Final Report
Project NT045

Managing timber's moisture content in the supply chain, construction and in service

2023

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Managing timber's moisture content in the supply chain, construction and in service

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by

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TR-S1 Final project summary report

Timber's MC in the supply chain

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December 2022

NT045 / NIF109 Managing timber's moisture content in the supply chain, construction and in service

Contents

Introduction

This is the final summary report for the National Institute for Forest Products Innovation's (NIPFI) project: *NT045 / NIF109 Managing timber's moisture content (MC) in the supply chain, construction and in service*.

This project's objective was to generate informed industry guidance on best practice for the economic and effective MC control of timber and wood products in the Australian timber supply chain. It aimed to identify regular problems and key influencing factors; build an initial knowledge base of equilibrium moisture content (EMC) conditions and timber's MC performance in the timber supply chain; and generate a refined suite of industry best practice guidance.

Timber and wood products in service contain water. The amount of water contained in wood at a particular time is known as its MC. Wood is hygroscopic and timber's MC will vary with its surrounding conditions. Once seasoned in production, timber and wood products lose or gain moisture to be in equilibrium with the surrounding atmosphere. As their MC changes, their dimensions' change.

Managing timber's MC is a critical part of its production, use in design and construction, and management in buildings in service. As wood is a hygroscopic material, it's MC variation and consequent movement are vital considerations in the design of timber-rich objects and the behaviour of timber-rich components in construction. While changes in dimension may be small in any one board or sheet, the cumulative effect can be critical to product performance in an application and to customer confidence.

A broad understanding of MC changes outside of the immediate production environment is relatively limited. An improved understanding of the EMC and ventilation rates of the environments in which timber and wood products are transported, stored, installed or serve can enable companies to take effective preventative action when the risk of damage or loss is high. Industry guidance and practice based on this knowledge can lead to improved storage practices for timber and wood products throughout the supply chain, help maintain sawn-timber and wood products in a condition that satisfies the project requirements, reduces avoidable loss of material or value and ultimately increases customer confidence in product reliability.

Acknowledgement

The CSAW team recognises and appreciates the assistance and support from all the industry participants who have assisted in data collection, goods distribution, access to production facilities, construction sites and supply chains throughout the project. This type of research was only possible with ongoing support and the collaborative nature exhibited.

Project overview

This project focused on understanding and providing guidance on managing the MC conditions that timber and wood products are exposed and react to in the timber supply chain, in the wood distribution network, at construction sites, and in-service in operational buildings. As timber and wood products are stored and used in numerous workplaces, sites, and buildings, the methodology concentrates on areas of known product loss or risk and aims to identify necessary and effective preventative action.

Project deliverables include the results of the project's:

- Review of MC problems and influencing factors.
- Static sample monitoring component.
- Monitoring of timber's MC content in the supply chain under varying wrapping conditions
- Supply chain, building site, building and species assessments and subsequent risk modelling for the economic and effective MC control of timber and wood products in the timber supply chain

Methodology

The methodology covers the broad wood product suite at the major stages of the supply chain in representative areas of Australia. The wood products studied include: Australian produced native forest hardwood; plantation pine and hardwood; LVL; and native forest hardboard. The supply chain stages studied include the distribution network; the construction phase; and in-service. The areas studied include National Construction Code (NCC) climate zones (CZ) 7 Tasmania; CZ 6 Melbourne; CZ5 Sydney, Adelaide and Perth; and CZ2 Brisbane.

The methodology's sub-programs include:

1. Review MC problems and influencing factors through user survey.
2. Determine timber's MC response in the supply chain.
3. Environmental and performance modelling.
4. Industry guidance development and distribution.

These are discussed in more detail below.

Exposure to MC change and degradation risk

In considering the methodology and sub-programs, a characterisation of the timber's likely exposure to MC change and the risk of potential degradation is useful.

Timber stored in the supply chain is exposed to a range of environmental conditions that vary with its geographical location, the product's general exposure at the location, and its immediate protection.

- Location determines the climate that drives an area's natural ambient conditions. Locations in this project can be efficiently grouped by the CZ defined in the NCC and listed in Table 1
- The general level of protection that buildings or similar enclosures afford determines the stored timber's exposure to ambient conditions at a location. Table 2 lists the exposure conditions considered in this project.
- The stored timber's immediate protection includes whether the product is grouped together in a pack (with or without wrap) or be an individual items (with or without coating) exposed to the surrounding environment. Table 3 lists the immediate protection levels considered in this project.

The impact of this exposure and the potential risk of degradation relates to the products involved. See Table 4. The risks that MC change poses for these products occurs when:

- The product's MC varies so that they don't comply with the allowable MC range and dimensional tolerances defined in the relevant standards. This is particularly relevant for commodity products.
- The item's design or handling generates unacceptable movement when it relocated from one exposure condition to another, or the conditions in a location change considerably. In these cases, the item may be regarded as not fit for purpose.

There is a relationship between the MC change experienced and the risk of the products degradation. However, there is insufficient information at this time to usefully define the boundary between one level of risk and another, given the variability of location, exposure, protection and products.

Table 1: NCC CZ and example location

CZ	Description	Example locations
1	High humidity summer, warm winter	Cairns, Broome
2	Warm humid summer, mild winter	Brisbane, Byron Bay,
3	Hot dry summer, warm winter	Alice Springs
4	Hot dry summer, cool winter	Albury, Tamworth
5	Warm temperate	Sydney (coastal), Adelaide, Perth
6	Mild temperate	Melbourne, Mt Gambier
7	Cool temperate	Hobart, Launceston
8	Alpine	Thredbo, Tasmanian highlands.

Table 2: Exposure conditions

Exposure condition	Description
Fully exposed	Exposed to natural ambient conditions outside at a building site, storage area or building in service.
Sheltered	Under a roof at a building site or storage area.
In store	In an enclosed, ventilated building that has limited insulation, such as a timber store or joinery workshop.
In construction	A building site during construction and after envelope lock-up.
In service: unconditioned	Generally, a building with an NCC-compliant envelope but without central heating, cooling, and ventilation systems. It may be heated in summer or have localised cooling in summer.
In service: conditioned	Generally, a conditioned office or accommodation space with active heating, cooling, and ventilation systems.

Table 3: Immediate protection

Item	Description
Uncoated in service	An uncoated board exposed to ambient conditions in service.
Coated in service	A coated board exposed to ambient conditions in service.
Unwrapped pile	Boards removed from a configured pack, and exposed to the ambient conditions in an unconfigured pile.
Unwrapped pack	Boards in a configured pack, with some exposure to the ambient conditions.
Temporary wrapping	Boards in a configured pack, with some wrapping.
Fully wrapped.	Board in a fully wrapped configured pack.

Table 4: Product groups

Item	Description
Structural	Structural framing, glulam, plywood, and similar commodity products.
Appearance	Strip flooring, appearance grade feedstock, and similar commodity products.
Cladding	Naturally durable, treated or similar commodity cladding products.
Structural components	Assembled structural components, such as large glulam components, CLT assemblies, and architectural structures.
Joinery and furniture	Assembled architectural components, such as joinery panels, benchtops, tables, and similar items.

Results

Review MC problems and influencing factors

The stage's involved:

- Identifying literature on MC-related problems in the supply chain.
- Conducting structured industry inspections, surveys and interviews to identify key problem areas.

Literature on MC related problems

For this project, literature includes published research results, industry reports, and product and installation practice guides. A review of published research literature was conducted that covers the monitoring of the MC of wood products in transportation and construction. It is reported in detail in Technical report TR-1. A summary of wood's MC basics is included below.

Wood's MC basics

Timber and wood products in service contain water. The amount of water contained in wood at a particular time is known as its MC. Wood is hygroscopic and timber's MC will vary with its surrounding conditions. Once seasoned in production, timber and wood products lose or gain moisture to be in equilibrium with the surrounding atmosphere. As their MC changes, their dimensions' change. If they gain moisture, they expand. As they lose moisture, they shrink. Timber's EMC is the MC where timber neither gains nor loses moisture from the surrounding atmosphere. There are direct relationships between the wood's EMC, species (or product) properties, and the ambient temperature and relative humidity of a location. There are also relationships between species properties and rate of MC change in the piece (or in zones in the piece) with changes in the ambient conditions. Ambient conditions in an internal space may change hourly but these are too rapid to impact timber significantly. However, locational or longer-term seasonal changes in conditions impact material MC significantly.

Managing timber's MC is a critical part of its production, use in design and construction, and management in buildings in service. As wood is a hygroscopic material, it's MC variation and consequent movement are vital considerations in the design of timber-rich objects and the behaviour of timber-rich components in construction. While changes in dimension may be small in any one board or sheet, the cumulative effect can be critical to product performance in an application and to customer confidence. Timber's characteristic dimensional changes in response to changing MC, known as its dimensional stability, can be measured by a variety of laboratory methods, such as equilibrium humidity-cycling tests. In these tests, wood samples are allowed to equilibrate in a constant humidity environment, measured and then allowed to equilibrate to a different humidity condition, before they are measured again (Sargent 2019). While this produces useful results, it does not replicate the constantly fluctuating EMC conditions found in the supply chain.

