B
1,2-dichloroethylene	48-60	35	D	35	11	47	110	140	250	2.0×10^6	–	26,300	–	790,000	–
n-hexane	50	8	O	26	12	47	110	66	230,000	–	1.4×10^6	6,000	–	180,000	–

Table 11 continued

Compound	B.Pt. °C	Building		Derived Concentrations (µg/m^3)					Odour Threshold (µg/m^3)[g]		Irritation Level[h] (µg/m^3)	Ambient Air Objective (µg/m^3)		Occupational Exposure Standard[n] (µg/m^3)	IARC Class[a]
		No.	type[b]	No. of meast	WAGM[c]	90PC[d]	98PC[e]	AMC[f]	low	high		EPAV[i]	WHO[j]		
n-hexane	50	602	D	656	5	19	45	110	230,000	–	1.4 x 10^6	6,000	–	180,000	–
acetic acid	118	1	S	5	12	50	110	–	24	25,000	12,500	500[l]	–	25,000	–
camphene	158	44	MD	44	14	55	130	270	–	–	–	–	–	–	–
dichloromethane	41	41	D	101	17	70	160	170	3,000	2.2 x 10^6	8.3 x 10^6	12,000	3,000	175,000	2B
m,p-xylene	138-9	945	D	1587	18	73	170	120	350[k]	170,000[k]	435,000[k,m]	14,000[l]	–	350,000[k]	–
limonene	178	584	D	584	21	85	200	450	–	–	–	–	–	–	–
methylethylketone	80	262	D	316	4(21)[o]	16	38	29	740	150,000	300,000	5,900[l]	–	445,000	–
1,1,1-trichloroethane	74	937	D	1580	24	96	220	100	540,000	3.8 x 10^6	5.4 x 10^6	63,300	–	680,000	3
butyric acid	164	1	S	5	25	100	240	–	1.0	9,000	1.9 x 10^6	–	–	–	–
acetone	57	32	D	86	32	130	300	99	30,000	1.6 x 10^6	480,000	48,000	–	1.2 x 10^6	–
methanol	65	1	S	11	29	118	270	–	13,000	26 x 10^6	23 x 10^6	5,500[l]	–	260,000	–
toluene	111	712	D	792	37	150	350	320	640	260,000	70,000	650[l]	1,000	375,000	–
ethanol	79	39	D	39	120	490	1100	–	340	9.7 x 10^6	950,000	3,800[l]	–	1.9 x 10^6	–

Notes

a IARC (1987) classifications 1 – carcinogenic to humans
2A – probably carcinogenic to humans
2B – possibly carcinogenic to humans
3 – not classifiable as to their carcinogenicity to humans.

b D = dwelling; O = office; S = school; H = hospital (includes nursing homes); MD = mobile dwelling.

c WAGM = weight averaged geometric mean (weighting by number of measurements).

d 90PC = 90th percentile concentration, estimated from WAGM assuming that GSD = 3.0.

e 98 PC = 98th percentile concentration, estimated from WAGM assuming that GSD = 3.0.

f AMC = average maximum concentration, geometric mean of reported maximum concentrations.

g Lowest and highest odour thresholds reported (irrespective of test protocol or definition of threshold) from ASTM (1973), G. Leonardos *et al.* (1969), WHO (1989), Bloeman *et al.* (1990), Amoore and Hautala (1982), and Ruth (1986).

h Lowest concentration reported to not cause irritation in humans, gathered from information reported by ACGIH (1986), National Occupational Health and Safety Commission (1990), and Ruth (1986).

i Ground level concentrations as specified by the Environment Protection Authority of Victoria (Streeton 1990).

j Air quality guidelines for the ambient environment published by the World Health Organisation (1987).

k Data for isomers.

l Based on consideration of odorous properties.

m Occupational TLV (set at level to prevent irritation).

n National Occupational Health and Safety Commission (1990a).

o Due to sampling inadequacies the WAGM may underestimate actual MEK concentrations; the US EPA database of indoor air concentrations (Shah and Singh 1988) provided a median concentration of 21 $\mu g/m^3$ and this may be a better estimate for this compound.

Table 12 VOCs with elevated concentrations in new c.f. established buildings

Compound	Concentration Elevation WAGM (new) / WAGM (estab)	New Building		Derived Concentrations ($\mu g/m^3$)				
		no.	type[b]	no. of meast.	WAGM[c]	90PC[d]	98 PC[e]	AMC[f]
dichloromethane	3x	1	O	12	7	29	66	32
1,2,4-trimethl benzene	10x	1	H	18	8	32	76	–
1,2,4-trimethyl benzene	3x	1	O	18	40	160	380	–
1,1,1-trichloroethane	3x	5	O	57	59	240	560	91
n-nonane	6x	1	O	12	32	130	300	150
m,p-xylene	16x	7	D	7	280	1,200	2700	–
m,p-xylene	4x	4	O	53	25	100	240	68
m,p-xylene	2x	1	S	4	9	36	85	–
m-methyl ethyl benzene	2x	1	O	18	15	61	140	–
m-methyl ethyl benzene	7x	1	H	18	7	28	66	–
n-butanol	8x	1	S	40	7	29	66	–
n,i-propyl benzene	5x	1	O	18	5	20	47	–
n,i-propyl benzene	30x	1	H	18	3	11	28	–
tridecane	12x	1	O	9	23	94	210	110
α-pinene	66x	7	D	7	260	1,100	2500	–
α-pinene	4x	1	O	18	8	32	76	–
α-pinene	7x	1	S	4	13	52	120	34
α-pinene	30x	1	H	18	3	12	28	–
n-dodecane	15x	4	O	70	30	120	280	98
n-dodecane	40x	1	H	18	17	69	150	–
n-undecane	60x	5	O	74	62	250	590	170
n-undecane	40x	1	H	18	37	150	350	–
n-decane	80x	7	D	7	390	1590	3700	–
n-decane	25x	4	O	62	75	310	710	56
n-decane	12x	1	H	18	37	150	350	–
tetradecane	–	1	O	9	56	230	530	250
2-propanol	–	46	D	46	900	3,700	8500	–
2-propanol	340x	1	O	12	27	110	260	140
2-propanol	–	1	S	4	26	110	250	73
TVOC	4x	33	D	33	4,500	18,000	40,000	18,000
TVOC	23x	1	O	100	4,200	17,000	39,000	–
TVOC	3x	–	S	–	240	960	2,200	860

b-f Refer to Table 11

Table 13 Derived concentrations of major VOCs in indoor air of new buildings in comparison to health and exposure related information

Compound	B.Pt. °C	Building		Derived Concentrations ($\mu g/m^3$)					Odour Threshold ($\mu g/m^3$)[g]		Irritation Level[h] ($\mu g/m^3$)	Ambient Air Guideline ($\mu g/m^3$)		Occupational Exposure Standard[n] ($\mu g/m^3$)	IARC Class[a]
		No.	type[b]	No. of meast	WAGM[c]	90PC[d]	98PC[e]	AMC[f]	low	high		EPAV[i]	WHO[j]		
2-ethoxyethyl acetate	156	1	H	18	5	21	49	–	300	2,000	–	–	–	27,000	–
n-butanol	118	1	S	40	7	29	66	–	210	150,000	75,000	900	–	150,000	–
α–pinene[p]	156	10	DOSH	47	10	41	95	–	–	–	–	–	–	–	–
tridecane	243	1	O	9	23	94	220	112	–	–	–	–	–	–	–
n-dodecane[p]	216	5	OH	88	27	110	260	98	–	–	–	–	–	–	–
n-undecane[p]	195	6	OH	92	56	230	530	168	–	–	–	–	–	–	–
tetradecane	253	1	O	9	56	230	530	245	–	–	–	–	–	–	–
2-propanol[p]	82	48	DOS	62	360	1,500	3,400	–	–	–	–	–	–	500,000	–

a–n Refer to Table 11

p measurements in two or more building types were combined to derive single concentrations for this table.

Table 14. Comparison of WAGM concentrations in "complaint" buildings to those in established buildings[a]

Compounds Not Elevated	WAGM (compl) / WAGM (estab)	Compounds Elevated	WAGM ($\mu g/m^3$)	WAGM (compl) / WAGM (estab)
benzene	0.6	ethylbenzene	9	2
n-heptane	0.3	acetone	29,16	2,3
n-hexane	0.3	ethylacetate	2	5
methylcyclopentane	1.0	3-methyl pentane	21	7
o-methylethyl benzene	<0.1	n-butyl acetate	26	8
tetrachloroethylene	0.5	trichloroethylene	47	12
toluene	0.8	4-methyl-1-pentanone	15	38
1,1,1-trichloroethane	0.6	methyl cyclohexane	4	400
1,2,3-trimethylbenzene	<0.1	1,4-dioxane	11	530
o-xylene	0.9	4-methyl-1-pentanol	10	1,000
m,p-xylene	0.8,1.0			
		TVOC	520,490, 480,2100	0.5,3, 7,5

a references: Bayer and Black (1988), Hodgson *et al.* (1989a), Hodgson and Girman (1989), De Bortoli *et al.* (1990), Molhave (1979), Norback *et al.* (1990), Zweers *et al.* (1990), De Bortoli *et al.* (1986), Walkinshaw *et al.* (1987), Tsuchiya and Stewart (1990), Morey and Jenkins (1989), Berglund *et al.* (1990).

