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A review of the potential impact of VOC emissions on the future market share for engineered wood products

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A review of the potential impact of VOC emissions on the future market share for engineered wood products

Prepared for

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ABBREVIATIONS

ACCC: Australian Competition & Consumer Commission

ABCB: Australian Building Codes Board

AELA: Australian Eco-Labelling Association

AFSSET: Agence française de sécurité de l'environment et du travail (French Agency of Health and Security of the Environment and Work)

AgBB: Ausschuss zur gesundheitlichen Bewertung von Bauprodukten ((German) Committee for Health-related Evaluation of Building Products)

ASHRAE: American Society of Heating, Refrigerating, and Air Conditioning Engineers

AWPA: Australian wood panels Association

BCA: Building Code of Australia

BFH: Bundesforshungsanstalt für Forst- und Holzwirtschaft ((German) Federal Research Centre for Forestry and Forest Products)

BREEAM: Building Research Establishment Environmental Assessment Method

CEC: Commission of the European Union

CPD: (EU) Construction Products Directive

CSTB: Centre Scientifique et Technique du Bâtiment (French) Scientific and Technical Building Centre)

CTMP: Chemi-thermomechanical pulp

DIBt: Deutsches Institut für Bautechnik (German Institute for Building Technology)

DICL: Danish Indoor Climate Label

DSIC: Danish Society of Indoor Climate

ECA: Euroean Collaborative Action

EPLA: European Producers of Laminate Flooring Association

EWPAA: Engineered Wood Products Association of Australasia

FSC: Forest Stewardship Council

GBC: Green Building Council (of Australia)

GBCA: Green Building Council of Australia

GEI: Greenguard Environmental Institute

GEN: Global Ecolabelling Network

GEV: Gemeinschaft Emissionskontrollierter Verlegewerkstoffe e.V. (Association for the Control of Emissions in Products for Flooring Installation)

ICL: Indoor Climate Label (Denmark, DICL)

IEE: Institute of Environmental epidemiology (Ministry of the Environment, Singapore)

JFPMA: Japanese Fibreboard and Particleboard Manufacturers Association

JTCCM: Japan Testing Center for Construction Materials

LCI: Lowest Concentration of Interest (NIK values)

LEED: Leadership in Energy and Environmental Design

MAK value: Maximale Arbeitsplatz-Konzentrationen value (Maximum Workplace Concentration)

MEXT: (Japanese) Ministry of Education, Culture, Sports, Science and Technology

MHLW: (Japanese) Ministry of Health, Labour and Welfare

MSDS: Material Safety Data Sheet

NEPC: National Environment Protection Council (Australia)

NEPM: National Environmental Protection Measures (Australia)

NHMRC: National Health and Medical Research Council (Australia)

NIK-Werten: Niedrigiste Interessierende Konzentrationen Werten (LCI value)

REACH: Registration, Evaluation and Authorisation of Chemicals (European Union)

SBS: Sick building syndrome

TLV: Threshold Limit Value

TMP: Thermomechanical pulp

TNS: The Natural Step (New Zealand)

WHO: World Health Organisation

SUMMARY

Background

The potential impact of volatile organic compounds (VOCs) on the health and wellbeing of people has become an increasingly important issue over the last twenty-five years, driven in particular by changes in building codes around the world which have led to marked reductions in air turnover rates in enclosed living and work spaces. Whilst the initial driver for the focus on VOC emissions was undoubtedly caused largely by concerns over organic solvents emitted from finishes applied to a variety of materials, the focus has more recently turned to all VOCs emitted from all materials deployed in enclosed living spaces. As a consequence, the emission of VOCs as a whole (other than just formaldehyde) from wood products has come under increased scrutiny.

The first attempts to regulate VOC emissions was through green or so called eco-labelling of products. One of the first, and most widely recognised, of these was the German Blauer-Engel (Blue Angel) environmental label, launched in 1977; the label has been updated a number of times and now includes limits for emission of VOCs from wood products. In the mid 1990s an attempt was made to link all the various eco-labels together, and the Global Eco-labelling Network (GEN) was formed. Whilst this system is used, the individual labels are also still used and recognised in their own right.

The green consumer market has been a key driver for the increased focus on VOCs. This has been particularly prevalent in Germany, Scandinavia and Japan, where ‘green’ products can command a premium. Companies such as IKEA were quick to target this market, though not without some setbacks. For example, in the 1980s and 1990s the company was found to be selling products which exceeded mandated formaldehyde emissions in Denmark and Germany, which attracted adverse publicity and had a significant impact on sales; the public perception of particleboard’s potential impact on human health remains tainted to this day. These experiences have driven companies such as IKEA to develop rigorous internal procedures and develop a range of environmental strategies, which form the core of their manufacturing and marketing operations.

Whilst the regulation of formaldehyde emissions has been in place for a number of years, that of VOCs is still in its infancy. This is primarily because, compared to formaldehyde, it is much more difficult to identify and quantify VOCs. This has thus been a fertile area of research in Europe and Japan, with a focus on investigating the technology available for laboratory simulation of indoor spaces using various controlled test chamber systems and marrying these with available identification and quantification methodologies. In parallel to this some countries have also begun to consider limits for VOC emissions, with countries such as Japan and Germany going further and actually defining limits for certain VOCs. The most concerning aspect of

these developments is that the legislation being considered may limit, restrict of even exclude the use of wood products in homes as a result of the naturally emitted VOCs; in the case of the flooring legislation implemented in Germany, it is apparent that at least some wood species would be excluded from use based on their natural VOC emission characteristics.

Methods for Determining VOC Release

The methods for characterising VOCs emitted from wood products are generally more complex than those used to determine formaldehyde emissions. VOCs can be categorised in terms of their relative volatility, and the methodology for characterising them is to some extent determined by their volatility. Most standards e.g. ISO, ASTM, JIS, EN etc. have procedures for measuring VOC emissions based on chambers of various sizes. The sample of interest is held under constant conditions for a period of time, and air samples are taken from the chamber at intervals and the volatiles are collected using sorbent tubes. Different materials are used in the sorption tubes depending on the volatility of the VOCs. Following capture, the compounds are liberated by thermal desorption and subsequently characterised using GC/MS or GC/FID.

A number of research groups in Europe are active in developing other methods to measure VOC emissions, primarily because of the need to increase the rate of sample throughput or for pre-screening prior to selective further testing. One such approach is termed head-space testing, which involves streaming helium or air over a wood sample that is contained within a glass vial. In most cases the sample is heated to increase the emission of the volatiles, which are cooled to concentrate the gases and then reheated and measured directly using GC/MS or GC/FID. A variation on this approach is to sample from head-space directly into sorbent tubes.

Micro-chambers are also increasingly being used. The most common type (FLEC) is a dished cell (like a pot-lid) which is placed on a test sample (flat panel). Seals produce an air proof cavity between the flat board and the dish within the chamber. Air is fed into and out of the space between the test panel and the chamber. The air sample is collected into sorbent tubes for analysis using GC/MS. The method is documented in ISO16000, and is the method of choice for most European laboratories. A gas analysis method based on EN 717-2 for determining formaldehyde emissions has also been shown to be useful for characterising VOCs such as terpenes and aldehydes.

Owing to the complexity of the analyses and the analytical facilities needed, relatively few organisations around the world can currently carry out VOC emission work. The costs for doing such work can run to a few thousand dollars or more for individual samples, the actual cost depending on the method employed. At least one organisation in Australia offers a limited analysis service.

It is evident that the field of VOC measurement is currently fluid, with key groups attempting to identify the best approaches for generating reliable qualitative and quantitative data on VOC emissions in both a timely and cost effective manner. A number of different methods are currently used by research groups which generate data that are not directly comparable. It is also evident that in many cases the methodology developed to date is far from robust, and that the output data generated depend considerably upon operator/laboratory experience. These issues will need to be addressed before any rigorous legislation or regulations could be implemented to monitor and control VOC emissions from engineered wood products in Australia.

Regulatory Regimes

Around the world the regulation and control of VOCs from building products in general, and wood products in particular, is still very much a ‘work in progress’. The work on regulation only commenced in the 1990s and is yet to be implemented in many countries. As a result, there are few fully developed national systems.

The regulatory environment broadly consists of two types of regulations, mandatory and voluntary. The voluntary codes are often administered by independent special interest groups. However, they can also take the form of government developed or supported indoor air quality guidelines, often being precursors to legislated regulations. They can cover the material in the raw state such as particleboard or MDF, or they can cover the finished article such as a piece of flooring or furniture. The control can also be at a product level such as a label like Blue Angel, or it can be part of a purchasing or building certification program such as GreenStar.

The mandatory codes always take the form of government regulations. The most prominent of these for products is the German Institute for Building Technology (DIBt) scheme for flooring. This is a product emission regulation. Currently, other schemes rely on air quality guidelines. Generally, governments have been reticent to legislate in the area of indoor air quality because in the domestic housing market it may be seen to be too intrusive. It would is also very difficult to police.

The model that Germany and others appear to have adopted is to set specifications for emissions in the product standards. However, the desired maximum allowable concentration of VOCs is still to be determined, and there are issues relating to the additive effects of chemicals and the toxicological effects relating to these mixtures.

The voluntary codes are modelled on a standard product certification model. The certification body develops a standard which can be application or product-based. The company is required to submit an application to the certification body which undertakes an examination of the product, and if it meets the necessary criteria the certification body issues a certificate which allows the product to be marked in a certain way, usually with an identifying certification logo.

Available Data on VOC Emissions from Engineered Wood Products

Information in the literature on VOC emissions from engineered wood products is relatively limited, and what exists is primarily based on a few studies conducted by European and North American researchers. Wood species appears to be an important factor in determining VOC emissions, with terpenes, aldehydes and weak organic acids being the primary compounds of interest. Evidence suggests that emissions may be lower in products made from hardwoods, whilst in Europe it is evident that highly resinous species such as Scots pine can give rise to significant emissions from products, particularly terpenes. Research on North American softwood species suggests that the highest VOC emissions are associated with the southern pines (longleaf, shortleaf, loblolly and slash pines); this might be indicative of the likely behaviour of products manufactured from softwoods grown in northern NSW and QLD.

There is some evidence that, for a given wood feedstock, emissions from MDF are significantly lower than those from particleboard. Likewise, there is evidence that particle size, drying and hot pressing temperature, hot stacking and surface coatings can all influence emissions. The type of adhesive used in products is believed to be an important factor, though very little hard evidence exists in the literature to support this. There is little or no information on VOC emissions arising from production processes.

In summary, it appears that a range of raw material and process variables have an impact on VOC emissions from engineered wood products. Given this, it is very likely that emissions will be specific to individual production lines/plants, overlaid with seasonal variations. Australian products would therefore need to be comprehensively screened to determine their VOC emission characteristics.

Regulatory Scenarios for Australia

There are no compulsory indoor air quality or product emissions requirements for VOCs in Australia, but based on international experience it is likely that Australia will develop compulsory requirements in due course. A key indicator for this is the development of voluntary codes, which preceded the development of compulsory requirements in Europe.

The compulsory requirements are likely to take the form of a reduction of inputs from building materials and other sources. As a result, these requirements are likely to be reflected in product standards and the Building Code of Australia (BCA).

The engineered wood products industry is urged to develop a proactive approach to this standardisation process, or risk losing any input to the development of guidelines and product standards.

Conclusions and Recommended Actions for Industry

It is evident that globally the regulation of VOC emissions from wood products is still very much a 'work in progress'. Mandatory regulation is in its infancy, and regulation is currently predominantly through a variety of voluntary schemes.

One of the issues that is limiting the ability to progress the regulatory environment is the complexity of detecting and quantifying VOC emissions from wood products. Furthermore, there is relatively little available data on VOC emissions from either products or processes.

Whilst the regulatory environment around VOC emissions will be slow moving, in time it is highly likely that there will be a tightening of regulations both globally and in Australia. Given this, it is recommended that the following actions should be considered by the Australian engineered wood products industry:

- Undertake a program of work to evaluate product and process VOC emissions. This will enable the industry to identify any potential issues, and provide plenty of time to implement mitigating strategies.
- Engage in the setting of international standards on VOC emissions.
- Determine and agree appropriate levels of VOC emissions from products for inclusion in the appropriate product standards.
- Engage in the development process for Voluntary Codes or develop appropriate industry-based voluntary codes.
- Engage the Australian Building Codes Board to ensure that the Building Code of Australia approaches the issue of IAQ in a controlled manner.
- Engage government in the most appropriate way to set IAQ guidelines.

1. BACKGROUND

The emission of volatile organic compounds (VOCs) from wood products, and their potential impact on the health and wellbeing of people, has become an increasingly important issue over the last twenty-five years. This chapter presents a brief overview of the history of VOCs derived from wood products, focusing in particular on the various voluntary and imposed regulatory mechanisms that have evolved over time, and profiles the main stakeholders involved in the topic area.

1.1 Eco-Labels

The emission of VOCs from wood products was first categorised through the green labelling of products rather than by legislation. The history of the eco-labelling system can be traced back to 1977, when the most widely recognised of the environmental labels, the German Blauer-Engel (Blue Angel) environmental label, was launched. The label is owned by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, and as such uses recognised standards for sampling and testing. This eco-label was launched in Germany in response to growing green consumerism and false or unsubstantiated claims made by manufacturers. The category "Low-Emission Wood Products and Wood-Based Products RAL-UZ 38" documents the Blue Angel criteria for low emission wood products. After changes to include VOC criteria in the late 1990s and new criteria produced in 2002, the low emission wood product requirement now includes VOC limitations (Blue Angel RAL-UZ 38; Plehn *et al* 2000). In 1994 there was an attempt to link all the labels and the Global Eco-labelling Network (GEN) was formed. Whilst there has been some success with this system, the individual labels continue to be used and recognised in their own right.

1.2 Green Consumerism

The inclusion of VOC emission limits for wood products in the green label systems, and also into some Government legislation, has been driven by the increasing consumer demand for both 'safe' and 'green' products. This trend is partly fuelled by scientific evidence that low levels of VOC contamination can, at least in some circumstances, affect the health of people continuously exposed to these chemicals. The second related and possibly more significant driving force is the green consumer market. Green buying power in Germany, Scandinavia and Japan in particular has created a significant new market which continues to grow; these buyers, with large disposable incomes, are willing and able to opt for more expensive green products. In many cases the decision to buy 'green' is not motivated through recognition of rigorous scientific evidence, but rather by perceptions that products are safe and environmentally friendly; buying 'green' is also seen as a trendy lifestyle option. Companies like IKEA have targeted this large niche in the market through both modern designs and promotion of their environmental image.

The move by IKEA to target the green market has been an interesting progression (TNS 2001). In Denmark, the public were first becoming aware of the connections between indoor air quality and man-made materials in the mid-1980s. In 1981 Denmark introduced a law limiting the amount of formaldehyde that could be emitted from particleboard used in furniture. While the introduction of this law went relatively unnoticed, IKEA did nevertheless mandate that its suppliers comply with the Danish limits. However, after testing by the Danish Government, IKEA furniture containing particleboard was found to exceed the limits. IKEA was taken to court and fined, and the publicity that followed resulted in a 20% reduction in sales of IKEA products on the Danish market.