Structured industry inspections, surveys and interviews

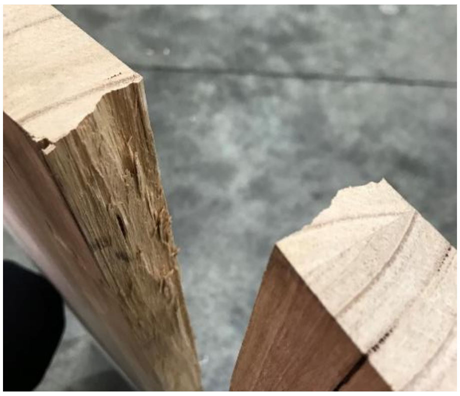
Industry's experience, observations and previous reaction to MC problems can be assessed through inspection of these problems and through more structured survey methods. In this project, this involves:

- Inspections at storage and production facilities and building site to investigate reported problems.
- An open online survey promoted to industry members.
- Detailed phone interview of survey participants.

Facility and site inspections

From 2019, inspections occurred of sawn appearance material interstate and of flooring, joinery and cladding issues in Tasmania and interstate. See Figure 1.

Board with MC-induced end splits



Panel with MC-induced fracture

Regular gapping in floor

Splitting in a desktop

Splitting across a tabletop at a gum vein

Board removed to relieve expansion pressure.

Figure 1: Inspected MC issues

This included inspection and reporting on:

- A series of issues identified with sawn appearance Tasmanian hardwood supplied to interstate fabricators. These occurred most regularly in Victoria in November or early December across several years. The recurrent feature of these issues was cracks or splits appearing in product that previously had been assessed as solid. In the most severe cases, boards or panels developed splits or broke into sections. This was expected to relate to periods of hot and dry weather commonly experienced in Melbourne as the seasons change from winter to spring.
- Unacceptable shrinkage in floor, furniture and other fittings in buildings. Shrinkage can occur when the floor has been sanded and finished, and the building occupied. With furniture and other items, it is when material assembled in a workshop is placed in drier, conditioned internal conditions, such as offices or hotels.
- Issues with cladding. These have occurred as the popularity of this selection increases while builder understanding of the potential MC issues is underdeveloped. This can result in no or inadequate expansion joints being provided into walls likely to be exposed to high MC conditions during winter. MC increases and the consequences for the installation can be considerable.

Structured industry surveys

While informative, occasional inspections do not provide the base required to inform more focused research results or industry guidance documents. To develop this base, two surveys were developed to collect industry experiences of MC issues: a concise online survey and more detailed phone interviews of survey participants. These surveys were developed after initial discussion with industry members and a formal review process.

Emails about the surveys were distributed to approximately 150 recipients in the CSAW network and an invitation to participate was included in industry publications. The survey asked timber and wood products manufacturers, business owner or retailers to provide their experience of the MC and moisture-related issues in their workplace. Sixty-one responses were received from six Australian states: VIC (39%), NSW (21%), TAS (16%), QLD (15%), WA (7%) and SA (2%). Key results were:

- 79% of respondents rate MC management as ‘Essential’ in normal quality control processes.
- Respondents could select up to three MC problems that occurred regularly. The MC problems most regularly reported were: Cupping (58%), Surface Checking (55%), Twisting, Bow or Spring (all approx. 48%), and Splitting and Unacceptable Movement (both approximately 35%).
- The occurrence of problems varies with state. NSW was prominent in cupping (85% of respondents) and bow and spring (69%), surface check is a significant issue in QLD (78%), while TAS has the highest reported incidence of splitting (60%)
- Respondents felt that MC issues most regularly occur with the customer; at the end of the supply chain (58%) and before the timber arrives at the start of the supply chain (45%). Regular problems were still reported in the business during storage and assembly (20% each).

- 70% of respondents say seasonal changes impact the frequency of MC related problems. Most MC related issues were reported to occur: January – February (51%); July – August (32%); and November – December (38%). 35% of respondents noted these issues generally occurred a ‘few times a year’.

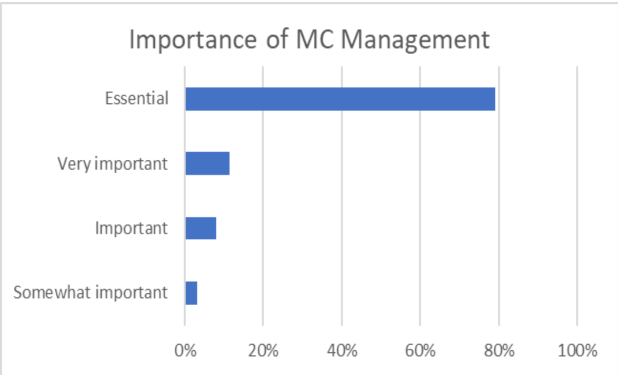


Figure 2: Importance of MC management

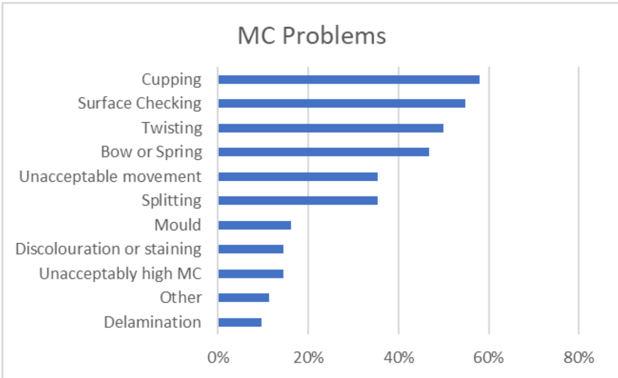


Figure 3: The MC problems that occur

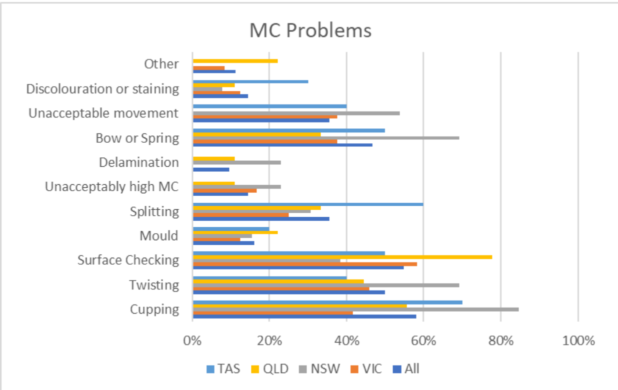


Figure 4: The MC problems that occur by state

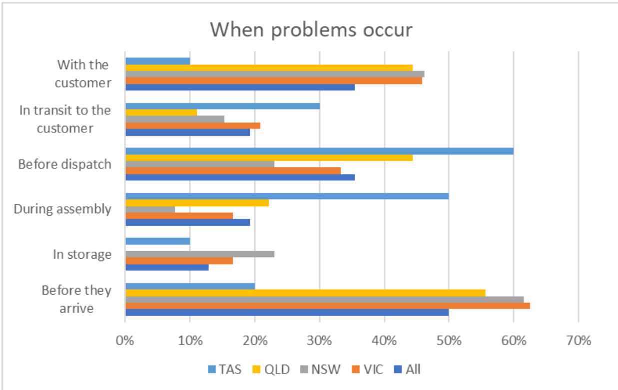


Figure 5: When the MC problems occur by state

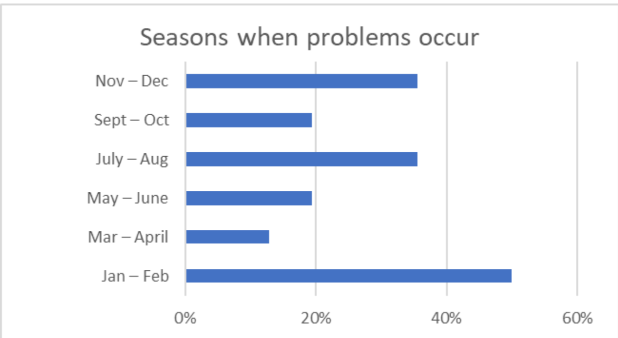


Figure 6: The seasons when problems most occur

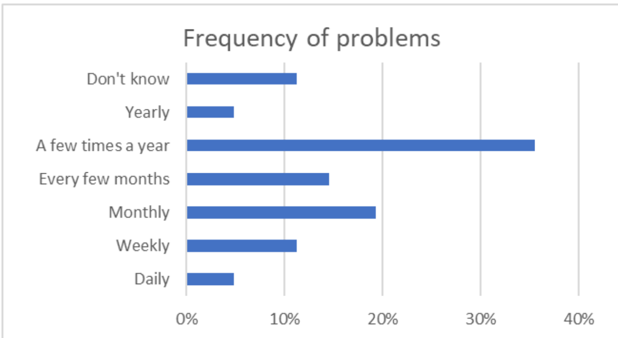


Figure 7: Frequency of MC problems

Detailed phone interview

Detailed phone interviews began in late 2019 but ceased in early 2020 due to industry lockdowns during the COVID-19 response. As the impacts of these lockdowns eased, interviews resumed, often informally and in connection with promotion of the open online survey. Key points from two of interviews are listed below. Appendix 1 includes fuller notes of these interviews.