Table 15. Derived TVOC concentrations for different building types

Building Type[b]	No. of buildings	No. of meast.	Derived TVOC Concentration ($\mu g/m^3$)			
			WAGM[c]	90 PC[d]	98 PC[e]	AMC[f]
D-established	1,081	2,478	1,130	4,630	10,700	3,160
D-new	33	33	4,500	18,400	42,700	18,100
D-complaint	14	28	520	2,130	4,930	2,800
O-established	60	384	180	740	1,710	1,080
O-new	1	100	4,150	17,000	39,300	–
O-complaint	51	331	490	2,000	4,650	4,040
S-established	21	27	70	290	660	530
S-new	–	–	240	960	2,280	860
S-complaint	9	56	480	1,970	4,550	1,780
H-established	2	8	410	1,680	3,890	1,300
H-complaint	6	51	2,080	8,500	19,700	98,000

b-f Refer to Table 11

Table 16. VOCs present as major components in different products

Product Description	VOC (VVOC)	Reference
1. Body deodorants/ hair sprays	– (Freon 12), (Freon 13), (isobutane), (dichloromethane), (propane), (butane)	Vireluzier *et al.* (1990)
2. Floor wax	– nonane, decane, undecane, dimethyloctane, ethylmethylbenzene;	Tichenor & Mason (1988)
	– 1,4-diethylbenzene, butylbenzene, decane, 1,3,5-trimethylbenzene, 1-nonene, ethylbenzene, xylene, limonene	Gebefuegi *et al.* (1990)
3. Surface cleaners and disinfectant	– limonene, p-cymene, undecane, α-pinene, heptene, decane, nonane, heptane	Gebefuegi *et al.* (1990)
	– borneol acetate, menthol, (formaldehyde), 1-methoxy-2-propanol, 2-methoxy-1-propanol	Colombo *et al.* (1990)
4. Furniture polish	– 3-methyl heptane, 2-methyl heptane, n-octane, n-heptane, methylcyclohexane	Colombo *et al.* (1990)
	– trimethylpentane, dimethylhexane, trimethylhexane, trimethylheptane, ethylbenzene, limonene	Tichenor & Mason (1988)
5. Room freshener	– nonane, decane, undecane, ethylheptane, limonene	Tichenor & Mason (1988)
6. Household 'shelf ' products	– (dichloromethane), 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, carbon tetrachloride, 1,1,2-trichlorotri-fluoroethane	Maklan *et al.* (1987)
7. Cleaning agents/ aerosol spot removers	– tetrachloroethylene, 1,1,1-trichloroethani, (propane)	Fishbein (1985)
8. Household waxes		
– water-based	– alcohols, esters, alkoxyalcohols, terpene alcohols/acetates	Knoppel *et al.* (1987)
– non-water-based	– alkanes, alkenes, terpenes	

Table 16 continued

Product Description	VOC (VVOC)	Reference
9. Moth crystals, toilet deodorizers	– p-dichlorobenzene	Tichenor & Mason (1988)
10. Adhesives-water-based	– nonane, decane, undecane, dimethyl-octane, 2-methyl-nonane, xylene	Tichenor & Mason (1988)
	– octaine, nonane, decane, undecane, toluene, $C_8 - C_{11}$ branched alkanes, C_8–C_{10} cyclo-hexanes, methylcyclohexanes	Girman *et al.* (1984)
11. Adhesives-solvent-based	– toluene, styrene, lower alcohols, n-decane n-undecane, branched alkanes, C_{10} cyclohexanes, cyclohexane, methyl cyclopentane	Girman *et al.* (1987)
12. Floor tile adhesive	– toluene, benzene, ethylacetate, styrene, ethylbenzene	Bayer & Black (1989)
13. Wood stain	– nonane, decane, undecane, methyloctane, dimethylnonane, trimethylbenzene	Tichenor & Mason (1988)
14. Paint-water based	– 2-propanol, MEK, ethylbenzene, propylbenzene, 1,1-oxybisbutane, butylpropionate, toluene	Tichenor & Mason (1988)
	– 1,2-propanediol, 2-butoxyethanol, acetone, limonene, hexanal	Wolkoff *et al.* (1990)
	– n-undecane	Seifert *et al.* (1987)
15. Polyurethane lacquer	– nonane, decane, undecane, MEK, ethylbenzene, xylene	Tichenor & Mason (1988)
16. Silicone caulk	– MEK, butylpropionate, 2-butoxyethanol, butanol, benzene, toluene	Tichenor & Mason (1988)
17. Drapery	– acetone, (dichloromethane), toluene, benzene, chloroform, ethylacetate, 3-hexanone	Bayer & Papanicolopoulos (1990).

Table 16 continued

Product Description	VOC (VVOC)	Reference
18. Carpet – rubber backed nylon	– toluene, benzene, n-decane – 4-phenylcyclohexene	Bayer & Black (1989) Black (1990)
19. Vinyl flooring	– iso-alkanes, C_8-C_{13} n-alkanes, methylethylbenzenes, xylenes, ethylbenzene, toluene, 2-ethylhexanol, (formaldehyde)	van der Wal *et al.* (1990)
20. Rubber flooring	– 1,1,1-trichloroethane, styrene, 1,3/1,4-diisopropylbenzene, isododecane, indene, acetophenone	Wolkoff *et al.* (1990)
21. Particleboard	– (formaldehyde), acetone, hexanal, benzaldehyde, 2-propanol, MEK, benzene	Nelms *et al.* (1986)
22. Plywood	– (formaldehyde), terpenes, methylacetate, n-butanol, tetrachloroethylene, xylenes, toluene, nonanal, n-undecane, tetradecane, naphthalene, p-dichlorobenzene	van der Wal *et al.* (1990), Monteith *et al.* (1984)
23. Polystyrene foam	– styrene, ethylbenzene, other aromatics	van der Wal *et al.* (1990)

Table 17. TVOC emission rates for different sources

Source Description	Emission Rate ($\mu g/m^2.h$)	Reference
<u>Household Products ("wet")</u>		
1. solvent based waxes/detergents	up to 260×10^6	Knoppel *et al.* (1987)
2. waxes spread on surfaces	$1.0 \times 10^6 - 94 \times 10^6$	Person *et al.* (1990)
3. toilet deodorizers	$1.3 \times 10^6 - 3.7 \times 10^6$	Person *et al.* (1990)
4. room deodorizers	$1.6 \times 10^5 - 2.0 \times 10^6$	Person *et al.* (1990)
5. liquid cleaner/disinfectant	1.1×10^6	Colombo *et al.* (1990)
6. carpet spray cleaner	1.1×10^6	Colombo *et al.* (1990)
7. water-based waxes/detergents	$1.2 \times 10^5 - 1.2 \times 10^6$	Knoppel *et al.* (1987)
8. furniture spray polish	3.0×10^5	Colombo *et al.* (1990)
9. floor cleaners	$<10{,}000 - 150{,}000$	Person *et al.* (1990)
10. floor wax paste	60,000	Colombo *et al.* (1990)
11. dry cleaned clothing	27,000	Sparks *et al.* (1990)
12. floor wax	20,000	Sparks *et al.* (1990)
13. liquid floor detergent	17,000	Colombo *et al.* (1990)
<u>Construction Products ("wet")</u>		
1. solvent-based adhesives	$5.1 \times 10^6 - 16.5 \times 10^6$	Person *et al.* (1990)
2. water-based adhesives	$< 10^4 - 2.1 \times 10^6$	Person *et al.* (1990)
3. wall/flooring glue (EVA)	2.7×10^5	Molhave (1982)
4. sealants (incl. silicones)	$300 - 72{,}000$	Molhave (1982)
5. wood stain	17,000	Sparks *et al.* (1990)
6. polyurethane lacquer	6,000	Sparks *et al.* (1990)
7. floor varnishes (3 types)	$830 - 4{,}700$	Molhave (1982)
8. PVA glue (water-based)	2,100	Molhave (1982)
<u>Construction Products ("dry")</u>		
1. new vinyl flooring	$19{,}000 - 43{,}000$	van der Wal *et al.* (1990)
	$120 - 2{,}300$	Molhave (1982)
2. rubber floor covering	1400	Molhave (1982)
	410	Wolkoff *et al.* (1990)
3. plywoods	$300 - 2{,}400$	van der Wal *et al.* (1990)
	40	Molhave (1982)
4. polystyrene foam	1400	Molhave (1982)
	$30 - 1{,}000$	van der Wal *et al.* (1990)
5. textile floor covering	$80 - 1{,}600$	Molhave (1982)
6. plastic floor covering	$220 - 590$	Molhave (1982)
7. rubber backed nylon carpet	300	Wolkoff *et al.* (1990)
	$50 - 180$	Black (1990)

Table 17 continued

Source Description	Emission Rate ($\mu g/m^2.h$)	Reference
8. felt carpet	80 – 110	Molhave (1982)
9. painted gypsumboard/ particleboard	240 – 260	Wolkoff *et al.* (1990)
10. particleboard, fibreboard	120 – 140	Molhave (1982)
11. polyurethane foam	120	Molhave (1982)
12. wallpapers (including vinyl)	30 – 300	Molhave (1982)
13. gypsumboard	30	Molhave (1982)
14. GRP sheeting	20	Molhave (1982)
15. mineral wool	10	Molhave (1982)

Table 18. Experimental studies of human exposure to VOCs

Author	Year	Subjects	Design	Exposure	Outcome measures	Conclusions
Molhave *et al.*	1984	62 SBS	Controlled Latin square	7,400 & 33,000 $\mu g/m^3$ 22 VOCs	Symptoms, irritation, odour, digit span, eye blink frequency	–Perceived air quality & odour dose related VOC → Mucosal irritation
Camp & Morgan	1984	30 symp-tomatic	Randomised controlled	Carbonless copy paper	Rhinomanometry	–NCR increased exp nasal work
Molhave *et al.*	1986	62 SBS	Controlled Latin square	7,400 & 33,000 $\mu g/m^3$ 22 VOCs	Symptoms, irritation, eye blink frequency, digit span, graphic performance, odour	–VOCs reduced air quality, skin temp & digit span
Thygesen *et al.*	1987	62 SBS	Open un-controlled	7,400 & 33,000 $\mu g/m^3$ 22 VOCs	Eye blink frequency Tear Na, K & albumin	–Unchanged –Increased median concentrations
Kjaergaard *et al.*	1987	63 healthy	Controlled Latin square	60,000, 200,000 & 580,000 $\mu g/m^3$ n-decane	Symptoms, irritation, Tear film stability Conjunctival cytology Performance testing	–Dose related –Sig decreased –Inc cuboidal epithel cells
Kjaergaard *et al.*	1990	35 SBS & normal	Double blind Latin square	33,000 $\mu g/m^3$ 22 VOCs	Subjective ratings Tear film stability Conjunctival cytol Performance testing	–Perceived odour –Unchanged –Inc polymorphs –Dec digit span & symbol test
Koren *et al.*	1990	28 normal	Controlled	33,000 $\mu g/m^3$ 22 VOCs	Nasal lavage	–Inc polymorphs 18 hours post 4 hour exposure

