

An investigation of environmental conditions experienced during the life of high-value wood components and products, to aid design and manufacturing processes that will ensure long-term quality and performance.

**A thesis submitted in total fulfilment of the requirements for the degree of
Master of Wood Science**

Gary P. Hopewell

June 17, 2004

**Institute of Land and Food Resources
University of Melbourne**

Declaration

This thesis was prepared and submitted by Gary Hopewell. Any material written by others (published or unpublished), or sourced by personal communication, has been appropriately referenced or quoted. The contents of this thesis have not been submitted previously for the award of any diploma or degree to any academic institution.

Gary P. Hopewell

University of Melbourne student no. 168 882
CRC Wood Innovations postgraduate no. 43

Brisbane
June 17, 2004

Related reports, papers and presentations

The following list details reports, papers and presentations prepared and undertaken by the author during the period of research for this project:

Reports and papers

1. Hopewell, G. P. (2002): The 42nd Annual Conference of Furniture transportation and Logistics managers, Orlando Florida USA. Internal report to the CRC Wood Innovations.
2. Hopewell, G. P. (2003) Timber and Wood Product Exporters- Victoria and Tasmania. Confidential report to the CRC Wood Innovations.
3. Hopewell, G. P. (2003) Timber and Wood Product Exporters- South-eastern Australia. General report to the CRC Wood Innovations.
4. Hopewell, G. P. (2003) EMC% in shipping containers- Gumnut Furniture Shipments 2002-2003. Report to Gumnut Furniture and CRC Wood Innovations.
5. Hopewell, G. P. (2003) Western Australian Timber Exports. General Report to the CRC Wood Innovations.
6. Hopewell, G. P. (2003) An investigation of environmental conditions experienced during the life of high-value wood components and products: a review of the literature. Report to DPI&F Forestry Research and the CRC Wood Innovations.
7. Allnut, L and Hopewell, G. P. (2003) Industry Interaction- Gumnut Furniture, Brisbane. Internal report to the CRC Wood Innovations.
8. Hopewell, G. P. (2003) Industry Interaction- N. K. Collins Industries, Queensland. Internal report to the CRC Wood Innovations.
9. Hopewell, G. P. (2003) Industry Interaction- FIAA and Paragon Furniture, Brisbane. Internal report to the CRC Wood Innovations.
10. Hopewell, G. P. (2003) Western Australian Timber Exports. Confidential Report to the CRC Wood Innovations.
11. Hopewell, G. P. (2003) Industry Interaction- QTEC International. Internal report to the CRC Wood Innovations.
12. Allnut, L. and Hopewell, G. P. (2003) Industry Interaction- Paragon, Queensport and Gumnut Furniture. Internal report to the CRC Wood Innovations.
13. Hopewell, G. P. (2003) Industry Interaction- Hyne & Son P. L. Internal report to the CRC Wood Innovations.
14. Hopewell, G. P. (2003) NSW Exporters- Boral Timber, Gilet Guitars and Guitar Woods. Internal report to the CRC Wood Innovations.

15. Hopewell, G. P. (2004) Industry Interaction- Ausgum Furniture, Moxon Timbers, Hyne & Son. Internal report to the CRC Wood Innovations.
16. Hopewell, G. P. (2004) High-value timber exports from sub-tropical eastern Australia. Internal report to the CRC Wood Innovations.
17. The CRC Wood Innovations- what's in it for North Queensland forest industries? North Queensland Forest Industry Development Conference, Cairns 28-29 April 2004. Rainforest CRC proceedings (in preparation).

Presentations

1. Investigation of environmental conditions during transport, storage and service. Student presentation, CRC Wood Innovations meeting, Melbourne 5 February 2002.
2. Investigation of environmental conditions experienced by wood products. Student presentation, quarterly meeting CRC Wood Innovations, Launceston Tasmania, 13 May 2002.
3. 42nd Annual Conference of Furniture Transportation and Logistics Managers. Dinner presentation to the CRC Wood Innovations and industry guests, Launceston, Tasmania 14 May 2002.
4. CRC Wood Innovations Project 2.4: environmental conditions research. Creswick November 2002.
5. Environmental Conditions Research Project. Student presentation, National School of Design, Melbourne 1-2 May 2003.
6. CRC Wood Innovations. Presentation to officers of QFRI, Indooroopilly staff forum 28/5/03.
7. Investigation of environmental conditions during manufacture, transport, storage and service. CRC 2nd year review, Melbourne 5 August 2003.
8. CRC Wood Innovations- what's in it for North Queensland forest industries? Presentation to delegates at the NQ Forest Industry Development Conference, Rainforest CRC, Cairns 28 April, 2004.
9. An overview of the CRC Wood Innovations. Presentation to officers of the Direction of Rural Development of New Caledonia, Southern Province. Forestry Study tour of Queensland, Indooroopilly, 11 June 2004.
10. Environmental conditions experienced during shipping of high-value wood products. 58th Annual Meeting of the Forest Products Society- technical forum presentation, Grand Rapids, MI USA, June 27 2004.

Abstract

Australian forest industries have a long history of export trade in a wide range of products, from woodchips and sandalwood, through to high value manufactured commodities such as outdoor furniture and assorted flooring products. Current export markets for high value wood products were found to be predominantly northern hemisphere countries, including, United States of America, China (including Hong Kong), Korea, Japan, Europe (including the United Kingdom) and the Middle East. Other regions importing Australian high value wood products were south-east Asia (Philippines, Indonesia, Thailand and Malaysia), New Zealand and South Africa.

A survey was undertaken to determine the range of value-added products currently exported and it was found that high volumes of flooring, decking, outdoor furniture and kiln-dried boards for furniture and pre-finished flooring products account for the majority of our value-added export effort. There are currently only minor volumes of assembled indoor furniture suites exported from Australia.

Data generated from the survey included the range of timber species used in the manufacture of export products, sawn orientation and typical section sizes used in components. Results from this work showed that the major timbers were: the ash-type eucalypts from south-eastern Australia; jarrah from Western Australia; spotted gum, hoop pine, white cypress, imported kwila, blackbutt, brush box and Sydney blue gum from New South Wales and Queensland.

Wood as a hygroscopic material will undergo changing moisture contents, fluctuating with changes in atmospheric conditions. As a consequence of these changes in moisture content, the wood will swell or shrink. For high value products, these changes can be detrimental to the utility of the product, for example panels can warp, drawers and doors can jam, and glued components can delaminate.

Environmental conditions, especially the combined effect of temperature and relative humidity microclimates as determined during this research project, can fluctuate extensively from one location to the next during transport. Equilibrium moisture contents (EMC) as low as 5% and as high as 20% were experienced during the shipping of wood

products. Further, the conditions at the place of manufacture, often 10 to 12% EMC, may be vastly different to the environment where the wood products are ultimately placed in service. The in-service conditions for many of our export destinations are between 6 to 9% EMC.

This range of conditions, from manufacturing through transportation and in-service, can potentially create problems, due to wood components swelling and/or shrinking corresponding with periods of higher and/or lower humidities. Packaging systems incorporating plastic and cardboard were shown to offer some protection against humidity changes.

In order for the Australian wood manufacturing sector to achieve and maintain a reputation for superior, high performance products in overseas markets, designers and manufacturers will require a clear understanding of the potential effects of changing environmental conditions on their products. When the range of conditions anticipated throughout the service life of an item is combined with data for timber stability, a manufacturer can allow for movement in the design of the item. An understanding of effective packaging systems is also necessary to ensure maintenance of timber moisture content during transportation.

The research highlighted the inherent risks of exporting high-value wood products to distant markets and the need for development of a user-friendly tool, which would allow manufacturers to determine appropriate design parameters such as species, dimensions and packaging for, export products.

Acknowledgements

The assistance of Matt Armstrong, William Leggate, Dr Susan House, Terry Copley (DPI&F Forestry Research, Indooroopilly), Dr Barbara Ozarska (CRC Wood Innovations), Dr Graeme Siemon (Forest Products Commission, WA) and in reviewing some, or all, of this thesis is gratefully acknowledged. Former Forestry Research employees Dr Stephen Catchpoole and Felix McDonald also provided technical support during the early stages of the research.

The data collection, for both export marketing information and environmental conditions, could not have been undertaken without extensive co-operation from Australian processors, manufacturers and freight forwarders of wood products. The following individuals offered data, advice or participation with data capture, and I am indebted to all of them:

Adam and Judy Gleeson, Ausgum Furniture, Qld
Felix McDonald, Moxon Timbers, Qld
Heather Creese, Hyne & Son, Qld
Leonie Foster, FIAA Queensland
Luke Cosgrove, DHL Australia, Qld
Martin Barry, QTEC International, Qld/Japan
Michael Uljarevic, Paragon Furniture, Qld
Nick Price and Linda Pym, Gumnut and Ausgum Furniture, Qld
Phil Lawson, N. K. Collins Industries, Qld
Tom and Guy Scullen, Carole Margand, Gumnut Furniture, Qld
Tony White, ITC, Qld

Gerard Gilet, Gilet Guitars and Guitar Woods, NSW
Gerry McCormack, Sydney Ports, NSW
Tom Bertinshaw and Lina Qui, Boral Timber, NSW

Alan Bajada, Hamilton Sawmills, WA
Edmund Damouni, Antry P. L., WA
Glen Holst, Glen Holst Furniture, WA
Graham Duncan and Joe Yozzi, Whittakers, WA

John Clare, Clarecraft Industries/ Australis, WA
Simon Gandossi, Select Freight Systems WA
Julie Sulley, Inglewood Products Group, WA
Julius Solomon, Paul Kelly and Rob Davis, Jensen Jarrah, WA
Les Brooker, Brooker Furniture, WA
Peter Jolob, Sotico, WA

Ben Smith, Coringle Furniture, Vic
Bradley Clark, Australian Native Musical Instruments, Vic
Ian Wright and Jane Richards, Neville Smith Timber, Vic
Keith Reeves, Black Forest Timbers, Vic
Malcolm Kay, Intex Pacific, Vic
Patrick Evans and Neville Kitchener, Maton Guitars, Vic
Peter Adams, Forrest Timber Products, Vic
Peter Halliday, Australian Hardwood Exports/ J. L. Goulds, Vic
Phil Delaney, Alternative Cargo, Vic
Ross Paxton, Whittlesea, Vic

Hamp Townsend, Mill Direct Sales, USA
Kimberly Pita, Jensen Jarrah/Meiko America USA
Mike McNulty, W-flooring USA
Rick Letounneau, California USA
Robin Sloan, Boral Timber USA

Andrew Gracie, Great Things, Bermuda, UK

Shaun Britton, Britton Brothers, Tas
Terry Harris, Gunns Limited, Tas

On the home front, thanks to my wife Erica for keeping the kids distracted while I was working, and for keeping up the coffee and cake.

Table of Contents

Declaration		i
Related reports, papers and presentations		ii
Abstract		iv
Acknowledgements		vi
Table of Contents		viii
List of tables		x
List of figures		xi
Plates		xiv
Abbreviations and symbols		xv
Chapter 1	Introduction	1
1.1	Problem statement	1
1.2	Background	3
1.2.1	<i>Australia's timber industry</i>	3
1.2.2	<i>The importance of exports</i>	5
1.2.3	<i>CRC Wood Innovations</i>	7
1.3	Aim and scope of the study	8
1.4	Research approach	8
Chapter 2	Literature review	10
2.1	Wood and moisture	10
2.1.1	<i>Moisture content MC</i>	10
2.1.2	<i>Seasoning</i>	10
2.1.3	<i>Fibre saturation point FSP</i>	11
2.1.4	<i>Equilibrium moisture content EMC</i>	12
2.1.5	<i>Indoor and outdoor EMC</i>	17
2.1.6	<i>Hysteresis</i>	18
2.1.7	<i>Effect of physical properties on EMC and hysteresis</i>	20
2.1.8	<i>Wood-based panels</i>	20
2.1.9	<i>Engineered products</i>	20
2.1.10	<i>Stability</i>	21
2.2	Australian timber and wood products exports	27
2.2.1	<i>Products and markets</i>	27

	2.2.2 <i>Shipping</i>	30
Chapter 3	Methodology	35
3.1	Industry survey	35
3.2	Climatic data collection	36
	3.2.1 <i>Dataloggers</i>	36
	3.2.2 <i>Location climatic conditions</i>	38
3.3	Environmental conditions data	39
3.4	Timber movement data	39
Chapter 4	Results	40
4.1	Industry survey	40
	4.1.1 <i>Markets for Australian value-added timber products</i>	40
	4.1.2 <i>Timber species</i>	43
	4.1.3 <i>Products</i>	46
	4.1.4 <i>Moisture content and packaging specifications</i>	51
	4.1.5 <i>Section sizes</i>	57
4.2	Climatic data	58
	4.2.1 <i>Processing and manufacturing sites</i>	58
	4.2.2 <i>Shipping routes</i>	59
	4.2.3 <i>In-service conditions</i>	88
Chapter 5	Discussion, conclusions and recommendations	89
5.1	Discussion of results	89
	5.1.1 <i>Markets and products</i>	89
	5.1.2 <i>Packaging</i>	92
	5.1.3 <i>Section sizes</i>	93
	5.1.4 <i>Stability</i>	94
	5.1.5 <i>Environmental conditions</i>	94
5.2	Limitations of the study	95
5.3	Conclusion and recommendations for further research	95
References		98

List of tables

Table 1. EMC values for various locations.	12
Table 2. Equilibrium moisture content for furniture timbers based on relative humidity (after Welch, 1937).	13
Table 3. Equilibrium moisture content values based on temperature and relative humidity.	14
Table 4. Comparison of results from two equilibrium moisture content equations.	15
Table 5. Unit shrinkage data for some commercial timbers. (Source: Kingston and Risdon, 1961).	26
Table 6. Average gain in lumber moisture content during ocean shipment from Canada (Source: Simpson and Ward, 1991).	32
Table 7. Primary export markets for high-value wood products from Australia (by region).	41
Table 8. Exported timber species by processing/ manufacturing region.	45
Table 9. Australian high-value wood exports- producer regions, species, products and markets.	50
Table 10. Cross-section dimensions for Australian high-value timber exports.	57
Table 11. Australian manufacturing sites' EMC conditions.	58
Table 12. Allocation of dataloggers by destination region, summary of voyage duration and environmental conditions.	59
Table 13. Indoor equilibrium moisture contents for some Australian wood product export markets.	88

List of figures

Figure 1. Principal cause-effect relationships of environmental conditions research with industry success (after Wissemann, Rogers and Duffield, 2003).	6
Figure 2. Recommended average moisture content for interior wood products in the United States. (Source: Simpson, 1999).	16
Figure 3. Typical sorption isotherms for timber (after Stamm, 1964).	19
Figure 4. Tangential and radial movement in timber.	21
Figure 5. Cross-section (end-grain of sawn boards) showing true quarter-sawn (5a) and backsawn (5b) board orientation.	25
Figure 6. Sawnwood exports 1997 to 2002. (Data source: Invest Australia, 2003).	29
Figure 7. Primary export destinations for high-value wood products from Australia (by region).	42
Figure 8. Environmental conditions Emerald to Manchester 18/12/02-27/2/03.	60
Figure 9. Environmental conditions Brisbane to Bermuda 16/11/02-27/1/03.	61
Figure 10. Environmental conditions Brisbane to Egypt 3/12/02-18/1/03.	62
Figure 11. Brisbane to Hamburg 18/12/02-12/2/03.	63
Figure 12. Environmental conditions Brisbane to Hong Kong 12/2/04-2/3/04.	
Figure 13. Environmental conditions Brisbane to Shanghai 12/2/04-13/3/04.	
Figure 14. Environmental conditions Brisbane to Philippines 12/2/04-2/4/04.	
Figure 15. Environmental conditions Brisbane to Virginia 28/11/03-25/1/04.	
Figure 16. Environmental conditions (shrink-wrap package) Brisbane to Virginia 24/6/03-27/7/03.	

- Figure 17. Environmental conditions (container) Brisbane to Virginia 24/6/03-27/7/03.
- Figure 18. Environmental conditions Brisbane to Philadelphia 1/8/03-11/11/03.
- Figure 19. Environmental conditions (container) Brisbane to Philadelphia 10/9/03-10/10/03.
- Figure 20. Environmental conditions (shrink-wrap) Brisbane to Philadelphia 10/9/03-10/10/03.
- Figure 21. Environmental conditions Sydney to Oakland 25/2/04-17/3/04.
- Figure 22. Environmental conditions Sydney to Philadelphia 1/4/04-7/5/04.
- Figure 23. Environmental conditions Woodend to Melbourne to Dunedin, 16/4/03-18/5/03.
- Figure 24. Environmental conditions Melbourne to Dunedin 9/5/03-18/5/03.
- Figure 25. Environmental conditions (container) Heyfield to Aarhus, Denmark 23/4/03-17/6/03.
- Figure 26. Environmental conditions (packaging) Heyfield to Aarhus, Denmark 23/4/03-17/6/03.
- Figure 27. Environmental conditions Heyfield to Nagoya 15/7/03-15/8/03.
- Figure 28. Environmental conditions Perth to Tokyo 10/10/03-12/11/03.
- Figure 29. Environmental conditions Perth to Hong Kong 20/9/03-10/10/03.
- Figure 30. Relative humidity comparison: container v packaging: WA to USA.
- Figure 31. Environmental conditions (container) Busselton to Virginia 23/12/03-5/2/04.
- Figure 32. Environmental conditions (packaging) Busselton to Virginia 23/12/03-5/2/04.
- Figure 33. Container environmental conditions Busselton to California 22/12/03-27/1/04.
- Figure 34. Package environmental conditions Busselton to California 22/12/03-27/1/04.

Figure 35. Environmental conditions Perth to Oakland 27/10/03-3/12/03.

Figure 36. Environmental conditions Perth to Laguna Beach 12/9/03-10/10/03.

Figure 37. Environmental conditions Perth to Hong Kong 8/4/04-25/4/04.

Plates

Plate 1. Side-opening containers for ease of loading strip-flooring packs.

Plate 2. Flat-rack used for shipping timber boards and flooring.

Plate 3. GPSE temperature/ relative humidity datalogger.

Plate 4. Engineered decking product, manufactured from jarrah (Ezydeck™).

Plate 5. Australian-designed and manufactured outdoor furniture: exported to more than 20 countries (Photo supplied by Gumnut).

Plate 6. Australian-made guitar, featuring Australian timbers and designed to tolerate changing conditions.

Plate 7. Australian hardwood parquetry, packaged and palletised for export.

Plate 8. Australian hardwood flooring for export: shrink film, particleboard and plastic sheet.

Plate 9. White cypress flooring packaged for export to USA and Japan.

Plate 10. Outdoor furniture: flat-packed, carton boxing, shrink film and palletised.

Plate 11. Celair foam between window joinery items.

Plate 12. Australian-made acoustic guitar packaged for export.

Abbreviations and symbols

ABS	Australian Bureau of Statistics
1R	first rotation
°C	degrees Celsius
CRC	Cooperative Research Centre
AFFA	Agriculture, Fisheries and Forestry- Australia
AUD	Australian dollars
DFAT	Department of Foreign Affairs and Trade
DPI&F	Department of Primary Industries and Fisheries (Queensland)
Ed.	Editor/s
EMC	equilibrium moisture content
FL	Florida
FPC	Forest Products Commission (Western Australia)
FSP	fibre saturation point
GSP	gross state product
<i>Ibid</i>	Abbreviation ibidem, in same reference
LVL	laminated veneer lumber
MC %	moisture content percent
MDF	medium density fibreboard
MI	Michigan
mm	millimetre/s
MS	Microsoft Corporation
PCARRD	Philippine Council for Agriculture and Resources Research and Development
pers. comm.	personal communication
PNG	Papua New Guinea
Qld Govt	Queensland Government
RFA	regional forest agreement
RH%	relative humidity percent
<i>sic</i>	Latin, 'so spelt', i.e. as spelt in original reference
st. deviation	standard deviation
USA	United States of America
USDA	United States Department of Agriculture
WA	Western Australia
9-pin-D	Nine-pin, D-shaped computer socket
”	inches

Chapter 1 Introduction

1.1 Problem statement

Governments at both State and Federal levels have networks and systems in place to cultivate trade with other nations. These have been established in order to provide the economic and social benefits associated with trade.

Trade in timber commodities has rapidly become globalised and for Australian manufacturers to compete effectively, their products need to develop and sustain a reputation for superior quality and performance. An important consideration for designers and manufacturers exporting high-value products is the stability of the wood components.

Timber is a natural material that will adsorb and desorb moisture in a continual attempt to equalise to the surrounding environmental conditions. If the potential for timber movement corresponding to these changes is not considered, there is a risk that the product will suffer degrade. For example if a dry timber product experiences increasing humidity, it will take on moisture from the atmosphere, and subsequently swell. Conversely, a timber product with a higher moisture content placed in a drier environment will lose moisture to the atmosphere and subsequently shrink. This is seen most clearly where doors and drawers in solid timber furniture ‘jam’, or when gaps appear in feature flooring after installation. This poor performance, often unacceptable to the consumer, can be to the detriment of the reputation of the designer, manufacturer, the material and even the broader timber industry.

Australia experiences huge variations in environmental conditions from locality to locality and also seasonally within a locality. Similarly, some of our key export markets have vastly different climatic conditions to those we experience in Australia. Exporting timber products has the added factor of shipping logistics to consider, where a container of wood products may spend several weeks at sea in addition to periods dockside awaiting transhipping. Many transhipping ports on routes out of Australia are located in the tropics, a zone experiencing periods of regular high humidity.

Many variables affect the rates of shrinkage and swelling associated with these environmental changes; for example, the rate of movement differs between species, with the section size (especially thickness), whether the wood is drying down or wetting up and type of surface coatings. A timber species' propensity for movement during climatic changes in its surrounding environment determines its classification as stable or otherwise.

Knowledge of the potential for timber components to 'move' is critical for successful design and performance of finished products. Timber products are often sold and used in a very different environment from where they were manufactured. Without due consideration to the potential for movement at the design stage, the product will possibly perform poorly.

The necessity for knowing the required timber moisture contents for various applications and differing geographic areas has been recognised for many years, however very little investigative work has been undertaken to determine the conditions experienced during manufacture and shipping of Australian wood products. Further, there is some disagreement within the industry that changing conditions, such as rising humidity during shipping, are problematic for the wood products.

The review of the literature supports the need to establish the range of conditions experienced at Australian sites, during shipping to Australia's major timber product markets and the in-service conditions for these destinations. Only when the range of conditions is known, can designers and manufacturers expect to confidently provide products that will afford superior performance in the Global marketplace.

“If it can be measured, it can be managed.”

Linwood Guthrie, President, Century Services Inc,
speaking at the 42nd Annual Conference of Furniture Transportation and Logistics Managers,
Orlando FL, USA May 1, 2002.

1.2 Background

1.2.1 Australia's timber industry

During the past twenty years, there have been significant changes to the accessibility and structure of Australia's timber resource. Since the late 1980s, World Heritage Listing of substantial areas of Queensland's wet tropical rainforest has meant that traditional cabinet woods have become increasingly difficult to obtain (Smorfitt, Herbohn and Harrison, 2002). This provided opportunities for importers who brought medium-density, tropical hardwood species, primarily sourced from south-east Asia, Papua New Guinea and the Pacific islands, to substitute for traditional woods which had been used for high value applications since colonisation.

With increasing awareness of the environmental aspects of processes and products and interest in sustainability, locally produced timbers are regaining market interest. However, further political developments (instigated with the Regional Forest Agreements (RFAs) but often extending beyond those recommendations) have resulted in reductions to the available native hardwood resource. The softwood sector has also witnessed some structural changes. For example the cessation of clearing sub-tropical rainforest, for first-rotation (1R) hoop pine (*Araucaria cunninghamii*) plantation establishment, has restricted the available land area for production of this species.

While the exotic softwood sector has successfully developed and marketed a range of engineered structural products, the native hardwood and native softwood industries have, during recent years, upgraded processing and seasoning facilities and looked to high value appearance products for both domestic and export markets.

Coinciding with government programs to increase the national plantation estate, has been growth of the private forestry sector, for example managed investment schemes engaged in plantation establishment, maintenance and product marketing. Tree plantations, whether for pulp or timber products, require relatively intensive and therefore expensive management regimes. For this reason, the grower must look for the best return on shareholders' investments, and though some companies concentrate on short-rotation pulp plantations,

others are intending to produce appearance grade timber for high value products over longer-rotations.

These developments have pressured the forestry and timber industries to re-consider how the current domestic resource and future forests are utilised. It is expected that the impetus to divert Australia's forest resource into high-value products and export markets will continue, resulting in larger volumes of product being transported around the globe.

For the purposes of this report, 'high-value' commodities includes indoor and outdoor furniture, internal flooring (strip, parquetry, engineered, pre-finished), decking and musical instruments, that is, products where stability of the material is critical to satisfactory, long-term performance. The building industry is the largest user of sawn timber in Australia and uses substantial volumes of other value-added products, such as engineered structural members (I-beams and laminated veneer lumber LVL); however due to the design-enhanced stability of these products (Forest Products Laboratory, 1989), they are not as susceptible to the effects of changing environmental conditions and have therefore not been considered in this project.

Approximately seven percent of Australia's sawn timber production is used for furniture manufacture. Domestically, consumers tend to base commodity selection on price rather than quality or long-term performance, therefore it is difficult for innovative, value-added products to compete with cheaper, imported products. Larger high end markets exist offshore in countries of high population and/or affluence, such as North America, Europe, Japan and countries of the Arabian peninsular. In order for Australian manufacturers to establish relationships with export clients in these countries, designers, specifiers and manufacturers need to understand how Australian timbers and modified wood products will perform throughout a wide range of environmental conditions, over the life of the product. This will ensure that Australian-designed and manufactured products are of the highest quality and will provide superior performance.

The increasing production of high value wood products for international markets requires a sound knowledge of the products' serviceability and lifetime performance. In particular, the performance of the products under conditions of changing temperature and relative humidity must be known (Ozarska, 1994). Therefore, quantitative and reliable information concerning the true service life of wood products, their appearance and behaviour over time, is critically important. Furniture in particular should be designed to allow some movement owing to shrinkage and expansion of

timber components. High priority on the research agenda of the Cooperative Research Centre-Wood Innovations has been the investigation of critical environmental and time-related factors which affect wood behaviour and therefore product performance.

1.2.2 The importance of exports

The onus of this research project was to gather data for certain parameters affecting stability, an understanding of which will be necessary for successful export of value-added timber products. The focus on export products is due to the importance of trade for employment and is also related to the size of the higher end market in Australia (relatively small) compared to other first-world countries, for example, USA, Japan and European nations (relatively large). Trade with other countries provides employment within Australia. The Department of Foreign Affairs and Trade, through Austrade, estimate that one in five Australian jobs relies on exports and if exports were to increase by 10%, 70 000 new jobs would be created (Austrade, 2003).

In Queensland alone, the export of goods and services represents 25% of Gross State Product (GSP), equating to 1 in 5 jobs overall and increasing to 1 in 4 in regional Queensland (State Development, 2001). In addition to the employment benefits, trade promotes quality in design, industry development, care of resources and recognition of Australia’s unique timber species. In current political parlance, these benefits and outcomes, summarised as ‘environmental, social and economic’, are referred to as ‘the triple-bottom-line’ (Wisseman, Rogers and Duffield, 2003).