The measurement of MC in hardwoods is more problematic than outlined in the Australian Standards.

There is also significant variation found in the MC along the length of a single board of these higher density species.

- Companies find the variation in EMC at the location of use is far greater than their ability to control the MC of the product. Once the product leaves the factory, there is no longer control.
- An experiment in southern NSW with a major pine producer in 2011 identified that reducing the thickness of wrap from 100 to 50 microns exacerbated the condensation effect in wrapped packs.
- Heat and moisture build up inside the packs from moist timber would condense on the thin, cold layer of wrap creating moisture impacts to the timber inside.
- A 70-micron white and black wrap was developed that reflected heat through the white outside layer and drew heat outwards through the inside black layer. The slightly thicker wrap had more insulative value which had better outcomes for the stored product.
- Anecdotally, most MC issues identified are with softwoods that still contain a high level of moisture.
- Damage to wrap in transport can occur through impacts in the environment, which can subsequently have MC impacts on the timber stored within. Forklifts and other equipment movement in storage can tear the wrap in the short-term. Over a long-term period, UV degradation can occur if packs are stored outside.

Determine timber's MC response in the supply chain

The stage's methodology involves:

- Collecting data sets covering the MC and dimensional change of representative timber and wood product samples at static location in the supply chain.
- Assessment of these sets to determining the characteristic behaviour of the species and products in the range of expected service conditions.

Static monitoring unit design and manufacture

To collect the required species and environmental information, static sensor and sample units were designed and fabricated. Each unit contained a set of generally nine timber or wood product samples of known species, size, weight, and MC, cut from standard seasoned commercial products. Table 5 list the samples in the set while Table 6 lists their densities and initial MC. A Minnow temperature and humidity sensor was used to monitor the environment conditions.

Table 5: Species

Species	Species	Species
Radiata pine *P. radiata*	Silver top ash *E. sieberi*	Blackbutt *E. pilularis*
Spotted gum *Corymbia maculata*	Tasmanian blue gum *E. globulus*	Weathertex high-density fibreboard
Messmate *E. obliqua*,	Plantation Shining gum *E. nitens*	LVL *P. radiata*

Brass pins were set into CNC routed holes in the front face of each sample. These were spaced 60 mm to the outside of the pins across the piece and 195 mm along the piece. The samples were grouped in sets, and each scribed with the species or product name and the set number. Once fitted with a cup hook, the sample's final weight was recorded.

Table 6: Sample densities and initial MC

	Weathertex	P. radiata	C. maculata	E. globulus	E. sieberi	E. obliqua	E. nitens	E. pilularis	LVL
Density (kg/m^3)									
Average	1024	464	1086	974	876	666	607	901	655
Maximum	1075	520	1164	1077	970	798	753	992	695
Minimum	662	407	849	867	778	593	455	798	610
Initial MC (%)									
Average	5.9	11.4	11.5	13.4	13.4	11.7	11.4	13.0	9.1
Maximum	6.6	13.3	14.5	14.7	14.7	12.5	12.4	14.2	9.7

Minimum	5.6	10.0	8.1	11.4	11.4	11.1	10.6	11.3	8.4

Unit distribution

At least 34 static monitoring unit were distributed to collaborator companies and other research groups in locations and operating businesses that broadly represent the range of conditions experienced in the timber supply chain. Useful data sets were recovered from 31 units. Table 7 shows the distribution by state. Table 8 shows the distribution by NCC climate zone, while Table 9 shows distribution by exposure conditions

Table 7: Unit distribution by state

State	Number of units.	State	Number of units.
NSW	5	TAS	10
QLD	6	VIC	5
SA	3	WA	2

Table 8:Unit distribution by NCC climate zones

CZ	Description	Example locations	No of units
2	Warm humid summer, mild winter	Brisbane, Byron Bay,	7
5	Warm temperate	Sydney (coastal), Adelaide, Perth	7
6	Mild temperate	Melbourne, Mt Gambier	6
7	Cool temperate	Hobart, Launceston	11

Table 9: Unit distribution by exposure conditions

Exposure condition	Description	No. units
Fully exposed	Exposed to natural ambient conditions outside at a building site, storage area or building in service.	1
Sheltered	Under a roof at a building site or storage area.	2
In store	In an enclosed, ventilated building that has limited insulation, such as a timber store or joinery workshop.	20
In construction	A building site during construction and after envelope lock-up	2
In service: unconditioned	Generally, a building with an NCC-compliant envelope but without central heating, cooling, and ventilation systems. It may be heated in summer or have localised cooling in summer.	4
In service: conditioned	Generally, a conditioned office or accommodation space with active heating, cooling, and ventilation systems.	2

Results and discussion

Technical report TR-2 includes the results of 28 monitored site bundled into 10 groups covering four climate zone and five exposure conditions. It also contains individual reports for 31 sites. The discussion below presented the results from assessment of:

- 28 monitored sites as a single group of results.
- A comparison of sites across climate zones and service conditions.

Single group results

Assessment of the readings of all sample in 28 monitored locations confirms basic understandings of timber interaction with MC while providing quantitative details of conditions that occur in the Australian timber and wood products supply chain. They show that:

- The MC of timber and wood products change to be in equilibrium with the surrounding environment. In the supply chain, this occurs across location and seasons.
- Species and products have individual EMCs. Engineered wood products (EWPs) generally have a lower EMC than solid timber species, with Weathertex lower than LVL and LVL lower than its constituent Radiata pine. Species EMC vary with the type of wood (hardwood and softwood) and other factors. See Figure 8.

- The average MC of species and wood products changes with climate zone and exposure conditions. See Figure 9. Timber in stores is driest in CZ6 (Melbourne) and wettest in CZ2 (Brisbane).
- Species expand and contract with changes in MC. Unit movement as measured across six CZ7 storage sites is low longitudinally but higher across the width of the samples. Average movement of all species measured at the six CZ7 sites across the width was 0.76% across a 100 mm board.

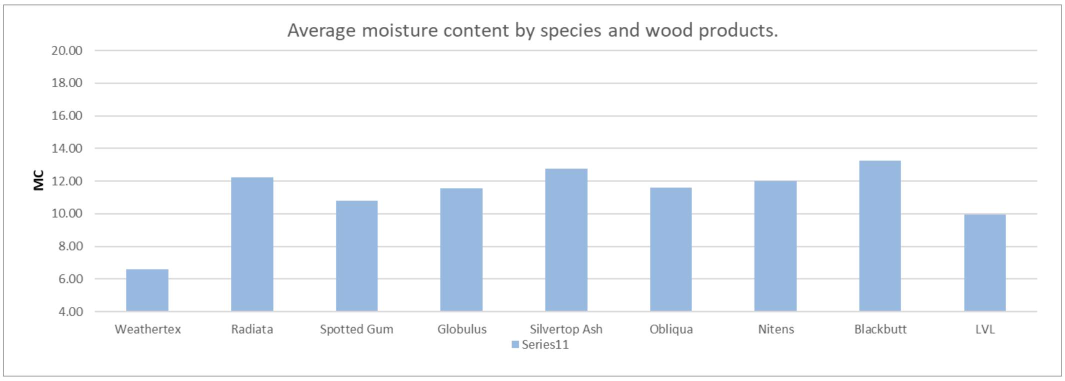


Figure 8: Average MC of all readings by species and product.

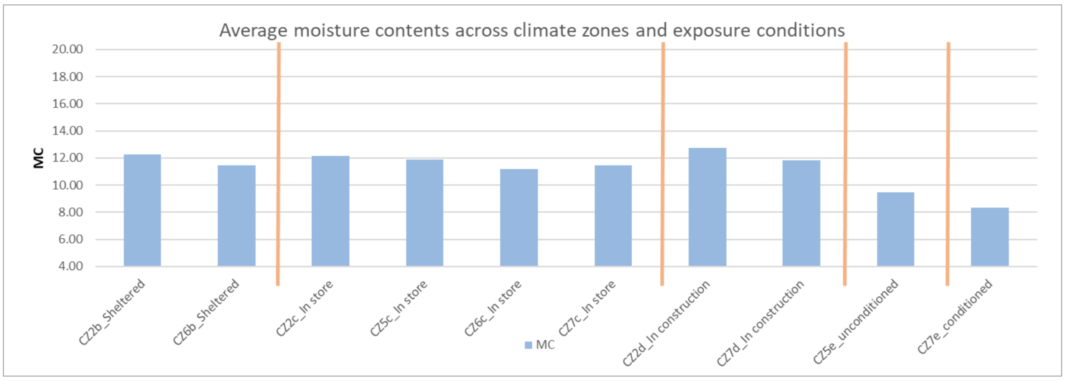


Figure 9: Average MC of all readings by climate zone and exposure condition.

