# Health Hazards of Building Materials

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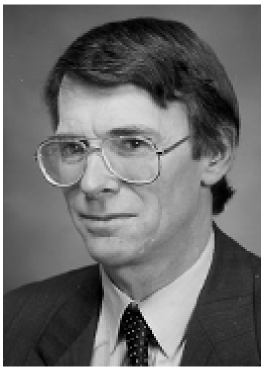

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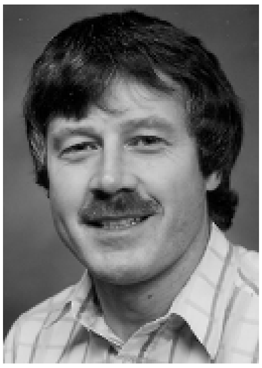

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## Contents

# 1 Introduction

## Problem

There is growing concern about the possible hazards which can result from the use of certain organic building materials. Many paints and preservatives contain chemicals which, in their concentrated forms, are toxic or can cause health hazards. Similarly, a number of plastic materials and insulation compounds have a significant vapour pressure at ambient temperatures, which can result in contamination of the interior air of a building. In some cases the hazards caused are only minor, such as throat irritation or headaches, but some individuals are more susceptible to the effects of the chemicals, and it is desirable to reduce their exposure as much as possible.

Certain of the materials (eg. paints) only present risks during the application process, or when being removed for maintenance. Building operatives need to take precautions when handling these materials, even if they do not cause problems for the eventual occupants of the building.

This report describes the hazards which can occur when dealing with four major classes of potential pollutants: namely paints, timber preservatives, formaldehyde, and Volatile Organic Compounds (VOC). Each of the classes is treated separately, but some of the general conclusions are also applicable to other potentially hazardous materials.

Brief mention is also made of the problems relating to asbestos and cement.

The intention is not to cover fully all health hazards related to building materials, but to initiate a discussion on about the problem in developing countries, in particular when introducing unfamiliar new materials.

## Method

The work is based on the literature and the authors' own research experience. It is desk study and refers to experience from Europe and North America.

## Organization of the report

This report describes the need for precautions to be taken when applying potentially hazardous chemicals. It also identifies some of the common building materials which can be associated with the sick building syndrome.

The following topics are included in the report:

- Health hazards from paints during application
- Health hazards from paints in service
- Health hazards from timber preservatives during application
- Health hazards from formaldehyde
- Sources and control of formaldehyde in building materials
- Health hazards from Volatile Organic Compounds.

Since the authors are specialists on different materials, this report addresses each group of potentially hazardous material separately. The problem and potential health hazards of each material are described in detail in Chapter 2. All the recommendations are summarized in Chapter 3.

# 2 General considerations

## Paints for buildings

Paint is a generic term used to describe an extremely diverse range of coatings applied to decorate and/or protect interior and exterior surfaces of buildings. A strict definition of "paint" implies a product that will completely obliterate the substrate, though often coatings that are semi-transparent or clear are used on buildings; these are known as stains and varnishes. Clear coatings may also be termed lacquers or sealers depending on their function.

Paint coatings can be considered as composed of pigmentary materials finely dispersed in a resinous binder usually blended with some form of solvent to facilitate application. Stains contain only very small amounts of pigments, and clear varnishes none at all, though they still contain resin and solvent. As well as these major constituents, many minor additives may be present to control and modify the properties of the resultant product.

Paints and other types of coatings used on buildings can therefore be considered as complex mixtures of chemicals, some of which can present health hazards to users. Hazards are normally encountered during application, or at the stage when a coating requires removal prior to maintenance operations. Only exceptionally do coatings that have been applied and are firmly adherent to the surface, present a health risk to building users.

### Health hazards during application

Most application of coatings to buildings or building components is performed on-site, generally using brushes or rollers. The main risk to health during application by these methods is associated with indoor application and arises from the evaporation of solvents into the breathing space of the operator and/or building occupants. Other risks include contact by the coating with the skin or eyes.

A high risk comes from those coatings that contain organic solvents. Typically aliphatic hydrocarbons, such as white spirit, form the major solvent of building paints, but specialist coatings may contain combinations of other solvents such as aromatic hydrocarbons, alcohols, ketones, and glycol ethers. Building paints and coatings can contain substantial amounts of organic solvents and are often described as "solvent-borne" paints. The major route of exposure is by inhalation of solvent vapours, and skin contact, typically by splashing during mixing and/or application.

Inhalation exposure to high levels of solvents will result in depression of the central nervous system, and present symptoms such as headache, dizziness and confusion, together with irritation of the eyes and breathing tract. At very high exposure levels unconsciousness may occur. These acute effects of inhalation are reversible on removal from the source of exposure. Recent concerns that exposure to organic solvents can result in permanent effects on the brain (the so-called "chronic painters syndrome") have not been fully substantiated, though clearly it is desirable that exposure to solvents should be reduced whenever possible.

Repeated and prolonged skin contact with solvent-borne coatings will cause defatting of the skin and may lead to dermatitis. Direct eye contact with pure solvents may only cause a mild reversible conjunctival irritation, but predicting the possible hazards from other constitutes of a paint or coating are such that it is essential that strict precautions should be taken to avoid eye contact with these materials.

Alternatives to these high solvent-content coatings are readily available in most countries. Such coatings often contain water rather than organic solvents. Such "water-borne" coatings may still contain small amounts of organic solvents, but levels are greatly reduced in comparison with solvent-borne coatings, and therefore the hazards by inhalation and body contact are lessened, (although still present). It should be noted however, that water-borne coatings can by their nature contain a wider variety of potentially hazardous compounds than solvent-borne coatings. In particular, irritation of mucous membranes can be caused by volatile monomers and ammoniacal compounds which, together with the preservatives and surface active agents in these coatings, can also cause skin irritation leading possibly to sensitization. Some of the specialized glycol ethers added in very small amounts to some water-borne coatings are suspected teratogenic[1] hazards.

In general though, water-borne paints are considered to contribute a much lower health and safety hazard than solvent-borne materials. Nevertheless as with solvent-borne coatings reducing the health hazards from water-borne products requires careful attention to occupational hygiene. In particular by ensuring that all interior work is performed under adequate ventilation, and that skin and eye protection is worn by painters.

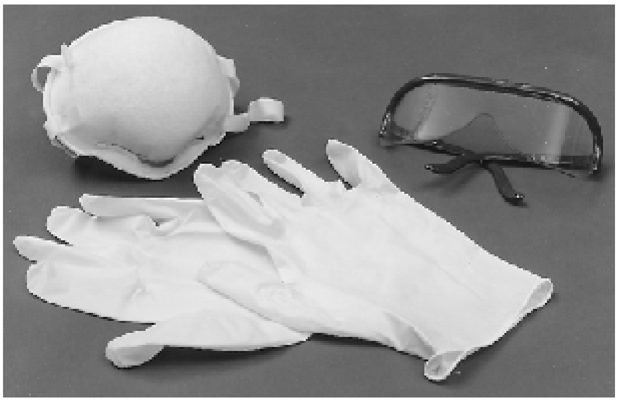

*Figure 1 shows some very basic safety equipment that should be used by all operatives.*

### Health hazards during service

Once applied and fully dried out, most coatings on buildings present no significant hazards to health. The main areas of concern would be if pigments that were toxic had been used to provide colour or protection, or if addi-

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[1] Causing deformation of an embryo.

tives toxic to fungi and moulds (known as fungicides or mildewcides) had been incorporated.