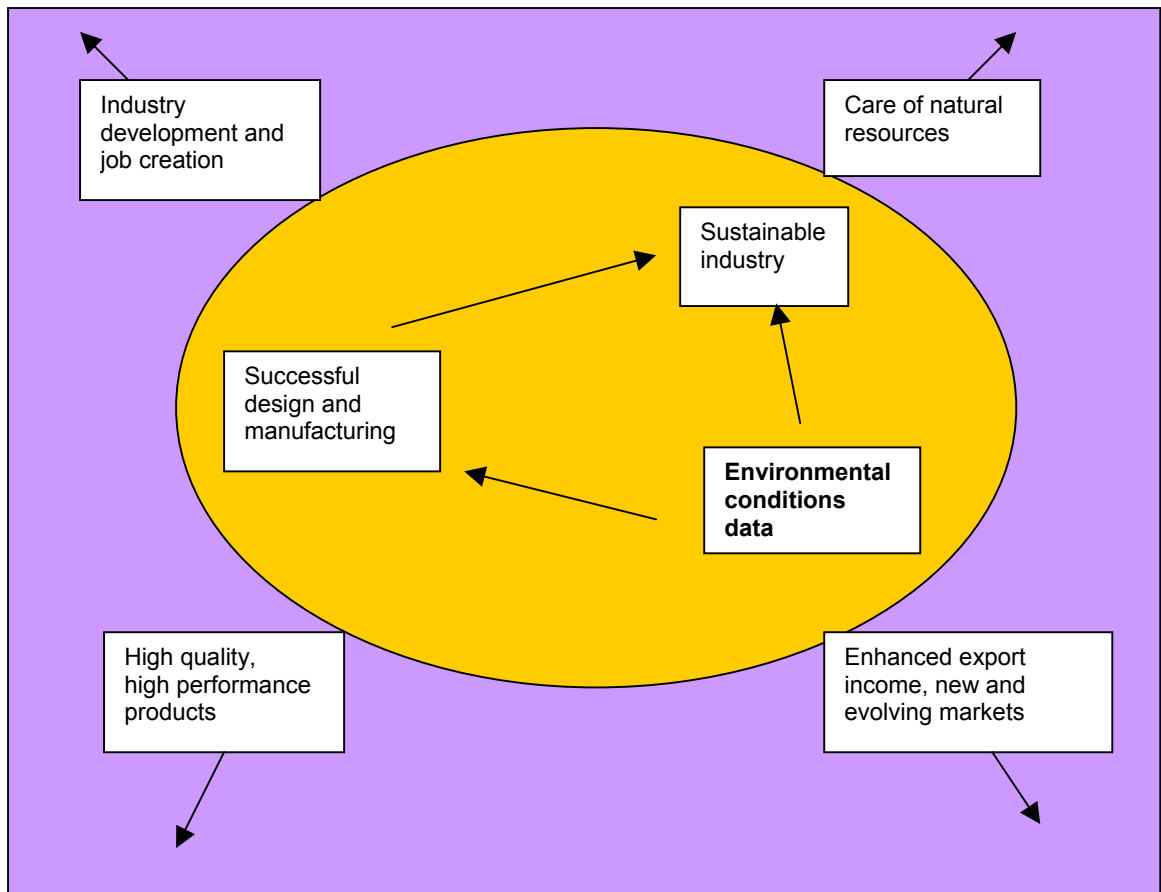


Figure 1. Principal cause-effect relationships of environmental conditions research with industry success (after Wisseman, Rogers and Duffield, 2003).

The forest products industry employs 86,000 Australians and is the second largest manufacturing group (AFFA, 2003). Australian exports of sawn timber increased from nearly 30,000 m³ in 1984 to over 128,000 m³ in 2001 (*Ibid*), and it is anticipated that domestic supply will exceed demand over the next decade, forcing producers to develop new, or expand existing, export markets.

Historically, one of the key barriers to exports of Australian wood products and components has been the relative lack of productivity in the ports and freight forwarding logistics systems (BIS

Shrapnel, 1998). Restructuring during recent years however, has resulted in improved efficiencies in Australia's port and distribution systems and subsequently enabled the forest products industry to improve its export market share (Invest Australia, 2003).

A reduction of international tariffs on forest products could have a major positive affect on Australian exports. However, it would still be difficult for individual firms to adequately address competitive threats in the growing global high value wood products market place. Generally, productivity is low in the Australian wood product manufacturing industry and labour costs are relatively high. Shipping distances, and therefore costs, are also relatively high for Australian exporters. Australian manufacturers need to gain a technological edge and reputation for superior quality to gain and hold marketshare over competitors who have other advantages in Global wood products' trade.

1.2.3 CRC- Wood Innovations

CRC Wood Innovations is a Cooperative Research Centre funded under the Australian Commonwealth Government's Cooperative Research Centres' Program and receives substantial backing from the timber and furniture industries. It is a collaborative network of research institutions and companies associated with the forest products industries.

The Centre is comprised of five interrelated and mutually dependent Programs-

- Program 1 Microwave processing of wood;
- Program 2 High value-added wood products;
- Program 3 Innovation, technology transfer and commercialisation;
- Program 4 Education, training and communication and
- Program 5 Raw wood value enhancements.

This Master of Wood Science Thesis was conducted within Program 2 which had the stated objective "to develop innovative techniques and methods for the design and manufacture of high quality and high performance furniture and other high value-added wood products, to ensure their competitiveness on international markets".

Typical value-added products include flooring, decking, joinery and manufactured articles such as furniture and musical instruments (Hopewell, 2003). Commodity value is ultimately determined

by these products meeting the performance requirements of the market (Manley, 2002). Evidence of this can be seen when comparing quality versus price in furniture retail outlets. The lower end of the price range often includes items with ill-fitting components and visible surface checks. Sometimes this is due to poor workmanship and sometimes it is due to seasoning degrade, occurring during transit from the country of manufacture or after a period of equalisation after delivery in Australia.

1.3 Aim and scope of the study

The objectives of this project were to provide data for mathematical models to enable prediction of long-term performance in a wide range of conditions and subsequently contribute to guidelines for assisting designers, specifiers, engineers and manufacturers.

In order to achieve this, it was necessary to determine the principal export markets and value-added timber items produced in Australia and to gather data for the environmental conditions that these products are exposed to during manufacture, shipping and during their service life. Export products such as logs, chips, and panel products were excluded from consideration by the definition of ‘value-added’ adopted for this research, i.e. products which have been dried and milled (planed or ‘dressed’) and which could subsequently be affected by changes in environmental conditions.

For the purpose of this thesis, ‘environmental conditions’ applies specifically to the combined effects of temperature and relative humidity. These are considered the key parameters affecting high value wood products such as furniture items and musical instruments. Other environmental effects, such as ultraviolet weathering, attack by pathogens and corrosion of fasteners and fittings, are outside the scope of the current project. Vibration during transport was also outside the scope of the study.

1.4 Research Approach

In order to achieve these aims and encompass the scope of work as described above, the study was organised in five stages. The initial phase of this project included the

development of the background and rationale for the research, considering the Australian industry and its increasing need to develop export potential.

The second phase entailed a review of the literature relevant to wood and moisture, timber movement, Australian value-added wood export products and markets, and the environmental conditions experienced by high value wood products. The results of the literature review form Chapter 2 of this thesis. The third stage of the project involved selection of appropriate datalogging equipment. The rationale for choosing the type of datalogger and associated software and the procedure adopted for their use, are explained in Chapter 3 Methodology.

The results of the industry survey on export markets and products and development of a suitable network of exporter participants to assist with data collection are detailed in Chapter 4 Results. The data generated during environmental conditions monitoring is provided in Chapter 4 as well.

Chapter 5 contains a discussion of the results and consideration of the implications. Also discussed are some limitations of the study as recognised by the author and recommendations for further research.

Chapter 2 Literature Review

The scope of the literature review for this project includes definitions and previous work on the subjects of wood and moisture, equilibrium moisture content equations, timber movement (stability), timber exports (species, products, packaging and markets) and shipping methods, routes and environmental conditions.

2.1 Wood and moisture

2.1.1 Moisture Content MC

Water is a natural constituent of all parts of a living tree and even after processing, some water remains within the wood cells (Haygreen and Bowyer, 1982). The amount of water present in wood at a particular time is known as its moisture content (Waterson, 1997). This value is expressed as a fraction, usually as a percentage, of the oven-dry weight of the wood (USDA, 1989). Freshly felled trees and freshly sawn boards have relatively high moisture contents, varying with species, growing conditions and other factors. Wood in this state, known as green or unseasoned, can have moisture contents ranging from 25%, e.g. dryland *Acacia* species, (Hopewell and Stephens, 1998) to more than 200% for plantation-grown radiata pine sapwood (Kinninmonth and Whitehouse, 1991). Whilst in this state, wood is not suitable for many applications due to the shrinkage that will occur, as moisture is lost during the process of seasoning. The effect of moisture content on the dimensional stability of wood is considered basic to all timber products.

2.1.2 Seasoning

Seasoning is the term applied to the process whereby moisture is lost from wood until it reaches a level approximately in equilibrium with the humidity levels of the surrounding atmosphere (Bootle, 1985). Seasoning, also called drying, is undertaken to improve the serviceability and utility of timber. Methods include either one of, or a combination of, air-drying (without the aid of artificial heat), and kiln-drying (utilising a heated chamber and fans). Part of the CRC Wood Innovations' research agenda is developing innovative seasoning technologies to improve drying times. These investigations are centred on the use of microwave generators (for more information, see www.crcwood.unimelb.edu.au).

Seasoning provides many benefits for timber use: higher strength for the majority of commercial species, increased durability, and satisfactory application of finish coatings and adhesives. Perhaps the most important benefit of seasoning for high value application is the ‘pre-shrinking’ of the wood to minimise movement in service (Hopewell and Kennedy, 1996). This ensures that movement in service is small and/or accommodated within product design (Waterson, 1997).

2.1.3 *Fibre saturation point FSP*

The seasoning process can be broken into two distinct stages of moisture removal (Campbell, 1997). During the first phase, ‘free’ moisture is removed from the cell cavities, but the cell walls are still saturated (Boas, 1947). At this point the wood is at ‘fibre saturation point’ (FSP) and no physical properties have been altered. The fibre saturation point for most species is in the range of 26 to 32% moisture content (Dietz *et al*, 1980), although 30% is often used as a convenient average for all species (Boas, 1947; Campbell, 1997; Dietz *et al*, 1980; Mullins and McKnight, 1981).

During the second phase, water is lost from the cell walls until equilibrium moisture content (EMC) is attained (Campbell, 1997). Physical properties, such as board dimensions and strength attributes, change during drying below fibre saturation point (Haygreen and Bowyer, 1982).

Rijsdijk and Laming (1994) noted that species with a relatively low FSP, for example 20%, are more likely to display small movement with changing environments, demonstrating greater dimensional stability.

2.1.4 *Equilibrium moisture content EMC*

Below FSP, wood is a hygroscopic material in that it has the ability to adsorb and desorb water (Haygreen and Bowyer, 1982). Equilibrium moisture content of timber is the moisture content at which wood is stable and in equilibrium with the humidity of its surroundings (Campbell, 1997; Corkhill, 1979). This level can be reached if wood is held in air at constant relative humidity and temperature (Koch, 1972). As with moisture content, EMC is usually expressed as a percentage and for practical purposes is often given as a range (McNaught, 2001). For example the indoor

EMC for the eastern coastal zone of Australia is often provided as 10 to 15%, allowing for the seasonal variation experienced through the region during the year. It is common practice to define EMC as the long-term average of timber-in-service for a particular locality, sometimes given as the mid-point of the range (Bragg, 1986).

An example of this is provided by Rijdsdijk and Laming (1994) for the Netherlands, where the RH in winter will range from 35 to 50% due to the use of artificial heating, then summer RH values will rise up to 60%. The corresponding EMC for common timbers used here such as Scots pine (*Pinus sylvestris*), will range from 8.5% in winter up to 11% in summer. Therefore joinery and furniture items manufactured from Scots pine for use in the Netherlands should be produced from wood having a moisture content target of 9%, with all pieces within the range 8.5 to 11%. If this recommendation is followed, timber items will provide satisfactory performance in regards to dimensional stability. For species with high movement attributes, the design of items such as furniture will need to consider the potential for movement during changing conditions for the range anticipated over changing seasons.

Other authors have produced tables providing mean moisture content requirements for different locations, some examples of which appear in Table 1 below.

Table 1. EMC values for various locations.

Destination	Range	Mean
New Zealand ^a	10-14	12
Japan ^a		11
USA- west coast, south-east states	8-13 ^d	11 ^a
USA- remaining states	6-9 ^a , 6-10 ^d	8 ^{a,d}
England ^a		11
Philippines ^b	11-17	14
Netherlands ^c	8.5-11	9

Sources: a Haslett and Kininmonth, 1983. (intermittently heated buildings)

b PCARRD, 1985. (furniture and flooring)

c. Rijdsdijk and Laming, 1994. (Scots pine, intermittently-heated buildings)

d. USDA, 1973. (interior applications)

Early researchers provided industry with simple EMC guides, apparently based solely on RH%. One such EMC ready reckoner appeared in *Furniture Trades* review in October 1937 (Welch, 1937) providing a rule of thumb for the timber furniture sector. A summary appears below in Table 2.

Table 2. Equilibrium moisture content for furniture timbers based on relative humidity (after Welch, 1937).

RH%	EMC% (approximate)
30	6
40	8
50	9
60	11
70	14
80	17
100	30 (FSP)

Note: FSP- fibre saturation point, approximately within the range 26-32% for most species.

Reliance on RH% only as an indicator of EMC%, i.e. without consideration of temperature, is still used in sections of the value-adding industry today, particularly by luthiers (Clark, Evans¹, pers. comm.). Brennan and Pitcher (1995) found that relative humidity is highly significant at predicting EMC and Van Wyk (1963) determined that temperature change at a constant RH has little effect on timber moisture content (see table 3 below).

Several researchers have undertaken experiments to predict equilibrium moisture contents for different species and in different locations, by applying regression techniques to sample board MC% and meteorological data (Bragg, 1986; Ellwood and Leslie, 1949 and Finighan, 1966). Others have applied thermodynamic sorption models to predict the changing moisture content of wood (Simpson, 1971, 1973, 1982; Wengert, 1976). Mathematical equations have resulted from this work, enabling estimation of timber equilibrium moisture content from relative humidity and temperature data.

Kinninmonth and Whitehouse (1991) found that results determined from regression equations using meteorological data were similar to those produced from using specimen boards.

¹ Bradley Clark (CEO, Australian Native Musical Instruments), Patrick Evans (Production Manager, Maton Guitars) Melbourne. 2003.

Psychrometric tables allowing determination of EMC by combining temperature values against RH values were published by Smith (1947) and have since appeared in references such as the Encyclopedia of Wood (USDA, 1989) and Timber Seasoning (TRADAC, 1995). Psychrometric data are used by timber drying kiln operators. Table 3 below provides a sample of this type of chart.

Table 3. Equilibrium moisture content values based on temperature and relative humidity.

Temperature °C	40% RH	50% RH	60% RH
10°C	7.9% EMC	9.5% EMC	11.0% EMC
21°C	7.7% EMC	9.2% EMC	10.5% EMC
32°C	7.4% EMC	8.9% EMC	10.0% EMC

Psychrometric charts are also available. Charts and tables can simplify the estimation of EMC from readily available meteorological data without the need to use complex formulae. However, for some applications, mathematical equations are useful for converting meteorological data to EMC values, especially when generating EMC from bulk data.

Several equations are available for calculating EMC from given meteorological data. An example of one equation, published in Wood and Fiber (*sic*) in 1973 (Simpson, 1973) is shown below:

$$\text{EMC}\% = \frac{1800}{W} \left[\frac{Kh}{1-Kh} + \frac{K_1Kh + 2K_1K_2K^2h^2}{1 + K_1Kh + K_1K_2K^2h^2} \right]$$

where T is temperature (°C), h is relative humidity (%/100) and W , K , K_1 and K_2 are coefficients of an adsorption model developed by Hailwood and Horrobin (1946), as listed below:

$$W = 349 + 1.29T + 0.0135T^2$$

$$K = 0.805 + 0.000736T - 0.00000273T^2$$

$$K_1 = 6.27 - 0.00938T - 0.000303T^2$$

$$K_2 = 1.91 + 0.0407T - 0.000293T^2$$

Australian hardwood processors have used another equation developed for predicting equilibrium moisture content from meteorological data, though the original source is unknown (Siemon², pers. comm.). This equation is expressed below:

$$EMC\% = \left[\left[\frac{-\ln(1-RH)}{23.7 + 0.0026 T^2} \right]^{2/3} \right] \times 100$$

where T = temperature (°C),

$-\ln$ = natural logarithm (the negative sign is required because a value of less than 1.0 would give a negative EMC)

RH = relative humidity, expressed as a decimal

23.7 = constant

The result obtained is very similar for either equation as shown in the examples provided in table 4.

Table 4. Comparison of results from two equilibrium moisture content equations.

Temperature °C	Relative Humidity %	Australian industry formula	USDA formula
23	65	12.1	11.9
25	65	12.0	11.8
27	65	11.9	11.7
30	65	11.8	11.6
31	65	11.7	11.6
32	65	11.7	11.5
23	45	8.3	8.4
23	50	9.1	9.2
23	55	10.0	10.0
23	60	11.0	10.9

Note: Mean value difference between equations across 10 scenarios=0.3%, standard deviation=0.9%.

² Dr Graeme Siemon, Timber Technologist, FPC, Harvey WA/ CRC Wood Innovations.

As an aid to establishing appropriate end-use timber moisture contents, several authors have produced maps demarcating EMC zones. USDA Forest Products Laboratory (Peck, 1947; USDA, 1973) have published maps for continental USA showing winter and summer seasonal EMC and the recommended moisture content averages for interior finishing woodwork, as depicted in figure 2 below.

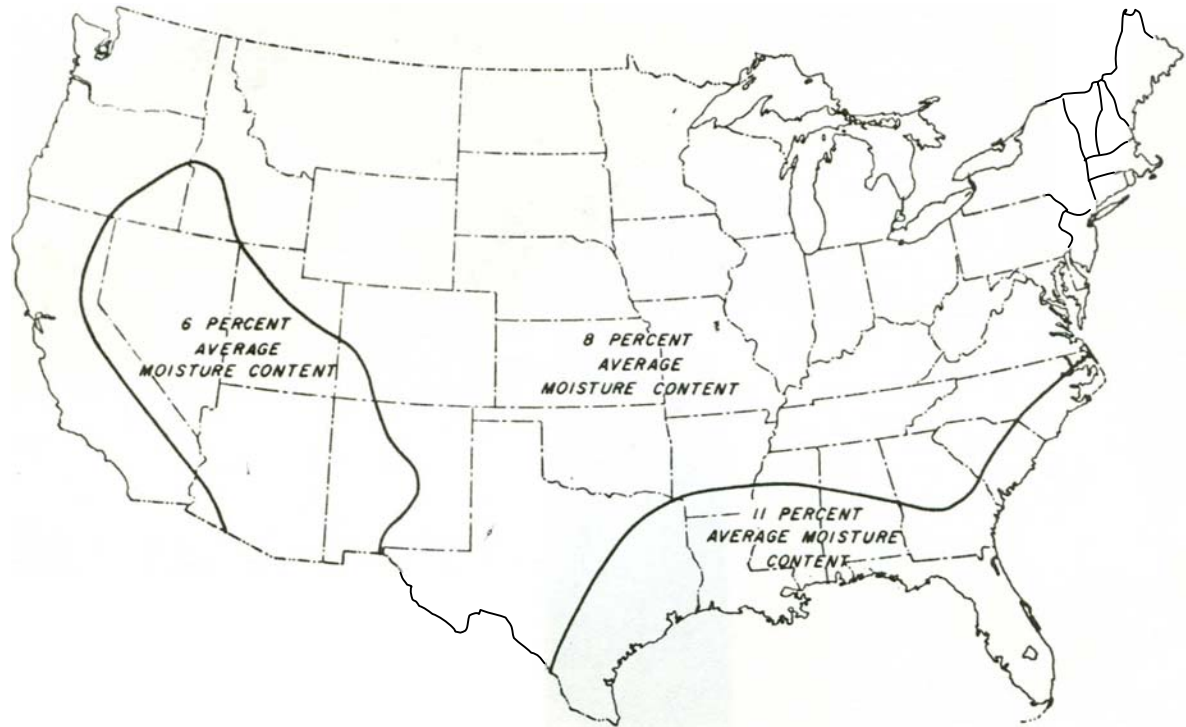


Figure 2. Recommended average moisture content for interior wood products in the United States. (Source: Simpson, 1999)

Bragg (1986) rationalised EMC zones to shire (Local Authority) boundaries to produce an EMC map for Queensland, providing a range and recommended average timber EMC value for indoor outdoor and air-conditioned situations in this State. The Timber Durability Compendium (Leicester *et al*, 2002) includes contour maps of timber moisture content in Australian building situations such as outdoor protected from rain, wall cavity, sub-floor and roof space. Orman (1966) produced maps for January, July and the yearly mean for sheltered outdoor EMC in New Zealand. A map for Western Australian delineating three EMC zones was produced by the Department of Conservation and Land Management (CALM) and published in Brennan and Pitcher, 1995.

2.1.5 Indoor and outdoor EMC

EMC values are usually given separately for indoor and outdoor environments. In practice, most seasoned timber is destined for internal applications (Finighan, 1966). Examples of interior timber use include flooring (strip, overlay, parquetry, etc), furniture, lining/panelling, window and door joinery and mouldings. Additionally, many households possess valuable objects with critical timber components such as stringed and woodwind musical instruments. Even when an indoor EMC range is provided for a location, some products have specific requirements critical to performance. For example the recommended indoor EMC range for strip flooring (fixed over joists) in the Brisbane area is given as 10 to 15% with a target of 12%, whereas mosaic parquetry used in the same region is required to be seasoned to 8 to 13% (Hayward³, pers. comm.). Similarly, successful gluing often requires moisture contents of 8-12% (e.g. laminated beams, Bragg, 1986). Australian Standard 2796.3-1999 recommends a moisture content range of 8 to 13% for sawn or milled hardwood for furniture components. High-value timber products (comprising seasoned, dressed components) used externally include decking, outdoor/garden furniture and cladding (e.g. chamferboards). Moisture content for these outdoor products is generally higher than for interior applications, due to the wider exposure to extremes of temperature and humidity.

Ellwood and Leslie (1949) presented data on the difference between indoor and outdoor (sheltered) EMC, however their work was not conclusive. Later, Finighan (1966) tabulated EMC predictions for outdoor sheltered situations for eight timber species at over 100 localities throughout Australia. Included in his report were estimates of the difference between indoor and outdoor EMC. Data obtained showed that there is a distinct tendency for indoor values (non air-conditioned or central-heated premises) to be 1-4% lower than outdoor values, varying depending on the specific microclimate of each building. Bragg (1986) noted that, in the absence of other data, appropriate indoor EMC values have been calculated using the following formula:

$$\text{Indoor EMC} = 5/6 \text{ outdoor EMC}$$

Air-conditioned and intermittently heated buildings present difficulties for timber products, highlighting the need for practical engineering and product design to accommodate potential

³ David Hayward, Assistant Technical Officer, Timber Queensland

movement (Ozarska, 1994). McNaught (2001) recommends a target of 9% moisture content as appropriate for timber in air-conditioned spaces in Queensland.

2.1.6 Hysteresis

Adsorption is the physicochemical process whereby water molecules are attracted to hydrogen-bonding sites present in the wood microstructure (Haygreen and Bowyer, 1982). Desorption occurs when water is lost to the surrounding environment. The term sorption is applied to the combined or general phenomena of adsorption and desorption.

The relationships between relative humidity and timber equilibrium moisture content are not linear due to the different ways in which bound water is held. EMC is affected by the direction from which equilibrium is attained (Orman, 1966; Wengert, 1976). The difference between desorption and adsorption is referred to as hysteresis. Graphs are useful for illustrating the relationships between RH% and timber MC% and are known as sorption isotherms (Stamm, 1957). Stamm and Woodruff (1941) determined that the ratio of EMC on the adsorption isotherm to EMC on the desorption isotherm is generally constant at about 0.85 for normal temperatures during RH conditions between 10 and 95%. Koponen (1985, cited in Brennan and Pitcher, 1995) considered that EMC in adsorption is approximately 80% of the desorption value.

The general shape of the sorption isotherm is similar for most timber species and is depicted in Figure 3, below.

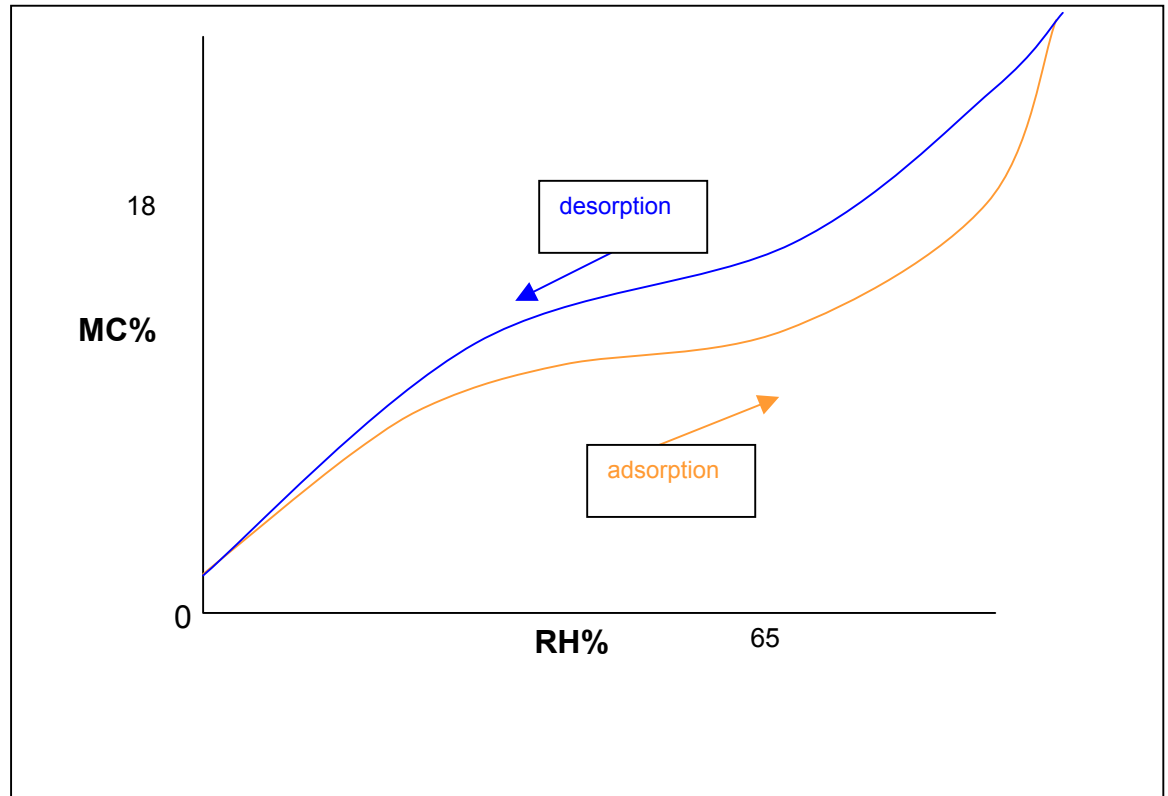


Figure 3. Typical sorption isotherms for timber (after Stamm, 1964).

If a piece of wood has desorbed to equilibrium moisture content, it may attain a MC% as much as 3% higher than a matched sample adsorbing in the same environment (Simpson, 1998). For this reason, many processors and manufacturers slightly over dry their timber then allow it to come up to EMC% rather than dry to the higher end of the desired range and hope that the wood will desorb down to EMC% (Redman⁴, Duncan⁵, Clark⁶, pers.comm.).