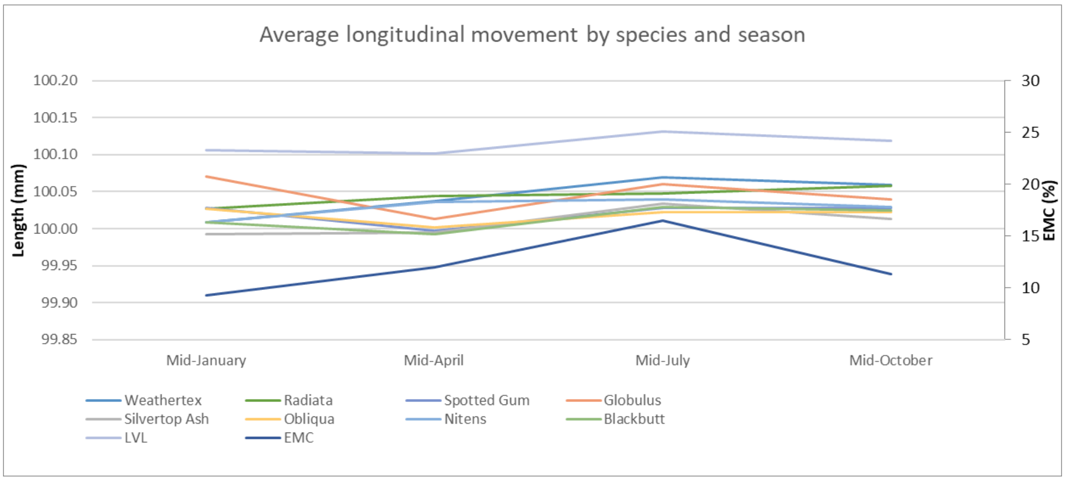


Figure 10: Average longitudinal movement in millimeters by species and season across six CZ7 sites. The seasonal EMC relates to the right axis.

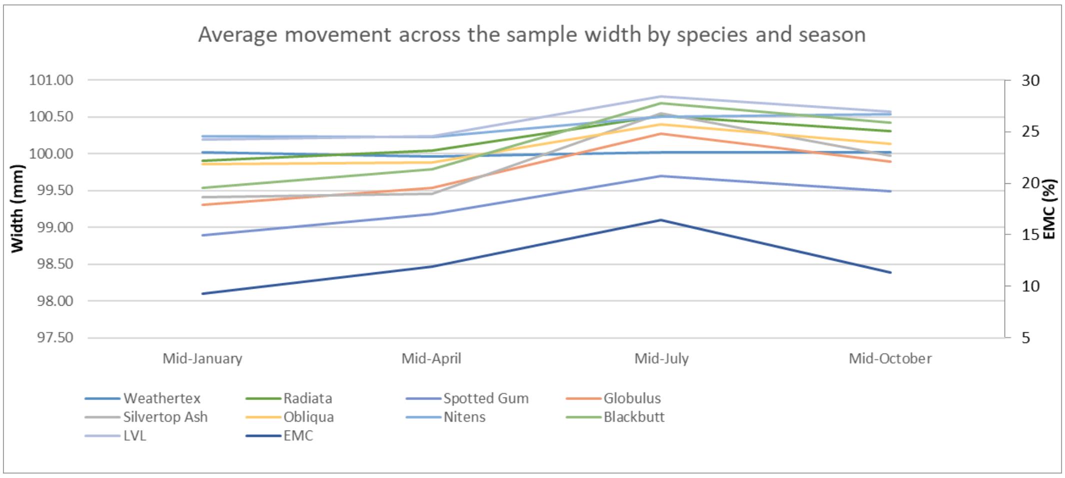


Figure 11: Average movement across sample width in millimeters by species and season across six CZ7 sites. The seasonal EMC relates to the right axis.

Comparisons across climate zone and service conditions

The risks of MC change and product damage can occur across seasons in a storage facility or workshop but occur more regularly when products are moved in the supply chain from the EMC conditions in one location to those in another. To represent the timber's response to seasonal conditions, four key periods were identified: Summer: mid-January; Autumn: mid-April; Winter: mid-July; and Spring: mid-October. For each site, the average ambient conditions were calculated for one week in each period (12th to 18th of each month), and partnered with the results of nearest sample measurement. These were then averaged as part of the group calculations. The following charts and tables compare the ambient conditions and measured species responses between sites for the *Summer: Mid-January* period of a comparison of store buildings. See Table 10 and Figure 12 for the ambient conditions while Table 11 and Figure 13 show the species and products MC response across seasons.

These comparisons can indicate the risk of moving material between stores in this period.

Summer: Mid-January

Table 10: Ambient conditions: January across regions

	Temperature (ºC)	Humidity (%)	EMC (%)
CZ7_In store_Tasmania	20.10	49.52	9.30
CZ6_In store_Melbourne	21.76	50.64	9.37
CZ5_In store_various	25.28	41.21	7.82
CZ2_In store_Brisbane	25.57	64.11	11.70

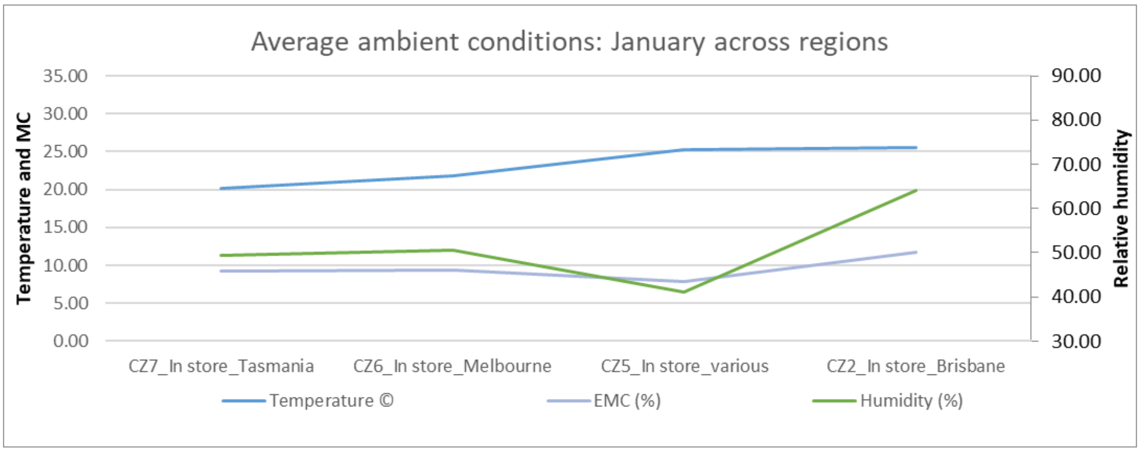


Figure 12: Average ambient conditions: January across regions

Table 11: MC responses of species and products: January across regions

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
CZ7_store	6.11	10.84	9.58	10.60	11.25	11.08	10.65	11.71	9.97
CZ6_store	5.48	10.43	10.00	10.51	11.67	10.53	10.79	10.94	9.09
CZ5_store	5.76	10.25	10.41	10.31	10.63	10.16	9.90	11.10	9.18
CZ2_store	7.14	12.88	10.80	11.44	13.28	12.02	12.39	13.64	11.27

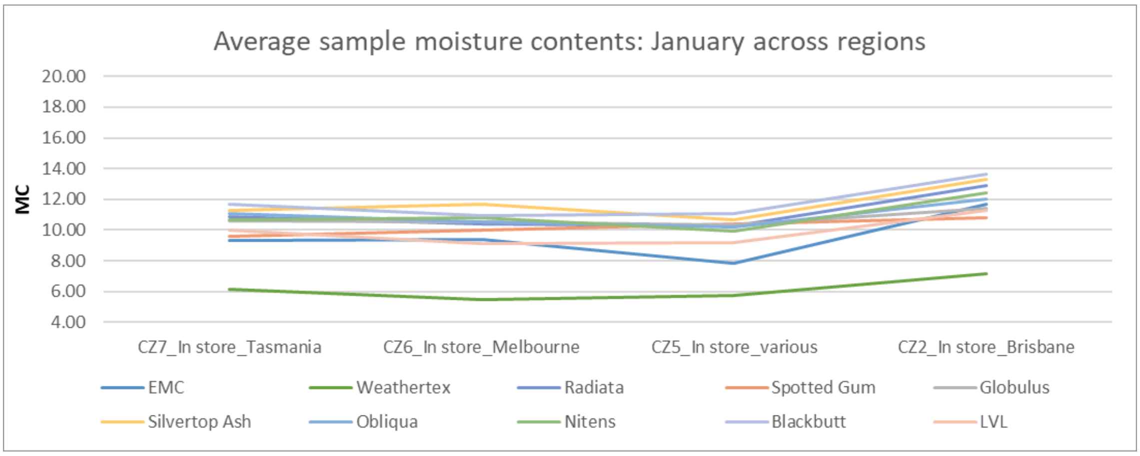


Figure 13: MC responses of species and products: January across regions

Conclusion

The project's static sample monitoring component was designed to collect and assess first-generation information covering the temperature and humidity conditions found in the Australian timber supply chain and the MC responses of common species and wood products stored in those conditions. In this component, 31 sets of data were collected from static monitoring units across four CZ, recording the temperature and humidity conditions and the MC responses of timber species and wood products.

Each full data set has value as it informs timber suppliers of likely conditions in their own facility and in facilities or location to who they supply product.

The component's results provide quantitative detail of the conditions found in the Australian timber and wood products supply chain. This can inform:

- Risk management, as areas of high risk can now be defined and the level of risk between site quantified.
- The review of existing construction and MC control processes. For example, the highly variable results documented from construction sites indicates that equilibration of seasoned timber on a building site prior to installation may be counter-production.
- Industry understanding of the duration of exposure times in particular environmental conditions that can result in unacceptable change in timber MC. This type of knowledge can be used to ensure timber components are detailed to accommodate predictable MC-induced movement and timber's MC is maintained to suit context specific building applications.