Table 18 continued

Author	Year	Subjects	Design	Exposure	Outcome measures	Conclusions
Johnsen *et al.*	1990	20 asthmatic 5 normal	Controlled	Rubber Particle Gypsum Carpet see text	Symptoms Tear film stability foam, lipid, epithelial damage Lung function	–Inc symptoms –Dec precorneal lipid& tear film stability –Unchanged
Wolkoff *et al.*	1990	20 asthmatic	Controlled	1,109 – 1,923 $\mu g/m^3$	Perceived air qual Decipols, Tear film stability	–Unrelated TVOC –Lipophilic VOC may degrease tear film
Otto *et al.*	1990	66 healthy	Controlled Counter-balanced	33,000 $\mu g/m^3$ 22 VOCs	Symptoms, Odour Mucosal irritation Neurobehavioural performance	–VOC → symptoms and discomfort but no change in performance
Harving *et al.*	1991	11 asthmatic	Controlled	3,500 & 33,000 $\mu g/m^3$ 22 VOCs	Discomfort Lung function (FEV_1) Bronchial reactivity	–Individual patterns –10% decrease –no change

Abbreviations:
SBS = Sick Building Syndrome;
NCR = No Carbon Required (R);
Na = Sodium; K = Potassium;
TVOC = Total Volatile Organic Compounds
Decipol = unit of odour measurement as defined by Fanger (1988)

Table 19. Constituents of VOC mixture used in experimental exposures at aggregate concentrations of 7,400 and 33,000 $\mu g/m^3$ by Molhave *et al.* (1984, 1986), Thygesen *et al.* (1987), Kjaergaard *et al.* (1987, 1990) Koren *et al.* (1990) Otto *et al.* (1990) and Harving *et al.* (1991)

Compound	Concentration ratio
n-Hexane	1
n-Nonane	1
n-Decane	1
n-Undecane	0.1
1-Octene	0.01
1-Decene	1
Cyclohexane	0.1
3-Xylene	10
Ethylbenzene	1
1,2,4-Trimethylbenzene	0.1
n-Propylbenzene	0.1
α-Pinene	1
n-Pentanal	0.1
n-Hexanal	1
Iso-propanol	0.1
n-Butanol	1
Methylethylketone (MEK)	0.1
2-Methyl-3-butanone	0.1
4-Methyl-2-pentanone	0.1
n-Butylacetate	10
Ethoxyethylacetate	1
1,2-Dichlorethane	1

Table 20. Quantitative Risk Assessments for benzene exposure and leukaemia

Author	Year	Studies considered	Dose-response model	Exposure level ($\mu g/m^3$.years)	Excess risk of deaths from leukaemia
Albert	1979	Infante *et al.* (1977) Ott *et al.* (1978) Askoy *et al.* (1976)	linear (non-threshold)	70	$2.8 \times 10^{-6} - 3.0 \times 10^{-5}$
IARC	1982	Rinsky *et al.* (1981) (updated Infante *et al.* 1977) Ott *et al.* (1978)	linear (non-threshold)	144×10^5 14.4×10^5 1.44×10^5	140 – 170 per 1000 exposed 14 – 140 per 1000 exposed 1.4 – 14 per 1000 exposed
White *et al.*	1982	Rinsky *et al.* (1981) Ott *et al.* (1978)	one-hit (linear at low doses)	14.4×10^5 1.44×10^5	44 – 152 per 1000 exposed 5 – 16 per 1000 exposed
Rinsky *et al.*	1987	Rinsky *et al.* (1981)	Exponential	14.4×10^5 1.44×10^5 0.144×10^5	OR = 154.5 (95% C.I.:3.1–7785) OR = 1.7 (95% C.I. : 1.1–2.5) OR = 1.05 (95% C.I. : 1.01–1.09)
WHO	1987	Rinsky *et al.* (1981) Bond *et al.* (1986) (updated Ott *et al.* 1978)	Linear	70	4×10^{-6}
Austin *et al.*	1988	Rinsky *et al.* (1981) Bond *et al.* (1986) Tsai *et al.* (1983) Wong (1983)	Linear	9.6×10^5 0.96×10^5	10 – 113 per 1000 exposed 1.0 – 11.3 per 1000 exposed

Table 20 Continued

Author	Year	Studies considered	Dose-response model	Exposure level ($\mu g/m^3$.years)	Excess risk of deaths from leukaemia
Crump *et al.*	1987	Ott *et al.* (1978) Rinsky *et al.* (1981) Wong (1983)	8 models	0.03×10^5 $- 12.8 \times 10^5$	Comparative risks only given. No absolute risks.
Swaen & Meyers	1989	(a) High exposure studies Rinsky *et al.* (1981) Bond *et al.* (1986)	Linear	9.6×10^5	5 per 1000 deaths
		(b) Low exposure studies Thorpe (1974) Rushton *et al.* (1980) Parkes *et al.* (1982)	Linear	9.6×10^5	6.3 per 1000 deaths

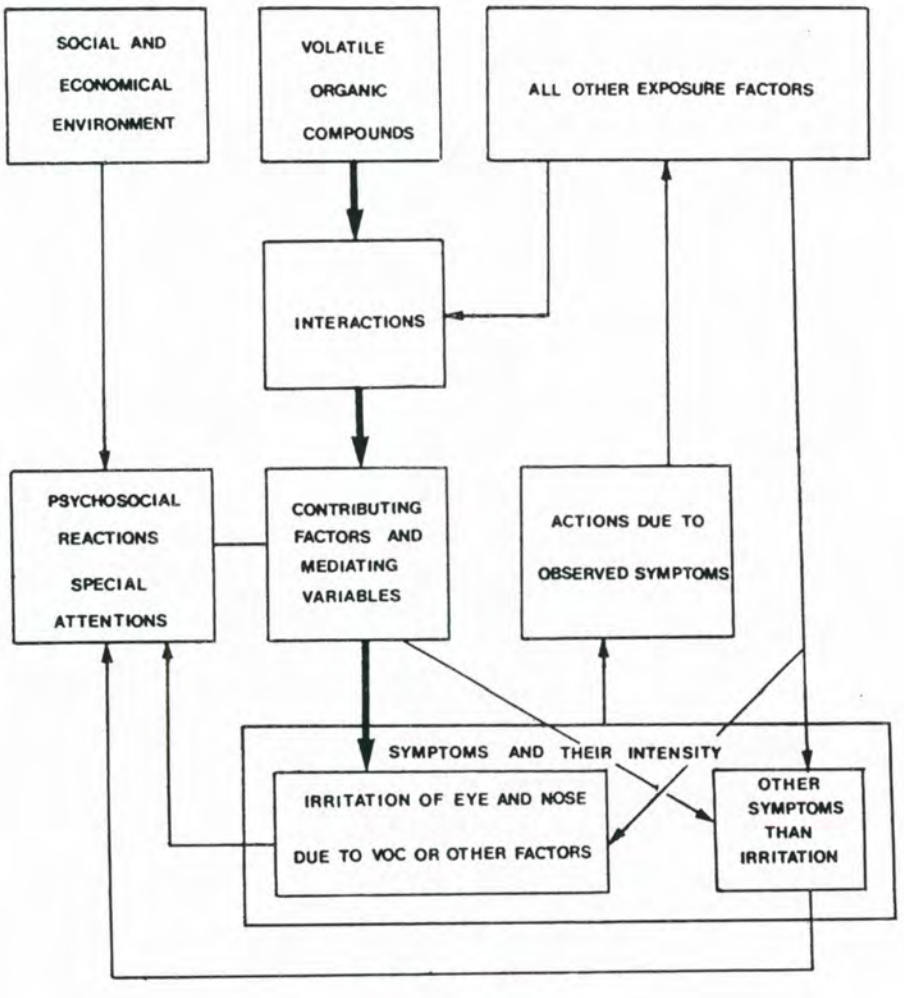

Figure 1. Classification of factors relevant for investigations of irritation by volatile organic compounds

———: Direct action of VOC leading to irritation
———: Reactions modifying the intensity of VOC-irritation

APPENDIX I

Survey of overseas organizations

(i) Indoor Environment Program, Lawrence Berkely Laboratory, California,

(ii) US Environmental Protection Agency, Research Triangle Park, North Carolina, USA,

(iii) American Conference of Governmental Industrial Hygienists, Ohio, USA,

(iv) American Industrial Hygiene Association, Ohio, USA,

(v) Canadian Centre for Occupational Health and Safety, Canada,

(vi) Building Research Establishment, United Kingdom,

(vii) Health and Safety Executive, United Kingdom,

(viii) Institute of Occupational Health, University of Birmingham, Birmingham, United Kingdom,

(ix) British Occupational Hygiene Society, London, United Kingdom,

(x) The Robens Institute, University of Surrey, Surrey, United Kingdom,

(xi) Institute of Occupational Medicine, Edingburgh,

(xii) Karolinska Institute and National Institute of Environmental Medicine, Sweden,

(xiii) Institute of Hygiene, University of Aarhus, Denmark,

(xiv) Institute of Water Soil and Air Hygiene, Germany,

(xv) Environmental Chemicals Sector, Commission of the European Communities, Ispra, Italy,

(xvi) International Agency for Research on Cancer, France,

APPENDIX II

Survey of Australian organizations

for VOC measurements

made in

indoor air of Australian buildings

– survey letter/report form

– organizations surveyed

M O N A S H U N I V E R S I T Y

Telephone: (03) 528 6433
Extension: 6166

Facsimile: (03) 523 0884

AUSTRALIA

Department of Social & Preventive Medicine
Unit of Occupational & Environmental Health
"Ashley Ricketson Centre"
Caulfield General Medical Centre
260-294 Kooyong Road
CAULFIELD VIC 3162

14 December 1990

Dear Sir,

Survey of Measurements of VOC Concentrations in the Indoor Air of Australian Buildings

The Unit of Occupational and Environmental Health, Monash University has formed a VOC Working Group to formulate options for the NH&MRC to develop Indoor Air Quality Goals for Volatile Organic Compounds (VOCs). As part of this process the VOC Working Group wishes to assess VOC levels in Australian non-industrial buildings and asks for your cooperation in doing so.

The Group is defining VOCs as all organic compounds within the boiling point range of 50° to 260°C. This includes many solvents, organic additives to consumer products, some combustion products, shown for example in the attached list, and specifically excluded are formaldehyde, pesticides, polynuclear aromatic hydrocarbons and particulate bound organic materials. Indoor air is defined as the air within the living spaces of homes, offices, schools and hospitals.