⁴ Research Scientist, Seasoning, DPI Forestry Research, Brisbane Qld 2003

⁵ Operations Manager, Whittakers Timber Products, Greenbushes WA. 2003

⁶ CEO Australian Native Musical Instruments, Melbourne, Vic. 2003

2.1.7 Effect of physical properties on EMC and hysteresis

Physical properties and characteristics of timber species can affect the rate of equalising. Orman (1955) and Marshall (1965) found that dense timbers do not adsorb or desorb moisture as readily as low-density timbers and have a lower EMC in service. The presence of extractives (compounds such as resins, gums, tannins and aromatic and colouring materials) can also affect wood-water relationships (Haygreen and Bowyer, 1982). Brennan and Pitcher (1995) found that EMC variations between species could be more than 2% for both indoor and outdoor situations.

2.1.8 Wood-based panels

Many high-value wood products incorporate wood-based panel components such as medium density fibreboard (MDF) or particleboard. These products tend to have slightly lower EMCs than solid wood, due to high temperature processing and addition of resins and coatings (Haygreen and Bowyer, 1982). These processes and additives also render panel products more stable in service than many solid wood components.

2.1.9 Engineered products

Glued laminated timber (Glulam) and laminated veneer lumber (LVL) are able to withstand extreme variation in environmental conditions and generally take up moisture at a slower rate than sawn timber, due to the chemistry of adhesives and additives such as wax (COFORD, 2001).

2.1.10 Stability

Stability (or instability) refers to a timber species' resistance to (or propensity for) dimensional change corresponding with changing environmental conditions. The amount of 'movement' that will occur during changing conditions varies between species and with grain orientation. An understanding of how much a timber species will 'move' with changing humidities is essential for successful design and performance of high-value items, for example flooring and furniture. As a general rule, tangential shrinkage (perpendicular to the ray parenchyma) is greater than radial shrinkage (parallel to the ray parenchyma) by a factor of 1 ½ to 3 and longitudinal shrinkage of normal wood is considered negligible (Haygreen and Bowyer, 1982).

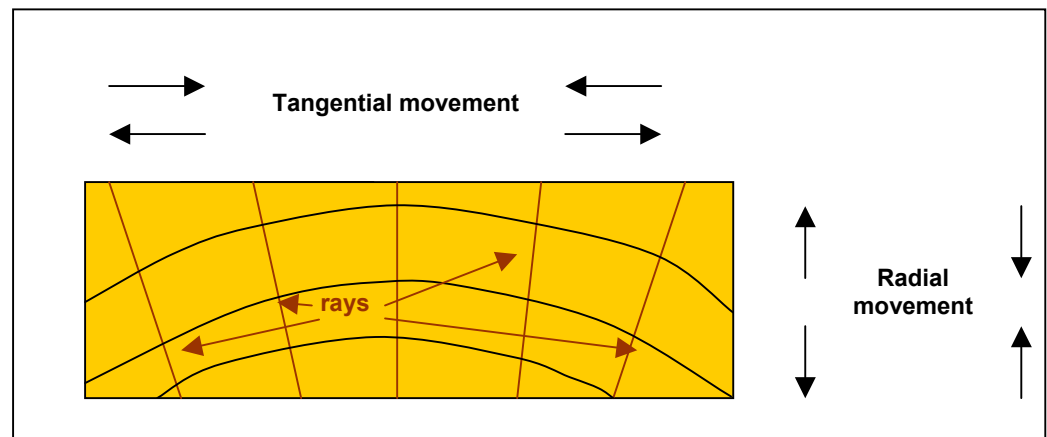


Figure 4. Tangential and radial movement in timber.

There is a significant correlation between density and shrinkage, being that higher density timbers generally have higher shrinkage rates, however a range of other variables including cell contents (known as 'deposits'), anatomy and microstructure of the cell walls can also influence timber movement (Rijsdijk and laming, 1994).

The change in dimension for each one per cent change in timber moisture content below fibre saturation point is called unit shrinkage in Australia. Published unit shrinkage figures exist for most commercial timber species.

The most comprehensive study of shrinkage in Australian timbers was published in 1961 (Kingston and Risdon, 1961), with over 300 species from Australia and other parts of the

southwest Pacific being investigated. The number of trees studied varied between species, with larger populations tested for key commercial species (Kingston and Risdon, 1961). Test specimens were single 4 by 1 by 1 inch, with the 4 inch dimension parallel to the grain, as recommended by Kelsey and Kingston (1957). Between-tree variation was reported to be more important than within-tree variation hence the sampling method focussed on fewer samples from a larger number of trees and means were calculated as tree means (Kingston and Risdon, 1961). Immature material and mature plantation-grown material, primarily exotic pine species but including the native conifer hoop pine (*Araucaria cunninghamii*), were listed separately.

Continued demand for information on shrinkage and density led to the reprinting of the more important data of Kingston and Risdon (1961) in Kingston and von Stiegler (1966). The latter report provided figures based on at least five trees for each species (except for those where no range in values was given) and for the more important species, many more trees were involved. No reference was made to data from species grown in plantations.

A report supplementing that of Kingston and Risdon (1961) and Kingston and von Stiegler (1966) was produced by Budgen (1981). This report tabulated shrinkage and density results for 172 species of timber from Australia, Fiji, Papua New Guinea and the Solomon Islands. The number of trees tested varied between species but generally two specimens from each of five trees were tested. No reference is made to plantation material having been tested. More recently, stability data were determined for several furniture hardwoods (spotted gum, *Corymbia* spp.; rose gum, *Eucalyptus grandis*; Gympie messmate, *E. cloeziana*; and blackbutt, *E. pilularis*) during the *metaform*AUSTRALIS™ research project (Ozarska, Thompson and Hopewell, 1998).

An understanding of how to calculate anticipated timber movement is useful to specifiers and designers. However, in their traditional published formats, unit shrinkage data (Australia) and dimensional change coefficients (USA) are not considered by industry to be user-friendly. Examples using both unit shrinkage data (Australian method) and dimensional change coefficients (North American method) are illustrated below.

Example of pre-determination of timber movement using unit shrinkage data:

<u>Species</u>	ramin, <i>Gonystylus macrophylla</i>
<u>Tangential unit shrinkage</u>	0.31%
<u>Radial unit shrinkage</u>	0.16%
<u>Cross-section</u>	100 mm x 25 mm
<u>Orientation</u>	backsawn orientation as in figure 3 above
<u>Moisture content</u>	12%
To determine dimensional change if this board was placed in a continuously air-conditioned location and equalised to 8% moisture content:	
<u>Change in timber MC%</u>	12%-8% = 4%, i.e. four units
<u>Tangential shrinkage</u>	100 mm – [4 x (0.31/100) x 100 mm]
	= 100 - 1.24 mm
width at EMC	= 98.76 mm
<u>Radial shrinkage</u>	25 mm – [4 x (0.16/100) x 25 mm]
	= 25 - 0.16 mm
thickness at EMC	= 24.84 mm
Board dimension when board wood attains EMC will be	
98.76 x 24.84 mm.	

Although this change in dimension would appear to be minimal, the cumulative affect, for example a tabletop comprised of 10 edge-glued boards, can result in unsatisfactory performance. In the example given, a table top manufactured from ten 100 x 25 mm boards seasoned to 12% moisture content would have an original width of 1000 mm. After equalising to 8%, the cumulative shrinkage would result in the width reducing to 987.6 mm, an overall reduction of over 12 mm, which could have adverse consequences for the glued joints or cause distortion. This example shows the importance of considering potential timber movement during the design phase, prior to manufacturing.

Haslett and Stadie (1992) recognised this when providing recommendations to the New Zealand furniture and joinery sectors. They illustrated the benefits of using narrower

boards, for example 6 @ 75 mm rather than 3 @ 150 mm, in edge-glued panel lay-up, to minimise degrade in-service. Haslett and Stadie also determined that, although slowing the rate of equalisation, surface coatings do not prevent moisture content change and corresponding timber movement.

In North America, the change in dimension within the range of normal use (e.g. 6% to 14%) is estimated by using a dimensional change coefficient based on the dimension at 10% moisture content (USDA, 1989). An example of how this coefficient is used, using the same section and species as in the Australian method example above, is described below:

<u>Species</u>	ramin, <i>Gonystylus macrophylla</i>
<u>Tangential change coefficient</u>	0.00308
<u>Radial change coefficient</u>	0.00133
<u>Cross-section</u>	100 mm x 25 mm
<u>Orientation</u>	backsawn orientation as in figure 3 above
<u>Moisture content</u>	10%

To determine dimensional change if this board was shipped to Nevada, USA, which experiences an average EMC for interior locations of 6% moisture content:

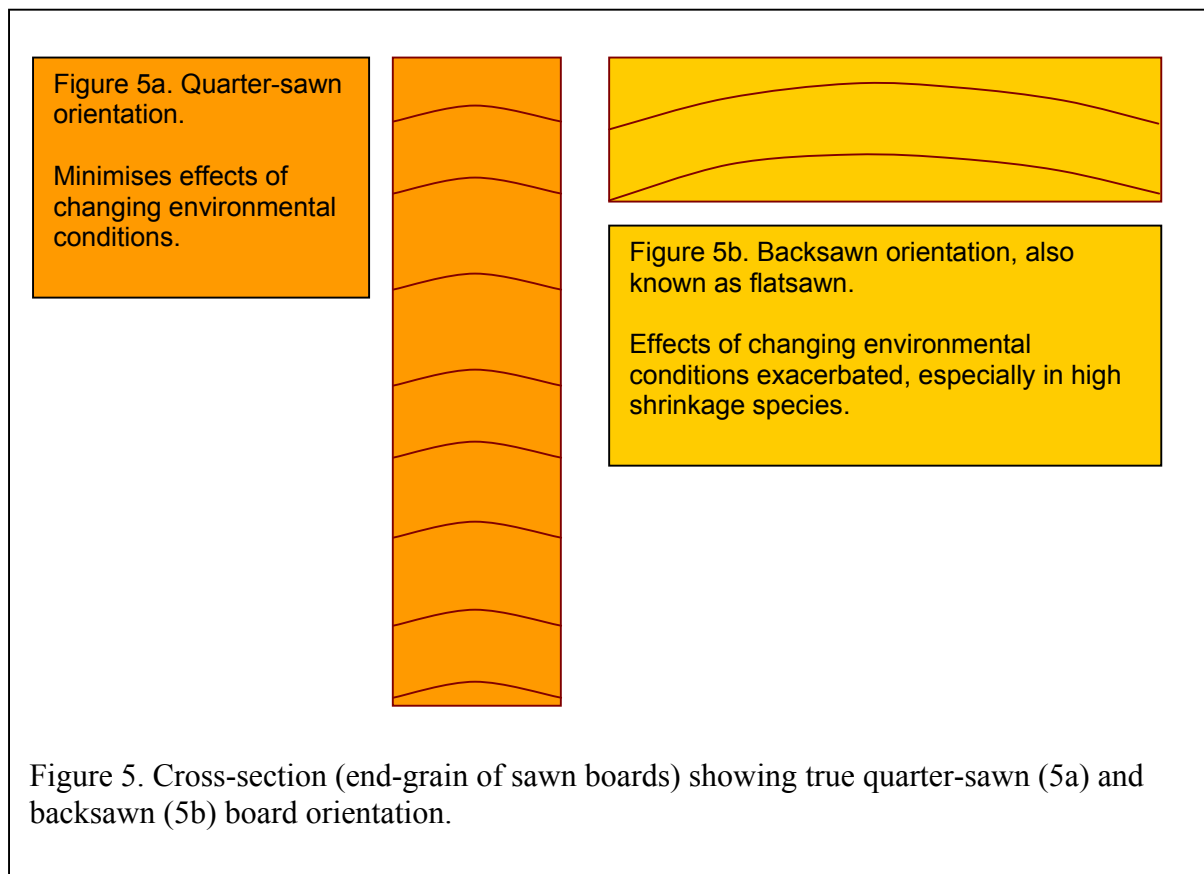
<u>Change in timber MC%</u>	10%-6% = 4%
<u>Tangential shrinkage</u>	100 mm x [0.00308 x (10-6)] = 100 -1.23 mm = 98.77 mm
<u>Radial shrinkage</u>	25 mm x [0.00133 x (10-6)] = 25 - 0.13 mm = 24.87 mm

Board dimension when board attains EMC will be 98.77 x 24.84 mm.

An understanding of how much a timber component will move during the range of environmental conditions experienced from the time of manufacture through shipping and in-service, is critical to successful design and marketing of wood products for target export countries. As demonstrated in the examples above, timber has a propensity to ‘move’ when

subjected to changes in environmental conditions. Knowledge of timber species' stability factors enables designers and manufacturers to engineer, store and package products to ensure satisfactory performance. Although stability factors have been published for many commercial timbers, their availability and usefulness are not well known in the timber industry, beyond professional wood technologists. Many of the industry participants surveyed during this project expressed an interest in a user-friendly tool that would enable them to make better use of unit shrinkage data. It is intended that follow-on CRC Wood Innovations work will provide a suitable tool to simplify these calculations and minimise the risk of error in determining the potential for timber movement.

Sawn orientation, also called grain orientation, is one method used by processors and manufacturers to overcome or minimise the effects of timber movement. As demonstrated in the examples above, radial unit shrinkage is less than tangential unit shrinkage, and this is true for all species of timber, although the degree of difference varies with species.



Timber species with known high shrinkage values are purposely sawn to maximise stability during drying and for the end product in service. That is, for applications where a wide face is required, e.g. flooring and boards for furniture, the widest dimension (face) is given to the radial longitudinal section. This method is known as quarter sawing and also benefits the seasoning process by minimising the detrimental effects of drying high shrinkage species.

For timbers of high unit shrinkage values (or high shrinkage coefficients), quarter-sawn material should be used in critical applications where movement of boards or components in-service needs to be minimised. Backsawn boards provide acceptable performance in low shrinkage species such as white cypress (*Callitris glaucophylla*), but for high shrinkage hardwoods such as mountain ash (*Eucalyptus delegatensis*) only quarter-sawn material is suitable. In some applications, especially stringed instrument manufacture, quarter-sawn material is required even with relatively low shrinkage species such as spruce (*Picea* spp.) and Bunya pine (*Araucaria bidwillii*). Published unit shrinkage values for a range of commercial timbers used in the manufacture of high-value Australian export products are presented below in table 5.

Table 5. Unit shrinkage data for some commercial timbers.

Timber standard trade name, botanical name	Tangential unit shrinkage	Radial unit shrinkage
jarrah, <i>Eucalyptus marginata</i>	0.30%	0.24%
mountain ash, <i>E. regnans</i>	0.36%	0.23%
messmate, <i>E. obliqua</i>	0.36%	0.23%
alpine ash, <i>E. delegatensis</i>	0.35%	0.22%
blackbutt, <i>E. pilularis</i>	0.37%	0.26%
spotted gum, <i>Corymbia</i> spp.	0.38%	0.32%
white cypress, <i>Callitris glaucophylla</i>	0.28%	0.23%
hoop pine, <i>Araucaria cunninghamii</i>	0.23%	0.18%
brush box, <i>Lophostemon confertus</i>	0.38%	0.24%
kwila, <i>Intsia</i> spp.	0.33%	0.18%

Source: Kingston and Risdon (1961).

2.2 Australian timber and wood products exports

2.2.1 Products and markets

Australia has exported timber since the early days of colonisation, when timber and veneers from desirable species such as red cedar (*Toona ciliata*) were shipped from eastern ports to England for joinery, cabinetry and boatbuilding trades (DPI&F Forestry Research).

In Western Australia, a booming export industry emerged in the 1800s when Asian markets for sandalwood (*Santalum* spp.) developed into one of the highest earning industries for the state, ahead of whale oil and second only to wool (Statham, 1988). Export industries based on sandalwood products eventually developed in other states and, although trading fluctuations have characterised the industry throughout its history, Australian sandalwood is still exported for ceremonial incense ('joss') sticks and carving timber to Asia. For several decades now, Australian sandalwood has dominated the world market, due to the virtual exhaustion of the resource in other producer countries, although plantation schemes for the species have been established elsewhere. Due to the cultural significance of sandalwood products, perpetual demand is guaranteed and plantation trials are also underway in Australia, to sustain production beyond the limitations of the natural sandalwood resource. Although sandalwood is a fascinating and important facet of Australia's timber exporting history, the nature of the product (i.e. not affected by changing environmental conditions) places further discussion of it outside the sphere of wood products considered in the research component of this thesis.

Australian heavy engineering hardwoods of the Myrtaceae family (e.g. *Eucalyptus drepanophylla*, grey ironbark and *Syncarpia glomulifera*, turpentine) were highly regarded in world markets and sought after for shipbuilding and wharf construction (Baker, 1919). In addition to superior strength and durability, Australian hardwoods were also in demand in overseas markets on account of the extraordinary log lengths available, for example *E. globulus*, Tasmanian blue gum, was exported to England and continental Europe for piers (*Ibid*). As with sandalwood however, structural timbers have generally been excluded from the research component of this project, due to the lack of relevancy to the environmental conditions research.

In the post-war era significant, high volume, woodchip markets emerged; especially in Japan who now take 95% of Australia's woodchip produce (Invest Australia, 2003). Of this, nearly 80% of the total export value, or AUD\$571.4 M, is generated from low quality hardwood logs, unsuitable for milling or veneering, the bulk of which are sourced from Tasmanian forests. Although woodchips account for a significant proportion of Australia's forestry exports earnings, this product is outside of the range of value-added forest products considered in this research project.

Data for commodities such as furniture, flooring and decking collated by Port Authorities and Australian Bureau of Statistics (ABS) are considered unreliable due to inconsistencies in the classification system for describing cargo of value-added products leaving Australian ports (McCormack⁷, pers. comm.).

Published data for sawnwood exports generally indicate year-on-year increases, as depicted in Figure 6 below, although the content of 'sawnwood' is undefined, and may include green boards.

⁷ Gerry McCormack, Commercial Account Executive, Sydney Ports Corporation)

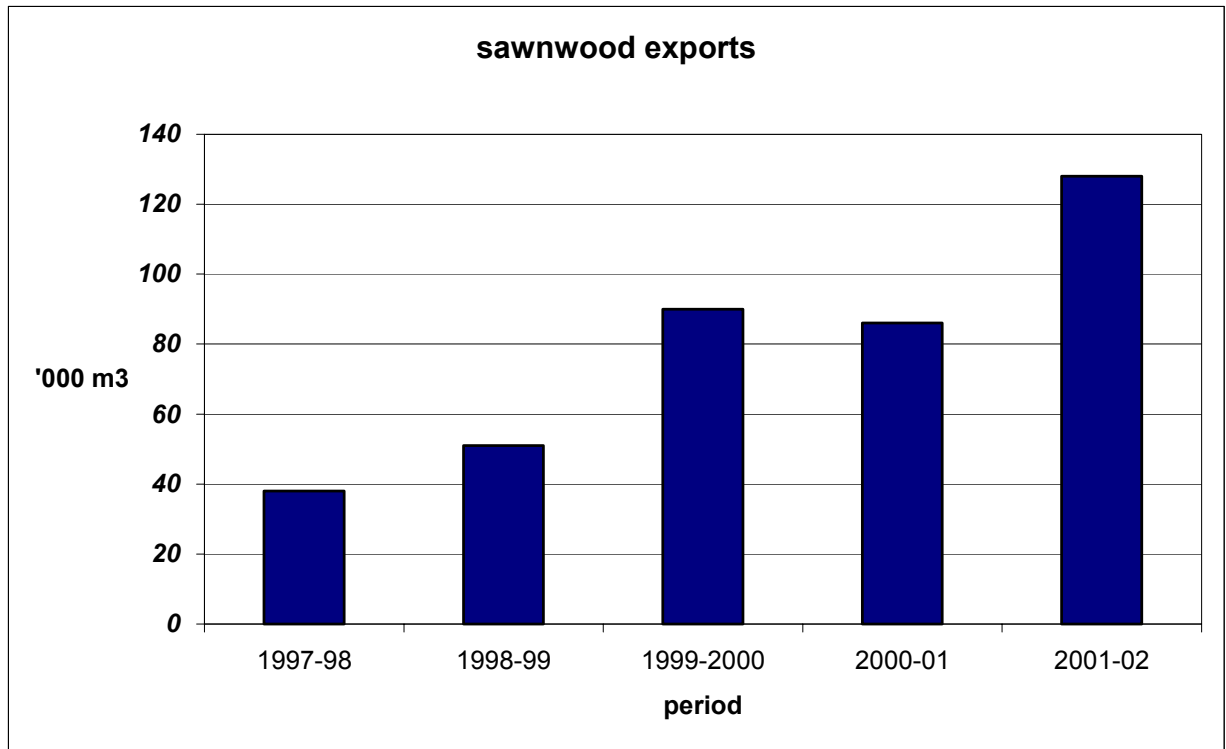


Figure 6. Australian sawnwood exports 1997 to 2001. (Source: Invest Australia, 2003).

Judging by the lack of published data on high value-added timber exports, that is finished or milled products, Australia could be considered a small player in the Global value-added products' trade scene. This perception may be due in part to the commercial sensitivity of such data, whereby successful companies remain low-key about their export sales to minimise risk from would-be competitors. The Australian industry is somewhat more secretive than others, in contrast to tropical countries, whose price trends, products and markets are reported on a regular basis in the Tropical Timber Market Report by the International Tropical Timber Organisation (ITTO), and New Zealand where timber market information is published weekly in the rural press (Wettenhall and Henderson, no date).

Cox and Quayle have noted that value-added products appear to have great potential for export, and further they suggest that the industry will indeed face the need to increase overseas market penetration in order to utilise Australia's forecast timber surplus (Cox and Quayle, 2001).

Potential sources of Australian export market data, such as websites, e.g. Austrade site <http://www.austrade.gov.au>, list companies who have exported at sometime in the past but don't have consistent, ongoing orders and also companies desiring to export but with no established customers. This makes it difficult to determine the current extent of Australian trade in products such as furniture, flooring and joinery, without actually contacting the companies listed.

As part of the development of networks for this project, the opportunity was taken to conduct a survey of companies purporting to, or known to, export value-added products, in order to collate data on the range of products and timber species comprising Australian exports in this category. The findings from this survey are reported in Chapter 4 Results.

2.2.2 Shipping

High value wood products are distributed by various means including shipping by sea and air, rail freight and road freight (Simpson and Ward, 1991). Many Australian export products are unitised for shipping to enable easy handling; however, some articles, for example flat packed outdoor furniture, are hand packed to optimise container space and minimise mechanical damage. Some exporters prefer side-opening containers (plate 1) to front-loading, which enables easier forklift access and assists in minimising mechanical damage (Hopewell, 2003).



Plate 1. Side-opening containers for ease of loading strip-flooring packs.

Not all products are shipped in closed containers (known as general purpose containers or GPs). Other modes include flat-racks (plate 2) and master-packs, which are open-sided racks with bolsters. Where these are used, heavy tarpaulins are employed to cover the load.



Plate 2. Flat-rack used for shipping timber boards and flooring.

Several authors have investigated the conditions experienced during shipping. Simpson and Ward (1991) reported that, in holds of ships, seasoned material usually absorbs about 1.5% moisture during normal shipping periods, although if green material was included in the cargo, this figure could double. They also reported that, despite relatively short transit times for truck freighting, seasoned boards can gain 3 to 7% moisture uptake during moist

weather. The US Forest Products Laboratory studied changes in moisture content of both softwood and hardwood lumber shipped by rail and found that no significant change occurred during transit by this mode (Simpson and Ward, 1991).

Ian Simpson (2001) monitored conditions in containers of wood products from New Zealand to key export market destinations including Australia, Canada, Japan and the USA. Results from this work concluded that:

- environmental conditions fluctuate more prior to and after the actual voyage;
- conditions whilst cruising through the tropics show only a gradual rise and fall in temperature and humidity;
- seasoned timber with no packaging showed little change in moisture content;
- plastic wrapping should hold seasoned timber at a relatively constant moisture content for extended periods.

Simpson and Ward (1991) discussed the results of a study conducted out of Canada. This trial investigated timber moisture content change during 33 shipments of 1-inch lumber to five ports. The study indicated that seasoned lumber may undergo significant moisture regain if stored on deck. A summary of the results is presented below in Table 6.

Table 6. Average gain in lumber moisture content during ocean shipment from Canada.

No. of shipments	Destination	Transit (days)	Stowed with dry lumber below decks	Stowed with green lumber below decks	Stowed on deck with green lumber
11	England	54	+2.9%	+4.7%	-
10	Australia	66	+1.7%	+3.2%	-
6	South Africa	85	+2.2%	+1.8%	+7.6%
3	Eastern Canada	47	+0.7%	+3.7%	+6.5%
3	Trinidad	37	+1.7%	+3.2%	-
Average			+1.9%	+3.3%	+7.1%

(Source: Simpson and Ward, 1991)

These results highlight the importance of stowing seasoned timber products separate from green timber and also the superior protection from environmental conditions offered below decks.

Similar tests were made with 2-inch Douglas fir (*Pseudotsuga menziesii*). In this case, timber kiln-dried to 9-10% moisture content gained:

- below decks with dried lumber, +1.3%;
- below decks with green lumber, +2.4% and
- on deck with green lumber, +4.2%.

It is evident from this trial that, in most cases, thicker section material is not as reactive to moisture uptake during shipping.

The food transportation and shipping industries have developed extensive expertise in specialised containers and use of desiccant products to ensure product quality during transit. Fresh fruit is exported from Australia in containers equipped with gas-purging systems to stave off early ripening and live seafood is air-freighted in controlled environment containers (Leighton⁸, pers.comm.). Some freight forwarding agents recommend the use of a dehumidifier in containers prior to loading to ensure that a dry container is presented (P&O Nedloyd, 2003). Other recommendations for hygroscopic cargoes include use of ventilated containers (highly ventilated refers to a container with vents along both the top and bottom rails and top ventilated containers only have vents along the top rail). Fantainers, with an extractor fan fitted, are also available, however none of the exporters interviewed during the interstate survey for this project considered that it was necessary to request this mode of container. Most tend to rely on packaging to insulate their products against changing conditions.

Desiccants are widely used by food producers to control moisture within containers during ocean-crossings (Desiccare Inc, 2003). This is necessary for both canned products (to prevent corrosion of tins and peeling of labels) and fresh produce (for example to prevent beans sprouting and inhibit the development of moulds in agricultural produce) (Desiccare Inc, 2003; Süd Chemie, 2003). Desiccants are commonly comprised of Montmorillonite clay, silica gel, calcium oxide, or calcium sulfate, which attract moisture from the surrounding air and are packaged in such a way that this moisture (often combining with the desiccant to form a gel) cannot return to the environment (Desiccant City, 2003). Upon

⁸ Darren Leighton, Processing Assistant, DPI Centre for Food Technology 2003.

arrival at the destination the desiccants are disposed of with other packaging materials (Anderson⁹, pers.comm.).

During the survey of Australian timber exporters, only one manufacturer had used desiccants, placing silica gel sachets in guitar cartons for shipping (Kitchener, pers.comm.¹⁰). However this practice has been discontinued in the absence of data to verify its necessity. Further research on the effectiveness of packaging options and use of desiccants is considered by the industry to be worthwhile, as these areas haven't received much consideration in the past.

Other methods used to control or alleviate humidity and condensation problems in shipping containers include porous, absorbent paint and insulation blankets. The latter are used mainly to combat cold being conducted through steel general-purpose containers to products such as wines and liqueurs (P&O Nedlloyd, 2003).

⁹ Carl Anderson, Managing Director The Carl Anderson Agency.

¹⁰ Neville Kitchener, Chief Executive Officer, Maton Guitars.