Environmental and performance modelling

Understanding of the temperature and humidity conditions that timber and wood products are subjected to in the Australian supply chain needs to be developed. In building this understanding, the supply chain can be usefully separated into the four stages: in storage and transit in the wood distribution network; the construction phase, and in service.

Timber's EMC is the MC where timber neither gains nor loses moisture from the surrounding atmosphere. However, the absolute EMC in ambient conditions varies with the species and product, and these ambient conditions change constantly in the supply chain at rates moderated by methods of packing and wrapping the products and its protection in shelters. This stage aims to establish useful correlations between observable site conditions, means for protecting wood products in the supply chain and the risk to product serviceability due to its MC behaviour and actual exposure conditions in storage, in transit, and in building under construction and in service. In this project data has been collected for three key areas:

- Timber in transit (nation-wide across CZ). See Figure 14.
- Environmental conditions on a construction site (frame to lock-up in Tasmania and Queensland). See Figure 15.
- Timber protected by various types and quality of wrapping and site exposure (in Tasmania and Queensland). See Figure 16.

Figure 14: Mobile unit pack with temperature and humidity sensor ready for transport.

Figure 15: Sensor-only unit on a timber frame.

This report summarises the data on the MC behaviour of wrapped packs in storage. The data collected for timber in transit and the environmental conditions on construction sites in Tasmania and Queensland is being assessed for later publication.

MC behaviour of wrapped packs in storage

This component includes the results of the project's monitoring of timber's MC content in the supply chain under varying wrapping conditions. It aimed to establish useful correlations between observable site conditions, means for protecting wood products in the supply chain and the risk to product serviceability due to its MC behaviour and actual exposure conditions in storage, in transit, and in building under construction and in service. Its results are being used to predict changes to timber MC caused by different storage techniques and identify associated risks.

Materials and Method

The trial included the monitoring of the ambient conditions of identical timber packs of plantation-grown Shining gum (*E. nitens*) with three different levels of immediate protection, stored at sites in two different CZ (CZ7 and CZ2), and in two exposure conditions, and the timber's MC response to these ambient and protection conditions. It ran over the summer of 2021-22 and collected evidence of the temperature and humidity conditions that timber packs are exposed to during transit and in storage. The packs were assembled in Tasmania at CSAW Newnham workshop and distributed to their allocated sites early in December 2021.

Packs, their protection, and condition monitoring

Each pack was nominally 600 wide x 600 high x 1200 mm long and assembled from nominally 25 mm board. They incorporated three temperature and humidity sensors for monitoring environmental conditions on the top, east and west side of each pack. Each of the three sensors was located 400 mm from the end the pack and centred to the face or side of the pack. Two types of sensors were used in this project; Minnow-1.0TH (top) and IC_EL_CC_2_001 (east and west). Each pack also consisted of five sample boards.

The sample board's provided the initial MC conditions of the timber in the assembled pack and were used to determine the change in MC at the trial's end. Table 12 details the wrapping arrangement of each pack. Industry provided all the plastic wrapping for the trial.

Table 12: Pack protection

Item	Description
Poorly wrapped	Opaque blue plastic wrap, previously used and recycled for this trial. The wrap was randomly slashed with cuts approximately 250 mm in length on top, side and ends of the pack. Exposed, unwrapped base
Fully wrapped - opaque	Opaque plastic, white external, black internal; the plastic was brand new; wrapped base; top wrap layer over bottom lap to exclude water pooling with overlapping wrap on the ends and both sides; tapped ends to prevent water penetration
Fully wrapped - clear	Clear plastic; plastic was brand new; wrapped base; top wrap layer over bottom lap to exclude water pooling with overlapping wrap on the ends and both sides; tapped ends to prevent water penetration

Figure 16: Three types of wrapping trailed in this sub-program. Poorly wrapped (left), fully wrapped - opaque (middle) and fully wrapped clear (right).

Exposure sites and conditions

Five packs were produced and exposed at sites at: an industry facility at Mowbray, a northern suburb of Launceston in CZ7; and the Queensland Department of Agriculture and Fisheries (QDAF) facility at Salisbury, Brisbane in CZ2. Each site included an internal storage area and an exterior yard, which were largely open to ambient conditions. Of the five packs for each site, three packs were placed in the exterior yard and oriented north-south and two packs were stored in the interior area. See Figure 17 and Figure 18. The three exterior packs were poorly wrapped, clear wrapped and opaque wrapped. The interior packs were poorly wrapped and clear wrapped.

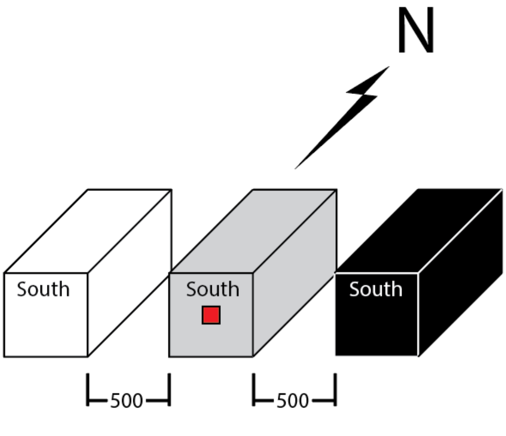


Figure 17 Location for each pack in exterior environment. Red square represents additional environment sensor facing south

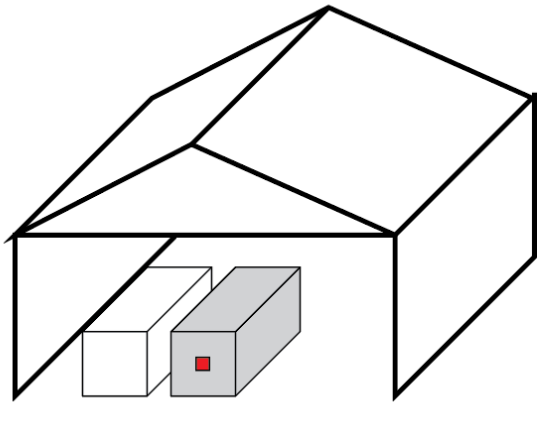


Figure 18 Location for each pack in interior environment. Red square represents additional environment sensor

The Queensland packs were dispatched from CSAW's Newnham workshop on December 7, 2021, and arrived at QDAF on January 5, 2022. Additional sensors were installed to the dispatched packs (exterior to the wrapping) to monitor the environmental conditions during transit. The packs were exposed on each site from 14/12/21 in Tasmania and 5/01/22 at Salisbury, and remained exposed to 9/05/22 and 5/05/22 respectively. The Tasmanian packs were then broken down at CSAW Newnham workshop, while QDAF recovered and processed the sample boards at Salisbury, Qld. All MC assessment was done using the oven dry method according to AS/NZS 1080.1:2012.

Results and Discussion

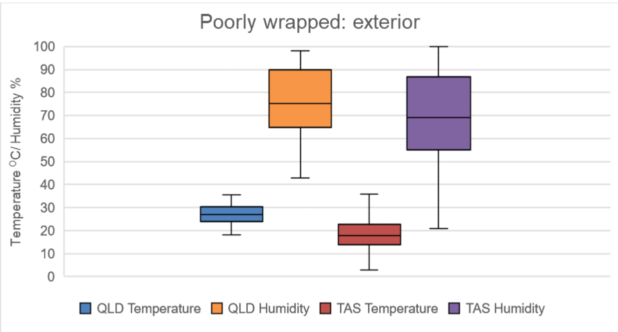
Ambient conditions outside and inside the wrap

This section of the report demonstrates the wide environmental range of temperature and humidity that a pack of timber can be exposed to over a short duration and over several months.

The results indicate that wherever possible storing wrapped timber in an interior environment is preferable to storing it in exposed locations. Table 13 and Figure 19 present the conditions of a poorly wrapped pack in an exterior and interior environment.

Table 13 Measured data from a poorly wrapped pack in exterior and interior environments

Poorly wrapped packs	Exterior		Interior	
	QLD	TAS	QLD	TAS
Max Temp (^{O}C)	50.3	46.6	33.3	24.3
Min Temp (^{O}C)	18.1	2.7	25.2	11.7
Average Temp (^{O}C)	29.4	19.7	27	18.4
Max RH (%)	98.1	99.3	67.1	74.9
Min RH (%)	42.9	38.7	62	52.8
Average RH (%)	76.1	64.8	63.9	63



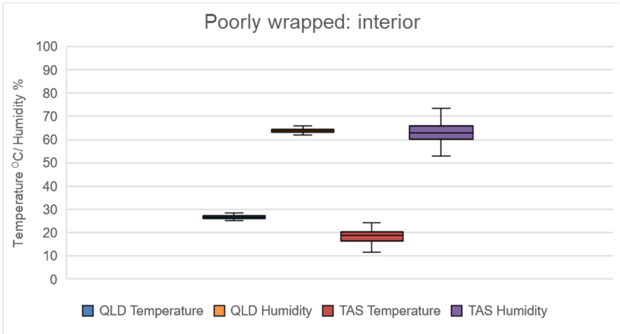


Figure 19 Measured temperature and humidity range: poorly wrapped pack in an exterior (left) and interior (right) environment In Queensland and Tasmania

The timber's MC response to conditions

Table 14 and Table 15 summarise the average MC change in sample boards in packs in CZ7 and CZ2.