From this point onward IKEA has proactively lead the way in the development of new adhesive technology and quality control procedures for panel manufacturers. The environmental awareness also spread to other areas such as transport, recycling and packaging materials. However, in 1992 IKEA experienced a second formaldehyde 'crisis'. This time it was in Germany, where "Billy the Bookcase" was found to have high formaldehyde emissions. In what is perhaps the best known case involving formaldehyde and wood-based materials, the resulting recall of product was estimated to cost IKEA US$7 million. The other indirect and associated costs were likely many times this. The public image of IKEA and wood-based panels is still affected by the case. Within IKEA, the effect of the bad publicity from both events has been instrumental in the development of a range of environmental strategies. These strategies have strongly influenced the evolution and development of the company, and have become integral to the way the company is marketed. The environmental systems at IKEA now cover the areas of life cycle analysis, transport, sustainability of the raw materials and health and safety of the products. The public are made aware of the company stance through the marketing of the company image and the way the company conducts its business. For example, recycling and waste reduction within IKEA stores is heavily promoted to its customers.

Interestingly, through all these changes and re-imaging, "Billy" survived the bad publicity and is still being marketed under the same name; the notorious bookcase is now one of IKEA's biggest selling items.

1.3 The move from Formaldehyde to VOCs

Most of the trading areas which impact upon Australia and New Zealand have some degree of legislative control over formaldehyde emission levels. This is because, firstly, in the past the extensive use of urea formaldehyde (UF) resin in the manufacture of wood products, when combined with reduced air turnover in modern apartments, produced relatively high formaldehyde levels in living spaces in Japan, Scandinavia and USA. Secondly, formaldehyde at these high levels was reasonably clearly linked to health problems. Lastly, formaldehyde emissions were relatively easy to measure. Legislation has only recently started to be considered for other VOCs. However, green labelling of products based on VOC emissions has occurred for some time within the major trade areas of Japan and Europe, and there is little doubt that it will increasingly be extended to more world regions. The most concerning aspect of this trend is that the legislation being considered may also limit and control the allowable level of even naturally emitted VOCs from wood products used within homes. However, there are a number of issues associated with quantifying VOCs and rating them based on their potential harm, which will likely slow this process.

With the increasing public and scientific interest in the more general issue of VOC emissions, many researchers around the world have been investigating the technology available for laboratory simulation of indoor spaces using various controlled test chamber systems; the marrying of these with available identification and quantification methodologies has also been a focus area. Scandinavia, Germany and Japan all have leaders in this research field. As would be expected, the countries with high discretionary incomes and a large "green" consumer population, such as Germany, Denmark, Norway and Japan, were the ones to also consider legislation to limit VOC emissions from building products. To some extent the ability to legislate has been handicapped by the difficulty in accurately measuring these compounds quantitatively. While measurement of formaldehyde is relatively simple compared to the wider issue of all VOCs, there are nevertheless many common technical issues. The pre-treatment and conditioning of samples, plus the environment and systems used during measurement must be tightly controlled. The techniques used must be meaningful in terms of adequately simulating indoor spaces and they must also be reproducible within and between laboratories. However, while formaldehyde measurement is carried out with relatively simple equipment, that used for other VOCs is much more complex; the methods must not only correctly identify but also quantify the very low levels of VOCs involved. In addition, the regulations have had to consider not only the available systems for measurement, but also the known hazard rating for each VOC found in wood products.

While the technology for measurement and assessment of VOCs is still in a developmental phase, the first of the VOC emission regulations in Germany are now in place, albeit covering just one category of flooring. An unexpected outcome from the regulation is that it may lead to restrictions in the use of some types of wood. The most recent development is that California will progressively introduce legislation to lower formaldehyde emission levels and will phase in requirements to certify products, but as yet there has been no move in the direction of VOC regulation.

1.4 European Trends

Germany was the first country in the world to regulate formaldehyde emissions from wood products and has also led the way with VOC regulation. In April 1980 the "ETB-Richtlinie uber die Verwendung von Spanplatten Hinshctilch der Vermeidung unzumutbarer Formaldehydlkonzentrationenin der Raumdolft" formaldehyde regulation was introduced. This was based on steady-state conditions in a chamber. In April 1989 this method was reviewed by European Collaborative Action's COST Project 613 "Indoor air quality and its effect on man" (ECA no.2, 1989). In 1989 the European Construction Products Directive (CPD) also came into force (CPD 1989). This contains some generalised statements about the emission of gases, but does not contain directives as to how these are to be controlled or set limits on concentrations.

Between 1990 and 1992 a CEC project, “Investigations on Comparability of a Large Chamber Test for Formaldehyde Emission from Wood-Based Panels”, checked the reliability of the large chamber test method, after which the ENV717-1 standard was used as the reference test standard for legislation in Denmark, Sweden and Germany.

In 1995, a reference book was published which discussed the allergy, irritation and long term effects of VOCs on health. This book, “Indoor Air Quality - A Comprehensive Reference Book” formed the reference for legislation (Maroni *et al*, 1995).

In Germany, the Committee for Health-related Evaluation of Building Products (Ausschuss zur gesundheitlichen Bewertung von Bauprodukten (AgBB)) was established in 1997. The committee is comprised of representatives from seven government groups with an interest in health, the environment and building products.

In September 2005 the AgBB committee produced the contribution to the construction products directive: “Health related evaluation procedure for Volatile Organic Compounds (VOC and SVOC) from Building products” (AgBB, Sept 2005). This has now been applied in Germany, albeit to fire resistant flooring products only. The CEN/TC 351/TG 2 N016 committee rejected its adoption for wider EU regulations, based on objections from Sweden and Spain. The Swedish position was possibly based on the knowledge that some Swedish products, such as non-glued softwood flooring (which is used extensively in Swedish summer houses), could potentially fail to meet emission requirements.

1.5 Japan, Australia and New Zealand

In the late 1990s, several papers were published in Japan discussing a range of human health symptoms associated with ‘sick house syndrome’. These symptoms were linked to gases emitted from the building products that were being used.

In 2000 the JANZ (Japan, Australia and New Zealand) standards harmonisation committee was formed to produce a set of harmonised standards to aid trade between the three countries. From the working committee, JANZ 16 was produced – this was an updated version of the formaldehyde emission test method known as the Japanese desiccator method, briefly documented in JIS5905 and JIS5908.

In 2001 the Japanese Industry Standards published JIS A 1460-2001 (Japanese Desiccator method). This method closely adhered to that described in JANZ 16. AS/NZS draft methods followed shortly after this.

On July 12, 2002 the “Promulgation of the Law Partially Amending the Building Standard Law” was issued (BCJ 2003). This law restricted the use of formaldehyde emitting wood products used in living spaces in Japan, and covers all building materials and permanent fittings used inside buildings. The law applies to all buildings whose construction was commenced after July 1st 2003. The law defines allowable chlorpyrifos and formaldehyde levels and also provides information on construction and ventilation practices, but does not extend to other VOCs.

In 2003, the Japanese Standards JIS A 1901 and JIS A 1911 were published. These standards give procedures for the measurement of VOCs other than formaldehyde in building products (including adhesives). They also contain target values for products for a number of VOCs. While these testing procedures have been in place for some time, to date there has been only one regulation applied to VOCs from wood products. This specifies the quality of indoor air in school buildings, which indirectly dictates the allowable VOC emissions from products used within schools.

1.6 The Future

Many consumers do not consciously distinguish between issues such as product safety and environmental impact. Advertising is thus tailored accordingly to appeal to green consumers. Carbon footprints, recycling and product healthiness are discussed daily in the popular media, and in response to public and scientific opinion Governments are now legislating to control these aspects of products sold in their countries. Additionally, they are increasingly able to enforce the legislation controlling the products coming into their regions through systems such as CE and JIS marking. There has been an increase in green consumerism in the wealthy regions of the world, which is being used to advantage by major brands like IKEA and supermarkets such as TESCO, which lead much of their advertising with claims of being environmentally and safety conscious. These claims are increasingly reinforced by proof of compliance using branding with one or more green labels. One example of green branding is that used for wood-based products in the UK, where many products are now FSC (Forestry Stewardship Council) branded. In the future it could be expected that green branding will become a pre-requisite for the sale of wooden products in the main home stores across Europe.

Australia has an opportunity to exploit green, high income off-shore markets. Australia already has a green image in Europe. However, in the future this image alone may not be sufficient to facilitate market access. The carbon footprint of products is now being measured and advertised to promote products in Europe, and products transported large distances are being targeted as environmentally unsound. This is clearly a distinct disadvantage for Australian wood products. However, a focus on the sustainable manner in which the resource is grown, the potential in future for wood products to be accepted as carbon ‘sinks’, combined with FSC and other green type branding, could overcome this and reinforce the present market perception of Australian products as being safe and beneficial for the planet.

However, before this type of marketing could succeed more knowledge is required on the processes and resulting products, in particular with respect to VOC emissions. This could potentially lead to changes in some processing methods (such as high temperature drying), to ensure that products will comply with more stringent future

VOC emission limits. The background scientific work should be done now to determine the future market positioning of Australian wood products. If this work is done before the provision of VOC emission data is a mandatory component of product sales, then the knowledge gained could be used to position Australian products to take advantage of health, safety and environmental legislation and the wave of ‘green’ consumerism.

The following chapters review the current knowledge on available technology and approaches for determining VOC emissions from wood products, the current state-of-play in the global regulatory environment, the available data on product and process VOC emissions, and the potential future regulatory scenarios for Australia. From this, a recommended action plan going forward for industry is proposed.

2. METHODS FOR DETERMINING VOC RELEASE

2.1 Types of VOCs

The World Health Organisation (WHO) has categorised airborne organic compounds in terms of their boiling point ranges (1989). With respect to VOCs, three classes are defined: very volatile organic compounds (VVOCs), with boiling points in the range <0 to 50-100 ^{o}C; volatile organic compounds (VOCs), with boiling points in the range 50-100 to 240-260 ^{o}C; semi-volatile organic compounds (SVOCs), with boiling points in the range 240-260 to 380-400 ^{o}C.

There are potentially hundreds of different VOCs that can be emitted from engineered wood products, depending on the wood species used and various processing parameters. However, other than formaldehyde, some of the more common ones include terpenes e.g. α-pinene, 3-carene, limonene, other aldehydes e.g. pentanal, hexanal, heptanal, and various organic acids e.g. formic acid, acetic acid (Ohlmeyer, 2008; Roffael et al, 2006).

Individual VOCs are only considered to be potentially harmful to humans above a minimum concentration threshold. Accordingly, the 'lowest concentration of interest' (LCI) is defined for a range of individual compounds that are emitted from wood products into the surrounding air. The LCIs typically fall in the range 500-2000 μg m^{-3} for the majority of compounds, but can be as low as 16 μg m^{-3} for compounds such as 2-heptenal (Ohlmeyer, 2008).

The potential effect of VOCs emitted from engineered wood products on human health is not definitively known. The LCIs for the various compounds have been derived from studies where a measurable effect on humans or laboratory animals is evident. At the lower concentrations such effects may be limited to mild irritation of eyes or the respiratory tract. The actual effects of exposure to VOCs will be dependent upon concentration levels, duration of exposure and the sensitivity of individuals. As well as eye and respiratory irritation, symptoms may also include headaches, dizziness, drowsiness, fatigue, blurred vision and skin irritation. Perhaps of most concern is that compounds such as α-pinene, which is commonly emitted from many commercial softwood species, have been shown to be mutagens, whilst the US EPA is on record as stating that many VOCs appear to pose a significant risk of cancer (Maroni *et al*, 1995).

2.2 Measurement Technology

2.2.1 Introduction

There are a number of steps involved in determining the level of VOCs in, or emitted from, wood products. The standard procedures specify some of these, but they are by no means definitive. However, each of them must be considered and controlled when carrying out VOC emission studies if meaningful data are to be generated. The main steps that need to be considered are as follows:

i) Sampling and pre-treatment history.
- Time after treatments such as heating.
- Packing.
- Temperature of sample prior to testing.

ii) Test chamber conditions.
- Relative humidity (RH) and temperature.
- Fixed air replacement using cleaned air.
- Air velocity over the sample.
- Sealing of edges and back.

iii) Collection and concentration of VOCs.
- Volume of sample and frequency of sampling.

iv) Identification and quantification of compounds.
- Extraction of VOCs from sampling system.
- Identification and quantification of various molecules.

Formaldehyde emissions can be determined by many methods. In addition to those documented in the international standards, many researchers have developed their own systems, ranging in complexity depending on the end use of the data. For example, the quality control methods used in factories are simplified methods to facilitate fast, economical factory testing. These methods often use established correlations to the standard reference methods to approximate the “true” emission values. The reference methods used as the standard by which other methods are validated generally use chambers representing small rooms at standard temperature, RH, air exchange rate and air velocity.

There are a number of differences between the test procedures used for determining formaldehyde content or emissions and those used for other VOCs. The identification and quantification of other VOCs is typically achieved by gas chromatography - mass spectrometry (GC-MS) or gas chromatography - flame ionization detection (GC-FID), rather than the spectrophotometric methods commonly used for formaldehyde determination. Another difference is that VOC testing is normally only carried out by specialised research groups of major companies, by research organisations or by contract testing houses. This is partly because the regulations are new and the procedures only recently documented, but also because the collection, concentration and measurement of the emitted compounds requires careful sample handling in clean air conditions, accurate technical work and good quality control and reference systems. Most manufacturing plant laboratories could not meet these requirements. The testing is also expensive, since both the chamber for collection of the sample and the analytical equipment are complex, and the procedures are time consuming compared with those used for determining formaldehyde emissions.

With one or two exceptions, such as the German AgBB scheme, VOC testing is currently carried out for green labelling or for research purposes rather than to comply with regulatory conditions of sale. The green labelling systems specify one or more international standards for sampling and testing. However, they also normally specify some additional requirements, such as the number of days after production for testing, the days in the chambers and sampling intervals.

Whilst there are a number of technologies used for assessing the VOC emission potential of wood products, only chamber emission testing has been migrated into the standards. The chamber test procedures specify not only the conditions of test in terms of RH and temperature, but also the sampling intervals, the collection system (normally into sorbent tubes) and the analytical methods to be used for identification and quantification of the molecules (normally GC/MS).

The methods outlined in the following sections are not exhaustive, but nevertheless represent the most common ones used by the leading researchers in Europe. The organisations consulted included the following: S.P. Technical Research Institute of Sweden; Hamburg University, Germany; Akzo Nobel, Casco Adhesives AB, Sweden; Dynea AB, Norway; IKEA of Sweden. These organisations use a number of techniques and methods for research or screening trials which are not documented international standard procedures. They have been developed in-house as quicker and less expensive options for screening large numbers of samples.

2.2.2 Sample Pre-treatment

The level and range of VOCs emitted is dependent on the sample pre-treatments, particularly heat treatment of the material. The relationship between the heat treatment and test result will be dependent on the particular sample and time to testing after exposure to the treatment.

It is recommended that samples are frozen (-60^{o}C) from the time of treatment (or sampling) until the sample is tested.