If you have measured concentrations of any of these VOCs in indoor air, please complete the enclosed survey form and return to the above address by February 12, 1991. Alternatively if you have not made measurements return only the top section of the survey form. Please contact Stephen Brown (Monday/Wednesday/Friday (03) 528 6433 [ext: 6167], Tuesday/Thursday (03) 556 2211) should you require further information.

Yours gratefully,

Stephen Brown
(VOC PROJECT OFFICER)

307 Volatile Chemical Compounds Detected in Indoor Air in Different Countries

n-ALKANES

n-Propane
n-Butane
n-Pentane
n-Hexane
n-Heptane
n-Octane
n-Nonane
n-Decane
n-Undecane
n-Dodecane
n-Tridecane
n-Tetradecane
n-Pentadecane
n-Hexadecane

BRANCHED ALKANES

2-Methylpropane
2-Methylbutane
C_6H_{14}
C_5H_{12}
2,2-Dimethylbutane
2,3-Dimethylbutane
C_6H_{14}
C_7H_{16} (6)
2-Methylpentane
3-Methylpentane
2,3-Dimethylpentane
2,4-Dimethylpentane
2-Methylhexane
3-Methylhexane
2,4-Dimethylhexane
C_8H_{18} (5)
2-Methylheptane
2,2,4-Trimethyloctane
3-Methylheptane
4-Methylheptane
2,3,3-trimethylpentane
C_9H_{20}(8)
$C_{10}H_{22}$(10)
Methylethylpentane
2,4-Dimethylheptane
2,6-Dimethylheptane
2,2,5,5-Tetramethylhexane
2,5,5-Trimethylheptane
2,3,6-Trimethylheptane
3-Methyloctane
2,5-Dimethyloctane
2-Methylnonane
2,6-Dimethyloctane
2,3,7-Trimethyloctane
4-Methyl-5-propyl-nonane
5-Methyldecane
4-Methyldecane
5-Ethyl-2-methyl-heptane
2-Methyldecane
2,2,3,4-Tetramethyl-pentane
3-Methyldecane
3,7-Dimethyl-undecane
$C_{12}H_{26}$ (8)
4-Methyl-undecane
2-Methyl-undecane
3-Mehtyl-undecane
$C_{13}H_{28}$ (2)
$C_{14}H_{30}$ (2)
$C_{15}H_{32}$

ALKENES AND CYCLOALKANES

1-Butene
1-Pentene
Cyclomethylbutadiene
Methylethylcyclopropene
Methylcyclobutane
Ethylcyclobutane
Cyclopentadiene
C_6H_{12}
Cyclopentene
2-Methyl-3-butadiene
Cyclohexane
1-Hexene
3-Methyl-1-pentene
Cyclopentane
Methylcyclopentane
5-Methyl-1-hexene
1-Heptene
Methylcyclohexane
C_7H_{14}(2)
C_8H_{16}(2)
2,4-Dimethyl-1,3-pentadiene
1,4-Dimethylcyclohexane
Methylethylcyclopentane
1-Octene
Ethylcyclohexane
1,1,3-Trimethylcyclohexane
C_9H_{18}
1,3,5,7-Cyclooctatetraene
5,5-Dimethyl-1-hexene
3,5,5-Trimethyl-1-hexene
1-Nonene
1-Ethyl-4-methylcyclohexane
cis-1-Ethyl-3-methylcyclohexane
n-Propylcyclohexane
n-Butylcyclohexane
iso-Propylcyclohexane
Alkylcyclopentane(2)
iso-Butylcyclohexane
Bicyclodecane
$C_{16}H_{32}$ (4)
1-Decene
$C_{11}H_{22}$ (7)
1-Undecene

HALOGEN DERIVATIVES

Dichlorodifluoromethane
Trichlorofluoromethane
Dibromochloromethane
Trichlorofluoroethane
1,2-Dichloroethane
1,1-Dichloroethane
Chloromethane
Dichloromethane
Trichloromethane
Tetrachloromethane
Freon 113
1,1,1-Trichloroethane
Trichloroethene
1,1,2-Trichloroethane
Tetrachloroethene
1,1,2-Trifluoro-1,2,2-trichloroethane
1,2-Dichloro-1,1,2,2-tetra-fluoroethane
1,2-Dichloropropane
Chlorobenzene
1,2-Dichlorobenzene
1,4-Dichlorobenzene
Trichlorobenzene

ALCOHOLS

Methanol
Ethanol
2-Propanol
1-Propanol
2-Methyl-1-propanol
2-Methyl-2-propanol
1-Butanol
2-Butanol
2-Methyl-1-butanol
2-Methoxy-ethanol
1-Methoxy-2-propanol
2-Ethoxy-ethanol
1-Pentanol
2-Methyl-1-pentanol
2-Ethyl-cyclobutanol
1-Hexanol
2-Ethyl-1-butanol
2-Buthoxy-ethanol
2-Bis(2-ethoxy)-ethanol
2-Ethyl-4-methyl-1-pentanol
4-Methyl-2-propyl-1-pentanol
2-Ethyl-1-hexanol
Octanol
1,8-Cineol
Terpeneol
Cresol
Phenol

ETHERS

Vinylethylether
Methoxyvinylethylether

ALDEHYDES

Formaldehyde
Acetaldehyde
Propanal
Crotonaldehyde
Butanal
Pentanal
Hexanal
Heptanal
Octanal
Benzaldehyde
Phenyl acetaldehyde
α-methyl-benzene-acetaldehyde
Nonanal
Ethylbenzaldehyde
2,5-Dimethylbenzaldehyde
n-Decanal

KETONES

Ketene
2-Propanone
2-Butanone
Cyclohexanone
3,3-Dimethylcyclobutanone
Methylethylketene
Methylbutylketone
4-Methyl-2-pentanone
3-Methyl-2-butanone
3-Heptanone
2-Heptanone
1-Phenylethanone
2,6-Di-t-butyl-benzoquinone
Methyl phenyl ketone

ESTERS

Methylacetate
Ethylacetate
n-Propylacetate
n-Butylacetate
iso-Butylacetate
tert-Butylacetate
2-Ethoxy-ethanolacetate
2-Ethoxy-ethylacetate
2-Methoxy-ethylacetate
2,2,4-Trimethylpenta-1,3-diol-*iso*-butyrate
2,2,4-Trimethylpenta-1,3-diol-di-*iso*-butyrate
2,2,4-Trimethylpenta-1,3-diol-1-*iso*-butyrate
n-Butyl-n-butanoate
ß-Butyl-methacrylate
Benzylacetate
Phtalate
Diethylphtalate

NITROGEN COMPOUNDS

Nitromethane
Acetonitrile
Acrylonitrile
Pyrrole
Pyridine
4-Methyl pentyl nitrile
1-Butyl-1,2,4-triazole
Cyanobenzene
Benzyl cyanide
Benzothiazole
Indole

AROMATIC HYDROCARBONS

Benzene
Toluene
Ethylbenzene
1,3-dimethylbenzene
1,4-dimethylbenzene
1,2-dimethylbenzene
1-Methyl-2-ethylbenzene
iso-Propylbenzene
n-Propylbenzene
1-Ethyl-3-methylbenzene
1-Ethyl-4-methylbenzene
1,3,5-Trimethylbenzene
Styrene
Phenylacetylene
1-Ethyl-2-methylbenzene
1,2,4-Trimethylbenzene
1,2,3-Trimethylbenzene
C_3-Alkylbenzene
C_9H_{12}, Alkylbenzene (6)
Trimethylbenzene
2-Methylstyrene
1,1-Dimethylethylbenzene
1-Methyl-4-(1-methylethyl)-benzene
(1-Methylethenyl)benzene
2-Propenyl-benzene
$C_{10}H_{14}$, Alkylbenzene (5)
C_4-Alkylbenzenes
1,3-Diethylbenzene
1,4-Diethylbenzene
Dimethylstyrene
1-Ethenyl-3-ethylbenzene
1-Ethenyl-4-ethylbenzene
1-Methyl-2-propyl-benzene
1-Methyl-3-propyl-benzene
1-Methyl-4-propyl-benzene
Diethylbenzene
iso-Butylbenzene
sec-Butylbenzene
1-Methylpropylbenzene
Dimethylstyrene
1-Propyl-4-isopropylbenzene
2-Ethyl-1,3-dimethyl-benzene
2-Ethyl-1,4-dimethyl-benzene
3-Ethyl-1,2-dimethyl-benzene
4-Ethyl-1,2-dimethyl-benzene
1-Ethyl-2,4-dimethyl-benzene
1-Ethyl-3,5-dimethylbenzene
1,2,3,5-Tetramethyl-benzene
1,2,3,4-Tetramethyl-benzene
2,3-Dihydro-2-methyl-14-indene
n-Pentylbenzene
C_5-Alkylbenzene
Indan
Methylindan
Dimethylindan
Dimethylhydroindene
Naphtalene
Tetralin
Decahydronaphtalene
Tetrahydronaphtalene
1-Methylnaphtalene
2-Methylnaphtalene
$C_{11}H_{16}$ Alkylbenzene (2)
$C_{14}H_{22}$ Alkylbenzene
Biphenyl
Methyldiphenyl
Methylfluorene

TERPENES

α-pinene
ß-pinene
Δ^3-carene
Limonene
4(10)-Thujene
Myrene
Ocimene
Camphene
Terpene

HETEROCYCLES

Furan
Methyl furan
Tetrahydrofuran
2-Methyl-1,3-dioxane
p-Dioxane

MISCELLANEOUS

Acetic acid
2-Epoxy-4-methylpentane
Hexamethylcyclotrisiloxane
Octamethyl-cyclo-tetrasiloxane
Siloxane
Carbonyl sulphide
Carbon disulphide
Tetramethylsilane
Diphenyl ether
Sulfurdioxide
Camphor

Footnote: The list of compounds was prepared by I Johansson of the National Institute of Environmental Medicine, Stockholm, Sweden, by compilations from Berglund, Berglund, Lindvall & Nicander-Bredberg (1982), Berglund, Johansson & Lindvall (1982), De Bortoli, Knöppel, Pecchio, Peil, Rogora, Schauenburg, Schlitt & Vissers (1985), Jarke, Dravnieks & Gordon (1981), Johansson (1978), Mølhave (1982), Mølhave, Andersen, Lundqvist, Nielsen & Nielsen (1982), and Wallace, Pellizzari, Hartwell, Rosenzweig, Erickson, Sparacino & Zelon (1984).