Table 14 MC change (%) by pack wrapping and location in Tasmania (CZ7)

Sample board position in pack	Exterior			Interior	
	Poorly wrapped	Fully wrap - opaque	Fully wrap - clear	Poorly wrapped	Fully wrap - clear
Top middle	8.8	8.7	20.6	-0.2	-0.1
West	2.2	-0.1	-0.7	-0.5	-0.4
Middle	0.3	-0.1	0.0	-0.7	-0.2
East	0.5	1.0	-0.5	-0.3	-0.7
Bottom middle	0.6	0.9	0.1	-0.6	0.0
(average)	(2.5)	(2.1)	(3.9)	(-0.5)	(-0.3)

Table 15 MC change (%) by pack wrapping and location in Queensland (CZ2)

Sample board position in pack	Exterior			Interior	
	Poorly wrapped	Fully wrap - opaque	Fully wrap - clear	Poorly wrapped	Fully wrap - clear
Top middle	10.9	26.2	27.7	0.2	-0.3
West	16.3	5.9	8.3	0.2	0.3
Middle	10.9	8.5	9.4	0.4	0.2
East	13.0	7.8	4.4	0.3	0.3
Bottom middle	8.4	4.2	4.5	0.4	0.6
(average)	(11.9)	(10.5)	(10.9)	(0.3)	(0.2)

Both interior sites across CZ7 and CZ2 had minimal change in timber MC after several months of exposure. By comparison there is an obvious increase in risk of unacceptable MC conditions in packs in CZ7 where the MC change was greater 5 % over the trial's duration. Four packs in this trail where exposed to a very high risk with a measured increase in MC of more than 10 % in some boards. The clear wrap in CZ7 and the poorly, opaque and clear wrap in CZ2 all experienced a significant increase in MC over the trial's duration. The MC increase measured in the top middle samples for these four packs was unacceptable, particularly in the fully wrapped packs in CZ2 which increased in MC as high as 27.7 % above their initial MC.

Conclusion

Summarised by climate zone, the reports key findings are:

For CZ7 (Tasmania)

- The top layer middle board for each timber pack exposed to an exterior environment suffered the greatest increase in MC. All other samples located in the same pack remained stable.
- Every MC sample stored in an interior environment decreased in MC.
- The absolute temperature and humidity ranges were larger in CZ7 than those recorded in CZ2.
- The coldest temperature recorded in this trail was 2.5 ^{O}C (clear pack exterior).

For CZ2 (Queensland)

- The poorly wrapped exterior timber pack suffered the greatest average change in MC than any other pack in this trial (11.9 %).
- All exterior packs increased on average more than 10 % MC. Unlike the MC samples located in exterior packs in CZ7 which remained stable, all samples located throughout the packs increased in MC by more than 4 %.
- The highest temperature recorded in this trial was 66.4 ^{O}C (clear pack exterior).

Similarities between climate zones.

- All timber packs exposed to an exterior environment increased in average MC.
- All timber packs stored in an interior environment remained stable with minimal change in average MC.
- Both clear wrapped timber packs exposed to an exterior environment had the largest single MC sample change (CZ7 = 20.6 % and CZ2 = 27.7 %). This was in the top layer, middle board.
- The highest temperature recorded was in clear wrapped exterior packs (CZ7 = 65.3^{O}C and CZ2 = 66.4 ^{O}C).

Industry guidance development and distribution

The stage's methodology involves:

- Reviewing existing guidance
- Envisaging a new guidance suite that include a set of complimentary guidance documents on MC management in the supply chain, and development of an online advisory app for MC management.

Reviewing existing guidance

For this project, existing guidance includes published research results, industry reports, and product and installation practice guides. The major sources of existing Australian guidance include:

- WoodSolutions technical design guides. These cover aspects such as engineering design, component manufacture and flooring installation.
- WoodSolutions Campus technical guides. These cover MC and supply chain issues.
- FWPA research reports.
- Other industry association produced guides, such as the Window and Door Industry Council (WADIC) Window design guide and Australian Timber Flooring Association's (ATFA) flooring guides.

While of use, much of this advice is imbedded in significant documents, such as technical design guides, that are relatively general and slow to change.

Envisaging a new guidance suite

This project envisaged a more flexible suite of guidance documents and mechanisms.

Initial examples were prepared. To ensure relevant information can be accessible readily in the supply chain and on building sites, a series of A4 brochure, A5 flyers and A6 cards is proposed. Table 16 includes the guidance formats and their intended areas of use.

Table 16: Guidance formats

Type	Format	Area of use
Directives	Short statement (10 – 30 words)	Immediate response to site risk assessment. Key points of things to do, and things to avoid.
Cards	A6 cards in landscape format; downloadable PDF.	Support of immediate responses to site risk assessment. Ready reference items providing immediate advice with a group of directives, and support graphics and tables.
Flyers	A5 flyer in portrait format; downloadable PDF.	Specific topic-focused responses that includes more detailed information graphics and tables than a guidance card.
Brochures	A4 document in portrait format; downloadable PDF.	General topic-focused responses that building from the card and flyer information. These could be compiled into a simple manual.

Guidance is also planned for discrete sectors of the supply chain. These are listed and described in Table 17. Figure 20 shows an example A6 card, while Figure 21 shows an example A5 flyer. Icons would be used in the text to simplify key concepts and information.

Table 17: Guidance sectors

No	Sector	Content areas
1	Cross-sector aspects	MC basics, product characteristics, EMC conditions with varied climates.
2	Wood distribution network	This includes receipt, storage, and handling at producer, distributor, fabricator, and retailer facilities.
3	Material in transit	This is within the distribution network, or from the network to a construction site. It includes planning for future impacts, dispatch and transit.
4	Site and construction	This includes receipt of material, storage and handling, installation, planning for future impacts.

5	In service	Performance Expectation
6	Design	This includes allowance in design and planning for future impacts

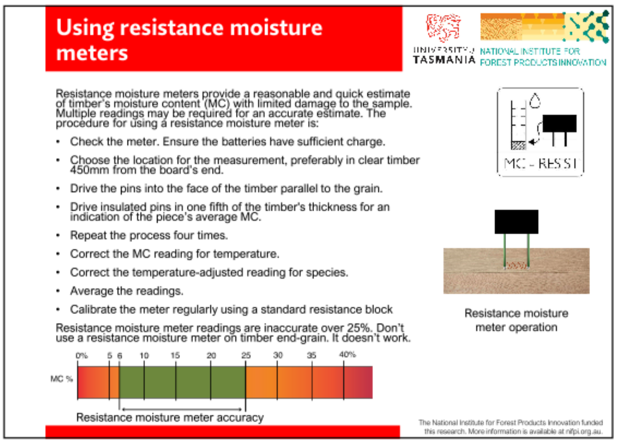


Figure 20: Example A6 card

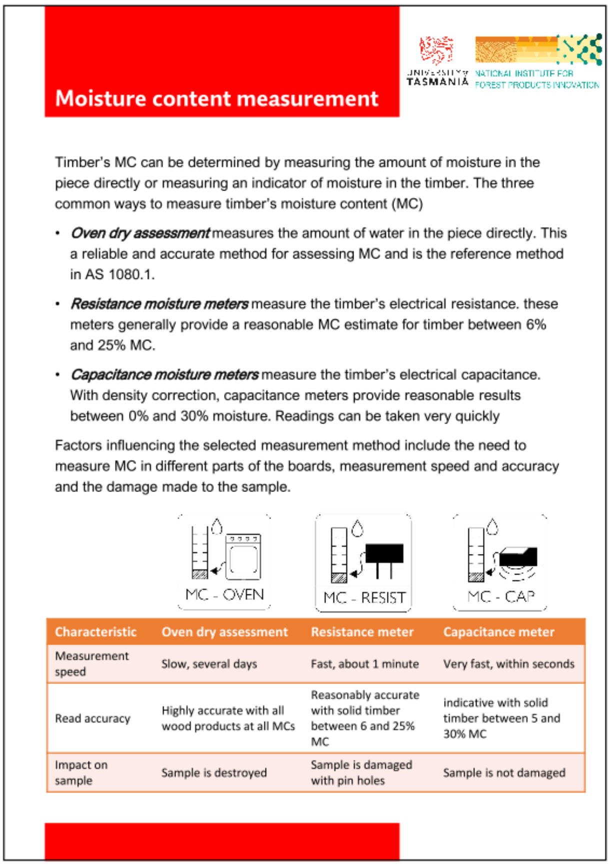


Figure 21: Example A5 flyer

An online advisory app for MC management

To overcome the static nature of existing industry guidance, the project envisaged development of a 'first-generation' online advisory application (app) for MC management. Similar to the WoodSolutions Species information mobile app, this MC management app would be a market support tool for timber and wood products producers, timber suppliers, builders and building and design professionals.