2.2.3 Sorbent and Thermal Desorption

Most of the methods used to determine VOC emissions or content involve capturing the VOCs in air or other gases, and sampling of the air into sorbent tubes. Different materials are used in the sorption tubes depending on the volatility of the VOCs; charcoal is used for VVOCs, Tenax for VOCs and polyurethane foam or XAD-2 for SVOCs. Following capture the compounds are liberated by thermal desorption and subsequently characterised using GC/MS or GC/FID. For interested readers, the technology associated with thermal desorption is well described on the Markes International website (http://www.markes.com).

2.2.4 Chamber Tests

ISO, ASTM and JIS have standards for VOC measurement from wood materials. The ISO standards are now also cloned into EN and country standards such as BS.

Each of these standards allows chambers to be made in various sizes. The sample is held under constant conditions for a period of time. While the standards do not specify that shape of the chamber, only the JIS chambers are commonly made as cylinders, whilst the rest are typically cubes or rectangular cuboids. In all cases air samples are taken from the chamber at intervals and the volatiles are collected using sorbent tubes. These tubes are subsequently heated and the VOCs measured using GC/MS or GC/FID.

One exception to the common chamber shapes is a development of Hamburg University which uses standard 20 litre glass desiccators modified with circulation fans and sampling systems to comply with the ISO and EN chamber standards. There are some issues sampling into sorbent tubes using such small chambers since the air volume that can be taken from them does not allow a standard test to be completed. However, the ability to carry out a large number of tests at one time makes this an economical option for screening trials where the use of, say, $1m^3$ chambers may be prohibitively expensive.

S.P. Technical Research Institute of Sweden is one company that manufactures large chambers. According to its website “The $1m^3$ chamber was originally developed and designed for measurement of emissions of volatile organic compounds (VOC) and formaldehyde from materials. The chamber is made of electro-polished stainless steel with inner dimensions 65 x 102 x 150 cm (breadth x length x height). The volume of the chamber is nominally 0.9945 m^3. The internal surface is 6.337 m^2 thus giving a surface to volume ratio of 6.37 m^{-1}. The chamber is equipped with several inlets/outlets for introduction of gaseous reactants and for connection of sampling devices. A circulation (squirrel cage) fan for internal mixing is placed in the bottom part of the chamber. The chamber can be operated either in static or a dynamic mode. Dried and filtered air is supplied through a separate line; the flow is controlled by a flow meter and measured by a volume meter. Air change rate (ACR) can be regulated between 0.1 – 4 h^{-1}. The chamber can be operated at room temperature of 23 ºC and atmospheric pressure; if needed it can be regulated between 15 and 30 ºC. Relative humidity can be varied between 20 and 80 %. Distilled water is used for humidification. The temperature and relative humidity are controlled by sensors. Air and gaseous components are supplied to the chamber through a mass-flow controlled system (model 5850S, Brooks Instruments) and Teflon® lines. The chamber can be used for emission measurements of organic compounds from materials, as well as a reaction chamber”.

Figure 2.1: Example of a $1m^3$ test chamber.

2.2.5 Head-Space Thermal Desorption

Head-space testing is not documented in international standards, though several research organisations, including Hamburg University and SP Technical Research Institute of Sweden, use this technique. The technique is economical and fast compared to the chamber methods.

Head-space testing involves streaming helium or air over a wood sample that is contained within a glass vial. In most cases the sample is heated to increase the emission of the volatiles. The volatiles are cooled to concentrate the gases and then reheated (thermal desorption). The gases are then measured directly using GC/MS or GC/FID. This head-space system is often used as a screening technique before further testing in chambers.

A version of the head-space technique used by Hamburg University and SP Technical Research Institute of Sweden is to cut a sample about 30mm long and 10mm square. The sample is machined on one surface and the other surfaces sealed. The sample is placed into a glass tube and heated in a thermal extraction attachment for a GC/MS. The volatiles are fed directly into the GC. The heating process can produce sufficient volatile levels to give results directly without concentration in sorbent tubes. In common with all the head-space variations the correlation between this method and the chamber systems are not proven, and detection at the lower concentrations may be limited. However, the system is used to screen material to find which volatiles are present in high concentration and to pinpoint samples of interest for further testing in standard chambers.

A variation on this procedure is to heat the test material in an EN717-2 chamber and to test a sub-sample in GC/MS. This option allows testing of large samples at one time and the larger samples can be used to produce a higher concentration of gases than the other head-space techniques.

There are a number of issues with the head-space procedure that need to be examined further. These include:

- Detection limits – in comparison to approved reference chambers.
- The effect of heat on the sample, especially when the emission caused by heating of the material during manufacture may be of primary interest.
- Inability to produce results plotted against time after production.

2.2.6 Head-Space Into Sorbent

A variation used at SP Technical Research Institute of Sweden is to sample from head-space into sorbent tubes.

The head-space tubes are part filled with the material of interest, possibly sawdust, and are heated at up to 200^{o}C. The gases are carried on helium into the sorbent tubes which are then heated to drive off the VOCs. Measurement is with GC/FID. This system concentrates the VOCs and would detect at lower concentration levels than the direct head-space testing system.

2.2.7 Micro-Chambers

The most common micro-chamber used in the panels industry is the Field and Laboratory Environmental Chamber (FLEC). The FLEC was a development by SP Technical Research Institute of Sweden in collaboration with Danish researchers. The system is rapid and relatively inexpensive. It also has the great advantage of complying with ISO and the ENV provisional standards. Many of the green labelling systems also allow the use of the FLEC.

The FLEC is a dished cell (like a pot-lid) which is placed on a test sample (flat panel). Seals produce an air proof cavity between the flat board and the dish within the chamber. Air of fixed humidity, temperature and flow rate is fed into and out of the space between the test panel and the chamber. The air sample is collected into sorbent tubes for analysis using GC/MS.

The method is documented in ISO16000, and is the method of choice by SP Technical Research Institute of Sweden and most other laboratories. The advantage it has over the large chambers is the ability to process many samples at one time. This means contract testing by this method is less expensive than the large chamber method. However, to produce time-emission curves, the samples must be kept in separated humidity and temperature controlled cabinets between measurement cycles. When considering wood materials and products in general, the major limitation of the method is that it can only be used with materials with flat surfaces of sufficient area to form a seal with the “pot lid”. In this respect the method is likely to be suitable for testing most engineered wood products.

Figure 2.2: FLEC micro-chambers at S.P. Technical Research Institute of Sweden.

Markes International also makes a micro-chamber system. It has the advantage of allowing the testing of six samples at a time. While this system does not claim to comply with international standards it may be a good way to screen large numbers of samples at ambient conditions.

Figure 2.3: Markes International micro-chamber

2.2.8 EN 717-2 Gas Analysis Method

Steckel & Ohlmeyer (2008) reported the use of a gas analyser (TimberTest™) to detect VOC emissions from samples of solid wood, OSB and fibreboard. They used a method based on EN 717-2 (1995), which is used for determining formaldehyde emissions from wood composites. The method involves heating the sample to 60^{o}C in a chamber, and emitted VOCs were collected on Tenax absorbent in glass tubes and subsequently analysed using GC/MS. The method was capable of detecting terpene and aldehyde emissions, though significant levels of dimethyl sulfoxide were also detected; this was attributed to the rubber seals in the instrument. The presence of this compound did not appear to influence the results obtained for VOCs emitted from the wood products. Repeatability varied with both the VOC and type of product e.g. 5% and 28% for aldehydes emitted from OSB and solid wood respectively, and 9% to 14% for terpenes. The authors also commented on the issue that it was difficult to correlate results with those obtained from the larger standard chamber tests.

2.2.9 Solvent Extraction

It should be noted that there are alternative ways of measuring VOC emissions from materials for the built environment. The simplest methods involve extraction using solvent and determination of the volatile molecules in the extract. This procedure requires material-specific correlation using test chambers. Except for the standard EN120 for formaldehyde, this system is not used routinely for measuring VOCs emitted from wood products. One reason why it is not favoured is likely linked to health and safety concerns associated with the use of organic solvents; this is the principal reason for the EN120 method largely falling out of favour.

2.2.10 ISO, ASTM, EN and JIS Methods

There are a number of national and international standards that cover the testing of wood products. The scopes of the key standards are detailed in Appendix 1. The international test standards vary in a number of ways; some of the main differences are summarised in Table 2.1.

The standard methods are referenced by the various labelling schemes, which also specify their own requirements for product sampling, testing and for interpretation of the results. ISO has recently published a set of “horizontal” standards, meaning that the sampling, chamber testing and evaluation of the VOCs are in separate standards, avoiding the repeat of sections within each standard.

To date there have been only a few attempts to assess the laboratories which conduct VOC testing for the voluntary labels. Evidence suggests that there are potentially huge discrepancies between results from laboratories supposedly using the same standard methods. Oppl (2006) states that 15-fold differences in values were reported by laboratories for certain compounds. Acetic acid and glycol, as well as SVOCs in general, were highlighted as compounds which generated high variance in measured values between laboratories.

Table 2.1: Main differences between chamber test standards.

	Emission Cells	Large Chambers			
	ENV 15052 ISO 16000-10	**JIS A 1911**	**JIS A 1901**	**ASTM D6330**	**ENV 13419-1 ISO 16000-9**
Chamber Material	SS or Glass	SS	SS	SS or Glass	SS or Glass
Volume (m^3)	Not spec	2 to 80	0.02 to 1	0.05 (or other)	Not spec
Duration (days)	3 and 28		1, 3, 7, 14, 28	1 and 3	3 and 28
Temperature (^oC)	23	28	28	23	23
RH (%)	50	50	50	50	50

Current situation with EN Standards

The following EN and ENV (provisional standards) are published:

EN 717-1: 2005: Wood-based panels. Determination of formaldehyde release. Formaldehyde emission by the chamber method.

ENV 13419-1:1999: Building products. Determination of the emission of volatile organic compounds. Emission test chamber method.

ENV 13419-3:1999: Building products. Determination of the emission of volatile organic compounds. Procedure for sampling, storage of samples and preparation of test specimens.

The two ENV13419 provisional standards have stalled and have not progressed to be full standards. The action to stall progression of these standards was taken because the ISO standards covering the same ground progressed faster than the EN standards. Some working group committee members are also on the corresponding ISO working groups and did not think duplication of the standards, at least in the early stage of development, was useful.

There is ongoing debate on the need to further develop the EN standards. Despite this, the CEN committees are progressing the EN standards and CEN/TC 112 is working on an extension of EN717-1 to include other VOCs (CEN/TC 112 plenary resolution 388 – Dresden 2004-09). This decision to continue the development of EN717-1 is based on the long experience of organisations working in this manner. In addition there is the belief that there are technical errors in the ISO series standards including the interference with formaldehyde and VOC determinations. Furthermore, the ISO standard does not require the establishment of steady state determination, unlike the EU methods, and this is considered to be technically incorrect by some researchers.

2.2.11 Summary of Measurement Issues

It is evident that the field of VOC measurement is currently fluid, with key groups attempting to identify the best approaches for generating reliable qualitative and quantitative data on VOC emissions in both a timely and cost effective manner. A number of different methods are currently used by research groups which generate data that are not directly comparable. Even where national and international standards are based on similar approaches e.g. chambers, there are differences which mean measured data are not necessarily directly comparable. It is also evident that in many cases the methodology developed to date is far from robust, and that the output data generated depends considerably upon operator/laboratory experience. Until these issues are resolved satisfactorily, it seems unlikely that any rigorous legislation or regulations could be implemented to monitor and control VOC emissions from engineered wood products in Australia.

Although unified standards and test procedures may be some way off, it is however likely that the Australian industry will want to conduct some tests on its products in order to identify any potential issues that will need to be addressed. If this is the case, the methods selected for any testing would need to take into consideration the objectives of the work, as some of the current research methods have limitations. Head-space testing, for example, uses heat to produce desorption directly from the sample. Unlike the chamber testing methods, head-space testing does not allow successive tests on one sample, so decay curves cannot be produced. A second issue is that head-space testing may complicate the interpretation of results from samples which have been previously heat-treated during processing, since the reheating for desorption may interfere with the results. Additionally, most of these quick methods have not been validated against the reference chamber methods; the results are only useful when referenced to internal control samples.

To further complicate interpretation of emission results, Hamburg University has reported studies indicating that the VOC emission after heating of the wood is not a simple decay curve – as observed in the case of formaldehyde. For some volatiles the emission increases for some weeks after heat is applied and then decays. This suggests that for heat treated wood it will be important to determine some decay curves - which is not possible using the direct desorption approach. One example of the importance of knowing the time-emission relationship is the case of the German AgBB/DIBT regulations for fire resistant flooring, which require that testing is conducted shortly after production. For this regulation, the relationship between time and emission result is clearly important.

Despite these drawbacks, the quick methods such as head-space testing may well still be very useful. For large scale trials, such as determining the differences between species/products, it may be a good first approach. If sufficient controls are used, these methods may be useful for initial examination of different process options. It may also be possible to limit heat input during head-space testing to less than the initial heat treatment to limit the interference between the heat treatment of the wood during processing and the heat applied during testing.

If head space testing is used for the assessment of Australian products, then it is recommended that some chamber testing is also conducted to provide reference results. If contract testing is conducted in Europe or elsewhere, at least some testing should be carried out in parallel in Australia or New Zealand to build experience with interpretation of the results.

2.3 Testing Services

2.3.1 Location

Europe

A considerable proportion of the expertise in VOC testing resides in Europe. The European organisations known to provide contract testing and consultancy services for VOC testing are profiled below, including details of the support facilities and services provided. Contact information for the organisations is provided in Appendix 2.

Eurochamp
Eurochamp is a scientific group which operates chambers for environmental testing. The following information is taken from the Eurochamp web site.

EUROCHAMP is a research project funded within the EC 6th Framework Programme, Section "Support for Research Infrastructures - Integrated Infrastructure Initiative". 12 European Partners are the backbone of this project, which provides a grid of environmental chambers designed for the scientific investigation of atmospheric chemical processes. A number of associated research groups world-wide contribute to the project by providing expert knowledge on specific fields of atmospheric science. The EUROCHAMP project started on June 1, 2004 and will be funded for five years. The different smog chambers operated within the EUROCHAMP grid can be used by any European scientist who is interested in the investigation of atmospheric processes.

Eurofins Environment A/S
Eurofins is the largest known commercial organisation providing VOC testing for wood products. It employs 8,000 people on 150 sites in 29 countries. The company has a wide range of test systems available, and can test VOC emissions in accordance with procedures stipulated in most standards and green labelling schemes.

Fraunhofer - Institute for Wood Research Wilhelm-Klauditz-Institut (WKI)
Has the following test equipment:

- GC/MS with thermal desorption unit
- GC/FID with thermal desorption unit

- GC/AED with Cold-Injection-Systems
- Head-space-GC/FID
- GC/ECD with Cold-Injection-Systems
- HPLC with Fluorescence/UV-Detection
- HPLC/MS-MS
- 1 m^3 Glass emission test chambers
- 1 m^3 Stainless steel emission test chamber
- 250 litre Stainless steel chambers
- 23 litre Glass emission test chambers
- 23 litre Stainless steel emission test chambers
- Emission test cells

Hamburg University
Has the following test equipment:

- 20 litre desiccator
- $1m^3$ chamber
- Head-space

SP Technical Research Institute of Sweden
Has the following test equipment:

- $1m^3$ chamber
- Direct thermal desorption (Markes International equipment)
- Thermal desorption for GC/FID
- FLEC chambers

Australia

At least one organisation in Australia provides an analysis service for measuring VOC emissions from building products. The company, Cetec, which is based in Notting Hill, Victoria, is able to measure total VOCs (TVOCs) emitted from products using the small chamber method and GC/MS, in accordance with ASTM and ISO test methods. The Laminex Group has used the company to evaluate TVOC emissions from selected products to confirm their compliance with limits set by the Green Building Council of Australia (Green Star Compliance).