Chapter 3 Methodology

3.1 Industry survey

As described in the literature review above, the effects of changing environmental conditions are directly related to the section size and species from which the component is manufactured. For example, wide, backsawn boards of high shrinkage species will exhibit more visible responses to a prolonged change in conditions than narrower, quarter-sawn components under the same conditions. The ranges of products, markets, species, typical section sizes relevant to the value-added wood product export industry were determined during the survey of companies engaged in export activities.

The initial phase of the survey involved a compilation of wood product exporters. This was undertaken in consultation with Austrade (Commonwealth Department of Foreign Affairs and Trade, DFAT), and various state industry bodies such as Timber Queensland, the Timber Promotion Council, Forest Products Commission (Western Australia), Furnishings Industry Association of Australia (FIAA, in each State), Tasmania's Department of Economic Development and the Queensland Department of State Development.

Telephone screening of the companies enabled identification of the preferred representative for each business, determination of whether they were actively exporting and potentially interested in participating in the industry survey and datalogging project.

Subsequently an itinerary of personal visits was organised to enable conduct of the market survey by face-to-face interviews and undertake on-site training for the management of datalogging equipment.

The scope of the survey included-

- background company history;
- past, current and future export experience and strategies;
- range of timber species processed or used in manufacture;
- range of value-added wood products for export;
- cross-section dimensions/ section sizes;

- markets;
- possibility of including dataloggers with shipments and likelihood of return of equipment;

These visits also enabled discussion of other areas of research being conducted at CRC Wood Innovations' nodes around Australia and dissemination of newsletters and annual reports. A tour of each company's facilities was usually undertaken during these meetings and commercial-in-confidence reports, summarising the results of the visits were prepared for CRC colleagues.

3.2 Climatic data collation

3.2.1 Dataloggers

The ideal experimental design for capturing environmental conditions would involve regular weighing and measurement of sample boards (representing the range of species used in the manufacture of export items), in conjunction with recording temperature and relative humidity data, with a final oven-drying of the sample boards. Some work using sample boards has been undertaken in the past as discussed in the literature review above; however it was considered impractical and highly difficult logistically to undertake that level of investigation within the timeframe and budget constraints of this project. Therefore, equations developed for predicting EMC from meteorological data, in particular RH% and temperature, were used to provide a theoretical EMC.

Climate dataloggers were assessed for suitability. The requirements were that they had to be:

- self-contained with no external wiring, sensors or probes;
- small and unobtrusive;
- capable of running continuously on battery power for extended periods of up to 12 months;
- able to capture temperature and relative humidity at pre-determined intervals and retain extensive data readings;
- robust enough to withstand knocks;

- able to download the data and transfer it into a proprietary software program (e.g. MS Excel) for ease of data manipulation and reporting;
- available at a price point to enable a bulk purchase of multiple units.



Plate 3. GPSE temperature/ relative humidity datalogger.

Based on relative cost, ease-of-use, size and durability, GPSE 301 200 HT-HR type dataloggers were the instrument chosen for collecting temperature and relative humidity readings (Plate 3). Each cylindrical unit measured 200 mm long x 20 mm diameter, ideal for placement within a pack of furniture or flooring, or to hang unobtrusively in a container. When configured for data reading at the range of intervals deemed suitable for this project (usually six-hourly), the dataloggers had an expected battery life of seven years, well in excess of the timeframe of this project.

The Omnilog Data Management software supplied with the dataloggers was simple to use, enabling the reading, displaying, organising and exporting of data. A connected datalogger can be configured, calibrated, started, read and stopped using this application. Connection between a logger and computer was via a download cable with a 3-pin socket for the logger and a 9-pin-D socket to the computer.

Data was retrieved directly from dataloggers and saved into datafiles, which could then be viewed and printed in a 'values' spreadsheet, graph or a statistics report.

Data could also be exported in a large range of industry standard formats so as to be used by other applications. These included MS Excel, Lotus 1, 2, 3, Lotus Symphony, DIF, MS Multiplan, Symbolic Link, Format CSV, HMTL and space-delimited text format. For the purposes of this research project, data was exported to MS Excel.

A network of participants, including selected processors and manufacturers, were assigned dataloggers. These were installed in factories, warehouses, shipping containers and in-service locations. Where possible in the case of container monitoring, two dataloggers were assigned to the one shipment, to enable monitoring of conditions within the packaging as well as in the general container space. This enabled an assessment of the effectiveness of the packaging system against the effects of changing climatic conditions. Variables such as colour of container, location on ship, etc in addition to route details and transit duration were recorded when available.

A system was developed whereby the receiver of the containerised goods would retrieve the datalogger/s and record the date and time that the container was opened and unloaded, then arrange for the return of the datalogger/s to the laboratory. Reply paid courier envelopes were included within the container or product pack to simplify return of the equipment.

A register was developed in an MS Excel spreadsheet to record the location and important dates for the movements of each datalogger as well as subsidiary data such as the cost of return of the equipment. An electronic map was also generated to plot static locations and assumed transport routes for each logger.

3.2.2 Location climatic conditions

Long-term climatic data is readily available for almost any location in the world. In Australia, the Bureau of Meteorology has long-term records for temperature and relative humidity available for research and other purposes. The World Meteorological Organisation, with headquarters in Geneva Switzerland also has a range of products for supplying long-term climatic data and averages for various locations. The National Oceanic and Atmospheric Administration (NOAA, US Department of Commerce) is another organisation that can provide climatic data. Australian Bureau of Meteorology data was accessed to provide data for Australian sites, and published data already compiled by Simpson (1998) was used to determine in-service conditions for outdoor (i.e. protected from precipitation and sunlight) locations around the world, and then applying Bragg's 5/6th rule (Bragg, 1986) to convert these data to estimated indoor EMC.

3.3 Environmental conditions data

When available, published EMC data for Australia's export destinations was sourced from references as described in Chapter 2 Literature Review above. Where published data was unable to be sourced, for example for containerised stock during shipping, theoretical EMC values were calculated with the equation for EMC provided by Dr G. Siemon (Forest Products Commission, FPC Western Australia) and expressed as:

$$\text{EMC\%} = \left[\left[\frac{-\ln(1-\text{RH})}{23.7 + 0.0026 T^2} \right]^{2/3} \right] \times 100$$

where T = temperature ($^{\circ}\text{C}$),

$-\ln$ = natural logarithm (the negative sign is required because a value of less than 1.0 will give a negative EMC)

RH = relative humidity, expressed as a decimal, e.g. 65% is 0.65

23.7 = constant.

When transposed into MS Excel as a formula, this equation is entered as:

$$=((-\text{LN}(1-\text{RH}))/23.7+(0.0026*(T^2))))^{(2/3)}$$

The use of this equation enabled the determination of the range and mean theoretical EMC conditions for typical container shipping as experienced by Australian wood product exports.

3.4 Timber movement data

At the time of writing, determination of unit shrinkage data for a range of modified woods was being undertaken within the CRC Wood Innovations' program, however results were not available. Future reports will incorporate new data as it becomes available. Until then, published data by Kingston and Risdon (1961), Kingston and von Steigler (1966), Budgen (1981) and Ozarska *et al* (1998) should be consulted in the interim. Feedback from designers and manufacturers on their requirements in regard to using timber movement data has been considered and will assist in the construction of a tool which will use movement data, section size and shipping route variables to aid the design process.

Chapter 4 Results

4.1 Industry survey- export markets, species, products, packaging and section sizes

4.1.1 *Markets for Australian value-added timber products*

The major markets for Australian timber products (excluding sandalwood, panels, chip, green boards and logs, for reasons mentioned in the literature review Chapter 2 above) were determined during the industry survey to be:

- United States of America;
- China and Hong Kong;
- Korea;
- Japan;
- South-east Asia: the Philippines, Indonesia, Malaysia and Thailand;
- New Zealand;
- Scandinavia;
- Western Europe including the United Kingdom;
- South Africa and
- the Middle East.

It was found that export sales are subject to cycles in the same way that the domestic building industry is, although the export and domestic cycles do not necessarily correspond. The northern hemisphere experiences the summer and winter seasons in the opposite months to the southern hemisphere, and this was found to influence sales overseas, especially for products such as outdoor furniture.

Export sales tend to be susceptible to changing values of the Australian dollar (AUD). Several exporters reported strong sales in the USA at the start of the project, when the AUD was comparatively weak against the US dollar (1 USD = 0.56 AUD). By early 2004 these exporters reported cancelled sales after the Australian dollar rose against the US dollar (1 USD = 0.70 AUD).

State government decisions on forest use in Victoria during this research resulted in total loss or diminished access to resource for several processors, further limiting the capacity for export from that state. No less than three companies were affected by these decisions to the extent that they were no longer able to maintain export sales.

A third factor arising during this project, having a significant affect on export sales to established markets, was increased shipping costs. The past two years have seen the fastest increase in freight rates in over twenty years. Several manufacturers considered that China’s phenomenal growth in manufacturing industries and the resultant demand for raw materials in that country has caused a supply/ demand imbalance for shipping.

Table 7 below provides the major export markets for each region surveyed. The Northern Territory, Australian Capital Territory and South Australia have no significant timber export industries at present. Figure 7 illustrates the data from table 7 in the form of a map.

Table 7. Primary export markets for high-value wood products from Australia (by region).

Region	USA	China Hong Kong	Korea	Japan	SE Asia	New Zealand	Scandinavia	Europe, UK	S. Africa	Middle East
South-western Australia	*	*	*	*		*	*	*	*	*
Temperate south-eastern Australia	*	*		*	*	*		*		
Sub-tropical eastern Australia	*	*		*	*	*	*	*		*

Several Australian companies have offices and warehouses overseas to facilitate the distribution of their products. Examples cited during the survey were a Victorian company with an office in Shanghai China, and Western Australian, New South Wales and Queensland companies with centres in the USA.

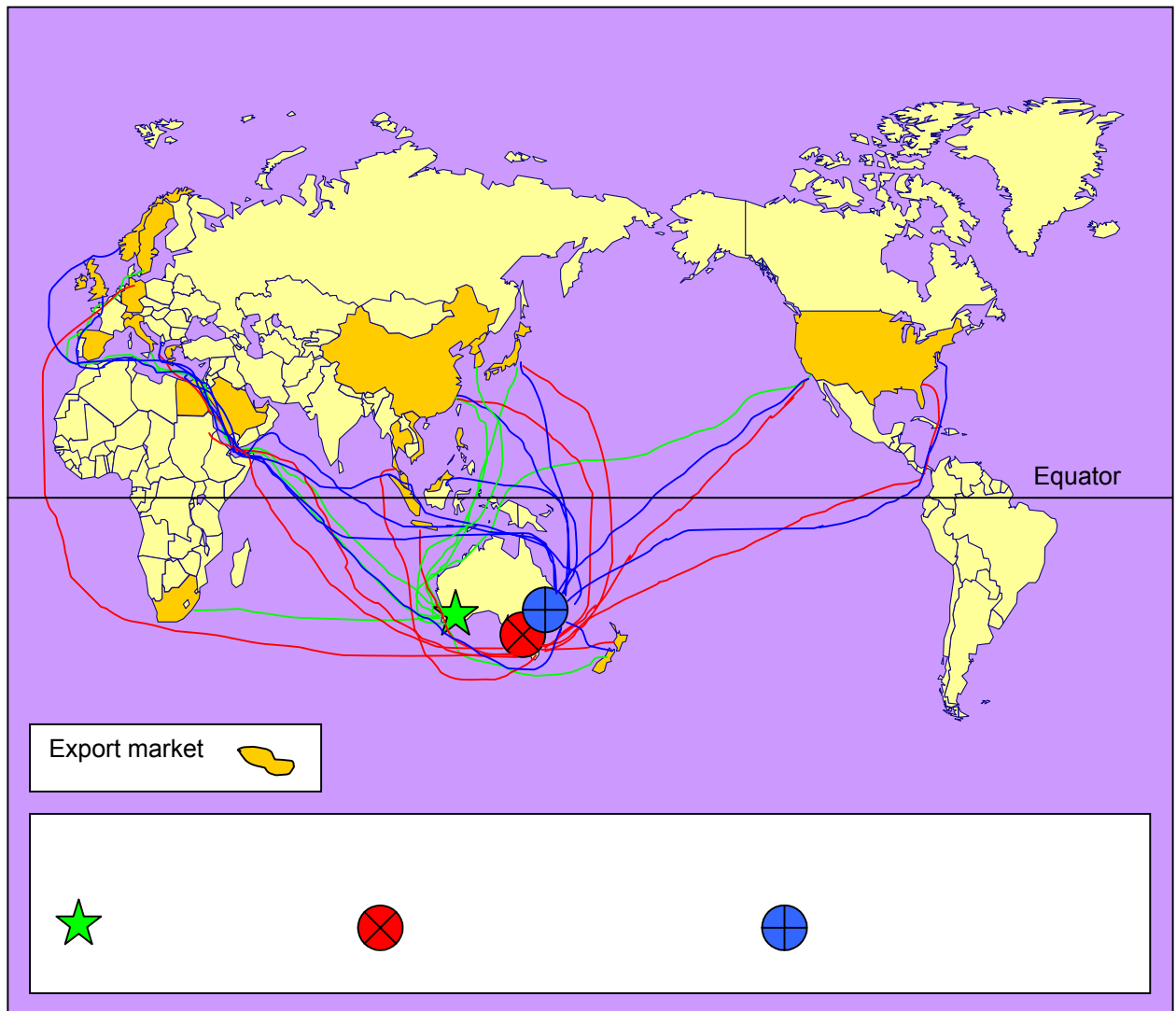


Figure 7. Primary export destinations for high-value wood products from Australia (by region).

The map presented in figure 7 highlights the geographical range, and therefore diverse climates, over which Australian high value wood products are exported. It also illustrates that the majority of Australian high value exports move through the tropics en-route to their final destination.

4.1.2 Timber Species

The industry survey revealed that a wide range of timbers are exported in value-added forms as can be seen from the following list of principal species:

- alpine ash (*Eucalyptus delegatensis*);
- blackbutt (*E. pilularis*);
- brush box (*Lophostemon confertus*);
- plantation-grown hoop pine (*Araucaria cunninghamii*);
- jarrah (*E. marginata*);
- imported kwila (*Intsia* spp.);
- messmate (*E. obliqua*);
- mountain ash (*E. regnans*);
- spotted gum (*Corymbia* spp.);
- Sydney blue gum (*E. saligna*) and
- white cypress (*Callitris glaucophylla*).

This list is arranged alphabetically by standard trade name and doesn't reflect ranking by volume or value. Although relative volumes of each type were unable to be determined for commercially-confidential reasons, it would be safe to assume that the ash-type eucalypts, comprised of *Eucalyptus regnans*, *E. obliqua* and *E. delegatensis*, processed in Victoria and Tasmania would comprise the highest volume exported overall. For Western Australia the only species used for export products was jarrah, *E. marginata*, with the two other primary hardwoods, karri *E. diversicolor* and marri *Corymbia calophylla*, used only for domestic markets. In the sub-tropical zone of Queensland and New South Wales, the highest volumes of exported timber species were the native softwoods, hoop pine *Araucaria cunninghamii* (plantation-grown) and white cypress, *Callitris glaucophylla* (from natural forests) followed by a mix of native hardwoods of the *Eucalyptus*, *Corymbia* and *Lophostemon* genera as then imported kwila, *Intsia* spp.

A relatively low volume of timber is exported in musical instruments, however due to the high unit value and importance of design and manufacturing to successful performance of items such as guitars, they were also included in the survey. The species used in the manufacture of Australian-made guitars include:

- blackwood (*Acacia melanoxydon*);
- Bunya pine (*Araucaria bidwillii*);
- mountain ash (*Eucalyptus regnans*);
- Queensland maple (*Flindersia brayleyana*);
- Queensland silver ash (*Flindersia* spp.);
- river red gum (*Eucalyptus camaldulensis*);
- imported rosewood (*Dalbergia* spp.);
- silver silkwood (*Flindersia acuminata*);
- imported spruce (*Picea* spp.) and
- imported sugar maple (*Acer saccharum*).

The principal timber species used for high-value products exported from each major region in Australia are summarised in Table 8 below.

Table 8. Exported timber species by processing/ manufacturing region.

Processing/ manufacturing Region	Timber species
South-west (Western Australia)	jarrah
South-east (Victoria, Tasmania)	alpine ash messmate mountain ash blackwood (some #) Bunya pine ~ Queensland maple # Queensland silver ash # Indian rosewood * silver silkwood # sugar maple + spruce +
Sub-tropics (Queensland, New South Wales)	blackbutt brush box hoop pine kwila * spotted gum Sydney blue gum white cypress

Notes: ~ feedstock supplied from NSW and Qld

* feedstock imported from the PNG and/ or SE Asia

feedstock supplied from North Queensland

+ feedstock imported from North America

4.1.3 Products

The survey focussed on value-added products that can be affected by changing environmental conditions. As discussed earlier in this report, although other products such as sandalwood, woodchip, logs, green (unseasoned) boards, panels, heavy engineering members, etc, constitute an important part of Australian forest products' trade, they are not relevant to the scope of research being conducted here. The minimum processing necessary to deem a product 'value-added' for the purposes of this report was sawn, seasoned and graded. Many products had been through further secondary processing, such as machining or profiling and assembly and finishing. The range of exported products as determined during the industry survey included:

- kiln-dried boards for furniture- predominantly exported to China for manufacturing and re-export as assembled, finished items. Solid timber coffee tables, buffet hutches, entertainment units, dining suites, bedroom suites and baby cots are the primary products manufactured from Australian timbers in Chinese factories. The highest volume species for these purposes are the ash-type eucalypts from south-east Australia, followed by plantation hoop pine;
- kiln-dried boards for overlay flooring- shipped to south-east Asia and Scandinavia for manufacture and re-export. Both jarrah from the south-west and the ash eucalypts from the south-east are currently exported for engineered flooring production. Pre-finished overlay flooring manufactured from white cypress is currently undergoing marketing trials and if feasible, part-processed off-cuts of white cypress will be exported to China for final processing and re-export;
- flooring- Australian hardwoods and white cypress have enjoyed consistent sales in overseas markets, particularly USA and Japan. Tongue and groove strip flooring (T&G) represents the highest volume by flooring type, with overlay, parquetry and sports flooring accounting for smaller, intermittent sales. Overseas markets are more accepting of short length flooring than the domestic building sector, resulting in better utilisation of the timber resource where sales can be maintained;
- decking- decking products include pencil-round strip decking for domestic construction, boardwalk decking for public places and engineered decking products such as Ezydeck™ panels (plate 7). As with flooring, USA and Japan are the main markets;



Plate 4. Engineered decking products, manufactured from jarrah (Ezydeck™).

- indoor furniture- some furniture manufacturers have had success in export sales and others are currently conducting market research and feasibility studies. There are only small volumes of internal furniture suites exported at present.
- outdoor furniture- also known as garden furniture, exported to over 20 countries. Outdoor manufacturers in Western Australia and Queensland have been very successful in attaining sales in more countries than any other product group. This has mostly been achieved through attendance and displays at major international furniture exhibitions. Sales into the Northern Hemisphere during their summer assist outdoor furniture companies' sales and scheduling through our winter season. The range of products includes outdoor dining settings, bars and stools, sun-lounges, garden benches, barbeque trolleys, drink trolleys and louvred screens. Timbers used for the manufacture of outdoor furniture are jarrah (Western

Australia), spotted gum (Queensland) and kwila (feedstock imported from PNG, furniture manufactured in Queensland, plate 5 below);



Plate 5. Australian-designed and manufactured outdoor furniture: exported to more than 20 countries (Photo supplied by Gumnut).

- joinery- a range of dimensioned boards, laminated square-section material, and finished window and door products are exported from Australia. Markets are Asia, South Africa and Europe;
- structural- The Australian cypress industry, situated in the region west of the Great Dividing Range from central Queensland to New South Wales, includes several processors with consistent sales of traditional Japanese construction members. Although these posts, joists and bottom plates are not fully seasoned, they are dressed all-round and often used in appearance applications, representing a value-adding product;
- guitars- due to the strict grade quality requirements, moisture content specifications and species of timbers used, guitars probably represent the highest value-adding manufacturing that can be undertaken with wood fibre. The traditional high volume factories are in the USA, China, Taiwan, and Korea. More recently Vietnam and Indonesia have begun producing reasonable to high quality guitars, making use of a different Australian export, *viz* technical consulting¹¹.

¹¹ Sydney-based Master Luthier Gerard Gilet, has been engaged by Asian guitar factories to improve quality systems.

Two Australian factories (with more than seven employees and high technology equipment as opposed to smaller ‘craft’-size workshops) are located in Melbourne. Both companies manufacture acoustic and electric instruments and have niche, high-end export markets in the USA and Europe and occasional sales to the UK. Guitar manufacturers store timber in controlled chambers, where temperature and relative humidity variables can be managed to ensure wood moisture contents are appropriate before manufacturing.



Plate 6. Australian-made guitar, featuring Australian timbers and designed to tolerate changing conditions.

- Wine-making- In addition to flooring products, a Queensland company participating in the survey reported development of export markets for a range of niche wood products for the wine-making industry. Boards of oak, *Quercus* spp., are imported from Europe and North America and after very-high temperature (VHT) drying are processed into specially designed products for wine flavour-enhancement in barriques and stainless steel vats. These products are currently exported to the USA and expansion to other wine regions is predicted. Environmental conditions do not affect the performance of these items, so they are not considered further here. A summary of Australian export

products that can be affected by changing conditions, including data for production region, species and markets is provided in table 9 below.

Table 9. Australian high-value wood exports- producer regions, species, products and markets.

Region	Timber species	Products	Markets
South-west	jarrah	2, 3, 4, 5, 6, 7	USA, Ch, Jap, K, Sc, ME, Eu, NZ
South-east	alpine ash messmate mountain ash	1, 2, 3, 7	USA, Ch, Jap, SEA, Eu, NZ,
	blackwood (some #) Bunya pine ~ Queensland maple # Queensland silver ash # rosewood * silver silkwood # sugar maple + spruce +		
Sub-tropics	blackbutt brush box Sydney blue gum	3	USA, Eu, NZ
	spotted gum	3, 6	USA, Eu, NZ, Sc, ME
	kwila *	6	Eu, ME, Sc
	white cypress	3, 7, 8	USA, Eu, NZ, Jap
	hoop pine	1, 10	Ch, HK, Ja, SEA

Notes: ~ feedstock from NSW and Qld; * feedstock imported from the PNG and/ or SE Asia

feedstock supplied from North Queensland; + feedstock imported from North America.

Product Class Legend: **1** furniture feedstock or components; **2** flooring feedstock; **3** flooring; **4** decking; **5** indoor furniture; **6** outdoor furniture; **7** joinery; **8** structural; **9** guitars; **10** venetian blind slats.

Market Destination Legend: **USA** United States of America; **Ch** China (including Hong Kong); **Jap** Japan; **K** Korea; **Eu** Europe (including United Kingdom); **SEA** south-east Asia (Thailand, Vietnam, Philippines, Indonesia, Malaysia); **Sc** Scandinavia (Norway, Sweden, Finland); **NZ** New Zealand; **ME** Middle East (Egypt, Jordan, United Arab Emirates, Israel, Saudi Arabia, Bahrain).

4.1.4 Moisture content and packaging specifications

To ensure that products manufactured in Australia for export perform satisfactorily in service, producers should aim to manufacture components at the lower to mid end of the expected range of moisture contents for the destination. In some cases, the purchaser specifies the target moisture content required. Where this is different to the conditions experienced at the place of manufacture, plastic or carton packaging, or a combination of both, is often used in an attempt to minimise any moisture uptake or loss after processing or assembly.



Plate 7. Australian hardwood parquetry: boxed in cardboard and wrapped in thick plastic for export.

Ironically, some purchasers also specify minimal packaging due to the high cost of disposal in countries such as Japan. The specifications for moisture content and packaging as determined during interviews and observations at exporters' facilities around Australia were as follows:

- kiln-dried boards for furniture- This product is shipped to China after seasoning to 10-15% moisture content with a target of 12%. Packaging is minimal, usually only a single wrapping of standard industry timber-pack stretch wrap. Furniture feedstock packs are shipped by either flat-racks or general-purpose containers,

depending on arrangements with the purchaser. Where flat-racks are used, heavy duty tarpaulins are used to cover the load and the freight is stowed below decks;

- kiln-dried boards for overlay flooring- This feedstock product is dried in Australia to a target of 11%, then re-dried in Scandinavia to 6-8% and re-sawn into lamellae for engineered flooring. Packaging and shipping is similar to furniture boards as described above;
- flooring- The highest volume markets for flooring are Japan and the USA. Flooring is shipped in both general-purpose containers and flat racks. Purchasers in both countries specify a moisture content range of 6 to 9%. Exporters recommend that flooring be allowed to equalise to EMC on site before installation. The moisture content range for Japan and the USA is lower than the range experienced in Australian manufacturing plants; therefore packs of flooring are protected from moisture uptake after drying with several layers of plastic wrap. One hardwood-flooring manufacturer straps sheets of particleboard to the outside of flooring packs to minimise mechanical damage during forklift truck handling.

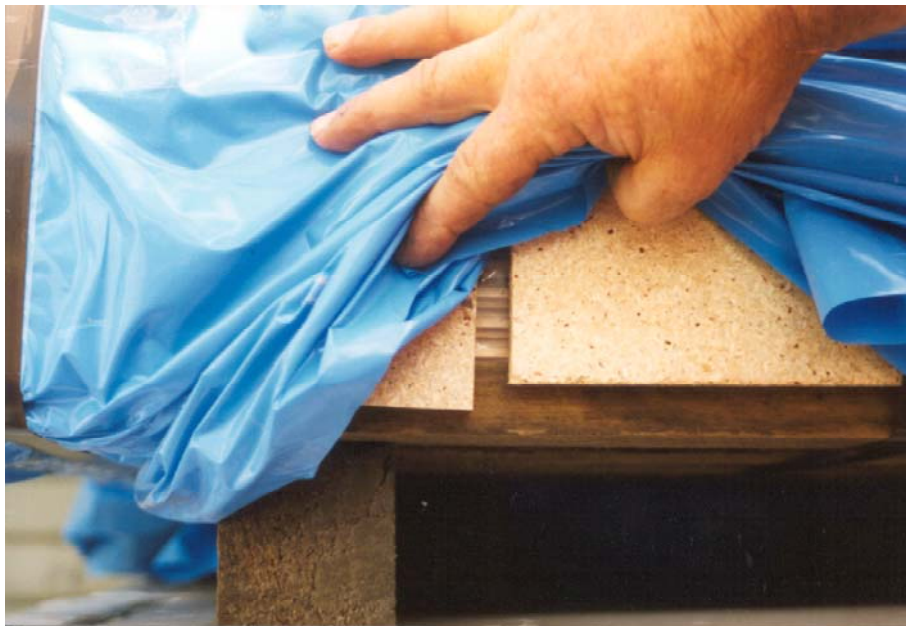


Plate 8. Australian hardwood flooring for export: shrink film, particleboard and plastic sheet.

Packs of white cypress flooring are sealed in shrink-wrap plastic film. The flooring is protected from damage (from metal strapping and handling) with lengths of flooring (plate 9).



Plate 9. White cypress flooring packaged for export to USA and Japan.

- decking- As for flooring, decking is kiln-dried to 6-9% for the Japanese and north American markets. Conventional decking products are plastic-wrapped, while the engineered decking tiles are packed in carton, palletised, then plastic-wrapped.
- indoor furniture- Australian indoor timber furniture manufacturers currently have virtually no marketshare of the global trade in this product group. High labour rates and prohibitive shipping charges for finished furniture items (as opposed to flat-packed outdoor furniture or components) to distant markets are considered the reasons for this. For example, a flat-packed chair costs AUD\$3 to ship from Brisbane to the USA compared with AUD\$19 for a fully assembled chair (Scullen¹², pers. comm. 2003). The target moisture content for intermittent sales is

¹² Tom Scullen, General Manager Gumnut Furniture, December 2003)

8-10%. Furniture is blanket-wrapped to protect against vibration, then plastic wrapped to hold timber moisture content during shipping;

- outdoor furniture- Outdoor furniture is dried to between 10 and 12% moisture content. Items are designed to be flat-packed to save costs in shipping and cardboard carton is used for packaging. One of the companies exporting outdoor furniture also wraps their cartons in shrinkfilm (plate 10) for extra insulation against changing conditions during transit.