My organization **has/has not** measured VOC concentrations in indoor air.

VOC SURVEY

(Please photocopy form and use one copy per compound per building)

Measurement made by: (your organization)

Date of measurement:

Building type:

Measurement in response to occupant complaint: **YES/NO**
(cross out if not applicable)

Air sampling method: (e.g. type of adsorbent, passive/active sampling etc.)

Sample period:

Measurement method: (e.g. GC/FID, GC/MS, reactive species)

Measurement:

compound	concentration	(units)
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

[If you have any comments on any of the above please make them on the back of this form]

Organizations Surveyed

Victoria

Dept. of Community Services and Health (Vic Div), Melbourne
Australian Government Analytical Laboratories, Melbourne
Health Dept of Victoria, Melbourne
Ministry of Consumer Affairs, Melbourne
Ministry for Environment and Planning, Melbourne
CSIRO Division of Atmospheric Research, Aspendale
AMDEL Environmental Services, South Melbourne
Telecom Research Laboratory, Clayton
Australian Chamber of Manufacturers, Melbourne
Gas and Fuel Corporation of Victoria, Scientific Services Dept, Highett
Gas and Fuel Corporation of Victoria, Melbourne
ICI Australia, SOHEP, Melbourne
State Electricity Commission of Victoria, Herman Research Lab, Richmond
Swinburne Institute of Technology, Dept of Applied Chemistry, Hawthorn
Dept of Labour, Occupational Health and Safety Div., Melbourne
State Chemistry Laboratory, East Melbourne
The Asthma Foundation of Victoria, Kew
Australian Construction Services, Port Melbourne
AMCOSH, East Melbourne, Victoria
Dept. of Architecture and Building, University of Melbourne, Parkville
National Analytical Laboratories, Ferntree Gully

New South Wales

Australian Government Analytical Laboratories, Pymble
Biological and Chemical Research Institute, Rydalmere
Public Health Dept., University of Sydney, Sydney
Dept. of Community Services and Health (NSW State Office), Sydney
Dept. of Environment and Planning, Sydney
Health Dept. of NSW, Sydney
Australian Gas Light Company, North Sydney
University of Newcastle, Faculty of Medicine, Occupational and Environmental Health, Newcastle
State Pollution Control Commission, Bankstown
Worksafe Australia, Forest Lodge
National Institute of Occupational Health and Safety, Sydney
Building Owners and Managers Association, Sydney
CSIRO Division of Coal Technology, North Ryde
Occupational Health, Safety and Rehabilitation Council of NSW, Division of Occupational Health, Lidcombe
Workers Health Centre, Lidcombe

Queensland

Dept. of Community Services and Health (Qld State Office), Brisbane
Air Pollution Council of Queensland, Brisbane
Queensland Dept. of Health, Environmental and Occupational Health Unit, Archerfield
Government Chemical Laboratory, Archerfield
Queensland Institute of Medical Research, Herston
Queensland Workers Health Centre, South Brisbane
Queensland Dept. of Administrative Services, Healthy Building Environment Task Force, Brisbane

Tasmania

Dept. of the Environment, Battery Point
Government Analytical Laboratory, Kingston
Dept. of Community Services and Health, Hobart
Dept. of Health, Occupational Health and Safety Division, Hobart

South Australia

Dept. of Community Services and Health (SA State Office), Adelaide
SA Health Commission, Public and Environmental Health Division, Adelaide
Government Analytical Laboratory, Seaton
SA Dept. of Labour, Occupational Health Division, Adelaide
Dept. of Environment and Planning, Adelaide
University of Adelaide, Dept. of Community Medicine, Adelaide

Western Australia

Environment Protection Authority, Perth
Government Analytical Laboratories, Cottesloe
Chemistry Centre, Health Chemistry Laboratory, E. Perth
Dept. of Community Services and Health, Perth
WA Health Dept., Occupational Health, E. Perth
Dept. of Occupational Health, Safety and Welfare, W. Perth
Building Management Authority, W. Perth
Murdoch University, School of Biological and Environmental Science, Murdoch

ACT

ACT Board of Health, Canberra
Dept. of Community Services and Health, Woden
Government Analytical Laboratories, Belconnen
Pollution Control Authority, Canberra
Dept. of Administrative Services, Canberra

Northern Territory

Dept. of Community Services and Health, Darwin
Work Health Authority, Darwin

APPENDIX III

Derivation of averaged concentration distribution of benzene in the indoor air of established dwellings

Country	No. of Meast.	Reported (or estimated[a]) Concentration ($\mu g/m^3$)						
		Maximum	Median	GM	AM	GSD	SD	90 PC
Netherlands	96	53	5	(5)	–	–	–	–
	134	148	7	(7)	–	–	–	–
	89	24	7	(7)	–	–	–	–
Netherlands	20	–	–	(3.3)	6	–	–	–
Germany[b]	230	39	7.8	(5.1)	9.3	–	–	17
Italy	14	204	–	(28)	52	–	–	–
	35	48	2.1	(3.7)	6.7	–	10.7	–
	48	59	–	(8.1)	14.8	–	–	–
	24	15	–	(5.8)	10.6	–	–	–
USA	687	510	16	11.9	28	2.6	–	54
	48	43	10	1.9	9	2.0	–	5
	224	86	15	14.4	18	2.4	–	44
	100	54	6	5.8	9	2.7	–	21
	65	163	13	11.6	18	2.6	–	39
	80	98	6	7.1	10	2.3	–	21
	137	32	5	5.7	7	2.3	–	17
	140	129	12	10.3	18	2.4	–	32
	2171	AMC = 71		WAGM=8.4	WAAM=18			

$$90\ PC = \log_e^{-1} (\log_e 8.4 + 1.41) = 34$$

$$98\ PC = \log_e^{-1} (\log_e 8.4 + 2.25) = 80$$

a estimated data are in brackets
b may underestimate concentration since a static passive sampler was used

APPENDIX IV

Derived concentrations of VOCs in the indoor air of different types of buildings

Compound	B.Pt. °C	Building		Derived Concentrations (µg/m^3)						Comments
		type	no.	no. of meast	AMC	Median	WAGM	WAAM	90 PC	
Acetaldehyde	20	S	1	11	–	–	2	5	9	bioeffluent
Acetic acid	118	S	1	5	–	–	12	22	50	bioeffluent
Acetone	57	D	32	86	99	–	32	60	131	
		O	2	20	–	–	11	23	44	
		O (new)	1	4	–	–	13	24	54	
		O (compl)	2	22	–	–	29	53	117	
		S	3	19	–	–	20	42	83	
		S (compl)	1	4	–	–	16	30	67	
Allyl alcohol	96	S	1	7	–	–	3	6	13	bioeffluent
i-Amyl alcohol	132	D	230	230	10	< 1	0.6	1	2	
		S	1	10	–	–	11	21	45	bioeffluent
Benzene	80	D	1388	2171	71	11	8.4	18	34	
		O	11	82	8	3.6	3.6	7.5	15	
		O (new)	4	62	14	4.7	2.5	5.0	10	
		O (compl)	11	93	16	–	2.1	7.2	9	
		S	4	42	16	9.5	3.1	6.2	13	
		S (new)	1	4	–	–	4.9	9.0	20	
		H	5	106	28	10	2.8	6.8	12	
		H (new)	1	18	–	–	1.1	2	5	
Bromodichloromethane	90	D	20	20	9	0.06	0.06	–	0.2	
Butanal	104	D	14	14	34	–	1.5	2.7	6	
n Butanol	118	D	248	302	25	–	0.7	2.5	3	
		MD	44	44	79	–	8.4	15	34	
		S	2	80	–	–	0.9	1.7	4	
		S (new)	1	40	–	–	7.1	13	29	
i-Butanol	106	D	230	230	20	2	1.6	3	7	
n-Butyl acetate	127	D	230	230	125	3.1	3.3	6.1	10	
		D (new)	46	46	–	–	1.8	3.3	7	
		O	4	56	–	–	3.2	7.0	13	
		O (new)	12	29	–	–	0.2	1.2	0.9	
		O (compl)	1	10	–	–	26	48	108	
		S	1	18	–	–	0.8	1.5	3	
		H	3	90	–	–	0.1	0.3	0.4	
		H (new)	1	18	–	–	<0.1	<0.2	<0.5	
Butyl acrylate	146	O (compl)	1	na	47	–	–	–	–	
n-Butyl benzene	183	D	339	339	29	0.9	0.9	–	4	
		O	1	132	1.7	–	–	–	–	

Appendix IV continued

Compound	B.Pt. °C	Building		Derived Concentrations (µg/m³)						Comments
		type	no.	no. of meast	AMC	Median	WAGM	WAAM	90 PC	
Butyric acid	164	S	1	5	–	–	25	47	104	bioeffluent
Camphene	158	MD	44	44	–	–	14	25	55	
		O	1	132	274	–	–	–	< 1.4	
Carbon tetrachloride	77	D	1046	1689	1.4	1.5	1.8	5.9	8	
		O	2	38	9	0.8	0.2	0.5	0.7	
		O (new)	2	40	3.1	0.5	0.4	0.7	1.5	
		S	1	34	2.6	0.7	0.1	0.3	0.6	
		H	2	88	2.4	1.0	0.2	0.7	0.8	
δ^3 Carene	167	O	1	132	1.6	–	–	–	–	
Chlorobenzene	132	D	450	504	0.4	0.6	0.2	4.0	0.7	
		O	1	20	1.4	–	0.1	0.2	0.5	
		O (new)	2	40	0.7	–	0.1	0.2	0.4	
		S	1	20	1.2	0.1	0.1	0.2	0.4	
Chloroform	61	D	672	1315	6.4	3	2	6	8	
		O	1	20	17	13	10	18	40	
		O (new)	4	60	110	1	0.6	1	3	
		S	1	16	4	0.03	0.07	0.1	0.3	
		H	2	52	0.5	2	1	2	4	
Cyclohexane	81	D	549	549	4	4	2	7	8	
		O (new)	1	6	49	2	4	–	9	
n-Decane	174	D	852	1085	6	–	5	10	20	
		D (new)	7	7	472	–	388	710	1590	factory-built
		O	4	188	–	4	3	7	12	
		O (new)	4	62	24	–	75	262	308	
		S	2	34	56	–	1	4	5	
		H	5	142	2	–	3	9	11	
		H (new)	1	18	35	–	37	68	153	
o-Dichlorobenzene	181	D	299	548	–	–	0.3	0.6	1	
		MD	44	44	45	–	0.3	0.6	1	
m-Dichlorobenzene	172	D	339	339	1	–	0.3	–	1	
		MD	44	44	7	–	0.9	2	4	
p-Dichlorobenzene	174	D	1256	1881	8	–	8	29	32	
		O	2	38	159	–	0.4	1	2	
		O (new)	4	78	(1)	–	0.5	1	2	
		S	1	16	4	2	1	2	4	
		S (new)	1	4	6	–	3	6	14	
		H	4	88	9	–	0.9	3	4	
		H (new)	1	18	6	–	1	–	5	
1,2-Dichloroethane	84	D	291	524	–	17	–	0.1	0.3	0.5
		O	2	36	–	–	0.4	0.3	2	
		O (new)	1	18	–	–	0.1	< 0.2	0.2	
		S	1	18	–	–	0.1	<0.2	0.2	
		H	3	54			0.2	0.7	0.6	
		H (new)	1	18	–	–	0.1	< 0.2	0.2	