2.3.2 Costs for testing

Costs for testing the VOC emissions of individual products vary according to the test standard under which testing is conducted, the level of detail required e.g. TVOCs, or quantitative determination of individual compounds. Typical prices quoted by Eurofins for testing a sample of an individual product range from around €1,000 to €3,500. Hamburg University is prepared to consider lower rates if data can be included in co-authored publications etc., otherwise it charges commercial rates for confidential contract work.

3. REGULATORY REGIMES

3.1 Introduction

The desire to reduce indoor air pollution and control indoor air quality is driving the regulation of VOC emissions from building products. This need has been established rightly or wrongly from the observation of Sick Building Syndrome (SBS) or Building Related Illness (BRI).

The control of VOC emissions is furthest advanced for materials such as adhesives, paints and carpets, but the focus has also been on flooring products as these represent a large surface area in buildings. Additionally, there has been some focus on emissions from furniture and raw composite wood products such as MDF and particleboard.

In parallel with the case of VOC measurement, the regulation and control of VOCs from building products in general, and wood products in particular, is still very much a 'work in progress'. The work on regulation only commenced in the 1990s and is still yet to be implemented in many countries. As a result, there are few fully developed national systems, and it is difficult to predict which might gain universal acceptance and implementation.

The regulatory environment broadly consists of two types of regulations, mandatory and voluntary. The voluntary codes are often administered by independent special interest groups. However, voluntary codes can also take the form of government developed or supported indoor air quality guidelines, which may be seen as precursors to legislated regulations. They can cover the material in the raw state such as particleboard and MDF, or they can cover the finished article such as a piece of flooring or furniture. The control can also be at a product level such as a label like Blue Angel, or it can be part of a purchasing or building certification program such as GreenStar.

The mandatory codes always take the form of government regulations. The most prominent of these for products is the German Institute for Building Technology (DIBt) scheme for flooring. This is a product emission regulation. Currently, other schemes rely on air quality guidelines. Generally, governments have been reticent to legislate in the area of indoor air quality because in the domestic housing market it may be seen to be too intrusive. It would also be almost impossible to administer.

The model that Germany and others appear to have adopted is to set specifications for emissions in the product standards. However, the desired maximum allowable concentration of VOCs is still to be determined, and there are issues relating to the additive effects of chemicals and the toxicological effects relating to these mixtures. The first step to setting the limit of emissions is to develop the LCI for a particular VOC. In general, LCI levels are calculated from the Occupational Exposure Limits

(TLV), and in the case of Germany these are the so called MAK values. The LCI is calculated by dividing the MAK value by a safety factor of 100-1000, depending on the hazard involved. Once the LCI is identified for a compound, in some cases the standard room loading for a material is used to calculate the maximum emission allowable from that material (see Section 3.4.1, Danish Indoor Climate Label system). The product standards are then referred to in the building code and therefore are the emission standards.

The voluntary codes are modelled on a standard product certification model. The certification body develops a standard which can be application-based, such as flooring, or it can be product-based, such as particleboard or MDF. The company is required to submit an application to the certification body which undertakes an examination of the product, and if it meets the necessary criteria the certification body issues a certificate which allows the product to be marked in a certain way, usually with an identifying certification logo.

The following sections provide insight into the current status of the various types of regulations. Mandatory and voluntary regulations are covered, as well as product labelling and building certification schemes. The information provided is not exhaustive for any given regulation; there is commonality in many cases, and this review has focused on highlighting the scope and differences amongst the types of schemes currently operating around the world.

3.2 Mandatory Codes

The requirement of a mandatory code obviously suggests Government involvement. Currently in Europe, government regulation is being driven by EU directives. Leading European nations involved in VOC regulation include Germany, the main Nordic countries (Denmark, Norway, Sweden and Finland) and France.

3.2.1 European Union

The European Construction Directive, 89/106/EEC (CPD 1989) contains a requirement for fulfilling the Essential Requirement No. 3 (ERN3) "Hygiene, Health and the Environment". This requirement has been devolved to the standardisation of all products. Ultimately products will not be able to be sold without the CE standardisation mark and this will in future cover environmental issues including emissions. However, the scale of the implementation means that many materials will not have requirements placed on them until the second generation of standardisation. Currently the regulation in the relevant wood panel's standards only relates to formaldehyde. It should also be noted that under proposed building products regulations, products will be forbidden to contain any carcinogens, mutagens and substances toxic to reproductive systems. Currently the regulations appear to exempt formaldehyde, even though it is considered a category 1 carcinogen by IARC. The European Union currently considers formaldehyde to be a category 3 substance, that is, a substance of concern for humans due to possible carcinogenic effects. It would be reasonable to expect that formaldehyde emission regulation will come under further scrutiny under these regulations over the coming years.

The DIBt (Ehrnsperger *et al*, 2006) in Germany has carried out research to look at how to implement ERN3 in the second standardisation phase. In the work two test examples were used: concrete and flooring materials. The results of this research form the basis for the regulations proposal for the entire EU.

Ehrnsperger *et al* (2006) recommend that because of the health relevance of VOCs and SVOCs, the total emission of these compounds should be determined in the form of the sum of the VOC (TVOC value) and the sum of the SVOC. All VOCs with a concentration >2 µg/m³ should be identified and quantified. The precise procedures should be based on the AgBB's (Sept 2005) VOC/SVOC evaluation scheme.

In Germany, the DIBt Approval Guidelines: Indoor Construction Products restrict the emission of VOCs and SVOCs from floorings (DIBt, 2004). Several countries have voluntary regulations for VOCs and SVOCs. They are limited, however, to determining the TVOC and SVOC values and individual VOC (e.g. styrene, toluene, 4-PCH, 4-VCH) and the VOC total parameter (e.g. sum of saturated n-aldehydes, sum of aromatic aldehydes). The AgBB's VOC/SVOC evaluation scheme goes further here, as approximately 140 individual substances are assessed in addition.

It appears that the proposed European Flooring regulations will be based on the German regulations, the so-called AgBB system.

Ehrnsperger *et al* (2006) note that the CEN standard Mandate 119 only gives cursory mention of health and environmental considerations in the standard for flooring and does not consider VOCs.

Recently there has been a flooring standard proposed by the CEN TC 134. The standard prEN15052 included VOC emissions from flooring products such as laminate flooring. However, the proposal was voted out in the last voting round, with what appeared to be some controversy. The responsibility for the development of a CEN standard has now been given to CEN/TC 351. The timing of this is likely to be 4 to 6 years.

3.2.2 Germany

Germany is the only country to have mandatory emissions standards for VOCs that cover flooring made from composite wood products. Ehrnsperger *et al* (2006) provide a general overview of German building regulations. The regulations have been developed and are administered by DIBt and involve the AgBB approval scheme. A detailed overview is given in the summary by AgBB (Sept 2005).

The specifications for VOC and SVOC flooring emissions in the DIBt regulations are given in Table 3.1.

In the AgBB's evaluation process for VOCs and SVOCs in floorings, products are first tested after 3 days in the chamber to determine if the $TVOC_3$ value is less than or equal to 10 mg m^{-3} and the carcinogenic compounds amount to less than 0.01 mg m^{-3}. If these two provisions are met, product testing is continued. In the second test, after 28 days many more parameters are evaluated: $TVOC_{28} \leq 1$ mg m^{-3}, $\Sigma SVOC_{28} \leq 0.1$ mg m^{-3} and other VOCs, which are evaluated with the help of the NIK (LCI) list of the AgBB scheme. The R value is determined ($R \leq 1$) with the NIK values by summing the quotients of concentration and NIK value of the respective substances. Further, the VOCs, for which no NIK value is available, are evaluated more precisely, with a sum value of $VOC_{without\ NIK} \leq 0.1$ mg m^{-3}. The sum of carcinogenic VOCs must also be ≤ 0.001 mg m^{-3}.

Table 3.1: DIBt specifications for flooring.

Parameter	**Day 3 Requirement (mg/m³)**	**Day 28 requirement (mg/m³)**
TVOC (C_6-C_{16})	≤10	≤1
∑ SVOC (C_{16}-C_{22})	No requirement	≤0.1
R (dimensionless)	No requirement	≤1
∑ VOC without LCI	No requirement	≤0.1
∑ Carcinogens	≤0.01	≤0.001

The requirement for DIBt approval for flooring products has gone through a number of phases, commencing with a trial period, then a requirement for fire retardant products, to the current stage that is compulsory.

In Germany, all flooring covered by EN 14041 (resilient, textile and laminate floor coverings) needs *de facto* approval of the DIBT based on VOC measurements made in accordance with the AgBB scheme. The same procedure is planned for products according to EN 14342 (wood flooring) (Emmler, 2007).

However, the EPLA (European Producers of Laminate Flooring Association) has recently applied to DIBt for a 'Classification Without Further Testing Procedure' for VOC emissions from DPL-laminate floor coverings (without sound absorption material). With this classification it is possible, that in the future, DPL flooring will not require initial tests.

3.2.3 Europe - REACH program

In addition to the proposed VOC scheme, a new registration scheme for chemicals was introduced in Europe on the 1st of June 2007. This regulation is called REACH

(Registration, Evaluation and Authorisation of Chemicals) (REACH Regulation 2006). Under this regulation, substances manufactured or imported (on their own or in preparations) in the European Union in volumes greater than one tonne per year have to be registered in a central database managed by a new European Chemicals Agency. The EC registration requirement applies to “articles” (objects composed of substances and/or preparations, with a specific shape, surface or design), where substances could be released during normal and foreseeable use. The proposal also contemplates pre-market authorisation of the use of chemicals of “very high concern,” placing a high burden of proof on businesses seeking to put these chemicals to any new use. Downstream users must also consider the safety aspects of their use of substances, take appropriate risk management measures and report required information.

It is believed that in due course these regulations will apply to VOC emissions from wood and wood products; how they will be applied is not clear.

3.2.4 Japan

In Japan there are three separate requirements that deal with indoor air quality or emissions. These requirements are controlled by different government ministries.

The Ministry of Land, Infrastructure and Transport (MLIT) regulates emissions of formaldehyde from the fixed components in buildings. This is the area that most manufacturers are familiar with, and covers the requirements of F**** and F*** formaldehyde emissions from wood panel products. The accompanying legislation restricts the use of panels with formaldehyde emissions greater than the F**** limit in fixed applications in buildings. These requirements are covered in the Building Standard Law dealing with Sick House issues. The only limitations are on formaldehyde and chlorpyrifos. However, there are guidelines for VOC emissions detailed in JIS A 1901 (see Table 3.2), but these are only mandatory in schools. Toluene, xylene, ethylbenzene, styrene, and acetaldehyde are likely to be made subject to VOC regulations at some stage (Dai Nippon, 2003), though sources in Japan suggest that this is unlikely to happen in the near future; industry has responded by introducing a voluntary certification scheme (see section 3.4.3).

Table 3.2: Guidelines for VOC emissions (JIS A1901)

Chemical Guideline Value from JIS A1901 Appendix 6	**(mg/m^3)**
Toluene	260
Xylene	870
p-Dichlorobenzene	240
Formaldehyde	100
Acetaldehyde	48

The Ministry of Education, Culture, Sport, Science and Technology (MEXT) has developed School Environment Health Regulations. The regulations stipulate limitations on some VOCs. A reference to relevant regulations was provided by the Building Centre of Japan. Pertinent information was taken from http://www.mext.go.jp/b_menu/houdou/16/02/04021302/001.htm and is summarised in Table 3.3.

Table 3.3: Limitations on some VOCs in Japanese schools (Japanese School Environment Health Regulations).

Compound	**μg/m^3**	**ppm**
Formaldehyde	100	0.08
Toluene	260	0.07
Xylene	870	0.20
Para dichlorobenzene	240	0.04
Ethyl benzene	3,800	0.88
Styrene	220	0.05

These guidelines are the same as those profiled in JIS A1901, with the addition of ethyl benzene and styrene and the exclusion of acetaldehyde.

The Ministry of Health Labour and Welfare (MHLW) publishes “Guidelines for Indoor Air pollution”. These guidelines cover formaldehyde and some VOCs (MHLW, 2007; Tanaka-Kagawa *et al*, 2005).

3.3 Voluntary Codes

It is apparent that the level of development in the voluntary codes for VOC control is greater than that for mandatory regulations. Many countries also publish guidelines for indoor air quality that invariably make mention of VOCs in some way.

Most regions have systems that cover VOC emissions from wood panel products. These are general product certification programs run by private or semi-private organisations.

AgBB requirements for indoor air quality with respect to VOCs and carcinogens are shown in Table 3.4.

The Institute of Environmental Epidemiology, Ministry of the Environment, Singapore (IEE, 1996) offers guidance on VOC and formaldehyde levels in indoor air (see Tables A3.1 and A3.2, Appendix 3). The guidelines specified have a wide margin of safety such that even if they are exceeded occasionally, toxic effects are unlikely to occur.

Table 3.4: AgBB requirements for indoor air quality.

AgBB Requirement	Day 3 (mg/m^3)	Day 28 (mg/m^3)
TVOC (C_6-C_{16})	≤10	≤1
∑SVOC (C_{16}-C_{22})	No requirement	≤0.1
R (dimensionless)	No requirement	≤1
∑VOC without LCI	No requirement	≤0.1
∑Carcinogens	≤0.01	≤0.001

The Japanese Ministry of Health, Labour and Welfare (MHLW, 2007) offers guidance on limits for VOC and formaldehyde levels in indoor air (see Table A3.3, Appendix 3). An interim guideline value of 41 $\mu g/m^3$ (7.0 ppb) is currently specified for nonanal, in the absence of sufficient toxicity data.

Brooksbank (2006) summarised regulations operating in a number of other Asian countries. Korean regulations for Indoor air quality are monitored by the Air Quality Management Act (1996). Standards exist for formaldehyde of 120ppb and guidelines exist for TVOCs as well as other pollutants. The builders of new apartments are required to measure and publish the results for several VOCs prior to building occupation. In China standards have been introduced recently which encompass TVOCs, formaldehyde as well as specific limits for toluene, xylene, and benzene. Hong Kong has guidelines which cover formaldehyde, TVOCs as well as toluene, xylene, benzene and ethylbenzene. Malaysia has published guidelines for TVOCs and formaldehyde.

Environment Australia (2001) has summarised and compared indoor air quality guidelines set by the National Health and Medical Research Council (NHMRC) of Australia with those for Canada, Norway and WHO, for a range of indoor air pollutants (see Table A3.4, Appendix 3). In most respects the LCI values for various VOC, TVOC and SVOC values have become the base guidelines for Europe.