Plate 10. Outdoor furniture: flat-packed, carton boxing, shrink film and palletised.

Some companies have their own assembly and distribution offices overseas, whereas others sell direct to the purchaser, providing instructions for assembly with the products;

- joinery- Jarrah joinery items and components are seasoned to 10% and wrapped in a foam sheeting product called Celair (plate 11), to protect against vibration. Cardboard carton is used to package items, then when palletised, the entire load is covered with shrinkwrap plastic film;



Plate 11. Celair foam between window joinery items.

Ash-type eucalypt joinery is shipped below decks on flat racks covered with plastic sheeting;

- structural- Jarrah structural members, such as decking support joists, are seasoned to 6-9%, but no packaging is used for these products. White cypress members are supplied dressed-all-round (DAR), unseasoned, and wrapped in heavy plastic sheeting;

- Guitars-In the case of guitars, timber components are dried down to 6-8%, then equalised to 8-11% prior to assembly. Packaging is either cardboard carton, or a plastic sleeve and outer carton as depicted in plate 12 below. Silica gel sachets were provided in the cartons as a desiccant however this practice was stopped due to a lack of evidence that it was of benefit.



Plate 12. Australian-made acoustic guitar packaged for export.

4.1.5 Section sizes

Due to the physical and chemical attributes of wood, the effects of changing environmental conditions are more visible in wide section material, particularly in backsawn boards. During the industry survey, data for typical section sizes used in the manufacture of Australian export wood products were determined. The results from this component of the survey are detailed in table 10 below.

Table 10. Cross-section dimensions for Australian high-value timber exports.

Product	Species	Cross-section dimensions
flooring	white cypress	57 x 19 mm (USA 2 ¼" x ¾")
		83 x 19 mm (USA 3 ¼" x ¾")
		108 x 19 mm (USA 4 ¼" x ¾")
		133 x 19 mm (USA 5 ¼" x ¾")
jarrah	ash eucalypts (¼ sawn)	83 x 19 mm (USA 3 ¼" x ¾")
		80 x 19 mm, 82.5 x 19.5 mm, 85 x 19 mm, 108 x 19 mm, 65 x 19 mm, 60 x 21 mm
feedstock for overlay flooring	jarrah	77 x 27 mm, 136 x 14 mm
parquetry	ash eucalypts	65 x 19 mm, 65 x 12 mm, 45 x 12 mm
strip decking	jarrah	100 x 17 mm, 100 x 25 mm, 100 x 38, 105 x 30 mm, 85 x 20 mm, 150 x 25 mm, 130 x 30 mm
engineered decking	jarrah	64 x 19 mm
joinery	jarrah, ash eucalypts	from 150 x 25 mm to 300 x 50 mm in standard increments
furniture	jarrah	45 x 12 mm, 50 x 25 mm, 65 x 25 mm, 75 x 25 mm, 85 x 19 mm, 85 x 25 mm, 100 x 38 mm
electric guitar solid body	various (¼ sawn)	180 x 33 mm (single half)
guitar necks	various	75 x 75 mm
acoustic guitar top and back	various (¼ sawn)	220 x 3 mm (single half)
feedstock for furniture	ash eucalypts (¼ sawn)	From 38 x 25 mm up to 200 x 50 mm in standard increments

4.2 Climatic data

4.2.1 Processing and manufacturing sites

Long-term meteorological records for manufacturing sites around Australia were collated to provide the estimated range of EMC conditions at these locations. Additionally, dataloggers were issued for installation at various sites in order to obtain a measure of the actual conditions experienced in timber storage sheds and assembly facilities. Results from this work are summarized below in table 11.

Table 11. EMC conditions for Australian manufacturing sites.

Location	Minimum	Maximum	Open shed annual mean	Indoor annual mean
Perth (WA)	9.3 (Jan)	16.2 (Jul)	12.0	10.2
Woodend (VIC)	10.5 (Jan)	20.4 (Jun)	14.8	12.6
Alexandra (VIC)	9.8 (Jan)	21.5 (Jun)	15.1	12.9
Heyfield (VIC)	10.6 (Dec)	16.4 (Jun)	13.3	11.3
Melbourne (VIC)	10.5 (Jan)	17.5 (Jun)	13.5	11.5
Smithton (TAS)	13.9 (Dec)	21.5 (Jun/Jul)	16.9	14.4
Emerald (QLD)	10.3 (Nov)	13.0 (Jun)	11.5	9.7
Toowoomba (QLD)	12.3 (Sep)	15.8 (Feb)	13.9	11.8
Gympie(QLD)	11.9 (Oct)	16.4 (Jun)	14.1	12.0
Brisbane(QLD)	11.1 (Nov)	13.3 (Jun)	12.2	10.4
Sydney (NSW)	11.4 (Oct)	14.9 (Jun)	13.2	11.2

Notes: based on mean monthly averages for 9 am RH% and temperature data; indoor = 5/6 outdoor.

Across all sites, the summer season provides drier EMC conditions, closer to the desired moisture contents for finished products. Conversely the middle year winter months produce climatic conditions with relatively high EMCs, especially in air-drying shed type situations, i.e. open-sided, roofed sheds. Tasmanian sites in particular measured high winter EMCs, even for indoor situations.

Shipping routes

A total of 56 dataloggers were distributed to 20 companies for inclusion with high value wood products destined for overseas markets. Changes in export dynamics (e.g. rising Australian dollar value against foreign currencies, increased shipping freight costs, etc) during the timeframe of this project resulted in a slow-down in wood product exports. At the time of writing, 30 dataloggers had been returned to the laboratory. The data collection phase of the project will continue beyond the term of this thesis and it is envisaged that further reports will be published in due course. A summary of the shipping routes covered to date and the conditions experienced appears in table 12 below.

Table 12. Allocation of dataloggers by destination region, summary of voyage duration and environmental conditions.

Destination region	Trips	Function	Days	T°C	RH%	EMC%
North America	6 (west coast)	range	22, 89	-12.4, 46.1	30, 84	5.2, 17.3
	11 (east coast)	average	41	22.3	53	9.8
	17 total	st. deviation	17.4	5.9	6.1	1.2
China/ Hong Kong	4	range	18, 31	8.9, 52.3	44, 88	7.5, 23.4
		average	23	27	63.8	12.1
		st. deviation	5.7	5.5	7.7	2.1
Middle East	1	range	-	12, 40	35, 68	6.2, 12.9
		average	50	25.1	54.5	9.9
		st. deviation	-	8.4	8.2	1.7
Europe/United Kingdom	4	range	56, 71	-5.7, 49.6	32, 97	5.5, 27.1
		average	62	23.9	57	10.5
		st. deviation	7.2	9.2	8.9	1.9
Japan	2	range	32, 34	9.7, 31.1	47-85	8.6,17.4
		average	33	23.2	69.1	13.2
		st. deviation	1.4	5.4	8.7	2.0
New Zealand	1	range	-	10.4, 16.3	57, 65	10.7, 12.3
		average	11	13.7	61.1	11.5
		st. deviation	-	2.2	3.0	0.6
South-east Asia	1	range	-	23.2, 40.4	53, 82	9.6, 16.4
		average	51	28.5	70.2	13.2
		st. deviation	-	4.2	7.8	1.9
Overall	30	range	11, 89	-12.4, 52.3	30, 97	5.2, 27.1
		average	41	23.2	56.9	10.6
		st. deviation	18	6.1	6.9	1.5

Detailed results for each voyage are presented below, including a discussion and charts of environmental conditions.

Emerald (Queensland) to Manchester (England), 18/12/02-27/2/03

This shipment was railed from Emerald in central Queensland to the Brisbane container park, where it sat for seven days awaiting loading and departure. During this period, conditions fluctuated, but were generally hot and dry, reflecting the drought experienced throughout south-east Queensland during the summer of 2002/03. Equilibrium moisture content averaged 8% until the container vessel left Brisbane, sailing north into tropical conditions and then north-west to the equatorial transshipping port of Singapore. During the five day stay in Singapore, the EMC rose to 11% and generally maintained this level during sailing the through Middle East and Mediterranean regions, after which cooler, drier conditions approaching the European winter, caused the EMC to drop back to 8%.

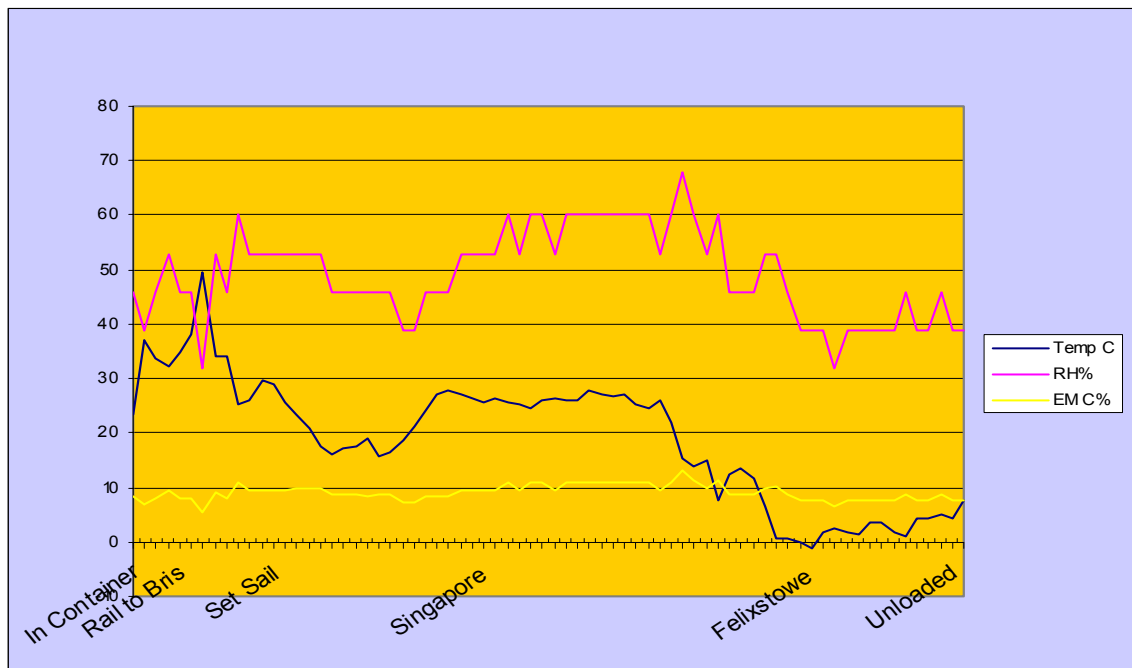


Figure 8. Environmental conditions Emerald to Manchester 18/12/02-27/2/03.

Brisbane was experiencing drought conditions during the two-week period that this shipment was awaiting loading at the terminal. These hot and dry conditions resulted in estimated EMC conditions of 8% inside the container. Relative humidity steadily increased for the voyage across the Pacific to the Panama Canal and into Freeport in the Bahamas, where the container was offloaded awaiting transshipping. EMC conditions picked up to 13% over this period of the voyage. From Freeport the container moved to New Jersey on the north-east American coast (40° N) where it was again offloaded and sat in freezing conditions for three weeks awaiting transshipping to waiting customers in Bermuda. The extended period in New Jersey was attributed to a long-shoremens¹³ strike and the prevailing cold and dry conditions pulled the EMC down to 8%. Conditions at the final destination were typical of a sub-tropical winter climate, resulting in an EMC in Bermuda of 12%.

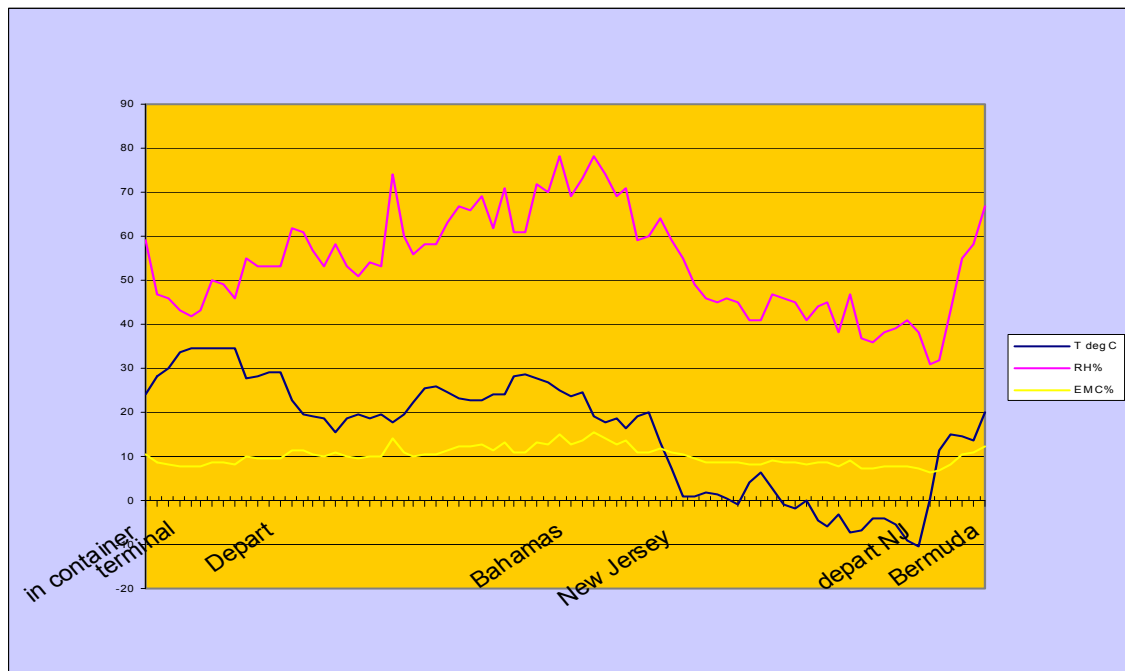


Figure 9. Environmental conditions Brisbane to Bermuda 16/11/02-27/1/03.

¹³ American term for dockside workers.

Brisbane to Port Said, Egypt, 3/12/02-18/1/03

Departing Brisbane during the drought of summer 2002, container conditions were estimated to be 8% at the time of departure. The eight-day voyage to Malaysia (approximately 5°N) and subsequent 6-day wait for transshipping, resulted in EMC fluctuations from 8 to 12%. This container also transhipped at Oman on the Arabian Peninsular, and when reaching the destination of Port Said, was sitting at dock for a further 17 days before delivery to its Egyptian customer. During this period, EMC fluctuated within the range of 8 to 13%.

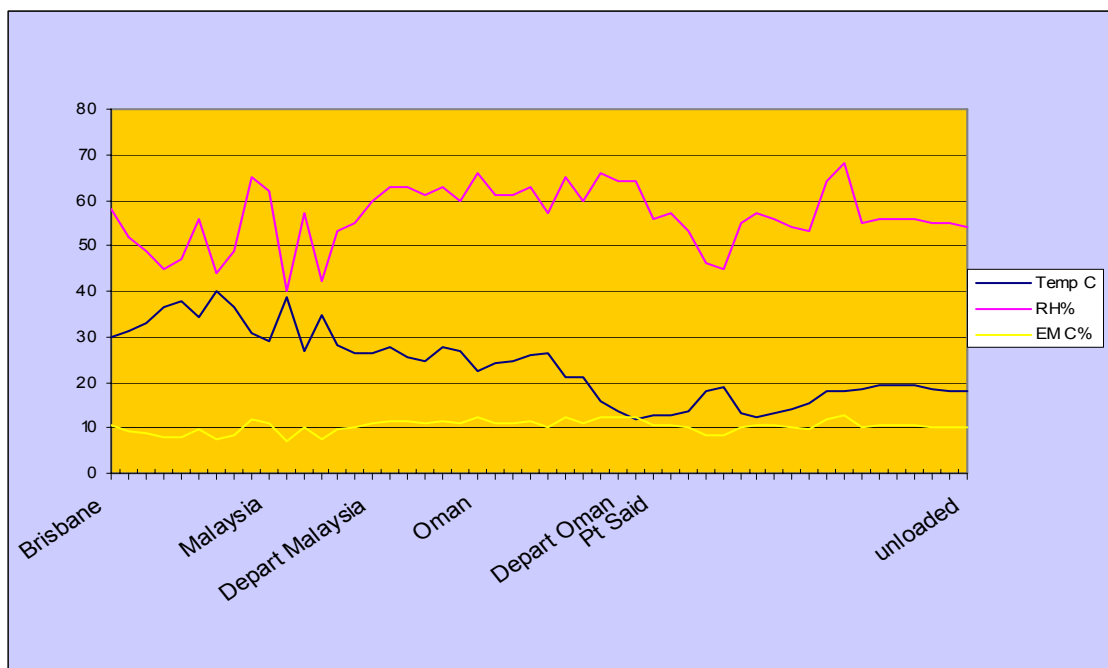


Figure 10. Environmental conditions Brisbane to Egypt 3/12/02-18/1/03.

Brisbane to Hamburg, Germany, 18/12/02-12/2/03

In contrast to other containers awaiting shipping at Brisbane's port facilities during summer 2002, this shipment held relatively consistent conditions during the two-week period prior to departure. This may indicate that the container was low in a stack with layers of containers insulating it from local climatic effects. Hot and drier conditions were experienced after sailing north from Brisbane and during the voyage to Malaysia for transshipping. EMC ranged from 8 to 13%, however after departing Malaysia, relatively stable conditions were experienced with a consistent 11% EMC. Conditions altered approaching the northern hemisphere's winter, with EMC falling to 8% by arrival at the terminal and this level was maintained through until distribution at the warehouse. This was an unusually dry and cold winter for the region, compared with normal February EMC warehouse conditions in Germany of 15% (N. Price¹⁴, pers. comm.).

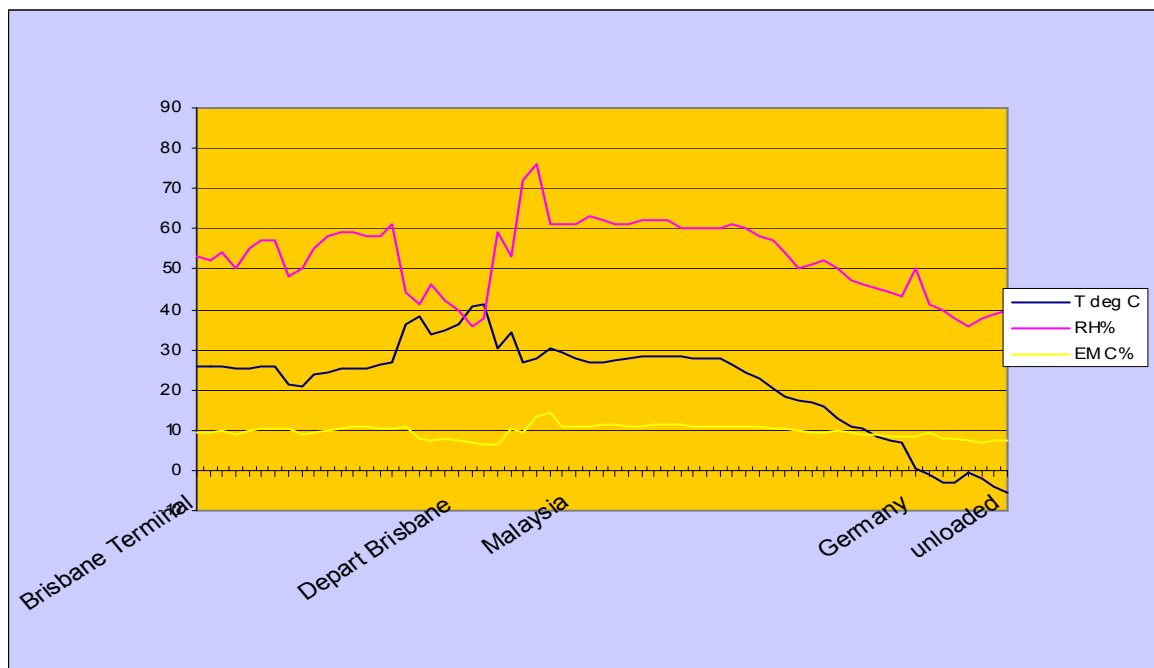


Figure 11. Brisbane to Hamburg 18/12/02-12/2/03.

¹⁴ Export Manager, Ausgum Furniture

Brisbane to Hong Kong, 12/2/04-2/3/04

During a direct shipment from Brisbane to Hong Kong, this shipment maintained EMC conditions of 12% until moving north into the tropics where higher humidity brought the estimated EMC up above 15% for the remainder of the journey to Hong Kong. The mean EMC for the voyage was 15.4%, which incidentally matches the estimated EMC for Hong Kong for that time of year as published in Simpson (1998).



Figure 12. Environmental conditions Brisbane to Hong Kong 12/2/04-2/3/04.

Brisbane to Shanghai, China, 12/2/04-13/3/04

This direct shipment from Brisbane to Shanghai (China) held conditions of approximately 10% for a week awaiting loading, then a sharp rise in temperature combined with falling relative humidity over the weekend of departure brought EMC down to 8%. During the voyage northwards to China, conditions remained warm and humid with EMC consistently around 14%, rising to approximately 20% prior to arrival in Shanghai, where the EMC commenced falling. Simpson estimated that the average EMC during March is 14.6% for Shanghai (Simpson, 1998).

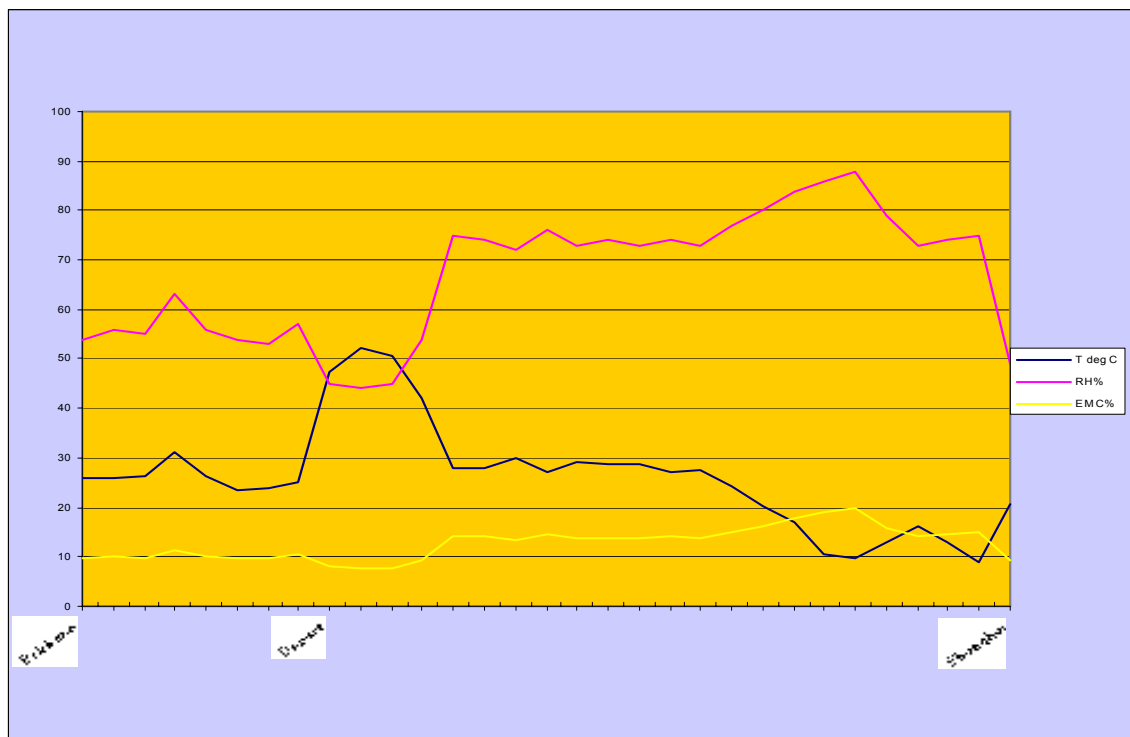


Figure 13. Environmental conditions Brisbane to Shanghai 12/2/04-13/3/04.

Brisbane to Cebu, Philippines, via Singapore, 12/2/04-2/4/04

According to the information supplied for this shipment by the freight forwarder, it departed Brisbane on 12 February and took 51 days to reach its final destination at Cebu in the Philippines. Analyses of the data and comparison of sailing times for similar distances would indicate that the container was more likely still at the Brisbane terminal until approximately 24 February. The weekend 21-22 February was the hottest February weather in Brisbane for 70 years and shows clearly on the graph with temperatures of approximately 40°. It is more likely that the ship departed Brisbane on or around 24 February. Assuming this is a more accurate scenario than that provided by the freight forwarder's information, the shipment experienced fluctuating conditions whilst at Brisbane terminal, then sailed through a region of high humidity giving rise to an average EMC through to Singapore of 15%. This is consistent with estimated EMC for Singapore during March of 15% as suggested by Simpson (1998). Similar conditions were experienced for the onward voyage to Cebu, an island in the Philippines renowned for timber furniture manufacturing.

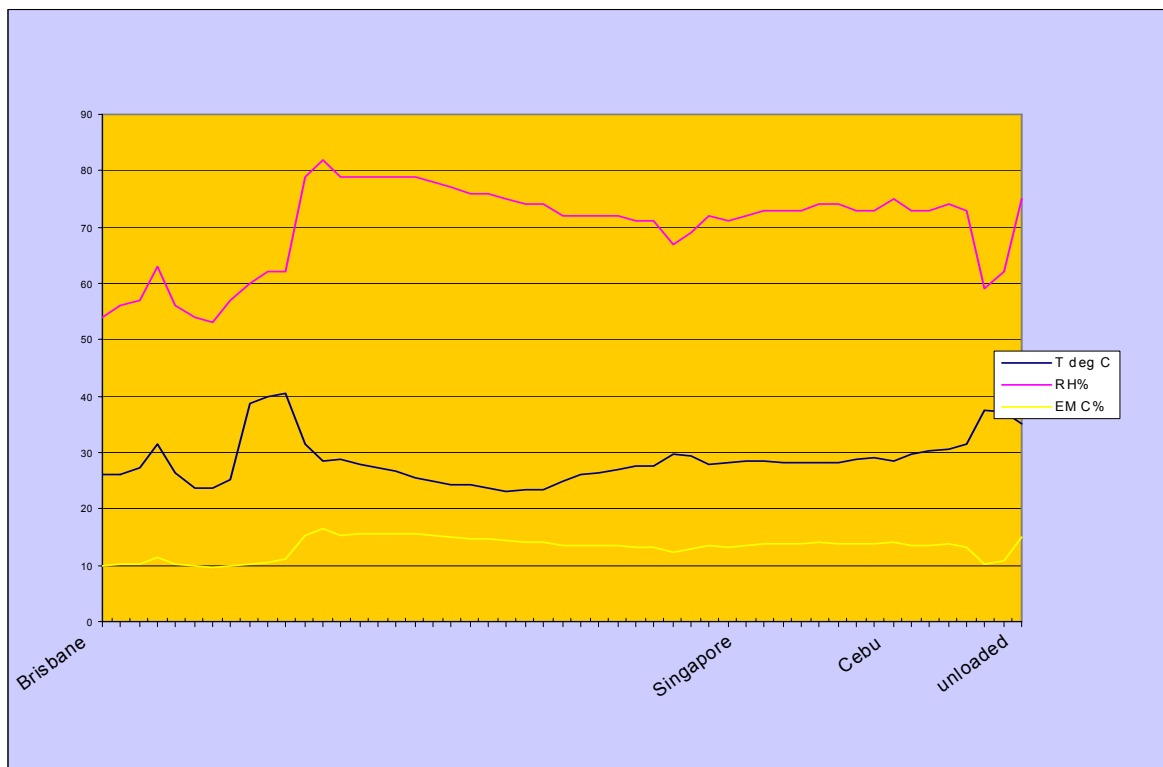


Figure 14. Environmental conditions Brisbane to Philippines 12/2/04-2/4/04.