Coatings containing fungicides would primarily be used on the exterior of buildings, though they are also used on some interior surfaces such as kitchens or bathrooms where conditions might encourage mould growth. Many compounds have been used as fungicides, and whilst they are very effective in eliminating the colonization and growth of micro-organisms, in normal use they would be harmless to humans. Health hazards can occur though, should a fungicide-containing coating be licked or chewed, an activity particularly associated with young children suffering from the medical condition of pica. Adverse health effects from ingestion of fungicide would depend on the type used, but at the very least might include rashes and irritation to the oral region, cough, headache, nausea and vomiting. In older coatings mercury compounds could have been used as fungicides; ingestion of mercury over a prolonged period can be life threatening.

The use of toxic pigments in present day building paints is unlikely. Until relatively recently though, the inclusion of large amounts of highly toxic lead-containing pigments was common in paints for use on certain types of masonry and timber components. Whilst these would mainly have been used outside, they might also be encountered on older interior surfaces, especially woodwork. Again, such lead-based paints present no risk to health if in good condition and left alone, but ingestion of even small amounts can result in lead poisoning leading to reduced brain function or even severe brain damage. Even in developed countries, the chewing of lead-containing paintwork is the main cause of acute brain damage in children, and it has been proven that even relatively small levels of ingested lead can impair children’s intelligence.

It is accepted that the major hazard to health associated with lead from old paint arises from the pollution of the atmosphere with dust, either as a result of removal by sanding or burning during maintenance, or simply as a result of powdering or flaking due to age or neglect. Lead so released to the environment may be breathed in as well as ingested, and thus presents a health hazard to adults as well as children. It has been argued that it is inappropriate to strip large areas of lead-containing paint, since if performed carelessly it may exacerbate existing problems, and disposal of the waste also requires special consideration. Maintenance by encapsulation can be an effective remedy in many circumstances.

## Wood preservatives

Wood preservatives contain active ingredients and solvents which can harm the health of individuals if exposed to excessive amounts. Safe use of wood preservatives requires that individuals are protected against excessive exposure and that application procedures minimize contamination of treatment rates and their surroundings.

This section describes the nature of the potential health hazards resulting from exposure to wood preservatives. It also sets out the routes by which building operatives or building users may become affected and recommends suitable protective procedures.

Timber used in the construction of buildings may be at risk from attack by insects such as termites and certain beetles, and when exposed to dampness, can be at risk from fungal decay. In situations where risks of rot or insect attack are known to be significant, selection of timbers with a high level of durability is an option. However, naturally durable timbers are generally too expensive for most routine construction purposes and sometimes come from environmentally sensitive forest sources.

An alternative approach therefore is to use timbers of low natural durability treated with wood preservatives to enhance their resistance to fungal decay and insect attack.

Wood preservatives contain active ingredients which are necessarily toxic to fungi and/or insects. However, these active ingredients, as well as some of the solvents in which they are dissolved, can be harmful to people unless used properly.

Safe use of wood preservatives therefore requires an understanding of the potential hazards and appropriately safe working procedures.

Many countries control the use of hazardous products such as wood preservatives by legislation governing their use. Approval under such legislation is conditional upon specified precautions being taken during production, distribution, use and disposal of waste. **The safety of operatives, subsequent building occupants and of the environment can only be assured by complete implementation and policing of these precautions**. The details of the precautions and restrictions to be observed should be supplied with a preservative product and deal with issues such as personal protective equipment and application procedures.

In addition to preservatives applied directly to timber, certain insecticidal formulations are sometimes sprayed onto (or injected into) soil around buildings to produce a barrier against soil-dwelling termites. The same general hazards apply for these products as for wood preservatives, but special care is needed to avoid contamination of water courses, wells and ponds.

### Health hazards

It is important to place the health risk from wood preservatives in an appropriate perspective taking into account the great benefits they provide. Accidental contamination of operatives, other site personnel or of building occupants with any potentially harmful product must be avoided. However, preservative products are approved under national regulations only after very careful consideration of the significance of their toxic properties and the way in which they will be used. Very occasional, accidental splashing or slight spillage of preservatives resulting in, for example, only small amounts of skin contamination of operatives is therefore unlikely to induce serious ill-effects provided action is taken immediately to wash off contamination. However, if more serious contamination is allowed to occur this may induce skin irritations, eye inflammation and nausea.

Serious health consequences, including death, can be expected if gross or persistent misuse of a preservative product occurs.

| *Types of wood preservatives* | *Examples* |
|---|---|
| 1 Organic solvent-borne preservatives | Pentachlorophenol (PCP), lindane, copper and zinc naphthenates, Dieldrin |
| 2 Water-borne salts | Salts of arsenic, chromium, copper, fluorine, boron |
| 3 Tar oils | Creosote |

*Sources: Mossberg 1990; Orsler 1994.*

### *Absorption through skin*

If a preservative product contaminates the unprotected skin of a person some of the active ingredients and solvents will be absorbed through the skin. Dependent on the area of skin contaminated and the toxic properties of the product, this may effect the health of that individual. Contamination of the skin may occur in a number of ways; for example by handling of damaged and leaking preservative containers, by splashing or misdirection of sprays during treatment or by handling treated wood before the preservative treatment has dried off.

In addition to the risk of absorption of toxic ingredients through the skin, some preservatives are corrosive or strongly irritant to the unprotected skin.

### *Inhalation*

When a wood preservative is spray-applied minute droplets of the product remain suspended in the air for some hours after treatment. These droplets can be inhaled into the lungs of unprotected individuals working or living in the vicinity and thus be absorbed into their body. Certain types of product are formulated in volatile petroleum-based solvents which evaporate from the treated timber as the preservative dries. This vapour may accumulate in unventilated areas around treated timber and can thus also be inhaled and absorbed by unprotected individuals. Very high concentrations of petroleum based solvents in the air can cause narcotic effects and loss of consciousness if exposure continues for more than a few minutes.

### *Contamination of eyes*

Many of the petroleum-based solvents and some active ingredients can cause serious and permanent damage to sight if preservatives are accidentally splashed or sprayed into the eyes.

### *Ingestion*

Ingestion of even small amounts of wood preservatives would represent a severe health risk to an individual. This would only be expected to occur if the product were mistaken for a beverage due to inadequate labelling of containers. More likely is that food products could become contaminated with preservative if not kept well away from the areas being treated. Every effort must be taken to avoid the transfer of preservatives to food stuffs and drinks as a result of handling with contaminated hands or gloves.