The NHMRC (1996) indoor air quality guidelines (Table A3.5, Appendix 3) have in fact now been withdrawn, and no guidelines are therefore currently available for regulating indoor air quality in Australia. There are several issues relating to regulating VOCs in Australia. There is lack of clarity about who is responsible for VOC issues and the consequential impact on indoor air quality. Is it a health issue or an environmental issue, or for that matter a product issue?

There has been some discussion about the inclusion of indoor air quality under the National Environment Protection Council Act (NEPC Act 1994). The recent review of the NEPC Act, which determines the areas in which NEPC can operate National Environmental Protection Measures (NEPMs), now allows for NEPC to determine what are suitable subjects for NEPMs, although it will require a unanimous vote of Federal, State and Territory Environment Ministers for any subject currently not listed in the Act to be included. Indoor air quality is of some interest to NEPC and is part of the strategic planning of the Air Quality Working Group (Scott, 2007). This would allow for the development of a NEPM relating to indoor air.

There is confusion about the best way to control indoor air quality. There is no clear way that Australia could legislate to regulate VOC emissions. Furthermore, public reaction to control of the environment in which they live may be adverse. It would be far simpler to control the emissions at the input stage, that is, control building material emissions. But along with this, research is required to define IAQ guidelines and the development of likely indoor environment models to help define emission limits. These have been developed for Europe and should be relatively easy to adapt. The BCA could be used to control building parameters and specify suitable materials for each building type.

3.4 Product Labelling Schemes

Product labelling schemes form a large portion of the non-mandatory regulatory environment throughout the world. Some of the main schemes are reviewed in the following.

3.4.1 Europe

Blauer Engel (Blue Angel)

This voluntary labelling scheme covers composites in two ways. Blauer Engel RAL-UZ 76 (Blue Angel 76, 2006) “Low-emission Composite Wood Panels” covers labelling of raw panels. Emission restrictions are limited to formaldehyde and the limit is set at 0.05ppm in the chamber. RAL- UZ 38 (Blue Angel 38, 2002): ‘Low Emission Wood Products and Wood- Based Products’ covers finished products such as flooring and furniture. The flooring and furniture standard does restrict VOCs. Products must not exceed the emission values specified in Table 3.5.

Table 3.5: Blue Angel product requirements (RAL UZ 38 and UZ 76)

Substance	**Limit**
*CMT 24hrs	< 1 µg/m^3
Formaldehyde 28days	0.05ppm
VOC 28days (b.p. 50-250^{o}C)	300 µg/m^3 (flooring) 600 µg/m^3 (furniture)
SVOC 28days (b.p. >250^{o}C)	100 µg/m^3
CMT 28 days	< 1µg/m^3

*Carcinogens, mutagens & teratogens

Österreichisches Umweltzeichen UZ 07 (2003) Holzwerkstoffe (Wood-based panels)

This is an Austrian scheme. Requirements are listed in Table 3.6.

Table 3.6: Austrian VOC product requirements (UZ 07)

	Limit ($\mu g/m^3 hr$)
TVOC - 28 days	380
Hexenal	70
Nonanal	20

NaturePlus, RL 0209 (2004): Bodenbeläge aus Holz und Holzwerkstoffen ('Floorings made of wood and of wood-based panels')

The methodology to meet NaturePlus requirements is specified in EN 13419, parts 1 and 3; and EN 717-1. Specified limits are given in Table 3.7.

Table 3.7: NaturePlus VOC emission product limits (RL 0209) (summary translated from the original source document (NaturePlus 2004)).

	Requirement $\mu g/m^3$ (28 Day)
TVOCs	≤ 300
Total Sensitisers (MAK IV)	≤ 100
Total Bicyclic Terpenes	≤ 200
Total Alkyl Aromatics	≤50
Total K3, M3, R3; MAK III3	≤ 50
Total n-Aldehydes	≤ 180
Formaldehyde	≤ 36 (0.03ppm)
Odour	≤ 3
Total SVOCs	≤100

EU-Blume (Flower) (2002): Rigid floorings

This is the mark promoted by the European Union (European Union Eco-label 2007) for floor coverings, but it doesn't refer to wood-based materials, only to stone/cement/ceramic. The requirements of the EU eco-labelling are similar to others but are more comprehensive in their application across the whole life cycle. There is a group working on furniture standards, but these don't appear to cover VOCs.

The EU is attempting to co-ordinate activities and have regulations specified in Regulation (EC) No 1980/2000 (European Union Eco-label 2000). The following web-site provides a useful background to the EU scheme: http://ec.europa.eu/environment/ecolabel/documents/pm_eueb_en.htm

M1 – Finland

Details for this scheme are available at: http://www.rts.fi/emission_classification_of_building_materials.htm

The classifications are granted by the Building Information Foundation RTS. The Building Information Foundation RTS is Finland's leading information service for the building and construction sector. Its mission is to foster and promote good planning and construction practices as well as sound property management procedures. The Building Information Foundation RTS is a private foundation with representatives from 43 Finnish building organisations.

Specified limits for materials (at 4 weeks of age) are given in Table 3.8.

Table 3.8: M1 – Finnish voluntary VOC emission code

Examined qualities	**M1 [mg/m²h]**	**M2 [mg/m²h]**
The emission of total volatile organic compounds (TVOC). A minimum of 70% of the compounds shall be identified.	< 0.2	< 0.4
The emission of formaldehyde (HCOH)	< 0.05	< 0.125
The emission of ammonia (NH_3)	< 0.03	< 0.06
The emission of carcinogenic compounds belonging to category 1 of the IARC monographs (IARC 1987)[1]	< 0.005	< 0.005
Odour (dissatisfaction with odour shall be below 15 %)[2]	Is not odorous	Is not significantly odorous

1* IARC 1987, does not apply to formaldehyde (IARC 2004)
2* The result of sensory evaluation shall be > + 0,1.

Testing is carried out according to European Standard EN 13419 Building products - Determination of the emission of volatile organic compounds. The requirements also cover odour. Applicants have to supply samples and once they have met the criteria they can apply the M mark. The supervising committee selects samples annually for analysis. There doesn't seem to be a requirement for a quality certification system.

Danish Indoor Climate Label (ICL) (Denmark & Norway)

The Danish Society of Indoor Climate developed this product mark. Product acceptability is based on testing according to EN 13419 as well as odour. The scheme is very similar to the Finnish M1 system. The following extract from Witterseh (2002) outlines the elements of the program.

"The main principle of the (Danish) ICL is the determination of the indoor-relevant time value. The time value is based on chemical analysis of emission of single volatile organic compounds combined with a sensory evaluation of air acceptability and intensity of odour from a newly manufactured product.

The chemical analyses are carried out until the emission rate converted to the concentration in a standard room is below half the threshold value for odour and irritation for all individual substances. The threshold values for odour and irritation used are those given in VOCBASE (Jensen and Wolkoff, 1996). According to ENV 13419-1 (CEN, 1999) a minimum 24 and 72 hours and 28 days should as a principal rule be included. In connection with measurements in excess of 28 days and comprising a minimum 4 measurement points, modelling can be used (DSIC, 2000).

The sensory evaluation is carried out as a control of the chemical measurements. The sensory evaluation criteria for an acceptable air quality is: 1) the air quality shall be perceived as "acceptable" (median of minimum 20 persons' evaluations) using the acceptability scale, and 2) the odour intensity shall be below 2 (moderate odour) using a 6-point continuous scale for odour intensity.

In addition to the chemical analysis and sensory evaluation, ceiling products are also tested for the emission of fibres and particles.

The indoor-relevant time-value is determined as the time (in days) from when the product is first released for sale and until the concentration (in a standard room) of all single volatile organic compounds is below half the threshold value for odour and irritation of mucous membranes. At the same time the product must fulfil the requirements for the sensory evaluation of the air quality.

The ICL also requires the product to be accompanied by directions for storage, installation, application, use, cleaning and maintenance etc. to ensure a low impact on the indoor air quality throughout the normal lifetime of the product.

The basic criteria for individual emissions are therefore those defined by the VOCBASE values. This information is not available unless a subscription is purchased."

Nordic Swan (whole of Scandinavia)

Criteria for panels are given at http://www.svanen.nu/Eng/criteria/kriterie.asp?pgn=010

Criteria for flooring products are given at http://www.svanen.nu/DocEng/029e.pdf

There are currently no requirements for VOC emissions for wood panel products or flooring. In the future any requirements will be harmonized with those of the Danish ICL scheme.

France

Maupetit *et al* (2007) provide some insight into the intention of the French Government to implement regulations relating to the release of VOCs from building products.

Currently there is no consensus on how VOC emissions from building products should be controlled. The French Prime Minister in June 2004 issued a priority directive 15 which included a requirement to focus attention on VOC and formaldehyde emissions with a target to have 50% of products evaluated by 2010 on a voluntary basis. Criteria have been set by a working group including AFSSET, the French Agency for Environmental and Occupational Health Safety and CSTB (Scientific and Technical Building Centre). Table 3.9 presents the AFSSET protocol and compares its requirements with those of the ECA and AgBB.

Table 3.9: French concept – AFSSET protocol (Maupetit et al, 2007)

Day	Parameters	ECA (1997)	AgBB (2005)	AFSSET (2006)
1	Carc. C1 (benzene)	[C]*LUR $\leq 10^{-4}$	/	/
3	TVOC	5 mg.m^{-3}	10 mg.m^{-3}	10 mg.m^{-3}
3	Σ Carc. (C1, C2)	/	10 µg.m^{-3}	10 µg.m^{-3}
28	TVOC	200 µg.m^{-3}	1 000 µg.m^{-3}	1 000 µg.m^{-3}
28	Σ SVOC	/	100 µg.m^{-3}	/
28	Carc. C1 (benzene)	[C]*LUR $\leq 10^{-5}$	/	/
28	Σ Carc. (C1, C2)	/	1 µg.m^{-3}	1 µg.m^{-3}
28	R = Σ $[COV]_i$ / LCI	1	1	1
28	Σ $[COV]_{ni}$ (without LCI)	20 µg.m^{-3}	100 µg.m^{-3}	100 µg.m^{-3}

The so called AFSSET protocol is now being considered in product certification schemes as a basis for product approval. If this approach is not successful, it is likely that the requirements will be mandated in law.

3.4.2 USA

Greenguard Certification Standards for Low Emitting Products

The Greenguard Environmental Institute (GEI) has established performance-based standards to define goods with low chemical and particle emissions for use indoors, primarily building materials, interior furnishings, furniture, cleaning and maintenance products, electronic equipment, and personal care products. The standard establishes certification procedures including test methods, allowable emissions levels, product sample collection and handling, testing type and frequency, and program application processes and acceptance.

All products are tested in dynamic environmental chambers following the GREENGUARD test method: “Method for Measuring Various Chemical Emissions using Dynamic Environmental Chambers”. The method follows the guidance of ASTM standards D-5116-06 and D-6670-01, the U.S. Environmental Protection Agency's testing protocol for furniture, the State of Washington's protocol for interior furnishings and construction materials, and California’s DHS standard practice for the Special Environmental Requirements, Specification Section 01350. Products are measured for emission levels, which must meet the indoor air concentrations given in Table 3.10 within seven days of unpacking. Air concentrations are based on the product being in a room 32 m^3 in volume with outdoor air ventilation based on ASHRAE 62.1-2004 or the US EPA’s recommended exposure factors. Maximum allowable emission levels are those required by the State of Washington's indoor air quality program for new construction, the US Environmental Protection Agency's procurements specifications, the recommendations from the World Health Organization, Germany's Blue Angel Program for electronic equipment, LEED for New Construction, and LEED for Commercial Interiors. Office furniture products meeting these allowable emission levels also meet the requirements of LEED credit 4.5 and the BIFMA X7.1 Conformance standard. When multiple emission values are recommended, the lesser, or more stringent, is used as the acceptable emission value for GREENGUARD Certification.

Table 3.10: Greenguard emission requirements for panel products.

Requirement	Limit
Individual VOCs	≤0.1 TLV
Formaldehyde	≤0.5 ppm
Styrene	≤0.07 mg/m^3
Total VOC	≤0.5 mg/m^3
Total aldehydes	≤0.1 ppm

3.4.3 Japan

In 2005 the Japan Testing Center for Construction Materials (JTCCM) started to develop a voluntary standard for VOC emissions, because of the interest shown by house builders, general contractors and consumers. This voluntary standard was established on April 1st, 2008. The Japanese Fibreboard and Particleboard Manufacturers Association (JFPMA) joined the project, which developed a set of rules based on the jointly developed voluntary standard. The JFPMA started a certification system in August 2008.

The standard utilises the requirements and method of JIS A1901-2003 and also sets out the criteria to enable industry associations to develop certification systems (JTCCM, 2009). Table 3.11 lists the VOCs of interest and their standard emission rate values.

Table 3.11: VOCs of interest and their standard emission rate values (JTCCM, 2009).

Target VOC	Symbol	Standard value of emission rate* (μg/m^{2}h)
Toluene	T	38
Xylene	X	120
Ethylbenzene	E	550
Styrene	S	32

*Note: A loading factor of 3.4m^2/m^3 was used in calculation of the standard value of emission rates.

To become certified a panel manufacturer must make application to the JFPMA. The application must cover or include a number of items, for example: a deed of JIS certification; product description; MSDS for the product; declaration that the product does not contain toluene, xylene, styrene or ethyl benzene; description of the adhesive used in production; production quality and process control methods used.

3.4.4 Australia

The Australian Eco-Labelling Association (AELA 2007) operates a labelling scheme called Good Environmental Choice. The scheme has a specification for furniture and fittings, but currently the emission requirements only cover formaldehyde. AELA is affiliated with other eco-labelling organisations through the Global Eco-labelling Network.

3.5 Building Certification Schemes

Many countries now have voluntary building certification schemes. In many of these schemes there are sections dealing with indoor air quality or emissions from fitments. Invariably these schemes list VOCs as an area of control.

3.5.1 Europe

The Building Research Establishment in the UK has developed a range of assessment methods for a variety of environmental issues. BREEAM (BRE Environmental Assessment Method) is a tool for assessing the environmental performance of any building. For office buildings, BREEAM does not evaluate VOC emissions. There is some scant mention of material certification in the specifications but nothing specific on VOCs.

3.5.2 USA

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ is a rating scheme for the design, construction, and operation of high performance green buildings managed by the US Green Building Council.

The low emitting materials section gives 1 point to the LEED score if no added urea formaldehyde resin is contained in the composite wood products used in the construction. There are no specified limits for VOCs from wood products. However, there are requirements to do building flushes prior to occupancy and to measure air quality (LEED, 2002).

3.5.3 Australia

The Green Building Council of Australia operates a GreenStar rating scheme for environmentally responsible buildings. Under the Indoor Environment Quality Clause 12 (IEQ-12), 2 points are allocated in the rating scheme if all tenancy fit-out items (workstations, walls/partitions, chairs, tables and storage units) are low-VOC (US EPA's Environmental Technology Verification test method) (GBCA 2007). There are also points awarded if low formaldehyde emission panels are used. This will change to give only one point for F**** products in the next version of the scheme.