Appendix IV continued

Compound	B.Pt. °C	Building		Derived Concentrations (µg/m^3)						Comments
		type	no.	no. of meast	AMC	Median	WAGM	WAAM	90 PC	
1,1-Dichloroethylene	32	D	18	72	32	–	4	7	15	
1,2-Dichloroethylene	cis 60 trans48	D	35	35	140	17	11	21	47	poor sample
Dichloromethane (Methylene chloride)	41	D	41	101	172	–	17	115	70	
		O	6	6	4	–	2	18	7	
		O (new)	1	12	32	–	7	13	29	photocopier
1,2-Dichloropropane	95	D	47	47	10	–	0.02	–	0.06	
Diethylamine	56	O (compl)	1	n.a.	75	–	–	–	< 75	
1,2-Diethylbenzene	184	O	1	132	4	–	–	–	< 4	
1,3-Diethylbenzene	182	O	1	132	0.5	–	–	–	–	
Diethylether	34	D	6	24	2	–	0.2	0.4	0.9	
Diethyl ketone (3-Pentanone)	102	S	1	12	–	–	6	13	26	bioeffluent
Dimethylacetamide	165	O (compl)	1	n.a.	4600	–	–	–	<4600	
1,4-Dimethyl cyclohexane	120-5	O (new)	1	3	–	–	2	3	7	photocopier
Dimethyl cyclopentane isomers	88-99	D	319	319	26	–	0.2	–	0.6	
1,4-Dioxane	102	D	233	466	–	–	0.3	0.7	1	
		O	2	20	–	–	< 0.02	< 0.02	–	
		O (compl)	1	10	–	–	11	20	45	
n-Dodecane	216	D	817	1050	81	–	2	4	8	
		O	4	188	10	–	2	6	9	
		O (new)	4	70	98	–	30	73	122	
		S	2	34	1	–	1	1	3	
		H	5	106	9	–	0.4	3	2	
		H (new)	1	18	–	–	17	31	69	
Ethanol	79	D	39	39	–	–	120	220	490	
		O	2	20	–	–	0.2	6	0.8	poor sample
		O (compl)	1	10	–	–	2	3	7	poor sample
		S	3	19	–	–	34	64	141	poor sample
2-Ethoxyethyl acetate (Cellosolve acetate)	156	O	2	36	–	–	1	2	4	
		O (new)	1	18	–	–	0.1	< 0.2	0.2	
		S	1	18	–	–	0.1	< 0.2	0.2	
		H	4	72	–	–	0.1	0.4	0.4	
		H (new)	1	18	–	–	5	10	21	
Ethyl acetate	77	D	248	302	109	–	8	23	31	poor sample
		O	4	26	60	–	0.4	11	2	poor sample
		O (compl)	1	10	–	–	2	3	8	poor sample
		S	1	12	–	–	10	21	42	bioeffluent

Appendix IV continued

Compound	B.Pt. ℃	Building		Derived Concentrations (μg/m^3)						Comments
		type	no.	no. of meast	AMC	Median	WAGM	WAAM	90 PC	
Ethyl benzene	136	D	1225	1867	57	–	5	13	22	
		O	12	214	1	–	5	5	21	
		O (new)	5	74	25	–	13	39	53	
		O (compl)	1	10	–	–	9	17	39	
		S	2	34	14	–	2	3	7	
		S (new)	1	4	4	–	2	4	8	
		H	7	142	10	–	1	3	5	
		H (new)	1	18	–	–	4	8	18	
Ethylene dibromide	110-31	D	35	35	24	4	3	6	14	poor sample
Ethylene oxide	13-14	H	2	n.a.	770,000	147,000	147,000	–	600,000	location?
2-Ethyl-l-hexanol	185	D	230	230	10	< 1	1	2	3	poor sample
n-Heptane	98	D	584	584	93	–	3	7	13	
		O	3	152	–	–	3	10	11	
		O (new)	1	12	13	–	3	6	14	
		O (compl)	11	93	194	–	1	–	6	
		S (new)	1	4	8	–	3	5	11	
1-Heptene	94	O	1	132	16	–	–	–	–	
n-Hexadecane	287	D	319	319	2	–	0.4	–	2	
		O	1	132	3	–	–	–	–	
Hexanal	128	D	245	245	24	–	1	2	5	poor sample
n-Hexane	50	D	602	656	111	–	5	13	19	
		O	8	26	66	–	12	39	47	
		O (new)	2	14	24	–	6	12	23	
		O (compl)	11	93	1730	–	4	–	17	
		S (new)	1	4	5	–	2	4	9	
Lactic acid	119	O (compl)	1	n.a.	2	–	–	–	<2	
Limonene	178	D	584	584	445	–	21	31	85	
		MD	44	44	162	–	7	12	27	
		O	1	132	84	–	–	–	–	
Methanol	65	S	1	11	–	–	29	55	118	bioeffluent
2-Methyl butane	28	O (new)	1	12	> 82	–	–	–	–	photocopier
Methylcyclohexane	100	D	549	549	81	–	2	–	7	
		O	2	20	–	–	< 0.01	< 0.02	–	
		O (new)	6	1	5	–	2	3	8	photocopier
		O (compl)	10	1	–	–	4	7	16	
		S (new)	2	1	–	–	1	1	3	
Methylcyclopentane	72	D	230	230	15	2	2	3	5	poor sample
		O	2	20	–	–	< 0.01	< 0.02	–	poor sample
		O (compl)	1	10	–	–	< 0.01	< 0.02	–	poor sample
o,m,p-Methylethyl benzene	162-5	D	569	569	310	–	3	13	14	
		O	1	132	44	–	–	–	–	

Appendix IV continued

Compound	B.Pt. ℃	Building		Derived Concentrations (μg/m^3)						Comments
		type	no.	no. of meast	AMC	Median	WAGM	WAAM	90 PC	
o-Methylethyl benzene	165	D	250	250	103	–	2	4	10	
		O	3	152	1	–	0.4	1	2	
		O (compl)	1	10	–	–	<0.01	< 0.02	–	
m-Methylethyl benzene	161	D	20	20	–	–	2	3	7	
		O	3	168	26	–	8	6	33	
		O (new)	1	18	–	–	15	27	61	
		S	1	18	–	–	1	3	6	
		H	3	90	–	–	1	1	3	
		H (new)	1	18	–	–	7	12	28	
p-Methylethyl benzene	162	D	55	55	25	–	1	2	5	
		O	1	132	18	–	–	–	–	car pollution
Methylethyl ketone (2-Butanone)	80	D	262	316	29	5	4.0	7.7	16	
		O (new)	2	16	51	–	12	23	48	
2–Methyl hexane	90	D	319	319	66	–	2	–	9	
3–Methyl hexane	92	D	319	319	52	–	2	–	7	
		O (new)	2	14	–	–	3	6	13	
		S (new)	1	4	–	–	2	3	7	
1-Methyl naphthalene	240	D	339	339	1	–	0.2	–	0.6	
3-Methyl pentane	63	D	319	319	76	–	3	–	11	
		O	2	20	–	–	3	10	12	poor sample
		O (compl)	1	10	–	–	21	38	84	poor sample
4-Methyl-1-pentanone	–	O	2	20	–	–	0.4	1	2	
		O (compl)	1	10	–	–	15	28	62	
4-Methyl-2-pentanone (Methyl isobutyl ketone)	117	D	230	230	12	<1	0.6	1	2	poor sample
4-Methyl-1-pentanol	148	O	2	20	–	–	<0.01	< 0.02	–	
		O (compl)	1	10	–	–	10	18	41	
1-Methyl-4-i-propyl benzene (p-Cymene)	177	D	339	339	15	–	0.7	–	3	
		O	1	132	5	–	–	–	–	
Myrcene	165-8	O	1	132	76	–	–	–	–	
Naphthalene	218	D	602	656	24	–	0.6	4	2	
		MD	44	44	62	–	5	9	21	
Nicotine	247	O	2	36	0.2	–	0.4	2	2	non smoking
		O	1	10	3	–	0.2	0.3	0.8	segregated smoking
		O	57	244	17	–	0.5	1	2	smoking
N-Nitrosodiethyl amine	177	O	4	8	0.03	–	0.006	0.01	0.02	smoking
N-Nitrosodimethyl amine	151	O	12	16	0.04	–	0.02	0.03	0.07	with & without smoking