*Figure 2 shows the personal protective equipment necessary when spraying a solvent-borne insecticide in a roof space.*

Wood preservative treatments leave their highest loading of active ingredients on the surface of the treated wood. If food products are placed directly on this treated timber some of the active ingredients may be transferred to the food itself, even through the packaging, and subsequently ingested. For this reason not all preservatives are suitable for use on timbers to be used in food storage or preparation areas.

Preservative containers must not be re-used for purposes which might generate health risks such as for containing water or foods because contamination can be transferred to the food or liquid. (Washing out containers before re-use will not remove all of the preservative residues).

It is also important to ensure that water storage tanks do not become contaminated with preservatives, especially those delivering drinking water from roof spaces.

### *Fire hazard*

Preservatives based on petroleum solvents are usually flammable and present a fire risk both during application and for some time afterwards.

## Insecticides for treatment of soil against termites

Some of the insecticides traditionally used as termiticides are no longer regarded as safe for this use and are banned or restricted in many countries. Products based on Dieldrin and Aldrin fall into this category.

More recently introduced, potentially safer, products include those based on the insecticides permethrin and chlorpyriphos.

Some termiticides are extremely poisonous to fish and other aquatic organisms and must therefore not be used where there is any possibility of them leaching out of the treated soil into nearby watercourses, ponds, lakes or rivers. In particular they should not be used near wells used for drinking water. Termiticides are absorbed and retained best by dry permeable soils and application to waterlogged, impervious soils or bedrock surfaces is not advisable as this may result in excessive run off of the termiticide to adjacent watercourses etc. For the same reason application should also be avoided during or immediately prior to rain.

## Formaldehyde

Formaldehyde is a gas and its empirical formula is $CH^2O$. Commercially formaldehyde is handled and processed for the most part as an aqueous solution (CAS No 50-00-0) or in the solid form (CAS No 30525-89-4). Formaldehyde is produced naturally in the environment by the photochemical oxidation of hydrocarbons, but it is also manufactured by the chemical industry and incorporated in a wide range of products including building materials, such as glued wooden boards. Other sources such as combustion of gas and smoking of tobacco are additional sources that can add to the background concentration of formaldehyde in buildings. This typically results in indoor concentrations of formaldehyde ten to twenty times outdoors. Much higher concentrations may be produced during and following works such as installation of urea formaldehyde cavity wall insulation and installation of wood based products containing formaldehyde resins.

This section reviews the health effects of formaldehyde, the sources in the indoor environment and the means of controlling exposure of workers and building occupants.

### Health hazards

The main routes of exposure of formaldehyde that may result in acute effects are those of inhalation and absorption through the skin. Common sites for adverse acute effects are the respiratory tract, the eyes and the skin. The effects can be classed as irritant reactions and sensitization/allergic reactions. Allergic reactions may be induced by levels of formaldehyde far below those which cause irritant responses. Irritant effects occur in most persons whereas allergic/sensitization reactions will only affect a few individuals.

Dermal exposure to formaldehyde can produce contact dermatitis which is an inflammatory response of the skin and also urticaria which is an immediate wheal and flare reaction. Allergic contact dermatitis is a particular reaction similar to contact dermatitis except that an antigen is formed and subsequent exposure to small quantities of formaldehyde produces an immunological response[2] some 24 – 48 hours after exposure. Contact with products containing small concentrations of formaldehyde can induce an allergic response in a small proportion of the population.

Inhalation of formaldehyde vapour primarily induces irritation of the eyes and respiratory tract. Symptoms are burning sensations in the nose and throat, tingling, sneezing, coughing and tears from the eyes. Irritation is proportional to the formaldehyde concentration, but there is wide variation in individual susceptibility. Studies report an odour threshold of about 0.05 mg/m$^3$, an irritation threshold of 0.1 mg/m$^3$ and significant increases in irritation symptoms between 0.3 and 1.0 mg/m$^3$. See Table 1.

*Table 1 Irritation as a function of formaldehyde concentration.*

| *Effect* | *Formaldehyde concentration (in mg/m$^3$)* | |
|---|---|---|
| | *Estimated median* | *Reported range* |
| Odour detection threshold (including repeated exposure) | 0.1 | 0.06–1.2 |
| Eye irritation threshold | 0.5 | 0.01–1.9 |
| Throat irritation threshold | 0.6 | 0.1–3.1 |
| Biting sensation in nose, eye | 3.1 | 2.5–3.7 |
| Tolerable for 30 minutes (lachrymation[3]) | 5.6 | 5–6.2 |
| Strong lachrymation, lasting for 1 hour | 17.8 | 12–25 |
| Danger to life, oedema, inflammation, pneumonia | 37.5 | 37–60 |
| Death | 125 | 60–125 |

*Source: World Health Organization 1987.*

There is sufficient evidence of the carcinogenicity[4] of formaldehyde in experimental animals; the evidence of carcinogenicity in humans is inadequate. Formaldehyde is classified as a Group 2B carcinogen (probable human carcinogen but evidence sufficient only in animals) by the International Agency for Research on Cancer (IARC).

The exposure of workers to formaldehyde is controlled by the setting of exposure limits expressed either as time weighted average concentrations as in the UK or ceiling values. For example the control limit for an 8 hour exposure period in the UK is 2 ppm[5]. Some countries also have a recommended maximum formaldehyde concentration for the atmosphere inside dwellings. Finland for example has a recommendation of 0.25 ppm for all dwellings and 0.12 ppm for houses constructed or repaired after 1983, see Table 2. In 1987 the World Health Organization reviewed the health effects of formaldehyde and recommended an air quality guideline for outdoor and indoor air (non-occupational). Their recommendation states that in order to avoid complaints from sensitive people about indoor air in non-industrial buildings, the formaldehyde concentration should be below 0.1 mg/m$^3$ (0.083 ppm) as a 30 minute average. The WHO adds that building codes and production and processing regulations should take into account the numerous sources that may contribute to indoor formaldehyde levels.

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[2] Reaction by the body.

[3] Crying, formation of tears.

[4] Cancer causing effect.

[5] A formaldehyde concentration of 1 ppm (part per million) is the equivalent of about 1.25 mg/m$^3$.