4. AVAILABLE DATA ON VOC EMISSIONS FROM ENGINEERED WOOD PRODUCTS

4.1 Introduction

There are many factors that can influence the emission of VOCs from engineered wood products, including:

- Wood species
- Wood type (heartwood, sapwood)
- Adhesive type
- Surface coatings
- Processing conditions
- Storage conditions

To further complicate matters, in many cases there are interactive effects between the key variables which can determine VOC emissions. Roffael *et al* (2006) elegantly summarised the key influencing factors (see Figure 4.1).

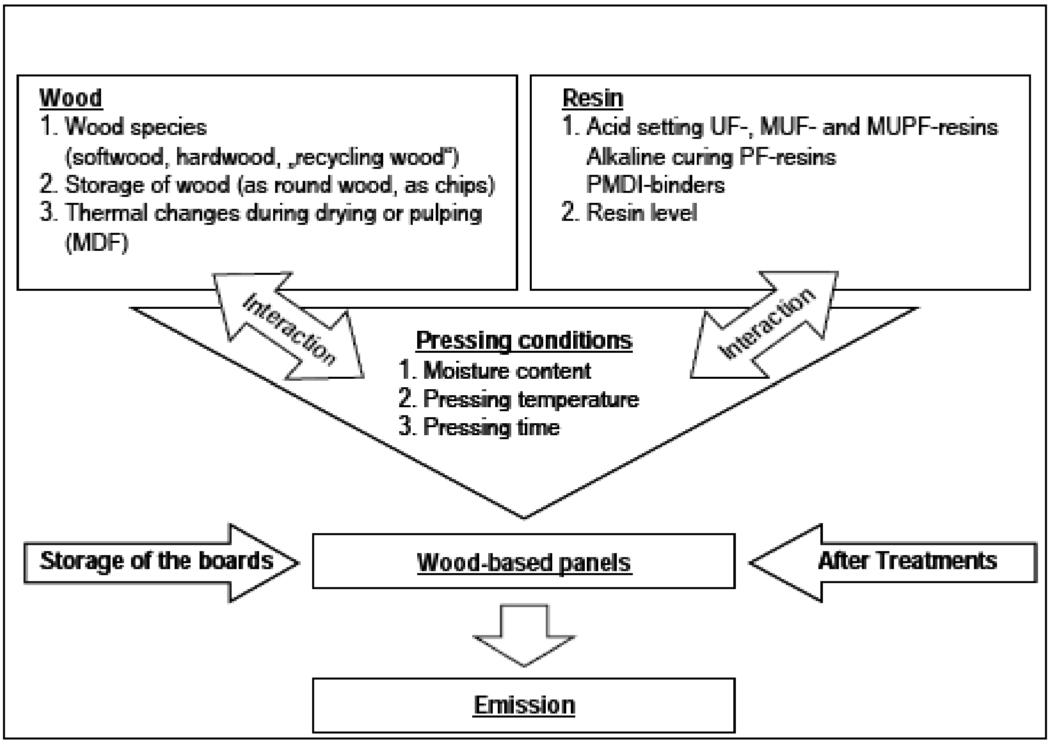

Figure 4.1: Factors affecting VOC emissions (Roffael *et al* 2006)

Key points arising from a review of the literature are summarised in the following sections.

4.2 Wood Species

Wood species is one of the most important variables in determining the types and amounts of VOCs emitted from engineered wood products. There are marked differences between softwoods and hardwoods in terms of the types of VOCs that can potentially be emitted from products.

Many softwoods contain significant amounts of natural resin, which is a source of VOCs such as terpenes. Some of the more common terpenes emitted by softwoods are α-pinene, 3-carene and limonene (Englund and Nussbaum, 2000); terpenes can potentially be oxidised to form aldehydes such as formaldehyde (Roffael, 2006). In addition, softwoods can contain free and esterified fatty acids, which are susceptible to autoxidation and the subsequent formation of aldehydes and organic acids (Chan, 1987; Makowski and Ohlmeyer, 2005; Back and Allan, 2000).

The AgBB has identified some of the most important VOCs of interest that are emitted from products made from softwoods (Ohlmeyer, 2008). These are summarised in Table 4.1, including the LCI values for each compound. It should be noted that these compounds most likely relate to the more common softwood species utilised in northern Europe e.g. Scots pine, Norway spruce; compounds of interest may differ in Australia owing to the different softwood species grown and utilised in the region.

Table 4.1: Key VOCs and their LCI values emitted from softwood products.

Compound	**LCI (µg/m^3)**
3-carene	1,500
α-pinene	1,500
β-pinene	1,500
Pentanal	1,700
Hexanal	890
Heptanal	1,000
Octanal	1,100
2-Heptenal	16
2-Octenal	18
Benzaldehyde	90
Acetic acid	500
Hexanoic acid	490

In contrast, hardwoods generally emit little or no terpenes. However, hardwoods are typically rich in hemicelluloses which are highly susceptible to thermal degradation, leading to the formation of VOCs such as formic and acetic acid, furfural and formaldehyde (Roffael *et al*, 2006; Roffael, 2006; Risholm-Sundman *et al*, 1998). Again, it should be noted that much of the work on VOCs from hardwoods has been conducted on commercial species of interest in Europe and North America; these differ from those used commercially in Australia.

Roffael *et al* (2006) note that the VOCs emitted by wood will vary according to the season in which it is harvested and other factors such as storage conditions and duration. They also reported differences in VOC emissions from heartwood and sapwood of Scots pine. It was found that the emission of terpenes from the heartwood was up to four to five times greater than that from the sapwood. No comparative analysis of aldehydes was performed in this work.

There is relatively little data in the literature on the affect of wood species on VOC emissions from engineered wood products. Baumann *et al* (1999; 2000) investigated the effect of North American wood species on the VOC emissions from both particleboard and MDF. The work showed that VOC emissions were highest in panels made from southern pine, with emissions being progressively reduced for panels made with a mixture of other pine species (lodgepole, ponderosa and western white), mixed hardwoods and a mixture of other species (firs, redwood etc.). Ohlmeyer (2008) investigated the influence of wood species on emissions from OSB. Modest differences were found between panels made from beech, birch, maple or aspen; the predominant compound emitted in all cases was acetic acid. Emissions from panels made from Douglas fir or larch were around double those made from either spruce or fir. There were marked differences in the composition of the VOCs emitted by the softwood panels; terpenes dominated emissions from larch panels, whilst those from the fir panels were almost exclusively acetic acid. However, the main finding was that emissions from both the hardwood and softwood panels were almost an order of magnitude lower than those from panels made with Scots pine; in this case the predominant VOCs emitted were terpenes.

4.3 Adhesive

There is almost no information in the literature on the influence of adhesive type on VOC emissions from engineered wood products. Roffael *et al* (2006) state that the type of adhesive and its interaction with wood are important factors in determining VOC emissions from products. However, they provide only limited supporting evidence. They suggest that after cure, some adhesives may still contain VOCs which could be released to the atmosphere e.g. methanol and free formaldehyde from UF and PF resins. They further suggest that formic acid could be produced from a reaction between formaldehyde and alkali in phenolic resins. They also speculate that alkaline phenolic resins could saponify the acetyl groups from wood hemicelluloses leading to the formation and emission of acetic acid.

This is clearly an area which requires further investigation.

4.4 Process Technology

4.4.1 Product Type

In the work by Baumann *et al* (1999; 2000), who investigated the effect of North American wood species on the VOC emissions from both particleboard and MDF, in most cases, for a given resource, the emission of TVOCs from MDF was significantly lower than that from particleboard. The exception to this was where panels were manufactured from southern pines. In this case, aldehyde emissions were markedly higher in MDF compared to particleboard; the reason for this difference is unknown.

The findings of Baumann *et al* (1999; 2000) are at variance with data for some products manufactured by The Laminex Group (2009). In this case, for products tested using ASTM D5116-97, MDF was certified as having slightly higher TVOC emissions compared with particleboard. However, it is recognised that these data could be misleading, as the wood feed-stocks and adhesives used to manufacture the products are likely to be different, as well as other processing parameters.

Steckel & Ohlmeyer (2008) reported results for terpene and aldehyde emissions from solid wood, OSB and wet formed fibreboard; all products were made from pine. The fibreboard exhibited very low VOC emissions. In OSB, using the standard chamber test method, terpene emissions were initially considerably higher than those of the fibreboard, but lower than those of solid wood. Over time (28 days), the OSB terpene emissions decayed to relatively low levels; those of solid wood, whilst falling over time, remained relatively high. In contrast, aldehyde emissions from all three products were initially similar, being relatively low. However, over time, emissions from the OSB climbed to significant levels, being an order of magnitude higher than those from the solid wood and fibreboard after 28 days; emissions from the latter two products remained relatively unchanged over the same time period.

4.4.2 Temperature (Drying & Hot Pressing)

Makowski *et al* (2006a) studied the effect of drying temperature and press factors on VOC emissions. Drying temperature had the most significant effect on VOC emissions. This was most pronounced with aldehyde emissions. Production based on wood dried at 170^{o}C versus 120^{o}C had much higher emissions of aldehydes, which initially increased and then decreased with time over the 94 days of testing. However, the aldehyde emissions in both cases were similar at the end of the test period. Hot pressing for longer (increasing the press factor from 9 sec/mm to 12 sec/mm) depleted terpene emissions slightly and increased aldehyde emissions. The terpene emissions were similar in both cases with some slight reduction of terpenes emissions with panels pressed and dried at the higher temperature. As with the aldehyde emissions, the final emissions of terpenes after 94 days were similar.

Further to this work, Makowski *et al* (2006b) also studied the effects of press temperature on VOC emissions. The authors found that increasing the press temperature from 180^oC to 220^oC and 260^oC resulted in lower emissions of terpenes with time. The aldehyde emissions initially rose with time, as found in other studies (Makowski *et al* 2006a; Baumann *et al*, 2000), but the maximum aldehyde emissions were lower for panels pressed at 260^oC. This result seemed at odds with the temperature effects observed from drying, unless there is a maximum temperature after which the aldehyde emission decreases. The investigators explained this by postulating that the reduced emissions result from the polymerisation of the fatty acids at the higher temperatures.

4.4.3 Surface Properties / Particle Size

Makowski *et al* (2006a) also reported on the effect of surface properties of OSB panels on VOC emissions. It was found that the emissions were lowered if the OSB was covered in a layer of fine strands similar to a particleboard surface layer. The result was explained in terms of an increase in surface porosity due to the fine particles, allowing for increased escape of VOCs in the manufacturing process, subsequently leading to lower emissions from the finished product. Another possible explanation is that the fine particles could lead to increased densification of the surface, preventing release of VOCs from the finished product.

Ohlmeyer (2008) also investigated the influence of surface structure in OSB on VOC emissions. All panels were made from Scots pine flakes. The emission of terpenes was significantly lower in panels made with fine particles on the surface. This was explained in terms of increased emission of terpenes from the finer particles during milling and screening prior to mat forming and pressing. In contrast, aldehyde emissions were significantly higher from the panels made with fine particles on the surface, particularly over the first 28 days. This was explained in terms of increased autoxidation of fatty acids in the final particles owing to increased surface area and accessibility.

The effect of particle size on VOC emissions is clearly complex and not fully understood.

4.4.4 Fibre Pre-treatment

Roffael *et al* (2007) investigated the influence of different pulping techniques for MDF on VOC emissions. The work showed that the emissions of formaldehyde were lower for chemi-thermomechanical pulp (CTMP) compared with thermomechanical pulp. Differences in volatile acid emissions were also noted. The emission of acetic acid was higher from CTMP and formate lower, probably due to the higher pH of the pulp.

Roffael *et al* (2006) investigated the effect of alkali treatment on VOC emissions from OSB made from Scots pine. They concluded that treatment with alkaline reagents in the form of 1-2% sodium hydroxide (NaOH) caused a significant decrease in TVOC emissions from OSB panels. It was observed that this treatment had no detrimental effect on the properties of the panels. However, it should be noted that these observations were only made on OSB bound with PF or pMDI adhesive systems.

Roffael *et al* (2006) also reported the effect on emissions from chips treated with oxidisers (hydrogen peroxide) and reductants (sodium sulphite). It was postulated that the oxidiser should enhance the production of aldehydes and the sodium sulphite should decrease it. Treatment with hydrogen peroxide increased the formation of higher molecular weight aldehydes enormously. In contrast, using sodium sulfite as a reducing agent decreased the emission of terpenes, whilst emissions of aldehydes were not significantly affected. It is not clear how emissions would be affected in panels manufactured from treated chips.

4.4.5 Hot Stacking

Hot stacking of wood-based panels is a well known post manufacturing approach to reducing formaldehyde emissions. Manufactured panels are stacked hot rather than cooled prior to finishing. This results in substantial decreases in formaldehyde emissions. Makowski and Ohlmeyer (2005) suggest that this technique would be suitable for reduction of other VOC emissions. These workers reported results from experiments on OSB made from Scots Pine that was hot stacked for 3 days and 6 months. It was found that the hot stacked panels had lower emissions of terpenes than the unstacked panels. The emissions of the stacked panels were significantly lowered at the end of the 28 day test period, which is the time period commonly used in many certification programs.

When emissions of aldehydes are considered, there was a noticeable difference in initial emissions. However, the emissions from panels hot stacked for 6 months gradually decreased over the test period and at 28 days were lower than the emissions from the unstacked panels and those stacked for 3 days.

4.5 Surface Coatings

It has long been thought that coatings on panel products reduce emissions. This belief is somewhat historic and relates in particular to formaldehyde emissions. The issue that now arises is that while formaldehyde emissions have been dramatically reduced, emissions from traditional melamine/formaldehyde-based paper laminates have stayed very much the same. As a result, these emissions may now be the dominant contributor to formaldehyde emissions from laminated panel products. This is particularly the case where the base panel product has an F*** or F**** emission rating.

Whilst the effectiveness of laminate coatings in reducing formaldehyde emissions is now questionable, Kelly *et al* (1999) reported the effectiveness of some coatings in reducing the emissions from wood panel products in California. The results of this investigation showed a reduction of formaldehyde emissions of around one order of magnitude. For example, emissions from particleboard were found to be around 100-200 $\mu g/m^2h$, and coated products were found to have emissions in the range <10-20 $\mu g/m^2h$. It is not clear what effect these coatings would have on VOC emissions, though it would be reasonable to expect that these would also be reduced if the coatings themselves did not contain significant levels of VOCs.

Data for products manufactured by The Laminex Group (2009) suggest that laminate coverings could potentially reduce VOC emissions. For products tested using ASTM D5116-97, laminated MDF was certified as having significantly lower TVOC emissions compared with raw panels. However, there was no difference in emissions in the case of laminated and raw particleboard. Again it must be recognised that these data could be misleading, as the wood feed-stocks and adhesives used to manufacture the products could be different, as well as other processing parameters

Hodgson *et al* (2002) studied formaldehyde, terpene and other aldehyde emissions in building materials with applied coatings. They also reported the effect of barrier systems on emissions from plywood flooring. The barriers consisted of traditional carpets as well as perforated foil and a non-woven fabric exterior weatherisation membrane. A standard carpet installation only affected heptanal emissions. For the other barriers, emissions of terpenes were largely unaffected, whilst those of formaldehyde, hexanal and heptanal were reduced by 20-40%. Pentanal, octanal and nonanal emissions were also significantly reduced in 3 cases. The extent of the long term effectiveness of these barriers is unclear. The same workers also reported the effectiveness of a vinyl barrier in reducing the emissions of formaldehyde and other aldehydes from particleboard and MDF.