Brisbane to Virginia, USA, 28/11/03-25/1/04

This container of white cypress flooring products was transported along a route in the opposite direction to most shipments to North America from Brisbane. In this case the container was railed to Sydney and spent a week at the Sydney port facility awaiting departure. This period was characterised by fluctuating environmental conditions resulting in EMC variations from 10 to 14%. From Sydney the vessel sailed south and west to Durban, South Africa and conditions were generally stable with EMCs of 10%. This trend continued for the majority of the remaining passage to Newport, Virginia USA, although wet, winter conditions upon arrival at Newport brought the EMC up to 14%.

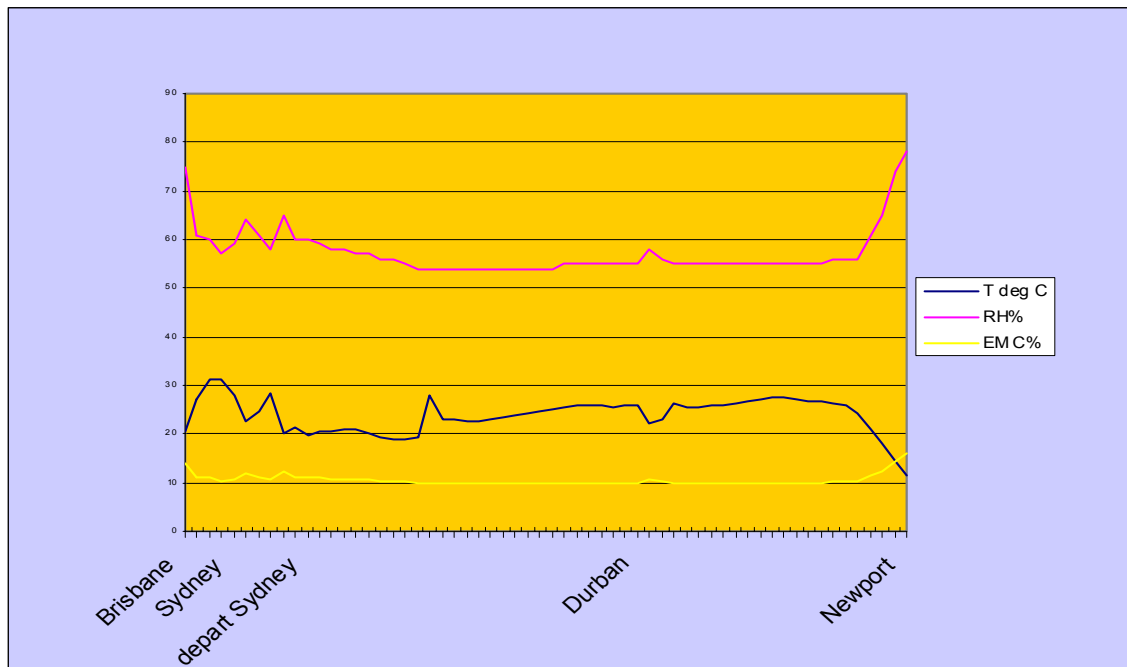


Figure 15. Environmental conditions Brisbane to Virginia 28/11/03-25/1/04.

The flooring products comprising this shipment were dried to 8-10% for the American market and shrink-wrapped after processing to retard the effects of changing environmental conditions. Two dataloggers were included in the shipment, one within a shrink-wrapped pack (figure 17) and one in the general container space (figure 18). Mild sub-tropical winter conditions in Brisbane equated to an EMC of approximately 11% for the container and 9% within the packaging. Temperature and humidity rose during the northeast voyage through the Bahamas and on to the Newport News in Virginia USA. Mean EMCs for the voyage were 10.2% and 9.8% respectively, with negligible standard deviation for either environment. Temperature data were virtually identical in both cases, however the packaging appears to have minimised the range of relative humidities experienced during the voyage, when compared with the general container space.

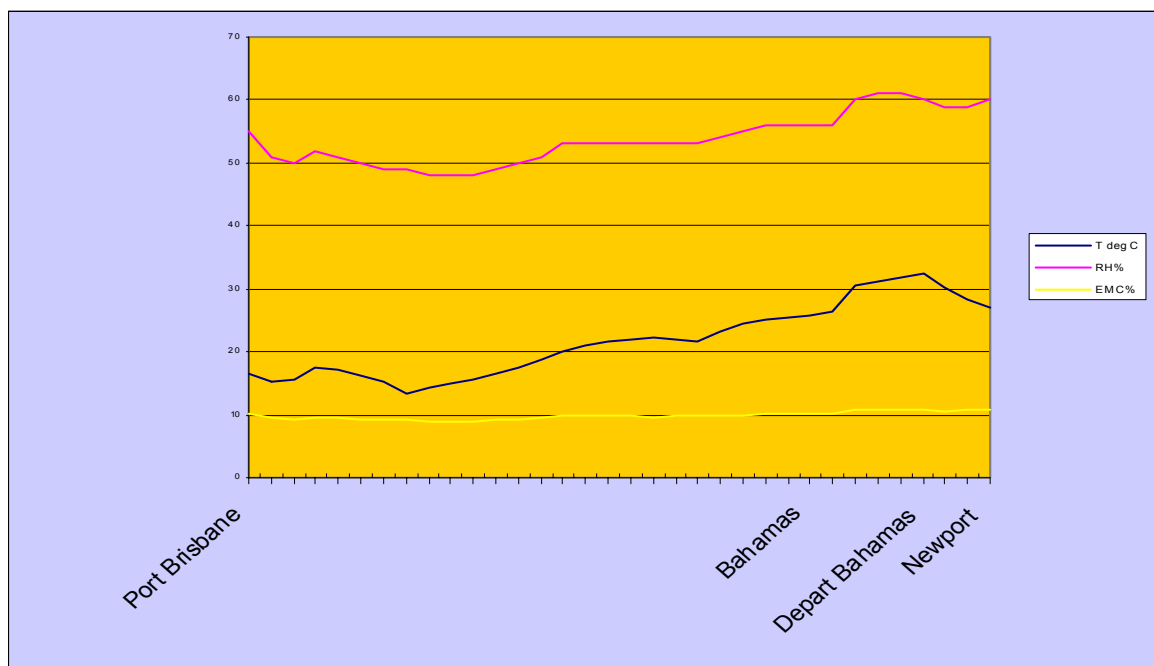


Figure 16. Environmental conditions (shrink-wrap package) Brisbane to Virginia 24/6/03-27/7/03.

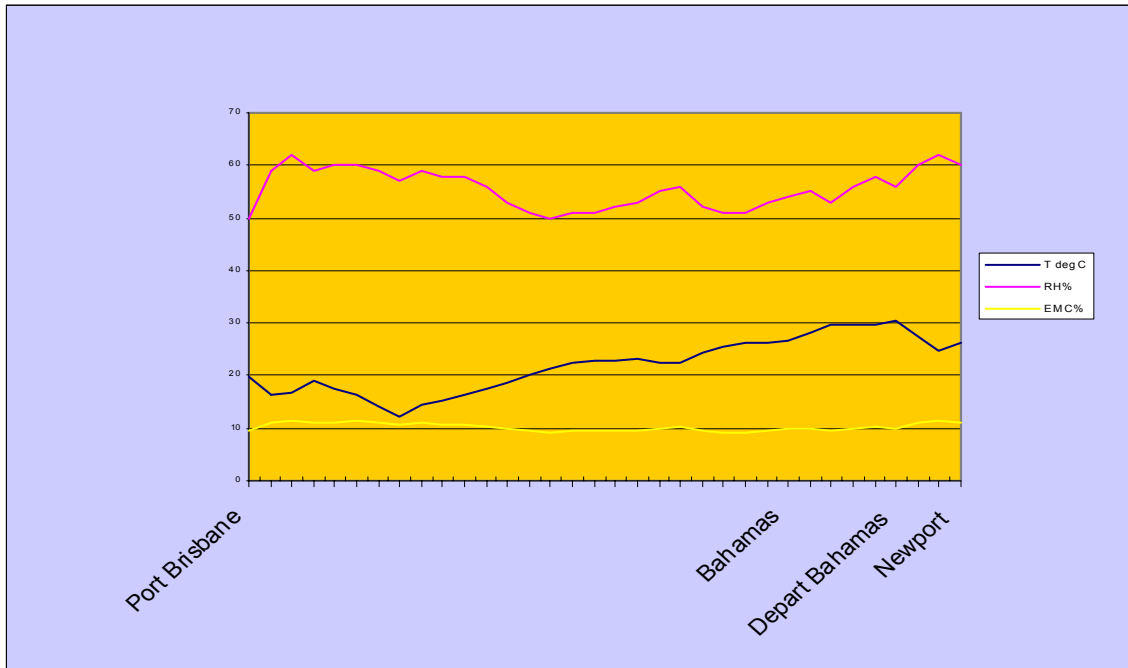


Figure 17. Environmental conditions (container) Brisbane to Virginia 24/6/03-27/7/03.

Brisbane to Philadelphia USA, 1/8/03-11/11/03

This container was packed in Toowoomba (approximately 150 km west of Brisbane) in late winter, a typically dry period due to prevailing westerly winds at this time of year. The product (white cypress flooring) was kiln-dried to a target of 8% MC and shrink-wrapped immediately after processing. The container was railed to the port terminal in Brisbane and was exposed to fluctuating conditions until departure. Sailing from Brisbane, temperature and RH% rose in parallel and stabilised for the majority of the voyage to North America. EMC conditions were consistently around 9-10%. Closer to arrival in Philadelphia, conditions fluctuated again, including a short period of dry weather pulling EMC down to 7-8%, before rising again to approximately 10% in Philadelphia.



Figure 18. Environmental conditions Brisbane to Philadelphia 1/8/03-11/11/03.

Toowoomba to Philadelphia USA, 10/9/03-10/10/03

As with the shipment from Brisbane to Virginia June/July 2003 described above, this container had two dataloggers installed: one in the general container space and one within the wood products' package. The usual fluctuations occurred during rail to Brisbane and at the terminal awaiting loading. Temperature conditions were identical for both datalogger placements, from 20°C to 10°C during the first week of the voyage, then rising back to 20°C during the following week and levelling out for a few days followed by brief warmer period of 25°C. The relative humidity remained fairly constant around 58% within the packaging for the duration of the voyage, whereas the general container space experienced a range of 13 percentage points within the same timeframe. The mean EMC within the packaging from loading in Toowoomba Queensland to unloading in Philadelphia was 10%.

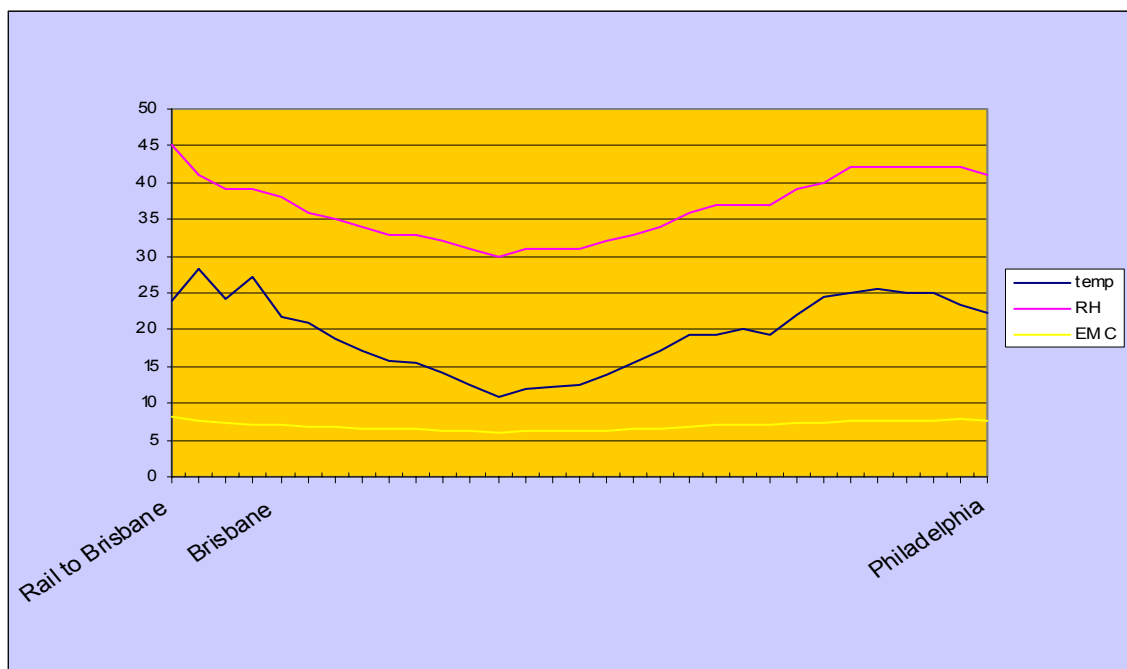


Figure 19. Environmental conditions (container) Brisbane to Philadelphia 10/9/03-10/10/03.

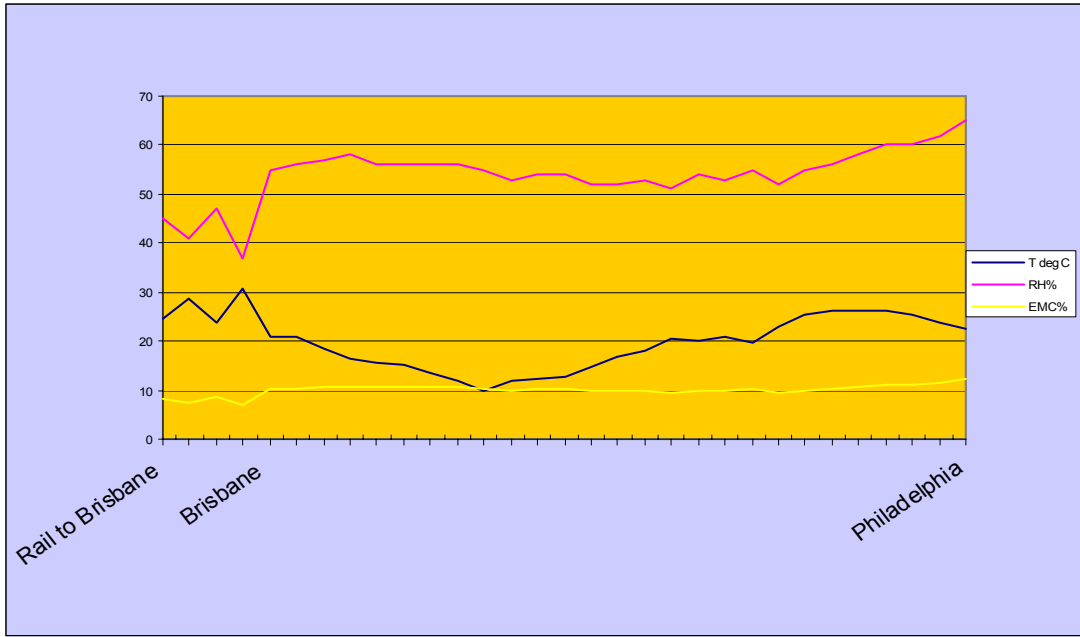


Figure 20. Environmental conditions (shrink-wrap) Brisbane to Philadelphia 10/9/03-10/10/03.

Sydney to Oakland, California USA, 25/2/04-17/3/04

Two dataloggers accompanied this shipment of high-value flooring products to the USA. Dropping temperature values combined with relatively high humidities resulted in EMC conditions of approximately 13% by the end of the first leg of the journey, culminating with transhipping in Auckland New Zealand. These conditions are consistent with published data for Auckland in February (Simpson, 1998). Sailing northeast from New Zealand to California, increasing ambient temperature, levelling out in the high 20°Cs, combined with RH% in the mid-50%s, resulted in consistent EMC conditions within the container of 9-10%. In fact, the EMC variation for the entire journey was restricted to 3 percentage points giving a range of 9.2% to 12.2%. The rising trend in RH% upon arrival and unloading in Oakland is consistent with Simpson's data for Oakland of 13.1% for March (Simpson, 1998).

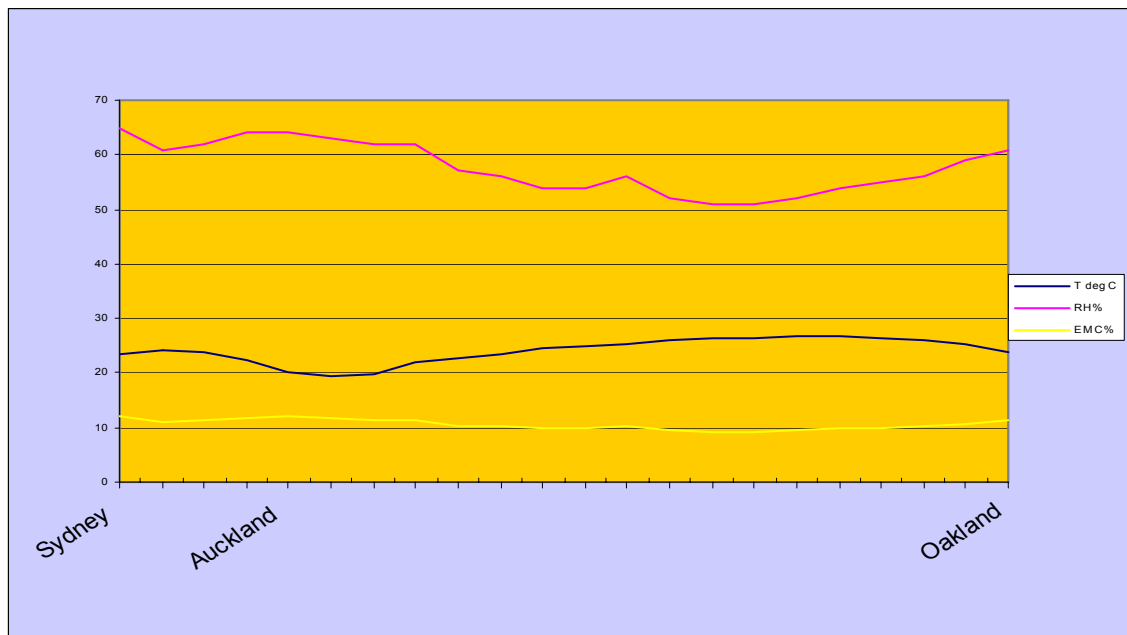


Figure 21. Environmental conditions Sydney to Oakland 25/2/04-17/3/04.

Sydney to Philadelphia USA, 1/4/04-7/5/04

The two dataloggers installed with this shipment provided virtually identical data for temperature and relative humidity conditions within the container. Both were fixed to pallets of flooring with minimal packaging, viz one layer of stretch-wrap. One was installed in a top layer and the other in the bottom layer of packs in the container. Although temperature conditions were identical for both positions, the lower datalogger experienced slightly higher relative humidity conditions throughout the voyage. This indicates that there is a humidity gradient within containers, with heavier, humid air lower in the container space and lighter, drier air towards the top.

Leaving Sydney for New Zealand, conditions approximated 10%, steadily decreasing during the first week of the journey north and east towards the Panama Canal. From Panama to Philadelphia, EMC rose to 9%, then after unloading and before unpacking a week later, fluctuated up to 12%. Once again, Simpson's estimates proved to be accurate, with a published mean EMC for Newark in May of 11.1% (Simpson, 1998).

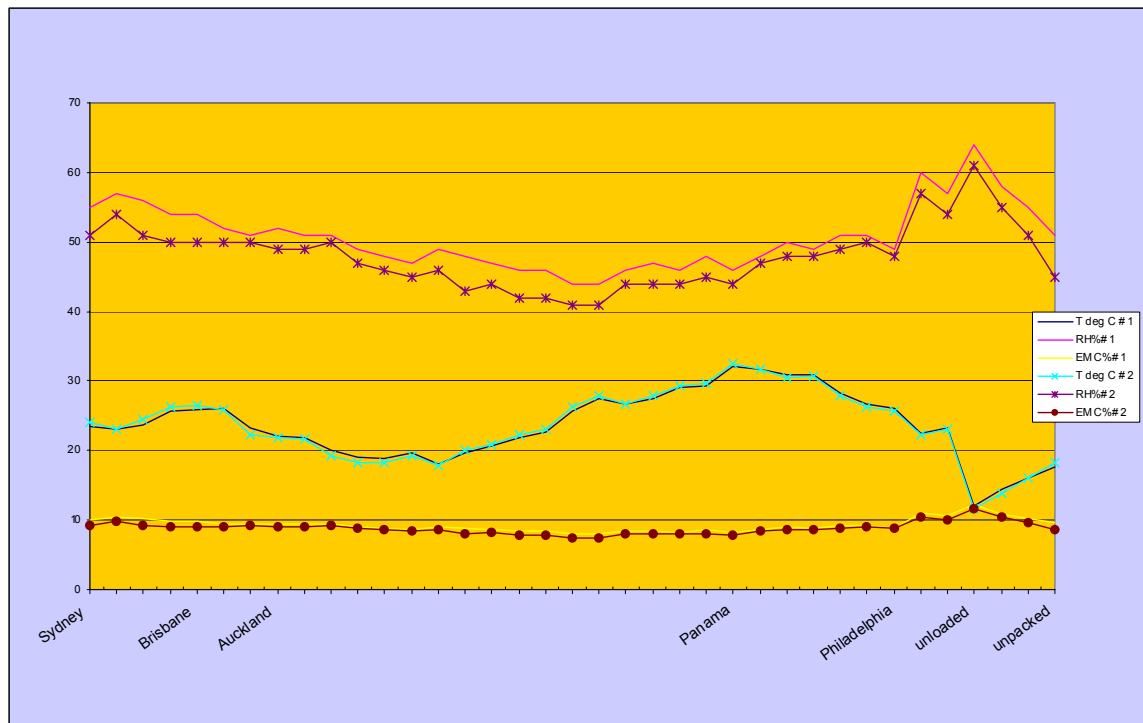


Figure 22. Environmental conditions Sydney to Philadelphia 1/4/04-7/5/04.

Woodend, Victoria to Dunedin, 16/4/03-18/5/03

This shipment was one of the few that sailed entirely within the temperate zone, crossing from Melbourne to Dunedin in New Zealand through a latitudinal range of 38°S to 48°S. Two graphs are provided below, figure 23 depicting the conditions in the package (shrink-wrapped sports flooring) including the two week period on-site at the Woodend processing facility awaiting transport to port, and figure 24 with just the passage to New Zealand from Port Melbourne. The former shows that conditions at Woodend (approximately 100 km north-west from Melbourne) were consistently providing an EMC of approximately 11% and this increased by one percent whilst awaiting departure at the Melbourne terminal. Both temperature and relative humidity tapered off during the passage to New Zealand so that upon arrival at Dunedin, conditions had equalised to 11%.

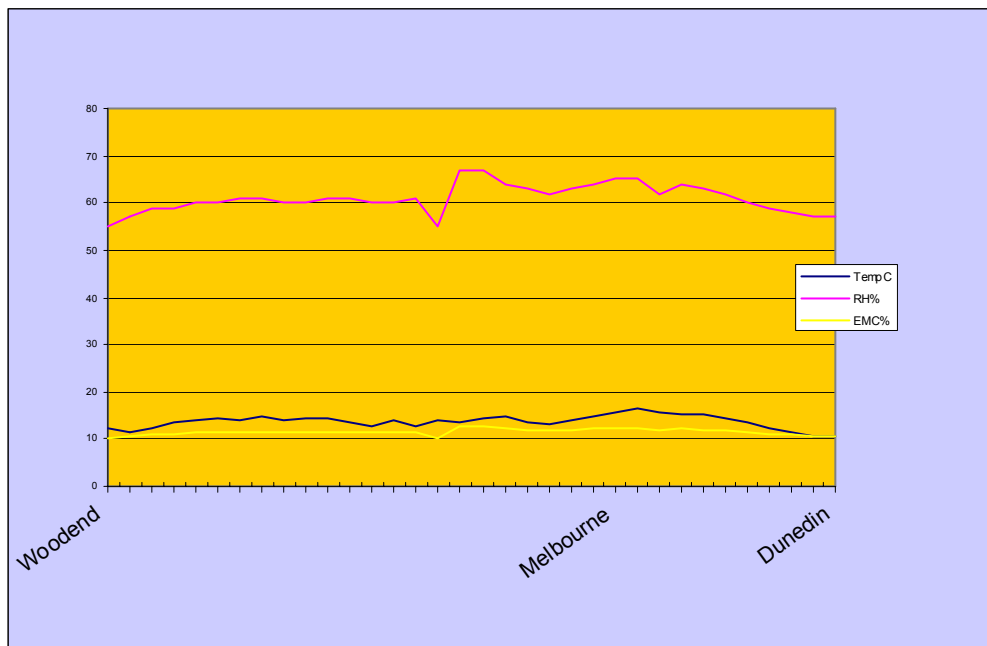


Figure 23. Environmental conditions Woodend to Melbourne to Dunedin, 16/4/03-18/5/03.

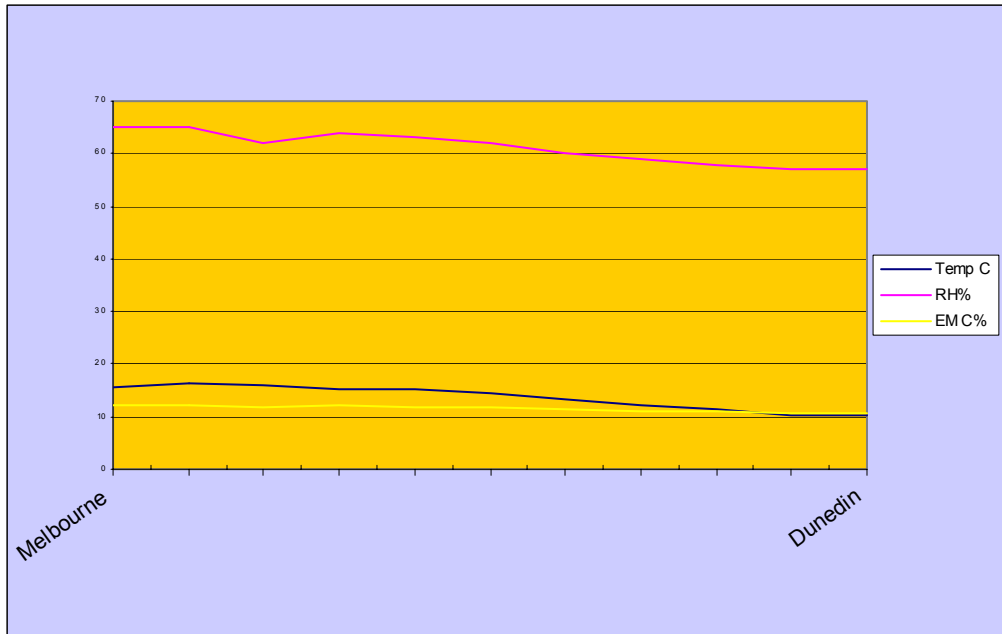


Figure 24. Environmental conditions Melbourne to Dunedin 9/5/03-18/5/03.