*Table 2 Guideline values for maximum formaldehyde concentrations inside dwellings.*

| *Country* | *Level (mg/m³)* | *Remarks* |
|---|---|---|
| Denmark | 0.15 | guideline value for the general population based on irritation |
| Finland | 0.15 | guideline value for buildings constructed after 1981 |
| | 0.3 | guideline value for older buildings |
| Germany | 0.12 | guideline value for the general population based on irritation |
| Italy | 0.12 | tentative guideline value |
| Norway | 0.06 | Recommended guideline value, not yet adopted |
| Spain | 0.48 | only for the initial period after installation of UF-foam |
| Sweden | 0.13 | guideline value, wood based panels, |
| | | 50% rel. humidity |
| | 0.2 | guideline value, remedial action |
| level | | |
| Switzerland | 0.24 | guideline value |
| The Netherlands | 0.12 | standard value, general population and sensitized subjects; irritation and carcinogenicity |
| USA | 0.486 | Federal target ambient level |
| WHO (1987) | 0.1 | 30 min average guideline value, general population |

## Sources and control

### *Types of source*

Medium-density fibreboard (MDF), particle board and hardwood plywood panelling are probably the most widely used potential emitters of formaldehyde among products used in buildings. All are bonded with urea formaldehyde resins (UFR). UFR or related reagents are also used on cotton and polyester-cotton fabrics that are used for making upholstery, drapery and clothing. Other potential formaldehyde emitters are fibre glass insulation, latex backed fabrics, urea formaldehyde foam insulation, and melamine-formaldehyde bonded plywood. However, emission from phenol-formaldehyde bonded particle board or exterior grade plywood is usually very low. Lacquers incorporating urea formaldehyde resins may be applied to timber and wood based products and be a further source of formaldehyde.

Exposure to formaldehyde can potentially occur at the production, site application and in-service stages of a products life.

### *Control of production stage*

As a resin supplier the chemical industry has controlled emissions by developing products that release less formaldehyde. This has been achieved by reducing the molar ratio of formaldehyde to urea in resins from a value of about 2 to typically 1.3 for use in particle board during the 1980s.

Reducing emissions during manufacture of board materials relies on control of the local environment by ventilation. First noticeable emissions occur during pressing of the boards, the gluing stage being less critical. Strongest emissions occur when presses are opened and the subsequent cooling stage is also significant.

An alternative to control of formaldehyde is use of products that do not contain formaldehyde. For board materials, inorganic binders such as cement are used, but the product is more expensive and the boards heavy. Isocyanates have been used in place of UF resins, but as far as manufacture is concerned, this involves substituting one set of health risks for another. Other resins such as phenol resins can also be used but there are cost disadvantages and problems of waste disposal. For cavity wall insulation there are a number of alternatives to UFFI, again their use can have a cost penalty and there may be other associated health risks such as handling of man-made mineral fibres.

### *Control during use*

Control of exposure to formaldehyde during installation and use of products can be achieved by control of quality of the product and installation procedures.

#### *Board materials*

For board materials it is possible to produce low formaldehyde emitting boards by control of the production process and/or after treatment of the board. The most widely used measure of the potential of a board to release formaldehyde is the "perforator test" which determines the free formaldehyde content of a board. A European Standard CEN EN-120 describes the test procedure. The method involves the extraction of all free formaldehyde from 100 g sample of board material with 600 ml boiling toluene, from which it is transferred into one litre of water. Formaldehyde is then determined by iodometric titration. The apparatus required is quite large, with complicated glassware and the procedure requires two hours of refluxing, taking a total of about four hours. Furthermore, the use of toluene creates a potential health and fire hazard. The test should therefore only be performed in a test laboratory with appropriate quality control and possibly within an accreditation scheme. It is recognized as not being ideal because it only broadly correlates to the actual emission as measured by environmental chamber tests, but it is a widely applied and useful indicator. A European Standard is currently under development based on environmental chamber tests of the emission rate of formaldehyde from wood based products.

In Germany the Regulations for Hazardous Materials describe the chamber test as the basis for formaldehyde limitations for wood based panels. Similar regulations apply in Austria, Denmark, Sweden and Switzerland. The German regulations classify boards into 3 categories (E1-3) based on the concentration of formaldehyde produced by the emission of a given area of chipboard in a climate chamber with controlled temperature, humidity and ventilation conditions. Category E1 is the lowest emitting board and does not produce concentrations in the chamber in excess of 0.1 ppm (0.12 mg/m³) under the test conditions. Production of E1 quality board requires principally a resin with a low molar ratio (1.2 or less) and a suitable wax. Waxes include paraffin wax, polyethylene and ready to use emulsion and these prevent a reduction in the mechanical strength of the board. The E1 class board as defined by the chamber test is approximately equivalent to a perforator value of up to 10 mg/100 g (formaldehyde per dry board weight). Current British Standards allow a value of 25 mg/100 g for general building applications, as compared with values of 80 to 120 mg/100 g being commonly manufactured during the 1970s in Europe.

An indication of the possible effect of the use of such high formaldehyde boards on indoor formaldehyde concentration is demonstrated by the environmental chamber test where a perforator value of 60 would give a concentration in air of about 2.3 ppm. It was concentrations of 0.5–2 ppm, particularly in homes with low ventilation in Scandinavian countries and in mobile homes in the United States (which were lined with particleboard), that resulted in complaints from occupants and pressure during the 1970/80s to reduce the formaldehyde content of building materials.

*Urea Formaldehyde Foam Insulation (UFFI)*

This product has been widely used in Europe and North America particularly to insulate homes by injection of the foam into wall cavities. The foam is formed on site by mixing resin, air and an acid hardener and injecting the foam through holes drilled in the wall. As with particleboard, complaints due to formaldehyde odour and irritation were reported in the late 1970s and early 1980s. The complaints were mostly due to emission of formaldehyde during installation and some weeks thereafter. Adverse publicity due to formaldehyde problems resulted in a considerable reduction in market demand and banning of its use in some countries. In the UK standards were introduced to:

i control the quality of foam production and hence the formaldehyde content,

ii restrict its use to buildings with masonry inner leaves which were a barrier to formaldehyde ingress,

iii required the contractor to ensure no foam had penetrated the living space by sealing cracks in the walls, etc.

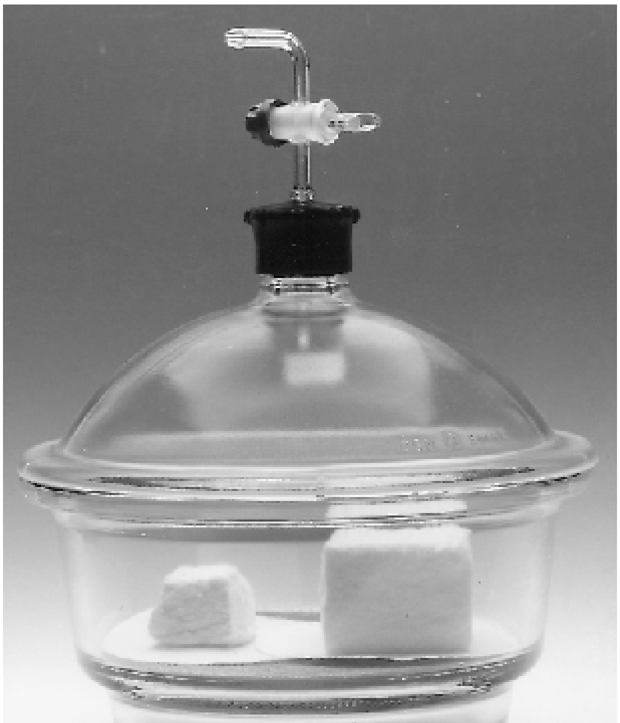

*Figure 3. Embrittlement of UFFI.*

As with other UF resins, the emission of formaldehyde from UFFI increases with higher temperature and humidity. There is a known mechanism of embrittlement and powdering of the foam on exposure to elevated temperature and humidity, see Figure 3. Hence any standards controlling use should not be adopted in a country with different climate and building practices without due consideration of the effects of the environment on the materials performance.