Powder coating, a relatively new coating for wood products, is claimed to reduce panel emissions (Dulux 2007); a TVOC emission rate of 0.119 $mg/m^2/hr$ for Dulux Trimatrix coated MDF is cited compared to 0.874 $mg/m^2/hr$ for uncoated board. No details of the individual VOCs emitted or the method of test are given.

4.6 Time

All researchers have reported significant reductions in emissions from products with elapsed time. Whilst simply leaving product for lengthy periods of time in storage is probably not a viable option, the development of treatment options that accelerate the natural processes that occur within a product after processing could be worth consideration.

4.7 Process Emissions

No information on the emission of VOCs from engineered wood product manufacturing processes could be found in the literature (there is some information on terpene emissions in softwood sawmills). Whilst the influence of processing parameters on finished product emissions is not fully understood, the fact that changes in some parameters (e.g. drying and hot pressing temperatures, surface particle size etc.) appear to influence product emissions suggests that they will equally effect process emissions. This is an area that needs further investigation.

4.8 Conclusions

Information in the literature on VOC emissions from engineered wood products is relatively limited, and what exists is primarily based on a few studies conducted by European and North American researchers. Wood species appears to be an important factor in determining VOC emissions, with terpenes, aldehydes and weak organic acids being the primary compounds of interest. Evidence suggests that emissions may be lower in products made from hardwoods, whilst in Europe it is evident that highly resinous species such as Scots pine can give rise to significant emissions from products, particularly terpenes. Research on North American softwood species suggests that the highest VOC emissions are associated with the southern pines; this might be indicative of the likely behaviour of products manufactured from softwoods grown in northern NSW and QLD.

There is some evidence that, for a given wood feedstock, emissions from MDF are significantly lower than those from particleboard. Likewise, there is evidence that particle size, drying and hot pressing temperature, hot stacking and surface coatings can all influence emissions. The type of adhesive used in products is believed to be an important factor, though very little hard evidence exists in the literature to support this. There is little or no information on VOC emissions arising from production processes.

In summary, it appears that a range of raw material and process variables have an impact on VOC emissions from engineered wood products. Given this, it is very likely that emissions will be specific to individual production lines/plants, overlaid with seasonal variations. Australian products would therefore need to be comprehensively screened to determine their VOC emission characteristics.

5. REGULATORY SCENARIOS FOR AUSTRALIA

5.1 Introduction

It is reasonably clear, based on activities in other parts of the world and Australia, that building materials will come under increasing pressure to restrict emissions of VOCs and other chemicals in the coming decade. The type of pressure and how the engineered wood products industry reacts will be crucial to the acceptance of engineered wood products as a material of choice in the buildings of the future. The regulatory landscape is very hazy at present and there has been very little public debate about the key issues. It is clear from the small amount of discussion held in Australia that there are currently sufficient regulations to afford a legal responsibility for building owners, building companies, designers and non-industrial workplaces to maintain indoor air quality or face prosecution. This would suggest that manufacturers also face a responsibility.

5.2 Regulatory Issues

It is apparent that there are no direct compulsory indoor air quality requirements in Australia. Mesaros (2003) suggests that this is because:

- Indoor environments are seen to be sacrosanct.
- Enforcement in residences is impossible.
- No single Government authority has responsibility for indoor air.
- Indoor air quality involves a complex set of factors – ventilation, sources, design, the outdoor environment.

The NSW enquiry on Sick Building Syndrome (SBS) (NSW Parliament 2001) points out several cases that had come before the court relating to indoor air quality.

The current mire of regulations that form a pseudo-regulatory framework that has been applied in these cases comprises:

- Common Law – Negligence.
- Legislation - Provision of safe a working environment.
- Regulation – BCA.
- Codes of practice
- Australian Standards: e.g. Ventilation

5.3 Potential Scenarios

Europe, and in particular Germany and the Nordic countries, is the region most advanced in regulation. What is apparent is that there are a number of themes to the process of regulation in these countries. Firstly, there is an underlying desire within Government to support these measures, both at a European and country level; this is driven by a need that has been identified as a result of complaints and concerns for public health. Secondly, there is infrastructure within these regulatory frameworks to support the activities required to develop the testing and surveillance measures required.

A common theme is that voluntary certification schemes seem to develop in advance of the regulatory requirements. There are a myriad of European schemes, some of which have direct support from Government agencies, as is the case in Finland.

There is also a need for official guidelines to be developed. Without them, pseudo-requirements are developed and proliferate, making it impossible for producers to manufacture their products to a consistent standard.

Finally, some form of Government regulation will develop. In Europe a decision has been made to regulate the input to the VOCs present in indoor air. This is being done mainly through the products' standards and requirements in the Building Code to use compliant materials.

The question now remains as to what the likely scenario will be in Australia.

Both the NSW enquiry (2001) and Mesaros (2003) offer recommendations for future activities. These, together with the experience that has been gathered overseas, gives a good indication that there is little doubt that there will be requirements placed on VOC emissions from building products in the future and the form that these regulations will take.

Mesaros (2003) suggests that it is only a matter of time before there is litigation against employers, building owners, managers and those involved in the design, construction and fit-out of buildings. She feels that this will force regulation and recommends amongst other things:

- The introduction of appropriate legislation.
- Use of building audits.
- New processes for implementing standards in Australia.
- Development of an Australian database of VOCs.
- Integration of IAQ issues into ambient air pollution programs including modification of the NEPM.
- Design of environmental standards applicable to the home, including exposure standards.

The NSW enquiry (2001) also offered an opinion on areas that need addressing. Broadly the areas were:

- Responsibility for indoor air.
- The need for further research.
- Prevention of SBS.

- Management of existing buildings.
- Education.

The NSW recommendations generally fall within these categories. It was believed that the States had the responsibility for IAQ/SBS matters. The recommendation was that NSW should establish an inter-agency standing committee on SBS. The principles of Ecologically Sustainable Design and the use of low environmental impact materials was supported, providing occupants with a sense of control over their immediate environment and the use of low energy consuming ventilation systems.

Other recommendations included:

- IAQ measure to be included in the BCA.
- Adoption of the IAQ goals of the NHMRC.
- Government to implement programs to phase out VOCs in finishes and fittings.

Despite the commentary above, there seems to be very little momentum in the regulatory environment in Australia to develop controls in the area of IAQ. There are, however, other indications that Australia is beginning to follow the European trends in the establishment of voluntary codes and standards.

The Green Building Council (GBC) and the Australian Eco-Labelling Association (AELA) have already established emissions requirements in their Office Interiors standards and Good Environmental Choice Label (formaldehyde only) respectively. It is reasonable to expect that in the coming years the requirements placed on VOC emissions from interior fitments and furniture will increase both locally and internationally. The lack of progress to date is multi-dimensional. The lack of perceived need in Australia is based in part on reduced exposure; Australians spend more time outdoors, and their homes have higher indoor air exchange rates. However, it is unlikely that the regulatory requirements will differ greatly from those being developed in Europe and elsewhere due to the move towards global markets and free trade, which is leading to international standardisation.

The question still remains as to how these requirements will be implemented in Australia and what is the best option for the industry.

The current situation the industry finds itself in is that there is very little engagement in the standard setting under the voluntary regulation system such as GreenStar and Good Environmental Choice labelling. There is also a risk that as time goes on voluntary codes will become *de facto* standards, and if the *status quo* continues, industry will have these voluntary codes forced upon it. It would be far better to be engaged in the process of setting these codes.

Australian industry needs to begin the process of considering VOC emissions in product standards. In this way it can ensure that the standards are relevant and reasonable. This will need to be supported by analysis and research into current emissions from existing products as well as the methods to potentially mitigate emissions from products.

The trend of inclusion of VOC emission requirements in product standards needs to be addressed both at a national and international level. Internationally protocols and specifications are being developed that, as time goes by, will filter to the Australian standards through the ISO standards process. Australian industry needs to be aware of and gain representation in these processes.

It should be stressed that this process does not need to be completed with any haste, but the current situation suggests that the journey down this path should be commenced in the near future. There is an obvious sequence of events that also needs to be completed before any standards can be established, and this sequence will take a reasonable period of time. The inclusion of these requirements in product standards also offers the option of certification of products through existing product certification programs offered by the AWPA and the EWPAA.

As an alternative, the industry could develop a voluntary environmental certification program similar to that offered by EMICODE for the adhesive industry in Europe.

The existence of product emission standards is, however, no guarantee that IAQ is correct or maintained. Recently we have seen the introduction of energy efficiency regulations (5 Star) into the BCA. These regulations have unintentionally provided an avenue to reduce the IAQ through increased building tightness in domestic buildings (i.e. reduced air exchange rate). Sustainability Victoria has recommended thorough sealing of all door, joints and gaps to increase energy efficiency and offer an improved energy rating for these modifications. It would seem remiss not to include reference to IAQ requirements in the BCA and to product emission requirements relating to materials used through reference to product standards. There is also a need to provide guidance in the BCA to ensure that as changes are made, consideration is given to the impact on IAQ. Industry would be able to gain adequate representation in this process through the current development of standards that it already participates in.

The building shell can be controlled via the BCA, but this does not ensure that the fittings meet the correct emission requirements. It would seem likely that various material components have emission requirements as well. This would relate to wall material and coatings, flooring materials and flooring material. To the extent that engineered wood products are used in these materials, the relevant standards and fitting standards would need to reflect this requirement. Owing to the lack of standards for furniture and fittings, it would seem likely that either new Australian standards will be developed to encompass these product emissions or voluntary standards will become the *de facto* standards. Appropriate engagement in these processes is required.

Guidelines from Government also need to be established. The various authorities have shied away from this. The NHMRC has withdrawn its guidelines because it does not have the resources to review them. Industry needs to participate at this level as well, to ensure that appropriate standards based on science are developed. The responsibility of the states for this issue also requires some consideration. The establishment of a NEPM, whilst providing a framework, does not address the fundamental issue of control. It is virtually impossible to control indoor air quality through legislation. It is much more likely that success will be achieved through control of the inputs (building material, air exchange rates etc.) than to control the outputs. The NEPM process may, however, provide the mechanism for the establishment of an inter-governmental/agency framework for the establishment of guidelines and monitoring that is required.

The use of consumer legislation may be another mechanism that could be used to control emissions from products. In the past these laws have been applied by the Australian Competition and Consumer Commission (ACCC) where there is a significant risk to public safety. Again, these laws have generally been developed around appropriate product standards. Graeme Samuel (2007) recently wrote that the ACCC could not bear the sole responsibly for product safety. He believes that product safety is a shared responsibility of manufacturers, importers, distributors, customers and regulators. It would appear that the regulatory response employed by the ACCC is often reactionary rather than proactive. For example, customs import regulations on lead in toys were only recently updated in response to issues and the recall of toys made in China that had entered Australia. It is interesting to note that in the recent case of residual formaldehyde levels in imported clothes, where there is no Australian regulation or standard, the ACCC has adopted the European Standard until local requirements are developed (ACCC 2007). Unless there is a major risk to public safety, it would seem unlikely that the ACCC will become interested in VOC emissions.

Australian industry is faced with the challenge of competing in a marketplace with imported products that do not meet Australian Standards. Currently, there is no requirement for engineered wood products to meet Australian Standards unless they are used in structural applications where they are often referenced in the BCA. There is no doubt that there will be a cost to ensuring that product emissions are lowered, but these costs will be borne by the manufacturer, with limited potential to pass the cost on given the competition from imports. This has recently been the case with products imported to Australia with extreme formaldehyde emissions. It would seem feasible that the ACCC could provide protection in this area by requiring all imported products to meet emission regulations, thus ensuring at least some levelling of the playing field. It would be beneficial if Government were engaged to ensure that the appropriate agency is identified to control and police product compliance. Alternatively, the BCA could be used, as discussed previously, to specify the emission requirements of engineered wood products in the built environment.

6. CONCLUSIONS AND RECOMMENDED ACTIONS FOR INDUSTRY

It is evident that the regulation of VOC emissions from wood products is still very much a 'work in progress', even in those countries that are more advanced in tackling this issue. Mandatory regulation is largely still in its infancy, and regulation is currently predominantly through a variety of voluntary schemes; this situation is likely to continue for some time.

One of the issues that is limiting the ability to progress the regulatory environment is the complexity of detecting and quantifying VOC emissions from wood products. Currently approved methods based on large chambers are expensive and time consuming, whilst more rapid methods are still in the development stage, and their correlation with standard methods is largely unproven. Furthermore, there is relatively little available data on VOC emissions from either products or processes.

Whilst the regulatory environment around VOC emissions will be slow moving, in time it is highly likely that there will be a tightening of regulations both globally and in Australia. Given this, it is recommended that the following actions should be considered by the Australian engineered wood products industry:

- Undertake a program of work to evaluate product and process VOC emissions. This will enable the industry to identify any potential issues, and provide plenty of time to implement mitigating strategies.
- Engage in the setting of international standards on VOC emissions.
- Determine and agree appropriate levels of VOC emissions from products for inclusion in the appropriate product standards.
- Engage in the development process for Voluntary Codes or develop appropriate industry-based voluntary codes.
- Engage the Australian Building Codes Board to ensure that the Building Code of Australia approaches the issue of IAQ in a controlled manner.
- Engage government in the most appropriate way to set IAQ guidelines.

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APPENDIX 1 – SCOPE OF TEST STANDARDS

JIS A 1901: 2003. Determination of the emission of volatile organic compounds and aldehydes for building products - Small chamber method

The scope states that the standard is for any building product (not only wood based materials); specifically listed are: wallpaper, adhesives and varnishes providing they are used in construction.

The samples should be taken as soon as possible after production and placed into sealed bags or foil.

Adhesive and varnish samples (section 9.3): The sample of varnish must be applied to glass or aluminium.

Sealing Edges (section 9.4): The standard allows for either option – sealed or unsealed edges and sealed or unsealed faces. So the standard may be used for measuring emission from any part of the sample. The sample may be sealed with aluminium foil.

Air sampling is into Tenex-TA for VOC and DNPH cartridge for formaldehyde and other carbonyl groups.

The samples are only taken after 8 hours of steady RH and temperature. Two sampling tubes may be used in series to check there is no “break-through”.

The analysis of VOC is by heating the tube in a thermal deorbsorption system, vaporising the VOCs which are tested by ISO 16017-1 and ISO 16000.

Formaldehyde and carbonyl groups is by first dissolving in acetonitrile and then by ISO 16000-3.

JIS A 1911: 2006. Determination of the emission of formaldehyde for building materials and building related products -- Large chamber method.

The chamber can be from 2 to 80m^3. The temperature is 28^{o}C and RH 50%. The large chamber allows large samples to be measured.

BS EN ISO 16000-1: 2006
ISO 16000-1: 2004 is intended to aid the planning of indoor pollution monitoring.