Appendix IV continued

Compound	B.Pt. °C	Building		Derived Concentrations (µg/m³)						Comments
		type	no.	no. of meast	AMC	Median	WAGM	WAAM	90 PC	
N-Nitrosopyrrolidine	–	O	8	8	0.04	–	0.01	–	0.04	with & without smoking
Nonanal	185	D	15	15	82	–	7	12	27	
		MD	44	44	43	–	7	13	30	
n-Nonane	151	D	586	592	219	–	5	10	19	photocopier
		O	1	132	25	–	–	–	–	
		O (new)	1	12	150	–	32	58	131	
1-Nonene	146	O	1	132	0.2		–	–	–	car pollution
n-Octane	126	D	817	1050	86	–	2	5	8	
		O	1	132	4	–	–	–	–	
1-Octene	121	O	1	132	2	–	–	–	–	
n-Pentadecane	271	D	339	339	4	–	1	–	5	
n-Pentane	36	O (new)	1	4	4	–	1.5	3	6	
		S (new)	1	4	12	–	5	9	20	bioeffluent
Phenol	182	S	1	5	–	–	9	16	36	
α-Pinene	156	D	524	757	242	–	4	30	16	
		D (new)	7	7	–	–	262	480	1070	factory-built
		MD	44	44	76	–	7	13	28	
		O	3	168	11	–	2	7	9	
		O (new)	1	18	–	–	8	14	32	
		S	1	18	–	–	2	3	6	
		S (new)	1	4	34	–	13	23	52	
		H	3	90	–	–	< 0.1	< 0.2	–	
		H (new)	1	18	–	–	3	5	12	poor sample
β-Pinene	165	D	245	245	34	–	1	2	3	
		O	1	132	1	–	–	–	–	
2-Propanol	82	D (new)	7	7	–	–	902	1650	3690	factory-built
		O	2	20	–	–	0.08	1	0.3	poor sample
		O (new)	1	12	137	–	27	50	111	photocopier
		O (compl)	1	10	–	–	0.006	0.01	0.02	poor sample
		S (compl)	1	4	73	–	26	48	107	
n,i-Propyl benzene	159-165	D	569	569	37	–	1	4	5	
		O	3	168	2	–	1	2	4	
		O (new)	1	18	–	–	5	9	20	
		S	1	18	–	–	1	1	2	
		H	3	54	–	–	0.1	< 0.2	0.5	
		H (new)	1	18	–	–	3	5	11	
Pyruvic Acid (2-oxo-propionic acid)	115	O (compl)	1	n.a.	6	–	–	–	–	
Styrene	146	D	856	1483	8	–	2	5	9	
		MD	44	44	35	–	2	3	7	
		O	3	56	8	–	2	3	6	
		O (new)	3	58	17	–	3	6	13	
		S	2	34	6	–	0.8	2	3	
		H	4	88	7	–	0.7	1	3	
		H (new)	1	18	–	–	2	3	7	

Appendix IV continued

Compound	B.Pt. ℃	Building		Derived Concentrations (µg/m^3)						Comments
		type	no.	no. of meast	AMC	Median	WAGM	WAAM	90 PC	
Terpinene	173-183	D	230	230	37	3	2	4	9	poor sample
Tetrachloroethylene (Perchloroethylene)	121	D	1276	1919	64	–	7	27	28	
		MD	44	44	105	–	3	6	14	
		O	11	82	48	–	4	7	16	
		O (new)	3	58	9	–	0.7	3	3	
		O (compl)	11	93	1250	–	2	–	8	
		S	2	34	18	–	3	5	11	
		H	5	106	39	–	2	4	6	
		H (new)	1	18	–	–	0.6	1	2	
Tetradecane	253	D	339	339	14	–	2	–	7	
		MD	44	44	56	–	3	5	12	
		O (new)	1	9	245	–	56	103	230	photocopier
1,2,3,5-Tetra methylbenzene	196	O	1	132	2	–	–	–	–	
1,2,4,5-Tetra methylbenzene	196	O	1	132	3	–	–	–	–	
Toluene	111	D	712	792	322	–	37	72	151	
		D (new)	46	46	–	–	3	5	12	
		MD	44	44	39	–	5	9	20	
		O	9	158	54	–	18	35	75	
		O (new)	14	27	33	–	10	34	42	
		O (compl)	11	93	280	–	13	–	53	
		S	4	88	–	–	3	8	12	
		S (new)	18	60	–	–	8	15	32	
123) 124)Trichlorobenzene 135)	208-219	D	374	374	39	–	0.5	–	2	
1,1,1-Trichloroethane (Methyl chloroform)	74	D	937	1580	102	–	24	66	96	
		O	11	82	50	–	18	36	75	
		O (new)	5	57	91	–	59	178	241	
		O (compl)	11	93	3670	–	13	–	53	
		S	2	34	120	–	8	16	34	
		H	5	142	175	–	5	13	20	
		H (new)	1	18	–	–	2	4	9	
Trichloroethylene	87	D	1276	1919	16	–	3	10	13	
		O	11	82	49	–	4	12	17	
		O (new)	5	72	26	–	2	15	7	
		O (compl)	1	10	–	–	47	87	194	
		S	2	34	–	–	2	6	7	
		H	4	88	2	–	0.3	0.6	1	
		H (new)	1	18	–	–	2	3	7	
n-Tridecane	243	D	584	584	27	–	2	6	8	
		O (new)	1	9	112	–	23	42	94	photocopier?
1,2,3-Trimethylbenzene	176	D	569	569	34	–	0.4	3	2	
		O	3	152	70	–	9	31	36	
		O (compl)	1	10	–	–	0.006	0.01	0.02	

Appendix IV continued

Compound	B.Pt. ℃	Building		Derived Concentrations (µg/m^3)						Comments
		type	no.	no. of meast	AMC	Median	WAGM	WAAM	90 PC	
1,2,4-Trimethylbenzene	170	D	619	619	193	–	6	12	23	
		O	3	168	65	–	13	27	52	
		O (new)	1	18	–	–	40	74	164	
		S	1	18	–	–	2	3	6	
		H	3	90	–	–	0.8	2	3	
		H (new)	1	18	–	–	8	14	32	
1,3,5-Trimethylbenzene	165	D	265	265	81	–	2	4	9	
		O (new)	1	3	–	–	2	4	9	photocopier
2,2,5-Trimethylhexane	124	O (new)	1	3	–	–	1	2	5	photocopier
2,2,4-Trimethylpentane	99	O (new)	1	12	> 8	–	2	4	9	photocopier
n-Undecane	195	D	835	1122	218	–	4	11	17	
		MD	44	44	41	–	2	4	10	
		O	4	188	9	–	1	6	5	
		O (new)	5	74	168	–	62	110	250	
		S	4	42	–	–	1	4	6	
		H	5	142	29	–	1	8	6	
		H (new)	1	18	–	–	37	69	153	
o-Xylene	144	D	891	1518	49	–	6	12	25	
		D (new)	46	46	–	–	7	14	30	
		MD	44	44	110	–	5	9	20	
		O	10	178	10	–	8	18	32	
		O (new)	15	67	36	–	10	30	42	
		O (compl)	1	10	–	–	9	17	38	
		S	1	16	15	5	3	5	11	
		S (new)	17	28	–	–	4	8	17	
		H	2	51	–	–	2	4	9	
m,p-Xylene	138-139	D	945	1587	120	–	18	37	73	
		D (new)	7	7	–	–	284	520	1160	factory-built
		MD	44	44	340	–	20	36	81	
		O	2	152	20	–	7	12	28	
		O (new)	4	53	68	–	25	67	101	
		O (compl)	10	83	20	5	5	–	10	
		S	1	16	35	8	6	10	22	
		S (new)	1	4	–	–	9	16	36	
		H	2	52	25	–	6	11	24	
o,m,p-Xylene	138 -144	D	319	319	208	–	10	–	43	
		S	2	8	–	–	7	12	27	
		O (compl)	1	n.a.	2040	–	–	–	–	
TVOC		D	1081	2478	3160	–	1130	2330	4630	
		D (new)	33	33	18100	–	4500	9300	18400	
		D (compl)	14	28	2800	–	520	950	2130	
		O	60	384	1080	–	180	320	740	
		O (new)	1	100	–	–	4150	7600	17000	
		O (compl)	51	331	4040	–	490	1580	2000	
		S	21	27	530	–	70	200	290	
		S (new)	n.a.	n.a.	860	–	240	430	960	
		S (compl)	9	56	1780	–	480	1510	1970	
		H	2	8	1300		410	750	1680	
		H (compl)	6	51	98000	–	2080	3800	8500	

n.a. = not available

APPENDIX V

Source emission characteristics for individual compounds

Compound	Indoor Air Source		Reference
	description	emission data	
ethanol	* bioeffluent	3080 µg/person.h	Wang (1975)
	* using detergents	air conc ~ 200 µg/m^3	Wooley *et al.* (1990)
toluene	* cigarette smoke	smoke conc 160–1200 µg/m^3	IARC (1985)
	* printed paper	150–400 µg/kg.h	Le Bret *et al.* (1984)
	* bioeffluent	420 µg/person.h	Wang (1975)
	* paint, lacquer, water based adhesive	150–750 µg/m^2.h	White *et al.* (1988)
	* floor tile adhesive	4.2 x 10^6 µg/m^2.h	Bayer & Black (1989)
	* vinyl flooring	60–70 µg/m^2.h	van der Wal *et al.* (1990)
	* drapery	136 µg/m^2.h	Bayer *et al.* (1990)
	* rubber backed nylon carpet	110 µg/m^2.h	Wolkoff *et al.* (1990)
methanol	* bioeffluent	2500 µg/person.h	Wang (1975)
acetone	* cigarette smoke	smoke conc 100-1250 mg/m^3	IARC (1985)
	* bioeffluent	2800 µg/person.h	Wang (1975)
	* rubber backed nylon carpet	30 µg/m^2.h	Wolkoff *et al.* (1990)
	* drapery	364 µg/m^2.h	Bayer *et al.* (1990)
	* aged particleboard	29-47 µg/m^2.h	Nelms *et al.* (1986)
butyric acid	* bioeffluent	1900 µg/person.h	Wang (1975)
1,1,1-trichloroethane	* using cleaning agents/ aerosol spot removers	short term room conc. up to 1.4 x 10^6 µg/m^3	Fishbein (1985)
	* using liquid cleaner/ spray insecticide	2200 µg/m^2.h	Wallace *et al.* (1987b)
	* rubber floor covering	87 µg/m^2.h	Wolkoff *et al.* (1990)
MEK	* aged particleboard	2–4 µg/m^2.h	Nelms *et al.* (1986)
	* caulks, coatings	major component	Tichenor & Mason (1988)
limonene	* household products	major component	Tichenor & Mason (1988)
	* particleboard/plywood	major component	Monteith *et al.* (1984)
	* adhesive	190 µg/m^2.h	White *et al.* (1988)
	* carpet, painted gypsum-board	12–14 µg/m^2.h	Wolkoff *et al.* (1990)
ethyl acetate	* bioeffluent	720 µg/person.h	Wang (1975)
	* drapery	54 µg/m^2.h	Bayer *et al.* (1990)