The two samples of UFFI were both maintained at 65°C for 12 hours. The sample on the left was exposed to 100% RH, and has shrunk considerably in comparison with the right hand sample.

If concern exists about the quality of installation that may be achieved locally and possible effects of climate on foam performance, then alternative insulating materials should be considered including mineral fibre, polystyrene and woodwool slabs (Johansson, 1994).

*Measurement of formaldehyde in air*

There are several sampling methods commonly used for measuring formaldehyde in air. Most require bubblers containing collecting solutions and sampling pumps to draw air through the solution at a rate of 1–2 l/min for 30 minutes to 1 hour. The UK Health and Safety Executive and the US National Institute for Occupational Safety and Health describe methods based on chromotropic acid collecting solution and analysis using colorimetry. These should be undertaken by an accredited laboratory.

Concentrations close to the occupational exposure limit can be monitored using indicator tubes such as supplied by Draeger[6] which require less experienced personnel and is relatively inexpensive. They are only effective at concentrations that could cause irritancy in some individuals. Diffusive, badge type samplers that do not require pumps and can reliably measure concentrations as low as 0.1 mg/m$^3$ are also available, but require analysis in an accredited laboratory. The UK Health and Safety Executive have validated the GMD 570 Series Dosimeter and this has been used widely in homes and offices by the Building Research Establishment.

## Volatile Organic Compounds

The term volatile organic compounds (VOC) describes a large number of compounds with a boiling point up to about 260°C. They have a significant vapour pressure which results in contamination of the indoor air if introduced into a building as a component of a building or

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[6] Drögerwerk AG, Lübeck, Germany.

consumer product. Definitions of VOC differ between authors, but a World Health Organization (WHO) group defined 3 categories of volatile compounds; very volatile, volatile and semi-volatile. Very volatile (boiling point < 75°C) normally off-gas rapidly from a building product, but may be introduced frequently in the indoor air such as in the form of propellant for sprays in household and personal products. Volatile (bp 75–250°C) and semi-volatile (bp 250–390°C) have been of greater concern in buildings in Europe and North America because their long term emission from building materials and furnishings results in concentrations of a wide range of compounds being higher indoors than outside.

Several studies have implicated VOC with cases of occupants complaining of symptoms such as eye and throat irritation, headache and a range of other effects of the type associated with sick building syndrome. Some compounds such as benzene are of concern because they are human carcinogens. Generally there is a lack of information about the health effects of levels of VOC which are considerably lower than permitted in the workplace, but are elevated typically 20 times outdoors. Exposure periods of occupants can be 24 hours per day compared with more typically 8 hours at work. The exposed group includes the most sensitive which are the newborn, children, pregnant women and the sick. Also the indoor pollutants are a mixture of typically 100 to 300 compounds and may include compounds such as plasticizers and emulsifiers that are not naturally occurring.

This review does not cover acute exposure to solvents, such as occurs during painting operations and wood treatment. (These have been covered in an earlier section.) Other possibilities of acute exposure to VOC can also occur during use of adhesives and the main control of exposure is to ensure adequate ventilation. If this is not possible personal protective equipment is required. This section considers the long term low level emission of VOC which can be a problem for building occupants and is the subject of considerable research and guideline development to ensure good air quality within the built environment.

### Health hazards

The effects of organic compounds that can occur in indoor air at concentrations well below standards used to control occupational exposure can be classed as

a odour and other sensory effects such as irritation,

b mucosal irritation and other morbidity due to systemic toxicity,

c genotoxicity and carcinogenicity.

Many chemical compounds have both odorant and irritant properties. Five main types of sensory systems that respond to irritants are situated on or near the body surface; systems related to the eye, nose, throat, facial skin and other body skin. Some of these systems tend to respond to an accumulated dose and their reaction is not so immediate and acute as in the case of odour perception. Effects of irritation are numerous and may include conjunctivitis, sneezing, coughing, hoarseness, a feeling of dryness of the mucous membranes, skin erythrema or oedema and changes in breathing patterns. Odour sensation may lead to a number of secondary effects such as vomiting, escape behaviour, triggering of hypersensitivity reactions and changes in breathing patterns.

Systemic toxic effects[7] include haemotological, neurological, hepatic, renal effects and mucosal irritation. Benzene causes aplastic anaemia and polycythaemia and dichloromethane produces carboxyhaemoglobin. Dichloromethane, toluene, styrene, trichloroethylene and tetrachloroethylene are neurotoxic. Styrene also produces mucous membrane irritation as does naphthalene.

Genotoxicity and carcinogenicity[8] are effects that inherently express themselves a long time after exposure to a toxic substance. It is assumed that there is no threshold concentration for effect and risk estimation is therefore performed down to very low concentrations. Five compounds commonly found in indoor air possess particular genotoxic and/or carcinogenic properties; benzene, tetrachloromethane, chloroform, 1,2-dichloroethane and trichloroethylene.

The health effects of levels of VOCs below occupational limits involving exposure to all population groups is poorly understood. Air quality guidelines for 12 organic compounds have been recommended by the WHO and some workers have proposed guideline concentrations of total VOCs (TVOC) to avoid discomfort and toxicity. An EC report identifies a target air quality guideline value of 300 μg/m$^3$ for TVOC.

Measurements of VOCs at the sub ppm concentrations of interest for possible irritancy effects requires quite sophisticated gas chromatography apparatus. Samples are collected using absorbent materials that remove the VOCs from air being drawn through. Analysis then involves either thermal or solvent recovery of the mixture of VOCs and their resolution for quantification and identification by chromatography. There are no simple procedures available that do not require trained technical staff and a well equipped analytical laboratory.

### Building materials as sources of VOC in indoor air

Pollution sources in a building comprise the occupants and their activities and materials in the building including furnishings, carpets and household chemicals. Some materials pollute a lot, some a little, but they may all contribute to the deterioration of indoor air quality. Examples of investigations reported in the scientific literature where building materials have been found to be a source of VOC which resulted in health effects are:

1 Creosote impregnated timber has been a source of naphthalene and methylnaphthalenes in indoor air.

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[7] Effects of poisons on parts of the body including: blood system, nervous system, liver, kidneys and mucous membranes. Benzene and dichloromethane causes abnormal blood cells and interferes with the body's production of new blood cells. Neurotoxic substances are poisons to the nervous system.