Heyfield(Victoria) to Arhus, Denmark 23/4/03-17/6/03

Two dataloggers accompanied a container during a voyage from Victoria through Malaysia to Germany and ultimately, Denmark. One logger was hung in the general container space and the other placed inside the packaging with the timber products. Conditions in both situations fluctuated from the time the container was packed and locked and transported to Port Melbourne. The first leg of the voyage exposed the container to rising temperatures combined with relatively stable humidities, producing EMC in both positions of approximately 10%. However during a two-week transshipping delay at port in Malaysia, conditions in the general container fluctuated from 7% to 14% EMC, with several extremely hot days (40°C). This compared with a narrower range of 9% to 11% within the protective packaging. The next leg of this voyage, from Malaysia to Hamburg, Germany provided very stable conditions, with 15% EMC and 12% EMC held in the container and packaged timber respectively. During barge transfer from Hamburg to Denmark, conditions fluctuated again, with humidity results indicating wet weather for part of this passage. It is also likely that the smaller craft used for this final leg offered less protection from climatic conditions than typical ocean liner cargo ships with multiple layers of containers. Denmark experiences high outdoor EMC conditions throughout the year, ranging from 13% to almost 20% (Simpson, 1998).

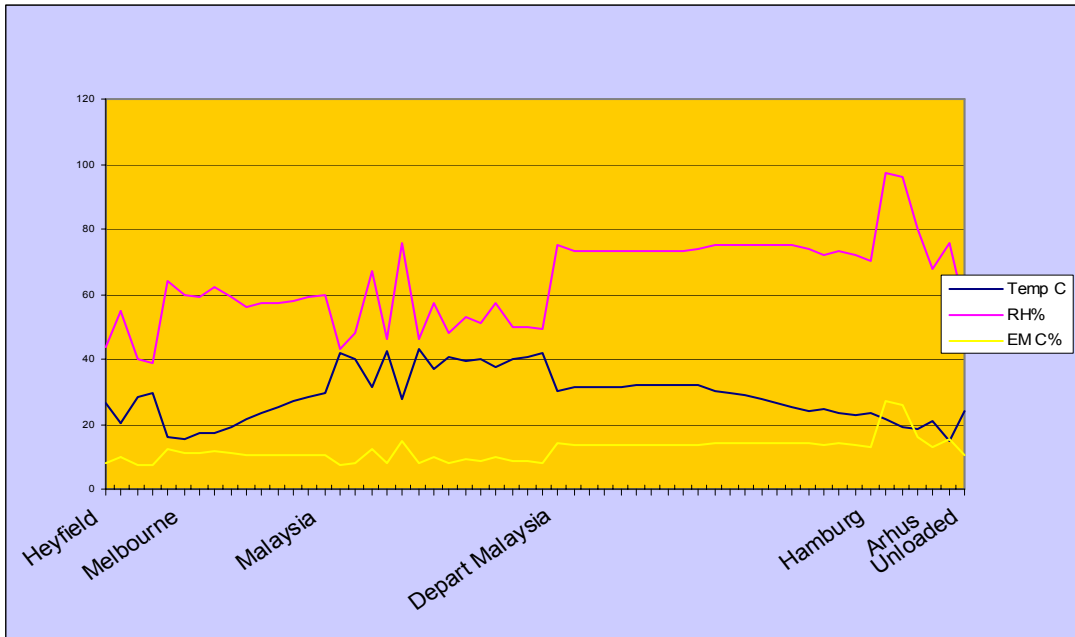


Figure 25. Environmental conditions (container) Heyfield to Arhus, Denmark 23/4/03-17/6/03.

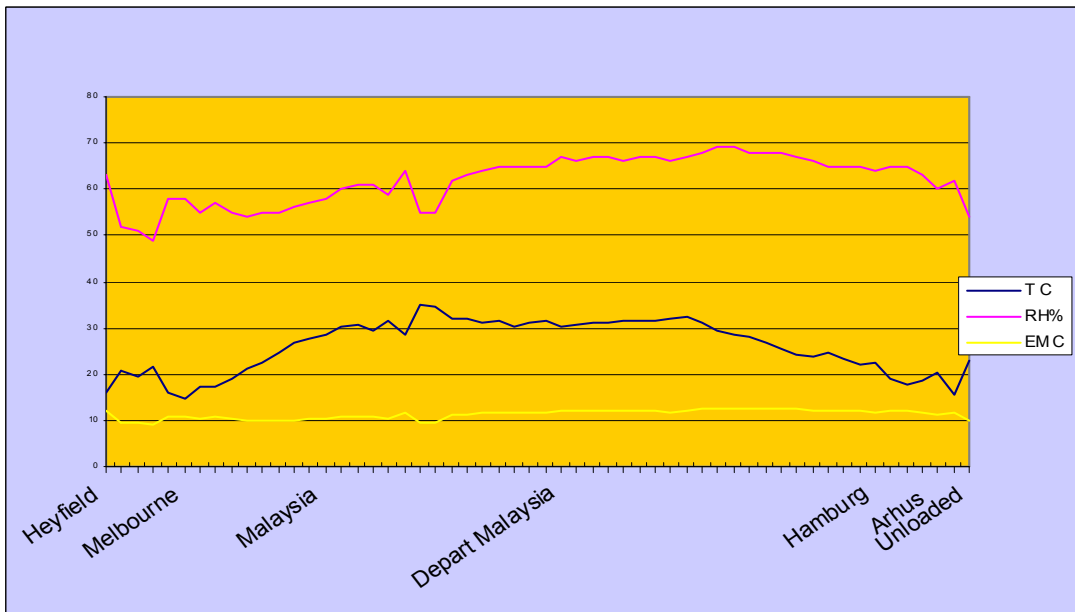


Figure 26. Environmental conditions (packaging) Heyfield to Arhus, Denmark 23/4/03-17/6/03.

Heyfield (Victoria) to Nagoya (Japan), 15/7/03-15/8/03

Cool, wet, winter conditions at the processing facility exposed this shipment to EMC conditions approximating 13% prior to departure from Port Melbourne. The ship sailed west-north-west, docking at Fremantle whereby conditions had dropped to an environment of 10% EMC. Rising temperature and relative humidity during the passage north to the tropical transshipping port of Singapore brought the EMC up to approximately 15% and from here conditions steadily increased until crossing the Tropic of Cancer, after which conditions became cooler and drier approaching Japan.

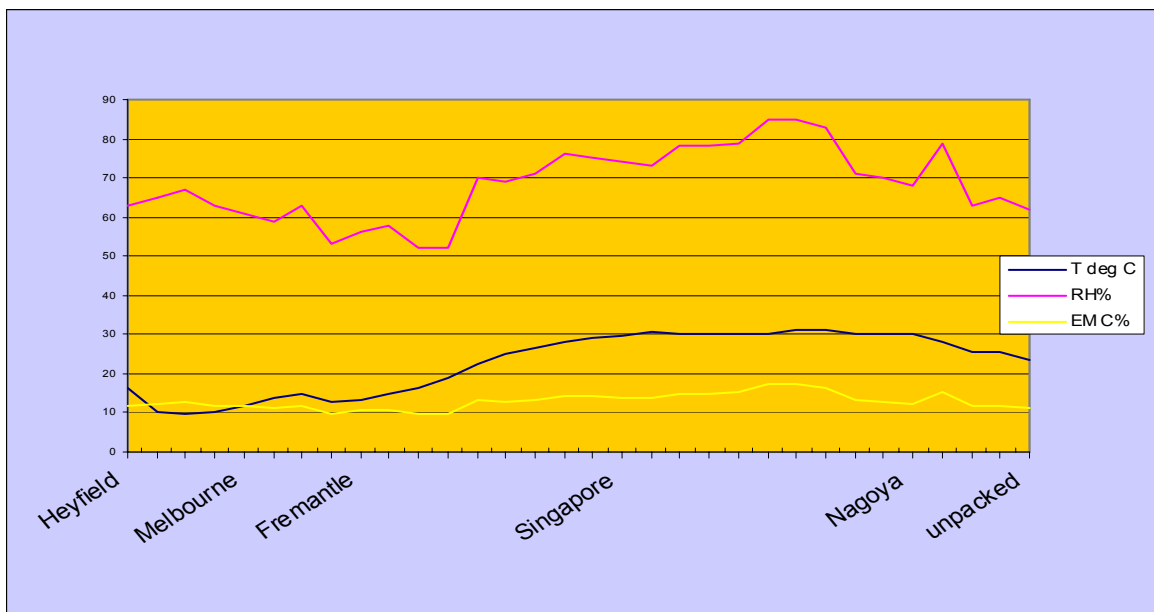


Figure 27. Environmental conditions Heyfield to Nagoya 15/7/03-15/8/03.

Perth to Tokyo, 10/10/03-12/11/03

Departing from Perth in October, this container of jarrah decking products experienced rising humidity and temperature conditions during transit to Singapore, equating to a high EMC environment of 15%. These conditions remained the same during passage through the South China Sea, and then ameliorated beyond the Tropic of Cancer and into Tokyo, by which time the EMC had settled to approximately 12%.

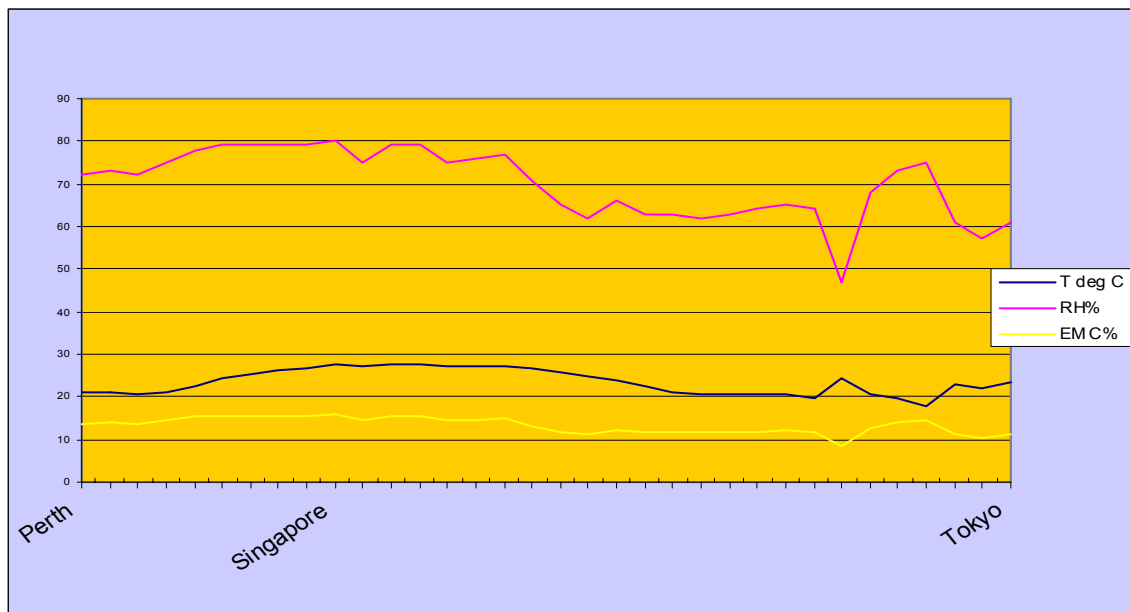


Figure 28. Environmental conditions Perth to Tokyo 10/10/03-12/11/03.

Perth to Hong Kong 20/9/03-10/10/03

During a direct shipment of jarrah furniture from Perth to Hong Kong, relative humidity and EMC conditions remained stable (standard deviation: 3.6% RH, 0.6% EMC). Temperatures were mild within the packaged products on departure from Perth, but rose to high 20°s and remained stable for the majority of the voyage to Hong Kong, only dropping to mid-20°s closing in to port. The stable RH% conditions experienced during this voyage provide an indication to the effectiveness of the carton and plastic shrink-film packaging used by this manufacturer.

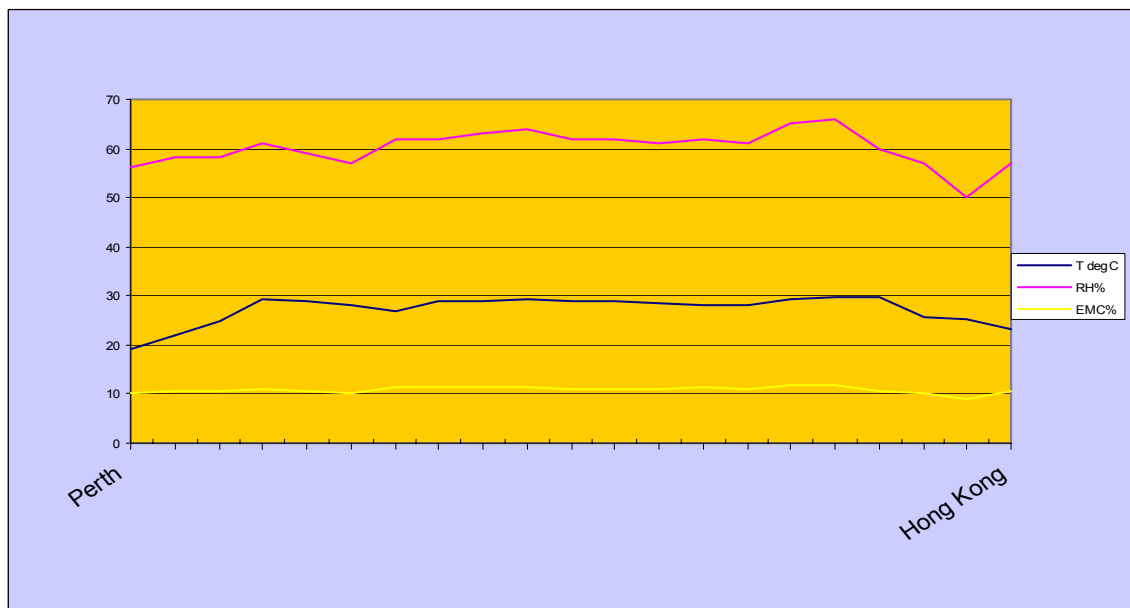


Figure 29. Environmental conditions Perth to Hong Kong 20/9/03-10/10/03.

Two loggers were installed in this shipment, one inside a carton of flat-packed outdoor jarrah furniture and the other in the general container space. Temperature conditions were virtually similar in both situations for the duration of the voyage, however the range of RH% and EMC% conditions was slightly larger in the general container space due to the insulative effects of the packaging used. This is illustrated in figure 31, showing the trend lines for the RH% data, where the trend line for RH% conditions within the carton packaging is flatter (less variation over time) than shown for the general container space. This chart also shows the increasing humidity conditions experienced during the ship's passage north towards the tropics from the port of departure.

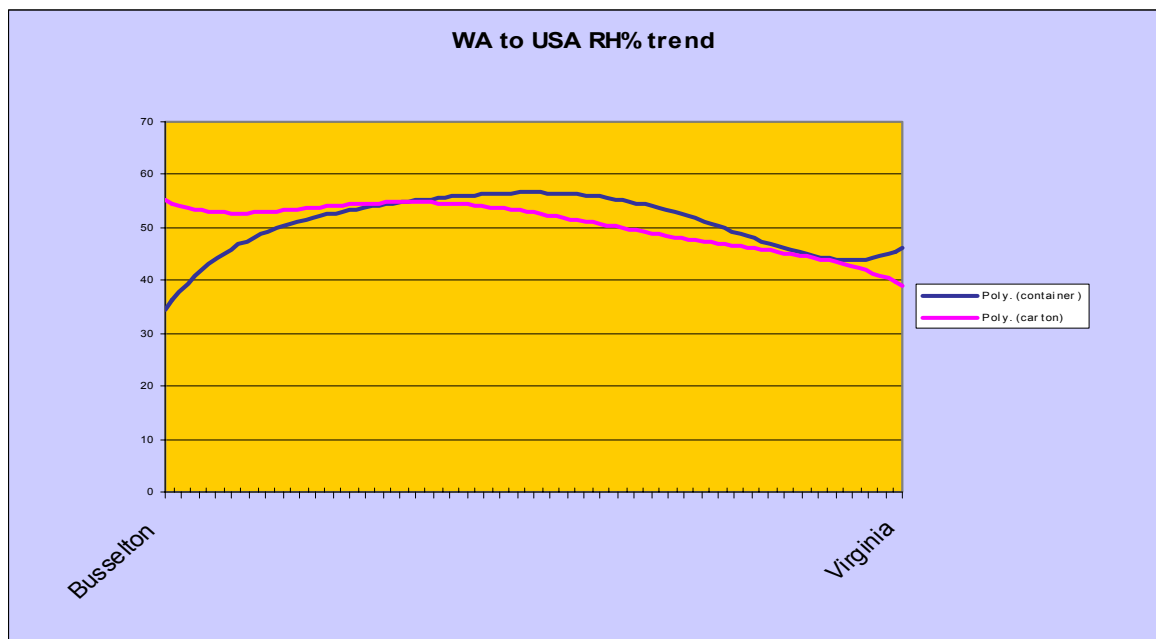


Figure 30. Relative humidity comparison: container v packaging: WA to USA.



Figure 31. Environmental conditions (container) Busselton to Virginia 23/12/03-5/2/04.

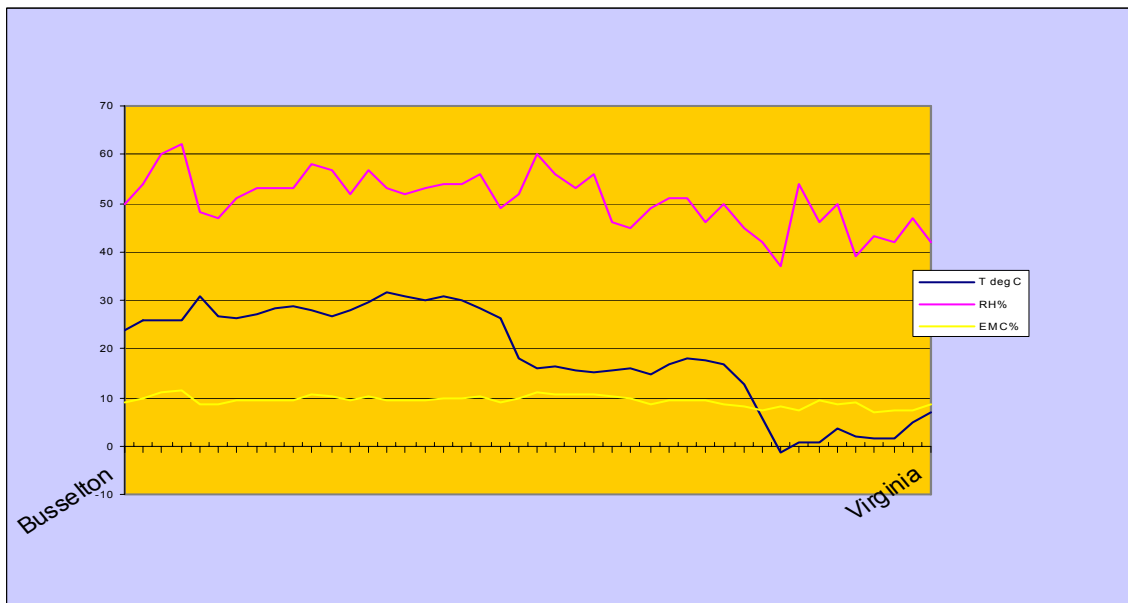


Figure 32. Environmental conditions (packaging) Busselton to Virginia 23/12/03-5/2/04.

Busselton to California via Singapore, 22/12/03-27/1/04

Unlike previously described trips where two datalogger installations in one container generally showed similar temperature recordings, the packaging and positioning of the datalogger in a carton appears to have provided thermal insulation during this voyage from Busselton to Ontario, California USA. In particular, during the period of sailing through the equatorial region, aligning with the docking at Singapore in figure 34, temperatures reached 40°C within the container compared to 28°C within the packaging.

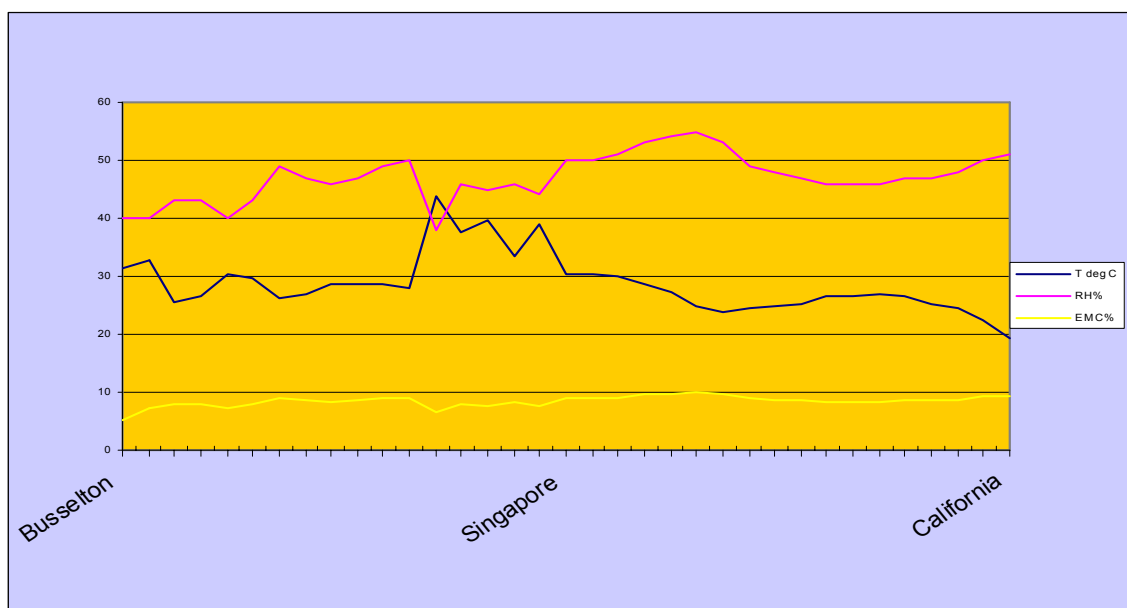


Figure 33. Container environmental conditions Busselton to California 22/12/03-27/1/04.

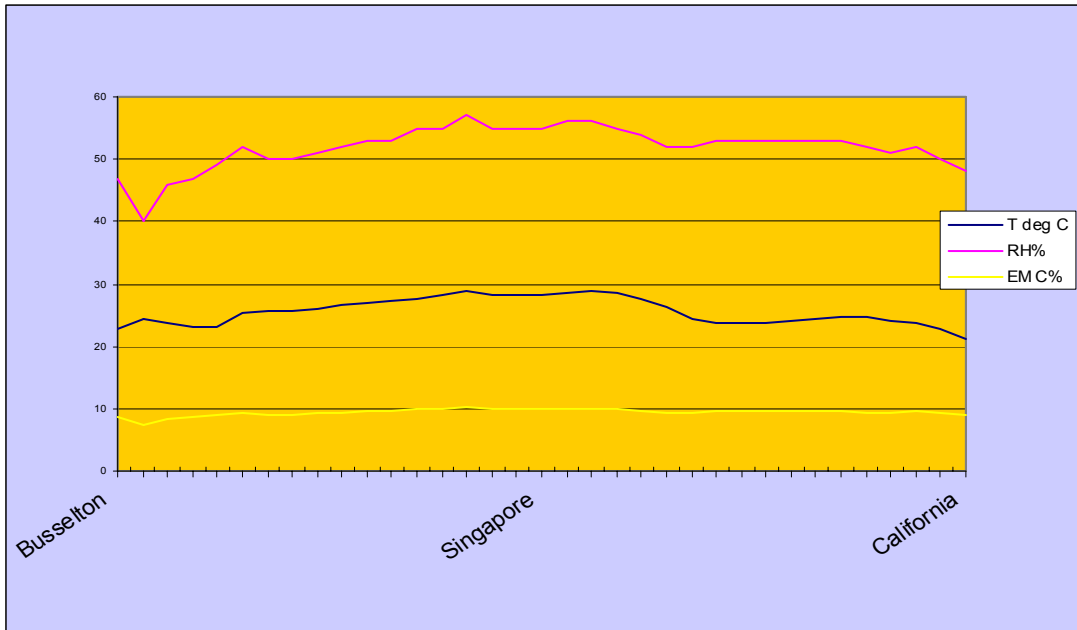


Figure 34. Package environmental conditions Busselton to California 22/12/03-27/1/04.

Perth to Oakland, California USA, 27/10/03-3/12/03

This container-load of jarrah flooring products was railed from Perth to Adelaide in late October 2003, from where it sailed east and then north to Oakland near San Francisco in California. Both temperature and relative humidity values rose as the ship progressed towards and through the tropics. Correspondingly, the estimated EMC rose to approximately 15% until crossing the Tropic of Cancer and meeting with temperate winter conditions, during which the EMC dropped back to 13%, which is typical for indoor conditions in this part of California during December.

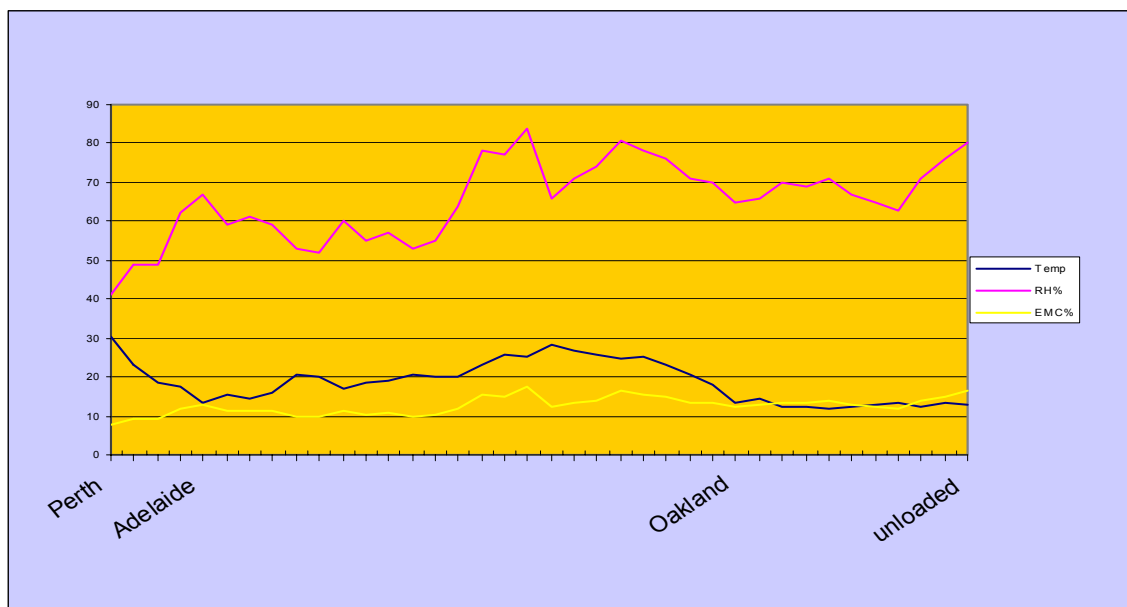


Figure 35. Environmental conditions Perth to Oakland 27/10/03-3/12/03.

Perth to Laguna Beach, California USA, 12/9/03-10/10/03

No information was available for the container movements after departing Perth, however the variable conditions experienced for the first ten days sailing from Perth probably indicates that the ship travelled north through the Indian Ocean on to an equatorial transshipping port. Conditions stabilised after 24 September with less variation and EMC% tapered from 13% to 12% by arrival in California. The average EMC for the Los Angeles area of California is 12.1% for December (Simpson, 1998).