The app was developed to an early developmental stages and now operates on the research-focused Nectar cloud service. In this prototype, users can navigate through a series of short, tabulated questions and answers to generate a risk profile. The app is yet to be populated with guidance flyers that can be promoted to the user based on the information provided in the app.

This form of guidance would advise users of the potential risk profile of timber under specific circumstances. If further developed, the app could provide users with:

- An estimate of risk of MC issues, based on the timber's current condition and location, or changes to those conditions with immediate guidance as directives and links to risk-specific guidance.
- Access to browse for useful guidance documents in A6 cards and A5 flyers by topic for download.

Factors that influence risk and potential inputs in the app's risk assessments are:

- The timber product type; such as structural framing or appearance joinery.
- The product species. This influences its reaction to environmental change.
- The activity that is to occur, and its location and date,
- The product's exposure to hazard and the protection provided to resist that hazard.

To generate a risk assessment, users would provide the information listed in Table 18. The app then uses information sources listed in Table 19 and the risk assessment logic flow shown in Figure 22 to calculate a risk rating. Table 20 lists the planned output generated, while Table 21 describes the risk ratings.

Table 18: User-provided input data

Data area	Description
Activity	***What is happening?*** This activity covered in the assessment.
Product	***What is it?*** The involved products.
Species	***What is it?*** The species used in the involved products.
Location	***What is the exposure?*** The timber's location or locations (such as the suburb) during the activity. Material in transit has a start and end location. See Table 1
Exposure conditions	***What is the exposure?*** The timber's immediate situation (such as in the open or in a store) during the activity. Material in transit may have a start and end situation. See Table 2
Protection	***What is the exposure?*** The protection provided to the product, such as the level of wrapping. See Table 3.
Date	***When is it happening?*** The date the event it to happen (or has happened).

Table 19: Information sources

Info. source	Description
Activity	The characteristic conditions of particular environments and the potential consequences if product is moved one from the other.
Species	Characteristic movement of species to changes in environmental conditions. This is drawn from the general unit shrinkage data and project research results.
Product	The implied value of the product and the implication of expected change.
Climate	The *natural or modified internal climate* of the product's location at the specified date. If the material is in transit, this would include the start and end location and date. • Public resources and relatively accurate 7-day forecast are available to define the *natural climate* in many locations. • Building envelopes, heaters and air-conditioners moderate the natural climate to create a *modified internal climate*. These conditions can be estimated from project data and other sources.
Protection factors	Factors for the protection provided to the material by wrapping immediately around the material.

Table 20: Application output

Data area	Description
Risk profile	App-generated assessment of risk, on a five-point scale.
Guidance set	App-generated guidance set based on the product, location and risk.

Table 21: Risk rating

Risk rating	Description
★★★★★	Very high risk of damage.
★★★★	High risk of damage.
★★★	moderate risk of damage.
★★	Low risk of damage.
★	Very low risk of damage.

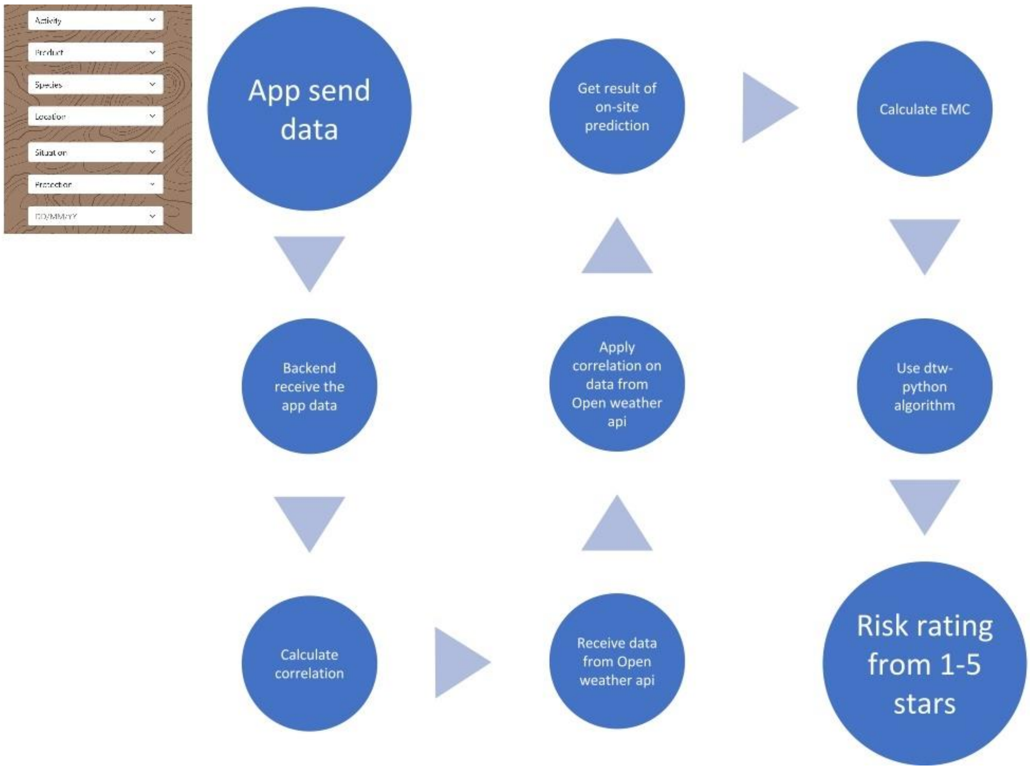


Figure 22: Risk assessment flow chart

Conclusion

This project's objective was to generate informed industry guidance on best practice for the economic and effective MC control of timber and wood products in the Australian timber supply chain. It aimed to identify regular problems and key influencing factors; build an initial knowledge base of EMC conditions and timber's MC performance in the timber supply chain; and generate a refined suite of industry best practice guidance.

Managing timber's MC is a critical part of its production, use in design and construction, and management in buildings in service. As wood is a hygroscopic material, it's MC variation and consequent movement are vital considerations in the design of timber-rich objects and the behaviour of timber-rich components in construction. While changes in dimension may be small in any one board or sheet, the cumulative effect can be critical to product performance in an application and to customer confidence.

This project focused on first-generation information collection and assessment to understand and provide initial guidance on managing the MC conditions that timber and wood products are exposed and react to in the timber supply chain, in the wood distribution network, at construction sites, and in-service in operational buildings.

Three technical reports provide guidance and findings on:

- MC problems and influencing factors in the supply.
- The environmental conditions and timber's response in static locations around Australia.
- Timber's MC content in the supply chain under varying wrapping conditions

Additional project findings include:

- Industry wide acknowledgement of: MC management as 'Essential' in normal quality control processes; the problematic control of timber and wood product MC once the product leaves production facilities; and the measurement of MC in hardwoods as being more problematic than outlined in the Australian Standards.
- Initial assessment of data covering the temperature and humidity conditions found in the Australian timber supply chain: in production, in store, in construction, and in service in buildings, and the MC responses of common species and wood products stored in those conditions over 31 sites and across four CZ.

- Comparison in wrapping type and quality over two CZ to demonstrate the difference between environmental conditions and MC behaviour.
- Establishing a framework for guidance and risk modelling for the economic and effective MC control of timber and wood products in the Australian timber supply chain.

Recommendations and future work

As outline above, this project has collected significant volume of first-generation data on environment conditions in the Australian supply chain and timber's MC response to these conditions. Initial assessment has occurred on a block of this data and been reported. This includes new knowledge that will have short to medium term impacts on current industry practice.

However, this assessment can be significantly extended, and the available data set augmented by further trials. This would aim to generate useful results relevant to particular product groups, CZ, species, or exposure conditions.

Further work can include:

- Development of improved guidance and risk calculators for associated producers and consumers of timber products in Australia.
- Data collection and analysis on specific timber and wood products in transit internationally.
- Extending the monitoring of timber MC change into the mass timber component supply chain, covering in production through the supply chain and in service.
- Further trails and data collection for different types and quality of timber protection such as wrapping and coating in the supply chain across Australian CZ.

TR-1 Timber's MC in the supply chain

Inspection results and user survey

Professor Gregory Nolan

Dr Nathan Kotlarewski

December 2022

NT045 / NIF109 Managing timber's moisture content in the supply chain, construction and in service

Contents

Introduction

This technical appendix report is part of the National Institute for Forest Products Innovation's (NIPFI) project: *NT045 / NIF109 Managing timber's moisture content (MC) in the supply chain, construction and in service*.

This project's objective is to generate and distribute informed industry guidance on best practice for the economic and effective MC control of timber and wood products in the Australian timber supply chain. It aims to identify regular problems and key influencing factors; build an initial knowledge base of equilibrium moisture content (EMC) conditions and timber's moisture content (MC) performance in the timber supply chain; and generate a refined suite of industry best practice guidance.

This report includes the results of *Sub-program 1: Review MC problems and influencing factors,* exploring the broad literature on MC problems in the supply chain, and in collecting industry's experiences, observations and previous reactions to these problems.

Methodology

The stage's methodology involves:

- Identifying literature on MC-related problems in the supply chain
- Conducting structured industry inspections, surveys and interviews to identify key problem areas.