[8] Genotoxic substances affect chromosomes and genes that carry biological inheritance, which means they may cause mutations that affect one's children. Carcinogenic substances are associated with the development of cancer.

Creosote is obtained by dry distillation of coal tar and is a mixture of a hundred or more different substances, mostly polycyclic aromatic hydrocarbons (PAH) but also phenols and aromatic amines.

2 Walls treated with water repellent for exterior surfaces have been sources of white spirit in indoor air. The repellents consisted of silicone oil dissolved in the organic solvent. Similar problems have occurred when this type of product has been used as an injected damp proof course.

3 Sealants containing 2,2-dithioldiethylthioether have oxidized to give an odorous compound 1,2,5-trithiepane.

4 Portland cement-based casein, containing self levelling compounds, have given rise to ammonia emission as well as reaction with DEHP described below.

5 A damp proof membrane material used in concrete floors that contains coal tar has been found to be a source of naphthalene and other polyaromatics in houses and offices.

6 Plastic-laminated cork tiles laid on the floor of a new office produced concentrations of phenol of 13–16 $\mu g/m^3$ and there were complaints from staff of bronchial illness. The phenol came from a phenolic resin in the cork layer of the tile.

7 Vinyl flooring has been found to be a source of alkyl benzenes such as dodecylbenzene. These are used as process solvents for plasticizers. A further process solvent associated with complaints from occupants is TXIB (2,2,4-trimethyl-1,3-pentadioldiisobutyrate). Emission of phenol and cresol has also been associated with vinyl flooring.

8 Chemical degradation of a plasticizer (diethyhexylphthalate – DEHP) present in vinyl flooring and carpet can occur in the presence of alkali and moisture. Damp concrete and self levelling compounds in contact with vinyl flooring has resulted in hydrolysis of the ester to produce higher alcohols with a heavy, sickly smell.

9 New carpets have been found to be sources of 4-phenylcyclohexene (4-PC) which is formed as an incidental by-product of the reaction of styrene and 1,3-butadiene. Styrene emission has also been associated with some carpet types.

10 Alkyd paint recommended particularly for central heating radiators has been found to be a long term source of hexanal and hexanoic acid.

There is a general acceptance in Europe and North America that to improve indoor air quality it is preferable to control sources of indoor air pollution rather than to increase the rate of ventilation. Benefits should include prevention of problems of the type discussed above, possible reduction in some types of sick-building problems and a reduction in the population exposure to toxic compounds. These benefits can be achieved by control of products without the increased use of energy and related environmental problems associated with provision of higher ventilation.

National and international standards are being developed for quantifying the emission characteristics of building and consumer products. These are based on environmental chamber tests, see Figure 4, and in Europe are expected to be a requirement to demonstrate compliance of a product with the Construction Products Directive. Voluntary emission standards exist in some countries (for example carpets in the US and Sweden) and labelling schemes based on VOC emission have been proposed. Problems include defining which of the many VOC emitted from a single product are of concern, whether a total VOC (TVOC) value relates to toxicity, and defining a test which can be carried out reproducibly in different laboratories as the chamber and air analysis procedures are sophisticated techniques.

At the present time the specifier can ask the manufacturer for details of VOC emission from products and the response is likely to be variable because of the lack of any requirement or standardization for such tests. Some manufacturers involved with existing voluntary schemes will be in a position to provide relevant information and others may only rely on product composition which may not be a reasonable indicator of emission. The situation is developing rapidly and it is likely that useful information will become widely available in the next few years. Where data on product emission is preferred, a judgement based on total VOC concentration can be used, although it is also advisable to check that there are no significant amounts of carcinogens or recognized irritants within the mixtures of compounds released.

*Figure 4 shows an environmental test chamber of the type used to measure VOC emissions from building materials.*

## Asbestos

Asbestos is a fibrous mineral which occurs in many parts of the world; the main sites of commercial production are in Canada, the former Soviet Union and Southern Africa. The three main types produced commercially are crocidolite (blue), amosite (brown) and chrysotile (white). Asbestos fibre is mechanically strong and highly resistant to heat and chemical attack and, because of its fibrous nature, it can be woven into fabrics and used as reinforcement for cement and plastics. It is the very fine particles, invisible to the naked eye, which are dangerous when inhaled, and processes which produce very small airborne fibres are, in general, the most hazardous. These fibres pose no threat to health when left intact in undamaged material containing asbestos, which should be left alone and managed (periodically assessed for deterioration), sealed or enclosed.

In the UK the supply of crocidolite and amosite and products containing them was banned in 1986 and any product containing asbestos requires labelling. Similar regulations were introduced even earlier in Sweden and other Scandinavian countries, and apply in many other countries. Asbestos use is also banned in certain types of product in the UK, including paints and varnishes and products for spraying.

The principal diseases known to be caused by exposure to asbestos are asbestosis (fibrosis or scarring of the lung), lung cancer and mesothelioma (a cancer of the inner lining of the chest or of the abdominal wall). The risk of contracting an asbestos related disease depends on a number of factors, including the cumulative dose to which an individual has been exposed, the time since first exposure and the type and size of the asbestos fibres. Crocidolite and amosite are thought to be more dangerous than chrysotile.

Major uses of asbestos in buildings have included spraying asbestos for thermal and acoustic insulation, now banned in most European countries. Other uses include lagging, asbestos-cement and in materials such as mastics, sealants and protected metals. Asbestos-free substitutes are now available for many building materials. Many of the substitutes are fibrous. These include natural organic fibres (cellulose and wool), synthetic organic fibres (polypropylene, polyvinylalcohol, aramid, polyimides, polyacrylonitrile), glass fibre, ceramic fibre and rockwool. Glass fibre in particular is widely used in thermal insulation and in fibre reinforced composites.

## Cement

Portland cement is a class of hydraulic cements whose two essential constituents are tricalcium silicate and dicalium silicate with varying amounts of alumina, tricalium aluminate and iron oxide. It is used as a binding agent in mortar and concrete. Contact between cement powder and body fluids (eg sweat and eye fluid) may cause irritation, dermatitis or burns. Cement dermatitis is usually due to primary irritation from the alkaline, hygroscopic and abrasive properties of cement. In some cases, cement workers have developed an allergic sensitivity to constituents of cement such as hexavalent chromate. Problems should be avoided by use of appropriate clothing to prevent repeated or prolonged skin contact. Eye protection should be used if there is a danger of eye contact. Work clothing should be changed and cleaned daily.

# 3 Recommendations

## Paints

There can be a health risk associated with all chemicals and chemical-based products, and paints and other coatings for buildings are no exception.

It is probable that with most modern paints potentially the greatest health hazard will be encountered at the stage when the liquid coating is applied to the surface. At this time the operative, and possibly the building occupants, will be exposed to volatile emissions as the applied film dries. Methods of ameliorating risks from volatile organic compounds are relatively straightforward however, requiring only careful attention to basic hygiene procedures and provision of adequate ventilation.