Before a sampling strategy is devised for indoor air monitoring, it is necessary to clarify for what purposes, when, where, how often and over what periods of time monitoring is to be performed. The answers to these questions depend, in particular, on a number of special characteristics of the indoor environments, on the objective of the measurement and, finally, on the environment to be measured. ISO 16000-1:2004 deals with the significance of these factors and offers suggestions on how to develop a suitable sampling strategy.

ISO 16000-1:2004 is applicable to indoor environments such as dwellings having living rooms, bedrooms, do-it-yourself rooms, recreation rooms and cellars, kitchens and bathrooms; workrooms or work places in buildings which are not subject to health and safety inspections in regard to air pollutants (for example, offices, sales premises); public buildings (for example hospitals, schools, kindergartens, sports halls, libraries, restaurants and bars, theatres, cinemas and other function rooms), and also cabins of vehicles.

ISO 16000-6:2004
Indoor air - Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS/FID.

ISO 16000-6:2004 specifies a method for determination of VOCs in indoor air and in air sampled for the determination of the emission of VOCs from building materials using test chambers and cells. The method is based on the use of Tenax TA® sorbent with subsequent thermal desorption and gas chromatographic analysis.

The method is applicable to the measurement of non-polar and slightly polar VOCs in a concentration range of sub-microgram per cubic metre to up to several milligrams per cubic metre. Using the principles described in this method, some very volatile compounds and semi-volatile organic compounds can also be analysed.

ISO 16000-9:2006
Indoor air - Part 9: Determination of the emission of volatile organic compounds from building products and furnishing -- Emission test chamber method.

ISO 16000-9:2006 specifies a general laboratory test method for determination of the area specific emission rate of VOCs from newly produced building products or furnishing under defined climate conditions. The method can also, in principle, be applied to aged products. The emission data obtained can be used to calculate concentrations in a model room.

ISO 16000-9:2006 applies to various emission test chambers used for determination of the emission of volatile organic compounds from building products or products. A general description of an emission test chamber is given.

ISO 16000-9:2006 is also applicable to wood-based panels and other building products, in order to determine the emission rate of formaldehyde.

ISO 16000-10:2006
Indoor air - Part 10: Determination of the emission of volatile organic compounds from building products and furnishing -- Emission test cell method.

ISO 16000-10:2006 specifies a general laboratory test method for determination of the area specific emission rate of VOCs from newly produced building products or furnishing under defined climate conditions. The method can also, in principle, be applied to aged products. The emission data obtained can be used to calculate concentrations in a model room.

According to the definition of an emission test cell, it is also possible to perform non-destructive emission measurements on building products on-site in buildings. However, the procedure for such measurements is not described in ISO 16000-10:2006. An example of an emission test cell is described.

ISO 16000-10:2006 is also applicable to wood-based panels and other building products, in order to determine the emission rate of formaldehyde

BS EN ISO 16000-11: 2006. (replaces DD ENV 13419-2:1999)
Indoor air - Part 11: Determination of the emission of volatile organic compounds from building products and furnishing -- Sampling, storage of samples and preparation of test specimens.

Studies of the emission of volatile organic compounds from unused building products or furnishing in test chambers or cells require proper handling of the product prior to testing, and during the testing period.

ISO 16000-11:2006 defines three types of building products or furnishing: solid, liquid and combined. For each type, specifications are given for the sampling procedures, transport conditions, storage, and substrate used that can affect emissions of volatile organic compounds. For individual products, the preparation of a test specimen for each type is prescribed.

ASTM D6330-98 (2003) Standard Practice for Determination of Volatile Organic Compounds (Excluding Formaldehyde) Emissions from Wood-Based Panels Using Small Environmental Chambers Under Defined Test Conditions

The practice measures the VOCs, excluding formaldehyde, emitted from manufactured wood-based panels. A pre-screening analysis is used to identify the VOCs emitted from the panel. Emission factors (that is, emission rates per unit surface area) for the VOCs of interest are then determined by measuring the concentrations in a small environmental test chamber containing a specimen. The test chamber is ventilated at a constant air change rate under the standard environmental conditions. For formaldehyde determination, see Test Method D 6007.

This practice describes a test method that is specific to the measurement of VOC emissions from newly manufactured individual wood-based panels, such as particleboard, plywood, and oriented strand board (OSB), for the purpose of comparing the emission characteristics of different products under the standard test condition. For general guidance on conducting small environmental chamber tests, see Guide D 5116.

VOC concentrations in the environmental test chamber are determined by adsorption on an appropriate single adsorbent tube or multi-adsorbent tube, followed by thermal desorption and combined GC/MS or GC/FID. The air sampling procedure and the analytical method recommended in this practice are generally valid for the identification and quantification of VOCs with saturation vapour pressure between 500 and 0.01 kPa at 25℃, depending on the selection of adsorbent(s) .

Note 1: VOCs being captured by an adsorbent tube depend on the adsorbent(s) and sampling procedure selected (see Practice D 6196). The user should have a thorough understanding of the limitations of each adsorbent used.

The emission factors determined using the above procedure describe the emission characteristics of the specimen under the standard test condition. These data can be used directly to compare the emission characteristics of different products and to estimate the emission rates up to one month after the production. They shall not be used to predict the emission rates over longer periods of time (that is, more than one month) or under different environmental conditions.

Emission data from chamber tests can be used for predicting the impact of wood-based panels on the VOC concentrations in buildings by using an appropriate indoor air quality model, which is beyond the scope of this practice.

The values stated in SI units shall be regarded as the standard (see IEEE/ASTM SI-10).

This practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of the standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specified hazard statements see Section 6.

ASTM D 5116 Standard Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products Dec 10, 1997

The use of small environmental test chambers to characterize the organic emissions of indoor materials and products is still evolving. Modifications and variations in equipment, testing procedures, and data analysis are made as the work in the area progresses. Until the interested parties agree upon standard testing protocols, differences in approach will occur. This guide will provide assistance by describing equipment and techniques suitable for determining organic emissions from indoor materials. Specific examples are provided to illustrate existing approaches; these examples are not intended to inhibit alternative approaches or techniques that will produce equivalent or superior results.

Small chambers have obvious limitations. Normally, only samples of larger materials (for example, carpet) are tested. Small chambers are not applicable for testing complete assemblages (for example, furniture). Small chambers are also inappropriate for testing combustion devices (for example, kerosene heaters) or activities (for example, use of aerosol spray products). For some products, small chamber testing may provide only a portion of the emission profile of interest. For example, the rate of emissions from the application of high solvent materials (for example, paints and waxes) via brushing, spraying, rolling, etc. is generally higher than the rate during the drying process. Small chamber testing cannot be used to evaluate the application phase of the coating process.

The guide does not provide specific guidance for determining emissions of formaldehyde from pressed wood products, since large chamber testing methods for such emissions are well developed and widely used. For more information refer to Test Method E 1333. It is possible, however, that the guide could be used to support alternative testing methods.

The guide is applicable to the determination of emissions from products and materials that may be used indoors. The effects of the emissions (for example, toxicity) are not addressed and are beyond the scope of the guide.

APPENDIX 2 – VOC TESTING ORGANISATIONS

Cetec
2/27 Normanby Road
Notting Hill
VIC 3168, Australia
Tel: 03 9544 9111
info@cetec-foray.com.au

Eurochamp
http://www-v2.sp.se/km/eurochamp/default.asp

Eurofins Environment A/S
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Tel: +45 70 22 42 66
Fax: +45 70 22 42 55
Inge.Bondgaard@eurofins.dk
http://www.eurofins.dk

Fraunhofer - Institute for Wood Research Wilhelm-Klauditz-Institut (WKI)
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Tel: +49 531 21 55 0
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info@wki.fhg.de
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Hamburg University
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21031 Hamburg
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Fax: +49 40 73962 480
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SP Technical Research Institute of Sweden
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APPENDIX 3 – AIR QUALITY GUIDELINES

Table A3.1: Recommended maximum concentrations for specific classes of contaminants (Institute of Environmental Epidemiology, Ministry of the Environment, Singapore (IEE, 1996)).

Parameter	Limit for acceptable indoor air quality	Units
Suspended particulate matter*	150	µg/m^3
Volatile organic compounds	3	ppm
Total bacterial counts	500	CFU**/m^3
Total fungal counts	500	CFU/m^3

*Respirable particles with aerodynamic diameters less than 10 µm sampled with a size selective device (commonly used devices; cyclones and impactors) having a median cut size of 4µm. **Colony-forming unit, a measure of viable bacterial or fungal numbers.

Table A3.2: Guideline maximum concentrations for specific indoor air contaminants (Institute of Environmental Epidemiology, Ministry of the Environment, Singapore (IEE, 1996)).

Parameter	Averaging time	Limit for acceptable indoor air quality
Carbon dioxide	8 hours	1800 mg/m^3; 1000 ppm
Carbon monoxide	8 hours	10 mg/m^3; 9 ppm
Formaldehyde	8 hours	120µg/m^3; 0.1 ppm
Ozone	8 hours	100 µg/m^3; 0.05 ppm

Table A3.3: MHLW Guidelines for Indoor Air Pollution (Japanese Ministry of Health, Labour and Welfare (MHLW, 2007)).

VOCs*	**Toxicity endpoint**	**Guideline value for indoor air concentration****
Acetaldehyde (1, 2)	Effects on nasal olfactory epithelium in rats exposed by inhalation	48 μg/m^3 (0.03 ppm)
Fenobucarb (3, 5)	Effects on cholinesterase etc. in rat orally exposed	33 μg/m^3 (3.8 ppb)
Formaldehyde	Nose, throat irritation in humans exposed by inhalation	100 μg/m^3 (0.08 ppm)
Toluene (1, 2)	Effects on central nervous system (CNS) behavior functions and development and reproduction in humans exposed by inhalation	260 μg/m^3 (0.07 ppm)
Xylene (1, 2)	Altered development of central nervous system in offspring whose mother rat exposed by inhalation during its pregnancy period	870 μg/m^3 (0.20 ppm)
p-Dichlorobenzene (1, 2)	Liver/kidney effects in beagle dogs orally exposed	240 μg/m^3 (0.04 ppm)
Ethylbenzene (1, 2, 3)	Liver/kidney effects in mice and rats exposed by inhalation	3800 μg/m^3 (0.88 ppm)
Styrene (1, 2)	Brain/kidney effects in rats exposed by inhalation	220 μg/m^3 (0.05 ppm)
Chlorpyrifos (4, 5)	Altered development of CNS and morphological effects on brain in offspring whose mother rat orally exposed	1 μg/m^3 (0.07 ppb) For children: 0.1 μg/m^3 (0.007 ppb)
Di-n-butyl phthalate (1, 3, 5)	Abnormal genitals in offspring whose mother rat orally exposed	220 μg/m^3 (0.02 ppm)
Tetradecane (2, 6)	Effects on liver in rat orally exposed to C8-C16 hydrocarbon mixture	330 μg/m^3 (0.04 ppm)
Di-(2-ethylhexyl) phthalate (3, 5)	Histopathological effects on testicle in rat orally exposed	120 μg/m^3 (7.6 ppb)
Diazinon (4, 5)	Effects on blood plasma and erythrocyte cholinesterase in rat exposed by inhalation	0.29 μg/m^3 (0.02 ppb)

* Numbers indicate the following criteria used for selection: 1) chemicals for which guidelines have been given by foreign governments or international organizations; 2) chemicals for which investigations demonstrated that the indoor air concentration has been found high because of apparent indoor chemical emission sources; 3) chemicals for which public comments have particularly claimed; 4) chemicals for which foreign governments have provided a new regulation and the like; 5) chemicals to be selected so as to comprehend indoor chemical sources; and 6) chemicals to be selected so as to comprehend chemical structural categories.

Table A3.4: Comparison of indoor air quality guideline concentrations for pollutants (Environment Australia 2001).

Indoor air pollutant	**Goal concentrations (μg/m³ unless specified)**			
	NHMRC (1993) (indoor)	Health & Welfare Canada (1987) (residential)	Norwegian Health Directorate (NHD) (1990)[a] (indoor)	WHO (1987)[b] (indoor)
Asbestos	-	-	Source control	Carcinogen
Synthetic mineral fibres	-	-	No free fibres	-
Radon	200 Bq/m³ (1y)[d]	800 Bq/m³ (1y)	200-800 Bq/m³	Carcinogen
Environmental tobacco smoke	-	-	Prohibited	-
Respirable suspended particles	TS90 (1y)	PM100 (1 hr)	40 (8 hrs)	100
Legionella	-	2.5	-	-
House dust mite	-	-	1 g/g Der p I[e]	-
Microbes	-	-	No pathogens or odour	-
Formaldehyde	120 (ceiling)[d]	60-120	100	60
VOCs	TVOCs 500 (1 hr)[d] VOC 250 (1 hr)[d]	-	Irritants, TVOCs 400	Some VOCs[c]
Nitrogen dioxide	Review	480 (1 hr)	200 (1 hr)	400 (1 hr)
Carbon monoxide	9 ppm (8 hrs)	11 ppm (8 hrs)	9 ppm (8 hrs)	9 ppm
Carbon dioxide	-	3500 ppm	1000 ppm (max)	1000 ppm
Ozone	240 (1 hr)	240 (1hr)	-	-
Sulfur dioxide	700 (1 hr)	1000 (5 min)	-	-
Lead	1.5 (3 months)	-	-	0.5-1.0
Mercury	-	-	-	1.0 (1 y)
RH(%)	-	30-80	-	-

[a] Values averaged over 24 hours unless specified. [b] Short-term exposure averages. [c] 1,2 dichloroethane 700, dichloromethane 3000, styrene 800 (70 odour), tetrachloroethylene 5000, toluene 8000 (1000 odour). [d] Final goals for radon and formaldehyde; level of concern for volatile organic compounds (VOCs) and total VOCs (TVOCs); other goals are interim goals using ambient air gas. [e] Der p 1 is the allergen specific to *Dermatophagoides pteronyssinus*. Bq = Becquerel; PM100 = particulate matter (less than 100 micrometres in diameter). - = no goal set.

Table A3.5: National indoor air quality goals recommended by the Australian NHMRC (1996).

Pollutant	Goals for maximum permissible levels of pollutants in air[a]		Measurement criteria	Comments
	µg/m³	*ppm*		
Carbon monoxide (CO)	10,000	9	8-hr average not to be exceeded more than once a year	This is not a threshold limit value
Formaldehyde[b]	120	0.1	Not to be exceeded	For dwellings and schools
Lead	1.5	-	3 month average	
Ozone	210	0.10	Maximum hourly average not to be exceeded more than once per year	
	170	0.08	4 hour average	
Radon[b]	200 Bq/m^3	-	Annual mean	Action level
Sulfates	15	-	Annual mean	
Sulfur dioxide (SO_2)	700	0.25	10 minute average	Levels may not be low enough to protect the most sensitive individuals
	570	0.20	Hourly mean	
	60	0.02	Annual mean	
Particles	90	-	Annual mean	
Total volatile organic compounds	500	-	Hourly average	A single compound shall not contribute more than 50% of the total

[a] At 0°C and 101.3 kPa. [b] Final NHMRC goals. - = no goals set in those units

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