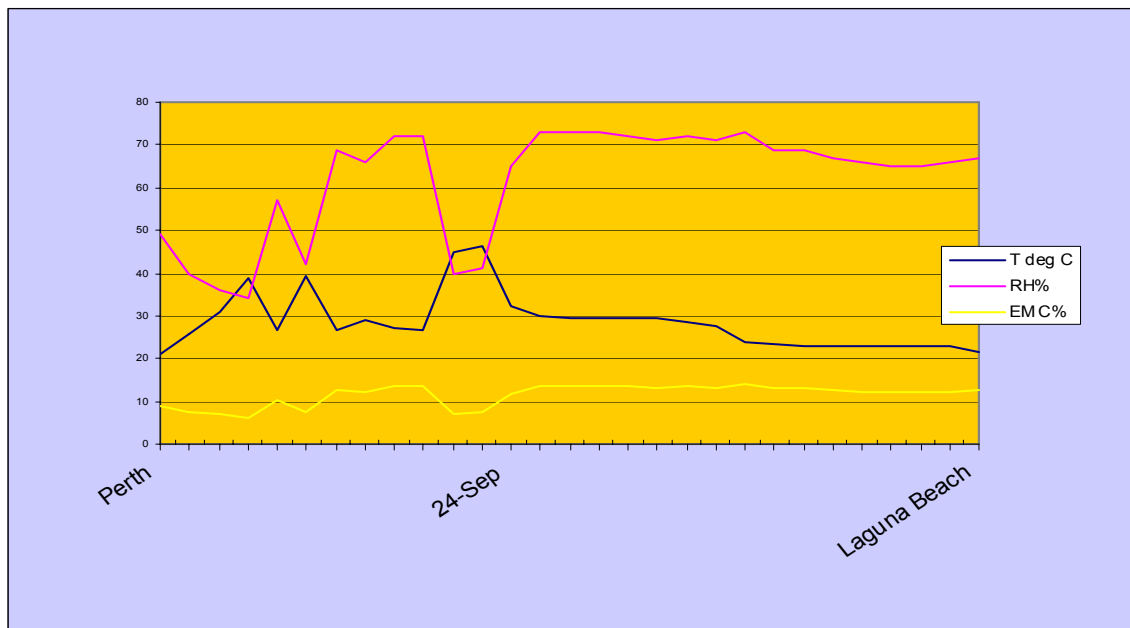


Figure 36. Environmental conditions Perth to Laguna Beach 12/9/03-10/10/03.

Perth to Hong Kong, 8/4/04-25/4/04

Conditions for this shipment of jarrah products from Perth were relatively stable, with a slight increase in EMC occurring during transit north from the equator into Hong Kong. Final conditions within the shipment were just above 10%. It would be expected that EMC conditions are as high as 15% during April in Hong Kong and consequently the timber components could swell as their moisture content equalised to local conditions after product distribution.



Figure 37. Environmental conditions Perth to Hong Kong 8/4/04-25/4/04.

4.2.2 In-service conditions

Equilibrium moisture contents for in-service applications for some export destinations were given in Chapter 2 Literature Review. The range of minimum and maximum monthly conditions and the annual average EMC for a wider cross-section of export markets were determined by drawing data from Simpson (1998) for outdoor (i.e. protected from precipitation and sunlight) locations around the world, and then applying Bragg's 5/6th rule (Bragg, 1986) to convert these data to indoor estimates. For air-conditioned and intermittently heated dwellings, the figures provided in Chapter 2 above should be referred to, however for normal interiors the EMCs provided in table 13 below could be used as a guide.

Table 13. Indoor equilibrium moisture contents for some Australian wood product export markets.

City, country	Minimum	Maximum	Annual average
Richmond, USA	9.6%	11.7%	10.9%
Philadelphia, USA	9.5%	11.1%	10.4%
Los Angeles, USA	10.3%	12.8%	11.7%
San Francisco, USA	11.4%	12.9%	12.0%
Beijing, China	5.9%	11.8%	8.1%
Shanghai, China	10.8%	13.6%	12.2%
Hong Kong, China	9.4%	13.2%	11.5%
Alexandra, Egypt	9.6%	11.1%	10.4%
Kobe, Japan	9.2%	12.2%	10.3%
Nagasaki, Japan	10.3%	13.2%	11.2%
Tokyo, Japan	8.1%	13.6%	10.7%
Seoul, Korea	8.6%	12.8%	10.0%
Oslo, Norway	9.0%	15.3%	12.0%
Manila, Philippines	10.1%	14.0%	12.2%
Cape Town, South Africa	10.3%	13.3%	11.5%
Pretoria, South Africa	6.6%	9.0%	8.1%
Bangkok, Thailand	10.1%	12.5%	11.3%
London, England	11.1%	16.5%	13.2%
Singapore	12.8%	15.5%	14.1%

Chapter 5 Discussion, conclusions and recommendations

5.1 Discussion of results

5.1.1 Markets and products

Australia has a long history of exporting its unique timbers in a range of products, however the overall market share for high value-added products is relatively small. This country is very experienced in exporting bulk, green forest products, such as woodchips and sandalwood, however these require little expertise or knowledge of the critical variables for exporting that are necessary in the case of high-value products, such as timber moisture content, grade quality, packaging and in-service moisture content. Consideration of the data generated during this research project highlights the volatility and dynamics of the global trade in high-value wood products. Sovereign risk, fluctuating monetary exchange rates and erratic freight costs are generally out of the control of manufacturers wishing to participate in exporting, but these factors can and do impact significantly on Australia's ability to grow and maintain its share of global wood products' trade.

Labour hire rates in Australia are comparatively high and there is likely to be a trend of Australian manufacturers out-sourcing some processes of their manufacturing to overseas factories where cheaper labour or improved technology is available. This has already happened for some pre-finished engineered flooring products (Scandinavia and Asia) and furniture suites (Asia). Since China's accession to the World Trade Organisation, almost 45% of its furniture and flooring companies are foreign owned, compared with 40% private-domestic ownership and 15% domestic co-operatives. The rapid growth of China's manufacturing industry over the past five years has seen major American, Italian, German, Swedish, Japanese and Singaporean interests set-up wholly foreign owned or joint-venture operations in China and Taiwan. Ikea, the world's largest furniture company in terms of global sales, has established five procurement and distribution centres in China, highlighting the suitability of the country for export logistics.

China's growth in manufacturing has resulted in high demand for materials, and Australian processors of both native hardwoods (especially the ash-type eucalypts from south-east

temperate Australia) and softwood (plantation hoop pine from Queensland) are exporting to China in a value-added form as kiln-dried (KD), skip-dressed and graded boards, or fully dressed boards and panels. Some of the finished products are then re-imported back to Australia. With China's reputation attaining credibility for timely delivery and excellent quality control, it is expected that this trend will continue to other manufactured wood products, ensuring continued demand for Australian wood resources.

Japan is considered by some as a difficult market to access, but others have developed and maintained niche markets for flooring, decking and structural products. Japan has an entrenched cultural preference for natural wood products, rather than composites and manufactured products, which contain adhesives and other chemical additives. Established markets for solid wood flooring and exposed feature structural products could lead the way for other products such as furniture to gain market share in Japan, exploiting that nation's affinity for natural products.

Appearance structural products, such as exposed beams, have the potential to be developed further for export markets, considering the unique properties of many Australian species, e.g. the high natural durability (not requiring preservative treatment) and attractive natural colouring of some of the eucalypts and white cypress.

North America, particularly the United States, has long been an important market for Australian exporters. Niche markets for flooring, based primarily on the natural attributes of colour and hardness, have enjoyed consistent, regular sales. Australian species are already known and established through the success of flooring products, but other Australian-made items, e.g. solid wood furniture, would not be able to compete on price in the low to mid-price range. If furniture manufacturers can resolve the economic (i.e. labour costs = high unit cost; fully assembled items = too expensive to ship) and design (timber movement = poor performance; density = weight issues) impediments, it may be possible to penetrate the high-end North American furniture market. The size of this high-end market can be indicated by support services such as 'deluxing', whereby furniture is delivered and installed by specialist, professionals who ensure the products are in perfect condition. This service includes assembly and final polishing. Some Australian furniture manufacturers admitted a lack of confidence in attempting to market their products overseas due to fears of unsatisfactory performance and the potential for movement in

changing or different climates. Part of the CRC Wood Innovations R&D effort involves closer examination of this problem, from the perspective of product design.

Australian timber species are less well known in Europe and market campaigning is required to achieve wider acceptance here. The exception is perhaps outdoor furniture, whose manufacturers have participated in international furniture fairs such as Cologne in Germany, and have exploited Australia's experience and reputation as an 'outdoors lifestyle culture' to gain sales in over 20 countries in the northern hemisphere. Wooden joinery, for example exterior windows, framing and doors, is still fashionable and popular in Europe, unlike the USA where composites and plastics have aggressively displaced wooden joinery, and even in the domestic market, which has seen aluminium joinery gain the majority of the external windows market Australia-wide. The potential for Australian timber joinery products in European markets would appear to be optimistic.

Australian timbers for flooring, including parquetry and decking products, already achieving continued market share in America and Japan, could potentially attain increased sales in Europe with appropriate marketing strategies. Our hardwoods offer better resistance to indentation than traditional European hardwoods, and also provide a wider choice of colours.

Australian instrument timbers have been proven in Australian markets and are undergoing market testing in Europe and America. Due to investment in state-of-the-art technology, attention to timber moisture content and product design and engineering, this sector of the high value-added wood products industry has the potential to achieve wider recognition. One foreseeable impediment to growth of Australian musical instrument exports is continuity of supply of native luthiery timber species. The majority of forest areas supporting Bunya pine and Queensland maple are reserved as National Park or World Heritage Listed tenure. Bunya pine is planted in small areas, principally frost-prone sites in hoop pine plantations, but there has been little attempt by guitar companies or forestry bodies to establish plantations specifically managed for production of guitar components. Queensland maple has also been trialed as a plantation species, but has its detractors as a candidate for plantation forestry due to its potential to develop into an invasive weed outside areas of its natural distribution.

The white cypress industries of Queensland and New South Wales have successfully entered flooring and structural markets in the northern hemisphere, particularly in Japan and USA. These sales are particularly useful in maintaining regular throughput in the sawmills, countering fluctuations in demand experienced during domestic building cycles. It is critical that ongoing resource security is guaranteed to these processors, who are the lifeblood of many rural communities, as continuous and regular supply is critical to ongoing sales in export markets.

The company manufacturing and exporting outdoor furniture from imported kwila are considering changing species to locally-grown spotted gum, in anticipation of demand for non-rainforest species by some customers. Although spotted gum is produced in sustainably managed, state-owned forests, sawmillers have been generally uninterested in supplying furniture stock, preferring to accommodate the flooring market. In the case of the existing spotted gum outdoor furniture manufacturer, stock is supplied through their sister-company.

The creation of niche wood products for the wine-making industry is a prime example of Australia's ingenuity and inventiveness. There has traditionally been an undercurrent of entrepreneurship and innovation in Australian culture (*viz*, the Hill's Hoist, the Victa lawnmower and the Triton work bench, to cite popular examples) and this atmosphere is currently being fostered through national and state government development and innovation departments and independent organisations such as the Triton Foundation (see www.triton.com). Despite recognised impediments to expansion in commodity markets, it would seem that Australia is experiencing an environment conducive to innovation, with possibilities of extending to our forest products industry.

5.1.2 Packaging

Beyond taking advantage of our unique timber species, this culture of innovation could extend to packaging. The current rationale for packaging requirements considers some or all of: the effects of vibration and handling damage during transport; purchaser's specifications (e.g. some Japanese specify minimal plastic due to high disposal costs) and, environmental conditions, particularly relative humidity. Usually packaging systems are developed in-house by trial and error. This is in contrast to European and American

manufacturers, who generally employ or contract a professional packaging engineer to determine the appropriate system for a given product for a specific destination and transport mode.

Most Australian high value wood product exports are destined for the northern hemisphere, necessarily enduring passage through tropical waters, and often involving a transshipping stop in a tropical port. Conditions during this period of transportation can exceed 15% EMC and where products and components have been manufactured or assembled in conditions closer to 10% EMC, there is the potential for the wood to swell causing degrade by delamination, deformation or development of checks (separation of fibres appearing as fine lines on the surface).

For cargo continuing on beyond the tropics, e.g. to the USA, Europe, the Middle East or Japan, climatic conditions towards the end of the freighting journey and also in-service conditions, will generally result in a reduced EMC%, causing the components to shrink, with the possibility of further degrade. Effective packaging systems are critical to ensure this doesn't occur, or at least minimise exposure to changing or extreme conditions. The packaging systems used during the experiments in this project were generally effective in holding RH%, but less effective in their capacity for thermal insulation. In most cases this is satisfactory, as RH% is the most important variable affecting EMC%. However, given that shipments can be subject to prolonged delays at the departure terminal, transshipping ports and also the destination port terminal, there are possibilities for high value wood cargos to be exposed to extreme conditions to the detriment of the products.

Disposable packaging is likely to lose favour in some markets, in line with environmental consciousness trends worldwide, and there is scope for development of effective alternatives.

5.1.3 Section sizes

Some products are required to be in wide, relatively thin sectional dimensions, often for appearance or fashion reasons, e.g. wide flooring. This can be a problem where different conditions are encountered during transport or in-service. Wide boards, especially from backsawn stock, are more prone to movement resulting in cupping or shrinkage, when

exposed to changing environmental conditions, than narrower boards. The use of quartersawn material can minimise detrimental effects and this is accepted practice in instrument making (e.g. strictly quartersawn 220 x 3 mm boards for guitar tops) and in some furniture manufacture. Ignorance of the potential for movement in wide backsawn boards could be problematic in some sectors of the industry. In particular, boards with dimensions in excess of 100 mm in width and less than 25 mm in thickness should be used with caution.

5.1.4 Stability

Published unit shrinkage data for timber movement is not widely available to the industry, and in its existing format, is not considered user-friendly. Much of the data determined for Australian commercial timber species was obtained from different material to the current resource, on the basis of age and tree size. For many species, including plantation species, trees are harvested at a younger age than occurred during previous generations and as a rule of thumb, younger trees produce timber with different properties to older wood. There is a need to update stability data to more accurately reflect the current resource, including plantation species and modified wood, and also to present the data in a more useful format.

5.1.5 Environmental conditions

From the results presented above it can be seen that Australian wood product exports will experience periods of different environmental conditions, during their life from manufacture through transport to their destination and finally, in-service. Climatic variations between summer and winter seasons can result in a wide range of EMC conditions at Australian manufacturing sites. This is less significant in the sub-tropics, but relatively variations of 10% from winter to summer are experienced in the temperate climatic zone including Tasmania and Victoria. Prolonged periods at port terminals can expose containerised-products to a wide range of conditions, and containers stored in the sun at port facilities can heat up like a solar kiln, achieving temperatures up to 50°C. Packaging of cardboard carton and plastic film provides some insulation against fluctuating humidities, but little research has been done to determine the most effective systems. Packaging was less effective in minimising temperature fluctuations.

5.2 Limitations of the study

As with all research projects, some limitations became apparent during the period of study. The export market information, although considered relatively comprehensive in the early stages of the project, could possibly be outdated at the conclusion of this phase of study. Examples have been cited whereby loss of resource, fluctuating exchange rates, and erratic shipping costs, colluded against exporters and diminished their capacity to maintain exports.

It was hoped initially to include unit shrinkage data representing the current resource of timber species, however delays in other experimental projects have precluded the possibility of incorporating that data into the results compiled here.

The shipping route records were not as detailed as desired, and it was rarely possible to determine from the freight forwarder or shipping agent, where the container was located on the ship. Also, container-tracking records only show date and times for port calls, with no data for co-ordinates and date/time between stops. In some cases, no routing data was provided at all.

A weakness with the dataloggers became apparent during the shipping program, *viz* the RH% sensor becoming loose if subject to a severe shock. This sensor is fitted by two fine metal probes within the housing, however no solder is used in the connection. Subsequently, relative humidity data was corrupted for five shipments due to this sensor becoming loose at some stage during handling of the dataloggers. Temperature data was intact upon completion of the voyage, however temperature as a variable on its own is of limited value for the purposes of this project and therefore the data from these shipments was excluded from reporting. Feedback on the performance of the dataloggers will be provided to the manufacturer.

5.3 Conclusion and recommendations for further research

The ultimate destination of wood products after their dispersment from distribution centres is usually impossible to ascertain and many products, especially items such as furniture, can move through several different climatic zones during their service life. For

high value wood products to perform satisfactorily, designers and manufacturers will need to consider the potential for movement as highlighted by the range of conditions determined during this project.

The average annual EMC conditions for manufacturing and processing centres around Australia is generally higher than the specified moisture contents for major export markets. During the transportation phase, moving the products from the factory to the market, conditions can reach 20% EMC. In conjunction with design and engineering considerations to accommodate anticipated timber movement with changing conditions, better systems for maintaining timber moisture content are required. Appropriate packaging systems can assist in minimising EMC% fluctuations, even through the tropics. However, increasing environmental awareness may lead to demand for less packaging, especially with regard to non-recyclable plastic products. Further research into recyclable packaging materials would benefit the industry.

Investigations into additional methods for controlling exposure to changing climatic conditions, especially increased humidity during shipping through the tropics, could include the following:

- design of specialised wood-products containers, with better insulation than currently offered by general purpose containers. Options might include moisture-absorbing paint systems; ceiling insulation, e.g. fibreglass, wool, recycled newspaper treated with mouldicide and fire retardant, and other proprietary insulation systems used in the construction industry;
- assessment of the effectiveness of desiccants that could be used in the container space to absorb excess moisture during periods of high humidity;

The dynamics of global trade in high value wood products includes variables outside the control of manufacturers and government bodies who would pursue export strategies. Changing monetary values, unforeseen freight charge increases and loss of resource (therefore raw material supplies) are some examples that affected companies participating in this research project. On the other hand, knowledge of timber's potential movement given the range of conditions that products will experience from manufacture through

transport and in-service, will contribute to successful, long-term export arrangements for high value products in niche markets.

References

- AFFA (2003). Australian forest products industry. Australian Government, Invest Australia, Department of Agriculture, Fisheries and Forestry Australia.
- Austrade (2003). Australia's trade- fast facts brochure. Australian Trade Commission, Department of Foreign Affairs and Trade. 8 pp.
- Baker, R. T. (1919). The hardwoods of Australia and their economics. Technical Education Series No. 23. Technological Museum, New South Wales.
- BIS Shrapnel Forestry Group (1998). Ocean freight and distribution logistics for forest products in the Pacific Rim in 1998.
- Boas, I. H. (1947). The commercial timbers of Australia- their properties and uses. CSIRO. 340 pp.
- Bootle, K. R. (1985). Wood in Australia- types, properties and uses. McGraw-Hill. 443 pp.
- Bragg, C. (1986). An equilibrium moisture content survey of Queensland. DPI Technical Paper No. 44. 26 pp.
- Brennan, G. K. And Pitcher, J. A. (1995). Equilibrium moisture content variations of timbers commonly used in Western Australia. CALMScience 2 (1). pp 25-49.
- Budgen, B. (1981). Shrinkage and density of some Australian and south-east Asian timbers. CSIRO Division of Building Research Technical Paper (Second Series) 38.
- COFORD (2001). Woodspec- a guide to designing, detailing and specifying timber in Ireland. CD-ROM COFORD National Council For Forest R&D.
- Corkhill, T. (1979). The complete dictionary of wood. Dorset Books, NY. 656 pp.

Cox, M. A. and Quayle, M. J. (2001). *Developing export markets for Australian products*. In Harrison, S.R. and Herbohn, J. L. (Eds), *Tropical small-scale forestry: social and economic analysis and policy*, pp105-118. Edward Elgar, Cheltenham.

CRC IWM (2001). CRC for Innovative Wood Manufacturing- Approved submission and related papers.

Desiccant City (2003). Selecting the right desiccant. Accessed 16-6-03. http://www.desiccantcity.com/selecting_desiccant.htm

Desicare Inc (2003). Cargo Drypak News. Accessed 16-6-03. <http://www.desicare.com/cdpnews.htm>

Dietz, A. G. H., Schaffer, E. L. and Gromala, D. S. (1980). *Wood as a structural material*. Pennsylvania State University. 282 pp.

DPI&F Forestry Research file ref: 836-12-103 Wood utilisation- *Toona australis*. Departmental file archives, Indooroopilly Brisbane.

Ellwood, E. L. and Leslie, R. T. (1949). Determination of the moisture content of seasoned wood from meteorological data. CSIRO Exp Report S17/6.

Finighan, R. (1966). Moisture content predictions for eight seasoned timbers under sheltered outdoor conditions in Australia and New Guinea. CSIRO Technological Paper No. 44. 71 pp.

Forest Products Laboratory (1989). *The Encyclopedia of Wood* (Revised edition). USDA. Sterling Publishing Co.

Hailwood, A. L. and Horrobin, S. (1946). Absorption of water by polymers: analysis in terms of a simple model. *Transactions of Faraday Society* Vol 42B: 84-92, 94-102.

Haslett, A. N. and Kininmonth, J. A. (1983). Correct moisture content essential for successful furniture export. *NZ Furniture*, September 1983. pp10-11.

Haslett, A. N. and Stadie, W. (1992). Watch that moisture content. NZ Forest Industries special feature. July 1992, pp 30-31.

Haygreen, J. G. and Bowyer, J. L. (1982). Forest Products and Wood Science- an introduction. The Iowa State University press. 495 pp.

Hopewell, G. P. (2003). South-east Australian Timber Exporters. CRC Wood Innovations report.

Hopewell, G. P. and Kennedy, J. F. (1996). Timber Note No. 39- Air-drying for wood enthusiasts. DPI Queensland.

Hopewell, G. P. and Stephens, L. (1998). Some properties for a selection of inland timbers. DPI Forestry Report.

Invest Australia (2003). Australian Forest Products Industry. Invest Australia- agribusiness report, Canberra.

Kelsey, K. E. and Kingston, R. S. T. (1957). The effect of specimen shape on the shrinkage of wood. Forest Products Journal 7 (7).

Kingston, R. S. T. and A. E. von Stiegler (1966) Shrinkage and density of Australian and other woods. CSIRO Forest Products Newsletter 322-6.

Kingston, R. S. T. and Risdon, C. J. E. (1961). Shrinkage and density of Australian and other South-west Pacific woods. CSIRO Technological Paper No. 13.

Kininmonth, J. A. and Whitehouse, L. J. (1991). Ed. Properties and uses of NZ radiata pine. Volume 1- Wood Properties. Forest Research Institute. Rotorua.

Koch, P. (1972). Utilisation of the southern pines Volume 1 the raw material. USDA. 734 pp.

Leicester, R. H., Foliente, G. C., Wang, C-H., Nguyen, M. N., Seath, C., and

Mackenzie, C. (2002). Timber Durability Compendium. CSIRO BCE Doc 02/062.

Manley, B. (2002). Fitness for purpose, wood quality and the forestry value chain, NZ Journal of Forestry, November 2002. p2.

Marshall, P. (1965). Cited in Bragg, C. (1986).

McNaught, A. (2001). Timber Note 23- Equilibrium Moisture Content of Timber. Dept. of Primary Industries Queensland. Reprint of 1988 Timber Note 23.

Mullins, E. J. and McKnight, T. S. (1981). Canadian Woods- their properties and uses. 3rd Edition University of Toronto Press. 367 pp.

Orman, H. R. (1955). The response of New Zealand timbers to fluctuations in atmospheric moisture conditions. Forest Research Institute, New Zealand Forest Service Technical paper No. 8.

Orman, H. R. (1966). New Zealand timbers and atmospheric moisture. TDA Bulletin 5 and 6. NZ Forest Service Reprint No. 379.

Ozarska, B. (1994). Performance of furniture in changing environmental conditions. The Australasian Furnishing Trade Journal November 1994. pp 42-47

Ozarska, B., Thompson, R and Hopewell, G. (1998). The use of Queensland hardwoods for fine furniture. *metaform*AUSTRALIS User manuals. CSIRO and DPI Forestry client report.

PCARRD (1985). The Philippines recommends (*sic*) for coconut timber utilisation. Philippine Council for Agriculture and Resources Research and Development. Technical Bulletin Series No. 60.

P&O Nedloyd (2003). Condensation issues for containers. <http://www.ponl.com/topic> accessed 10-6-2003.

Peck, E. C. (1947). Moisture content of wood in use. USDA Forest Products Laboratory Report 16155.

Rijsdijk, J. and Laming, P. (1994), Physical and related properties of 145 timbers-information for practice. TNO Building and Construction Research- Centre for Timber Research. Kluwer Academic Publishers, Netherlands.

Simpson, I. (2001). EMC of radiata Pine for export. Wood Drying Issue No. 30. Forest Research New Zealand.

Simpson, W. T. (1971). EMC prediction for wood. Forest Products Journal 21 (5). pp 48-49.

Simpson, W. T. (1973) Predicting equilibrium moisture content of wood by mathematical models. Wood and Fiber 5 (1): 41-49.

Simpson, W. T. (1982). The importance of relative humidity and temperature control in conditioning wood products. Wood and Fiber 14 (2).

Simpson, W. T. (1998). Equilibrium moisture content of wood in outdoor locations in the United States and Worldwide. USDA Forest Service Forest Products Laboratory Research Note 0268. 11 pp.

Simpson, W. T. (1999). 'Drying and control of moisture content and dimensional changes' in the Wood Handbook, US Dept of Agriculture, Forest Products Laboratory, Chapter 12.

Simpson, W. T. and Ward, J. C. (1991). Dry kiln operator's manual. Agricultural Handbook 188.

Smith, H. H. (1947). Relative humidity and equilibrium moisture content graphs and tables for use in kiln-drying lumber. US Forest Products Laboratory Report R-1651.

Smorfitt, D., Herbohn, J. and Harrison, S. (2002). Cabinet-maker's awareness and usage of rainforest cabinet timbers in Queensland. *Small-scale forest economics, management and policy*, 1 (1): 103-117, 2002.

Stamm, A. J. (1957). Adsorption in swelling vs non-swelling systems. *TAPPI* Vol 40 (9).

Stamm, A. J. (1964). cited in Haygreen and Bowyer (1982).

Stamm, A. J. and Woodruff, S. A. (1941). cited in Kollman and Côté (1968) Ed. *Ind. Eng. Chem. Anal.* Vol 13 (336).

Standards Australia (1999). AS 2796.3-1999 Timber- Hardwood- Sawn and milled products Part 3: Timber for furniture components.

State Development. (2001). Trade and Queensland. Queensland Department of State Development.

Statham, P. (1988). The Australian sandalwood trade: small but significant. Working paper no. 100. Working papers in economic history. ANU Canberra.

Süd Chemie (2003). Performance Packaging brochure.

TRADAC (1995). Timber Seasoning. Timber Research and Development Advisory Council of Queensland. Training Manual.

USDA (1973). Forest Service Research Note FPL-0226. Moisture content of wood in use (revision of FPL Report 1655, Peck, E. C. 1947). 6 pp.

Van Wyk, J. H. (1963). The importance of the moisture content of wood. *Forestry in South Africa* 2, 1-6.

Waterson, G. C. (1997). Ed. Australian Timber Seasoning Manual. 3rd edition. AFRDI. 206 pp.

Welch, (1937). From Furniture Trades Review article cited in Department of Forestry File Ref 932-03 Equilibrium Moisture Content.

Wengert, E. M. (1976). Predicting average moisture content of wood in a changing environment. Wood and Fibre. Winter 7 (4).

Wettenhall, G and Henderson, R. (no date). Farmwood Australia- export markets for farm-grown wood. RIRDC short report 127. <http://www.rirdc.gov.au/pub/dhortreps/sr127.html> downloaded 2/03/04.

Wisseman, A. Rogers, J. and Duffield, B. (2003). Changing roles for a State agricultural department: driving forces and organizational responses in the 21st century. Australian Journal of Public Administration 62 (4) 59-69 December 2003.