It is recommended that the risks from solvents are minimized by using water-borne coatings for interior painting whenever possible.

Certain types of paints may contain toxic lead-containing pigments, or fungicides, which could present serious health hazards if inhaled as particles or ingested due to neglect or careless removal. The preferred treatment is wet abrasion followed by overcoating with appropriate low-lead paints which will, by sealing in the lead, considerably diminish any hazard.

Painting operations in and around buildings should not be allowed to proceed unless the above recommendations for the protection of operatives and building occupants can be followed. It is also important to ensure that coatings and ancillary products, such as cleaning agents, paint removers, thinners etc. should be drawn from original manufacturers containers. Specific safety advice given by manufacturers, either on container labels or in data sheets, must also be followed.

## Wood preservatives

As with paints, the greatest risk is to the operatives when applying preservative treatments to timbers. Risks can be reduced by following a few simple rules.

- Only specify and use wood preservatives where they are necessary, and only use wood preservatives appropriate to the end-use and specifically approved or recommended by the manufacturer for that purpose.
- Ensure sites for storage of preservatives and treatment of wood have appropriate containment for leakage, spillage, dripping etc., good ventilation and wherever possible protection from rainfall.
- Store securely and safely to avoid misuse, vandalism and releases.
- Ensure operatives have appropriate protection during application, and that other site personnel, occupants and passers by are warned or protected: keep pets and animals away.
- Prevent leakage, spillage, or other accidental contamination of the surroundings, especially water courses.
- Ventilate well and avoid handling freshly treated timber.
- Do not permit eating, drinking or smoking whilst applying preservatives or in freshly treated areas, and do not allow food stuffs or drink to be placed on or near treated surfaces.
- Prevent naked flames, electrical sparks and any other risk of ignition when using flammable formulations.
- Do not allow occupants back into treated buildings until the minimum re-entry time specified by the manufacturer.
- Dispose of surplus, excess and wastes (including containers) safely; do not re-use containers for purposes other than containing more of the same product.
- Re-use treated timber appropriately, provided that the original treatment was suitable for the new use.

**Selection of preservative type**

The risk of insect or fungal attack to the timber components of a proposed structure should first be assessed. Preservative treatment should be specified only where there is an identified risk of timber decay or insect attack.

The main fungal decay hazard is with timbers exposed to the weather or in ground/or water contact.
A risk of insect attack, either from wood-boring beetles or termites is not always present and local guidance should be sought before specifying insecticidal preservative treatment.

Where the need for preservative treatment is identified the use of timber pre-treated with preservative under the controlled conditions of an industrial treatment plant should be the first choice of the specifier. This reduces those health risks associated with storage and use of preservatives under the rather less easily controlled conditions of a construction site.

If local economic or technical difficulties make the site-application of wood preservative unavoidable, only products specifically formulated as wood preservatives for this purpose should be specified and used.

All instructions issued by manufacturers must be complied with, especially in respect of any restrictions on use. For example, some products such as creosote are not recommended for use in the interior of dwelling houses due to their persistent odour and others are unsuitable for use in food storage or preparation areas. Under some national regulations it is an offence to apply wood preservatives other than in strict compliance with the conditions described on their labels.

**Products should not be used for which manufacturers instructions relating to application rates, methods of application and personal protective equipment are not available. In particular products of unknown origin and without adequate information regarding the hazards associated with their constituents MUST NOT BE USED.**

### Planning for safe use

Wood preservatives can be harmful to health and it is important therefore that the risks to which operatives and others will be exposed during their use on a particular site are fully assessed and proper instruction on safety precautions given to those who will use the preservatives. Assessments and instruction should be carried out by an appropriately qualified manager or site supervisor and completed before any preservative is handled on site.

An important first step in this planning process is to **carefully read the manufacturers instructions** issued with the preservatives to be used. All safety precautions must be complied with.

#### *Storage of preservatives on site*

Wood preservatives should be stored on site for as short a period as possible before use so as to minimize any risks of leakage or spillage from damaged cans, theft or misuse by site intruders and, in the case of those based on flammable liquids, to reduce the risk of fire.

Storage provisions on site should be secure, lockable and clearly marked to denote the hazard of the contents, eg “Toxic” or “Flammable.” The storage area should be constructed so as to contain leakage in the event of puncture of the stored containers. In particular stores should not be sited near wells or water courses and should have impermeable floors designed to contain any leakage.

#### *Training of operatives*

Misuse of wood preservatives can have serious consequences for the health of operatives and others. Managers and supervisors of construction projects therefore must ensure that operatives receive the necessary training to allow them to use the products safely.

Operatives should be given specific, unambiguous instructions on application methods and rates, personal protective equipment and disposal of waste materials. The level of on-site supervision must be commensurate with the quality of training and reliability of operatives.

#### *Precautions to be taken during application*

Wood preservatives are often applied on site by a number of methods. For small scale use, application by spray or brush may be used. In the case of large volumes of timber this may be dipped in temporary tanks constructed on site. In the case of specialized treatment plants comprising double vacuum, vacuum/pressure cylinders or hot and cold impregnation plants, engineering provisions provide a high level of protection of operatives and the environment.

The instructions issued by the preservative manufacturer must be followed carefully. This will normally require that operatives be protected from direct contact with the product. Solvent-resistant gloves, overalls and boots are normal provisions for most circumstances where products are applied or where freshly treated timber is handled. In addition where there is a risk of eye contamination, for example by splashing as timber is dropped into a dip-tank or when spraying, operatives should wear goggles or a visor.

To avoid accidental exposure to preservative, all containers used to dilute, apply or store products should be clearly labelled with the product name and the nature of the hazard eg “Flammable” or “Harmful.” Food or drink containers must never be used to store preservatives, no matter how briefly.

Wherever possible treatment of timber should take place under conditions which maximize ventilation. Where timbers are treated inside buildings, for example during refurbishment work, or in the case of any spraying operation, appropriate respiratory protection should be worn. Simple filter masks are adequate for non-volatile products. If volatile products such as those based on petroleum solvents are to applied in poorly ventilated situations then respirators containing carbon filters to remove solvent fumes are necessary.

Operatives applying preservatives should wash their hands before eating and at the end of the working day. Eating drinking and smoking during treatment work must not be allowed.

#### *Siting of treatment facilities*

Dip tanks and other treatment plants must be sited remote from any water courses or wells through the soil. Treatment plants and storage areas for freshly-treated timber should be sited on an impervious base, ideally of concrete with provision to contain accidental spillage. An open-sided, roofed cover over the plant will prevent the small amounts of preservative which may leak from tanks or drip from treated timber, from being washed into the soil by rain.

#### *Handling and drying of treated timber*

To avoid skin contamination, freshly treated timber should not be handled without protective gloves until the timber surface is dry.