Appendix V continued

Compound	Indoor Air Source		Reference
	description	emission data	
	* floor tile adhesives	31,000 $\mu g/m^2.h$	Bayer & Black (1989)
n-nonane	* adhesive	250 $\mu g/m^2.h$	White *et al.* (1988)
	* 42 building materials	frequently present	Molhave (1982)
	* household products	major component	Tichenor & Mason (1988)
p-dichlorobenzene	* moth crystals	1.4×10^6 $\mu g/m^2.h$	Sparks *et al.* (1990)
	* room deodorizers	occupant exposure 28-500 $\mu g/m^3$	Wallace *et al.* (1989)
1,2/1,4-methyethyl benzene	* new vinyl flooring	1200–1300 $\mu g/m^2.h$	van der Wal *et al.* (1990)
tetrachloroethylene	*dry cleaned clothing	R_o = 27,000 $\mu g/m^2.h$	Sparks *et al.* (1990)
	– different fabrics	R_o = 56 – 6,700 $\mu g/m^2.h$	Tichenor *et al.* (1988)
	* use of shower	air conc up to 80,000 $\mu g/m^3$ in simulation	McKone (1987)
diethyl ketone	* bioeffluent	640 µg/person.h	Wang (1975)
ethylbenzene	* furniture polish	major component	Tichenor & Mason (1988)
	* floor wax	major component	Gebefuegi *et al.* (1990)
	* 42 building products	frequently present	Molhave (1982)
	* new vinyl flooring	40–90 $\mu g/m^2.h$	van der Wal *et al.* (1990)
	new polystyrene foam	15–190 $\mu g/m^2.h$	
	* 7 day old glued carpet	5 $\mu g/m^2.h$	Wallace *et al.* (1987b)
	* floor tile adhesive	21,000 $\mu g/m^2.h$	Bayer & Black (1989)
n-decane	* wax, cleaner, room freshener	major component	Tichenor & Mason (1988) Gebefuegi *et al.* (1990)
	* wet process photocopier exhaust	major component	Tsuchiya *et al.* (1990)
	* 42 building products	frequently present	Molhave (1982)
	* new vinyl flooring	3900–9700 $\mu g/m^2.h$ (C_8-C_{13} n-alkanes)	van der Wal *et al.* (1990)
	* 7 day old glued carpet	33 $\mu g/m^2.h$	Wallace *et al.* (1987b)
	7 day old painted gypsum-board	15 $\mu g/m^2.h$	
xylenes	* caulking compounds	10– 24,000 $\mu g/m^2.h$	
	adhesives	<10–67,000 $\mu g/m^2.h$	White *et al.* (1988)
	lacquers	110–530 $\mu g/m^2.h$	

Appendix V continued

Compound	Indoor Air Source		Reference
	description	emission data	
	* vinyl flooring	240–625 $\mu g/m^2.h$	van der Wal *et al.* (1990)
	* 7 day old glued carpet	6–9 $\mu g/m^2.h$	Wallace *et al.* (1987b)
dichloromethane	* household solvent products	present in 34% of products	Maklan *et al.* (1987)
	* paint stripper/spray propellant	major component	Fishbein (1985)
	* drapery	95–109 $\mu g/m^2.h$	Bayer *et al.* (1990)
acetic acid	* cigarette smoke	smoke conc. 330–3200 $\mu g/m^3$	IARC (1985)
	* bioeffluent	1170 µg/person.h	Wang (1975)
	* silicone sealant	major component	–
n-hexane	* car exhaust/petrol vapors	–	Hodgson *et al.* (1989)
			Girman *et al.* (1987)
	* 42 building materials	major component	Molhave (1982)
chloroform	* shower & domestic use of tap water	up to 2×10^5 $\mu g/m^3$ in shower air	Andelman *et al.* (1987)
	* drapery	42–96 $\mu g/m^2.h$	Bayer *et al.* (1990)
	* using liquid cleaner/spray insecticide	900 $\mu g/m^2.h$	Wallace *et al.* (1987b)
phenol	* bioeffluent	300 µg/person.h	Wang (1975)
trimethylbenzenes	* adhesives	120 $\mu g/m^2.h$	White *et al.* (1988)
	* 42 building materials	frequently present	Molhave (1982)
benzene	* cigarette smoke	smoke conc. 12–480 $\mu g/m^3$	IARC (1985)
	* petrol fumes	petrol contains 1–2% benzene in US (& up to 5% in Aust.)	Wallace (1991)
	* drapery	45–112 $\mu g/m^2.h$	Bayer *et al.* (1990)
	* aged particleboard	3–8 $\mu g/m^2.h$	Nelms *et al.* (1986)
	* painted gypsumboard	7 $\mu g/m^2.h$	Wallace *et al.* (1987b)
	* floor tile adhesive	62,000 $\mu g/m^2.h$	Bayer & Black (1989)
	* products tested by NASA	present in 400/5000	Wallace (1989)

APPENDIX VI

References to measurement of pesticides concentrations in indoor air

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APPENDIX VII

Comments on draft report received by NHMRC

The air quality secretariat of the NHMRC circulated the draft report of 'Progress Towards National Indoor Air Quality Goals for Volatile Organic Compounds' (submitted 31 May 1991) to a large number of persons and organizations with expertise in this field. Comments were received from the following:

1. Dr K.S. Baden, Engineering & Environmental Consultant, NSW.
2. C. Broadbent, National Director of Engineering Services, Australian Construction Services.
3. Dr D. Kirke, Executive Director, Public & Environmental Health Division, South Australian Health Commission.
4. Dr D. Lange, Chief Health Officer, Queensland Dept of Health.
5. K.D. Lyall, Research Manager-Environment, The Australian Gas Association.
6. S. McPhail, A/Deputy Manager - Air Investigations, SPCC, NSW.
7. Dr P. Morgan, Assistant Director Environmental Studies, EPA, Victoria.
8. Dr M. Pain, Director of Thoracic Medicine, The Royal Melbourne Hospital.
9. J. Robertson, Managing Director, Healthy Buildings International, NSW.
10. Dr J. Sparrow, Chief Medical Officer, Dept of Health, Tasmania.
11. Dr J. Streeton, Consulting Respiratory Physician, Melbourne, Victoria.
12. Dr A. Woolcock, Prof. of Respiratory Medicine, University of Sydney.

The draft report was revised in light of these comments to produce this final report. Generally most commentors supported the draft report with little or no amendments. One recommended adoption of interim goals for benzene, dichloromethane, toluene and tetrachloroethylene on the basis that they had been found to be significantly elevated indoors by overseas studies and (ambient) goals had been established by reputable overseas organizations (eg WHO). However these same arguments apply to many VOCs (see Table 11) and no new scientific data was presented to justify the setting of interim goals for these specific VOCs. Also, benzene was specifically selected for more detailed discussion in the report (Section 7.4) because it was the only IARC Class I carcinogen in the major compounds.

One organisation provided raw data for VOC concentrations in office buildings in Australia, measured largely after the VOC Working Party had produced the draft report (ie mid to late 1991). Measurement was by Tenax sampling and GC/MS analysis and conformed to USEPA

Method IP-1B 'Determination of volatile organic compounds (VOCs) in indoor air using solid adsorbent tubes'. Sixty seven measurements of 25 VOCs were made in 18 office buildings. Characteristics of the buildings (eg age, ventilation system, construction, incidence of occupant complaints) were not provided. These measurements are summarised in the following table and were compared to VOC concentrations derived for established office buildings overseas (Appendix IV). Within the constraints of the unknown nature of the buildings surveyed and the limited number of buildings in both populations, the VOC concentrations in Australian office buildings were generally of similar magnitude to those overseas. Exceptions were chloroform and trichloroethylene which were significantly lower in the Australian measurements. It is considered that this data does not provide an adequate characterization of VOC levels in Australian office buildings (as required in Recommendation 2) due to the constraints outlined above.

VOC Concentrations in 18 Australian office buildings

Compound	Detection Limit ($\mu g/m^3$)	Percent Below Detection	Concentration ($\mu g/m^3$)		Derived WAGM in App. IV ($\mu g/m^3$)
			median	maximum	
Benzene	1.3	1	6	20	4
Methylethylketone	2.5	55	1	60	4
Carbon tetrachloride	1.3	87	<1	3	0.2
Chlorobenzene	1.3	99	<1	2	0.1
Chloroethane	2.5	100	<2.5	<2.5	-
Chloroform	1.3	96	<1	2	10
Chloromethane[a]	2.5	100	<2.5	<2.5	-
p-Dichlorobenzene	1.3	78	<1	9	0.4
1,1-Dichloroethane	1.3	100	<1.3	<1.3	-
1,2-Dichloroethane	1.3	100	<1.3	<1.3	0.4
Ethyl benzene	1.3	24	3	17	5
4-Methyl-2-pentanone	2.5	70	<1	43	0.6
Methyl-t-butyl ether	1.3	100	<1.3	<1.3	-
Dichloromethane[a]	1.3	54	1	940[b]	2
Naphthalene	1.3	70	<1	15	0.6
Styrene	1.3	69	<1	11	2
1,1,2,2-Tetrachloroethane	1.3	100	<1.3	<1.3	-
Tetrachloroethylene	1.3	31	2	13	4
Toluene	1.3	1	23	755[b]	18
1,1,2-Trichloroethane	1.3	100	<1.3	<1.3	-
1,1,1-Trichloroethane	1.3	1	16	338[b]	18
Trichloroethylene	1.3	85	<1	310[b]	4
Trichlorofluoromethane[a]	1.3	61	1	42	-
Vinyl Chloride[a]	2.5	100	<2.5	<2.5	-
o,m,p-Xylene	1.3	1	19	68	15

[a] sample volume exceeded retention volume for Tenax for these compounds

[b] next highest concentrations 12 (dichloromethane), 80 (toluene), 336 (1,1,1-trichloroethane), 10 (trichloroethylene)