Timber treated with petroleum-based preservatives will release volatile solvent vapour as the preservative dries. Treated timber should be allowed to dry thoroughly before being used. This can usually be achieved in about a week or two by stacking the timber under well ventilated conditions, with spacers between the timbers so that air can freely circulate through the stack.

Where timbers are treated in-situ in a building, for example during remedial works, the area affected should be ventilated well and building occupants should be excluded for the minimum period specified by the manufacturer to allow the preservative to dry and any solvent vapour to disperse. This typically will take between 24 and 48 hours. During this period all sources of ignition, such as cigarettes, lamps and any electrical supply should be excluded or disconnected when a flammable product has been used.

#### *Disposal of containers and residues*

Care is needed in the disposal of unwanted residues or contaminated containers after treatment. Disposal onto soil or into drains is illegal in many countries because it can contaminate nearby natural water courses and possible sources of drinking water. Many preservatives are toxic to fish and contamination of rivers or ponds must be avoided.

A safe system must be used for disposal of unused preservative products. Generally it is best to return unopened or used containers to a supplier or to safely store them for future preservative use. However, partially-used containers, unused preservative and indeed sludges from dip-tanks present more difficult disposal problems. Usually stringent national or local procedures for safe disposal apply and must be followed. Problems of disposal of surplus can be avoided or reduced if the quantity of preservative needed in the first place is calculated carefully in advance to minimize any excess.

Empty containers such as cans should be punctured and crushed prior to safe disposal so as to prevent their re-use as food or drink containers.

#### *Hazards from demolition*

Preservative-treated timber does not generally present any particular health hazard during demolition of a building . Such timber can be handled safely and often is suitable for re-use in other buildings or for other purposes. This is to be encouraged providing the re-use is appropriate to the original treatment, because it conserves and maximizes natural resources.

Preservative treated wood must not be used as a fuel in domestic stoves or cookers because volatile toxic compounds may be given-off during combustion. In a poorly ventilated room this could present a hazard to the health of occupants and to food prepared in or over the fire.

## Formaldehyde

Wood based products are the main building materials that involve use of formaldehyde in their production and emit formaldehyde during their use. Urea formaldehyde foam has also been subject of occupant complaint due to formaldehyde emission. Many other sources of formaldehyde can cause elevated levels of formaldehyde in buildings compared with outdoors.

Control of exposure to formaldehyde is required at the production, installation and in-service stages of a products life. An important control is that of limiting the formaldehyde content of the resins.

Methods of testing products to evaluate their potential to release formaldehyde may not be directly applicable to countries with different climates and building practices from Europe and North America where tests have been developed.

### Control of production stage

Control of exposure in the manufacture of formaldehyde is through control of emission and isolation of workers. Ventilation by sufficiently powerful extraction systems to prevent gas from polluting the workplace is the key to emission control. Wherever possible workers should be isolated from direct contact with formaldehyde by use of automatic equipment. When not possible, such as during maintenance works, suitable personal protective equipment should be worn.

### Control during use

Control of exposure to formaldehyde during installation and use of products can be achieved by control of quality of the product and installation procedures.

For board materials it is possible to produce low formaldehyde emitting boards by control of the production process and/or after treatment of the board. The most widely used measure of the potential of a board to release formaldehyde is the “perforator test” which determines the free formaldehyde content of a board. A European Standard CEN EN-120 describes the test procedure.

The German regulations classify boards into 3 categories (E1-3) based on the concentration of formaldehyde produced by the emission of a given area of chipboard in a climate chamber with controlled temperature, humidity and ventilation conditions. The E1 class board (the class with lowest emissions) as defined by the chamber test is approximately equivalent to a perforator value of up to 10 mg/100 g (formaldehyde per dry board weight). Current British Standards allow a value of 25 mg/100 g for general building applications, as compared with values of 80 to 120 mg/100 g being commonly manufactured during the 1970s in Europe.

Specifiers should insist that the manufacturers provide data that demonstrates compliance with a recognized standard method, in order to prevent problems associated with formaldehyde release.

### Application to developing countries

Application of the experiences in Europe and North America to situations in other countries requires due regard for the basis of the environmental chamber test and the prevailing climate and building practices. The chamber test described uses a climate of 23°C and 45% relative humidity, an air exchange rate of 1 per hour and a loading ratio ($m^2$ board to volume of chamber) of 1. Formaldehyde emission rates increase by a factor of 2 or 3 for each 10°C rise in temperature and a doubling of humidity causes a doubling of the emission rate. Higher ventilation rates will reduce the resultant formaldehyde concentration. Hence use of the types of controls developed in some western countries should not be extrapolated to other countries without considering the appropriateness of the test conditions being used to classify wood based products.

## Volatile Organic Compounds

Building materials are a source of a large number of volatile organic compounds in indoor air but in concentrations normally well below those permitted in the occupational environment.

There is concern that levels of VOC commonly occurring in buildings in Europe and North America can cause problems of sensory effects, systemic toxicity, genotoxicity and carcinogenicity.

A number of specific problems of VOC from building materials causing complaints of health effects have been reported. The presence of a mixture of VOC has been implicated in some cases of sick building.

Recommended air quality guidelines for some VOC have been published by expert groups.

Product standards to regulate the amount of VOC emission from building products are under development but may not be directly applicable to countries with different climate and building practices from Europe and North America.

There is a general acceptance in Europe and North America that to improve indoor air quality it is preferable to control sources of indoor air pollution rather than to increase the rate of ventilation. These benefits can be achieved by control of products without the increased use of energy and related environmental problems associated with provision of higher ventilation.

Voluntary emission standards exist in some countries (for example carpets in the USA and Sweden) and labelling schemes based on VOC emission have been proposed. Problems include defining which of the many VOC emitted from a single product are of concern, whether a total VOC (TVOC) value relates to toxicity, and defining a test which can be carried out reproducibly in different laboratories as the chamber and air analysis procedures are sophisticated techniques. Where data on product emission is preferred, a judgement based on total VOC concentration can be used, although it is also advisable to check that there are no significant amounts of carcinogens or recognized irritants within the mixtures of compounds released.

The period of emission should also be a factor; if the emission rate declines rapidly with time to a very low level, the product may be preferred over one showing sustained emission.

**Application to developing countries**

A developing country wishing to reduce energy consumption due to the built environment and improve comfort of occupants should recognize problems of indoor air quality that have arisen since the 1970s in Europe and North America. Avoidance of these problems is best achieved by controlling emissions from products as air tightness of buildings increases.

Information on emissions of VOC from products is becoming increasingly available and international standards are under development. These tests are based on temperature and humidities found indoors in North America and Europe and may not be directly applicable to countries with a very different climate. Particular problems of degradation of products in high humidities have been reported and rates of emission of VOC generally increase with temperature. Hence there may be a need to adapt test methods currently under development and consideration given to the range of products currently under investigation to ensure they include materials used in some other countries.

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