Literature review on MC-related problems in the supply chain

For this project, literature includes published research results, industry reports, and product and installation practice guides. A review of published research literature was conducted that covers the monitoring of the MC of wood products in transportation and construction. Its results are included in Appendix 2 of this report.

Structured industry surveys

Industry's experience, observations and previous reaction to MC problems can be assessed through inspection of these problems and through more structured survey methods. In this project, this involves:

- Inspections at storage and production facilities and building site to investigate reported problems.
- An open online survey promoted to industry members.
- Detailed phone interview of survey participants.

Facility and site inspections

Regularly involved with production companies and supply chain participants, the authors are occasionally asked to inspect and provide guidance on MC problems that occur in Tasmania and interstate. The most regular of these are inspections of flooring in Tasmania, and MC issues with fabricators using Tasmanian products interstate, particularly in Victoria.

Flooring and other inspections are generally conducted to a regular procedure that involves tracking the history of the product and its installation and site measure of board size, and where possible MC. However, the varied nature of fabricators' issues limits the potential to structure and fully document these inspections. However, the observed issues can be recorded.

Open online survey and detailed phone interview

While informative, occasional inspections do not provide the base required to inform more focused research results or industry guidance documents. To develop this base, two surveys were developed to collect industry experiences of MC issues: a concise online survey and more detailed phone interviews of survey participants. These surveys were developed after initial discussion with industry members and a formal review process. The University of Tasmania Social Sciences Human Research Ethics Committee approved the surveys and their support information in October 2020 (approval number H-72404).

Emails about the surveys were distributed to approximately 150 recipients in the CSAW network and an invitation to participate was included in Britton Timbers emails and in industry media, such as the Timber and Forestry E-News and Friday Off-cuts. The surveys are included in Appendix 1.

Results

Structured industry surveys

Facility and site inspections

From 2019, inspections occurred of sawn appearance material interstate and of flooring, joinery and cladding issues in Tasmania and interstate.

A series of issues were identified with sawn appearance Tasmanian hardwood supplied to interstate fabricators. These occurred most regularly in Victoria in November or early December across several years. The recurrent feature of these issues was cracks or splits appearing in product that previously had been assessed as solid. See Figure 1. In the most severe cases, boards or panels developed splits or broke into sections. See Figure 2. These failures puzzled suppliers and fabricators as they were unexpected. The panels had appeared solid when they were initially assembled and subsequently handled. With little data to assess, the cause of these failures remains unknown but is expected to relate to periods of hot and dry weather commonly experienced in Melbourne as the seasons change from winter to spring. The stress generated by the MC variation on the boards' surface may have caused splits to develop in the timber at previously unseen weak points in the board.

Figure 1: Board with MC-induced end splits

Figure 2: Panel with MC-induced fracture

Floor and furniture inspections occur when a potential dispute exists between a building owner, their builder or fabricator, and a timber supplier. The disputes' causes vary considerably but the most common feature is board shrinkage due to MC change. In floors, this is seen after the floor has been sanded and finished, and the building occupied. See Figure 3 and Figure 4. With furniture and other items, it is when material assembled in a workshop is placed in drier, conditioned internal conditions, such as offices or hotels. Flooring inspections are requested and occur most regularly in January – February of floors laid in spring. Several factors appear to be contributing to the pattern of flooring issues, including:

- Tasmania's fluctuating weather patterns between winter and summer. Material supplied from stored product between June and September may have a higher MC than was measured when the material was profiled, and this MC may increase as the material is stored on site.
- The increased thermal performance of modern homes. Increased insulation and double glazing in homes, and more effective wrapping of building envelope produces internal environments that are warmer and drier than those in homes built in previous decades. Thermal improvement occurs across all seasons but is especially noticeable during the increased solar gain of late spring and early summer. The EMC of these well-sealed, enclosed and often sunny spaces probably differs significantly from the EMC of the same space during the construction period, or similar buildings built to less demanding thermal standards.

- A lag in both builder experience and industry installation guidance given these changes in construction practice. For example, board acclimatisation is still an accepted practice in some flooring installation specifications and guides. However, acclimatising a board in an enclosed but breezy space in winter may not prepare it for satisfactorily performance in the same space when it is well sealed and sunny in summer.

Figure 3: Minor slabbing from board adhesion.

Figure 4: Regular gapping in floor

Figure 5: Splitting in a bedside tabletop.

Figure 6: Splitting in a desktop

Figure 7: Splitting across a tabletop at a gum vein,

Figure 8: Shrinkage along a tabletop leading to an exposed rail edge

Issues with furniture and other items have increased with the broader acceptance of edge-laminated solid timber bench tops and similar joinery items. Several factors appear to be contributing to the pattern of furniture issues that highlight:

- A lack of appreciation by designers and fabricators of:

    - The extent of timber's movement due to moisture change. This is leading to situation where elements with relatively low shrinkage are used to significantly constrain boards with relatively high shrinkage across the grain. See Figure 5 and Figure 6.
    - Changes in EMC that objects experience as they are moved from an assembly area into service conditions, particularly in air-conditioned spaces. See Figure 7 and Figure 8.
- A need for producers to encourage greater understanding of MC issues. While they have no control of the final applications for their products, they are often implicated when things go wrong.

Issues with cladding have occurred as the popularity of this selection increases while builder understanding of the potential MC issues is underdeveloped. This can result in no or inadequate expansion joints being provided into walls likely to be exposed to high MC conditions during winter. This can be aggravated by the lack of eaves and suitable flashings. See Figure 9 and Figure 10. MC increases can be considerable. In the application shown, the EMC of the boards probably rose from 14% at installation in summer while measured MC of the board in winter had reached 19%. This generated overall expansion of approximately 70 mm in a 7 metre run of wall.

Figure 9: Expansion in vertical cladding on a south-facing wall

Figure 10: Board removed to relieve expansion pressure.

Open online survey

The online survey described above has been available since it received ethics approval. This survey asked timber and wood products manufacturers, business owner or retailers to provide their experience of the moisture content (MC) and moisture-related issues in their workplace. To the start of December, sixty-three responses were received with the following results.

Location

CSAW have currently collected 53 responses to the national moisture content industry survey, from six Australian states: VIC (39%), NSW (21%), TAS (16%), QLD (15%), WA (7%) and SA (2%).

Type of business

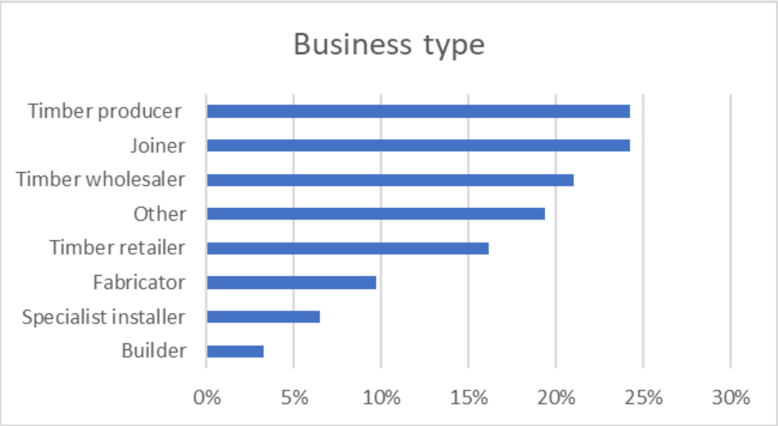


Figure 11: Type of business

The respondent's business types were: Joiner (24%); Timber Producer (24%); Timber Wholesaler (21%); Other (incl Furniture Makers) (19%), Timber Retailer (16%); Fabricator (10%); and Builder / Specialist Installer (9%). See Figure 11.

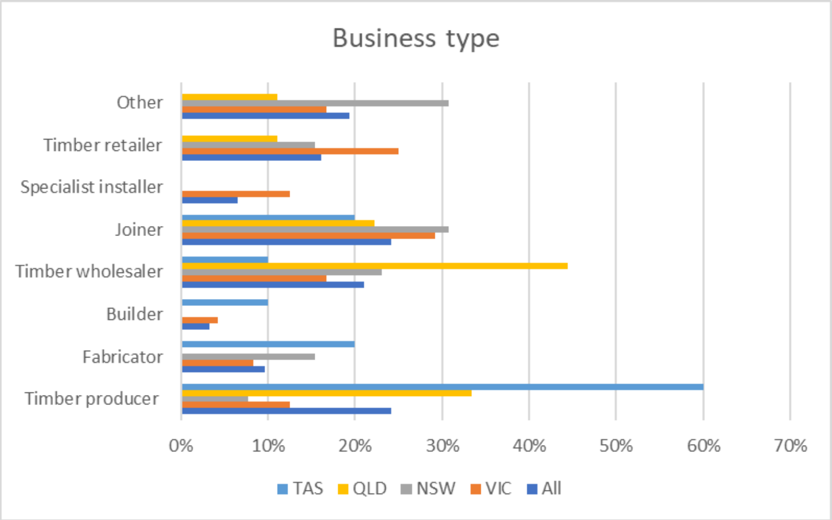


Figure 12: Type of business by state

Timber producers dominate responses from TAS (60%), timber wholesales are well represented in QLD (44%) while most fabricators are from NSW and VIC.

Products handled

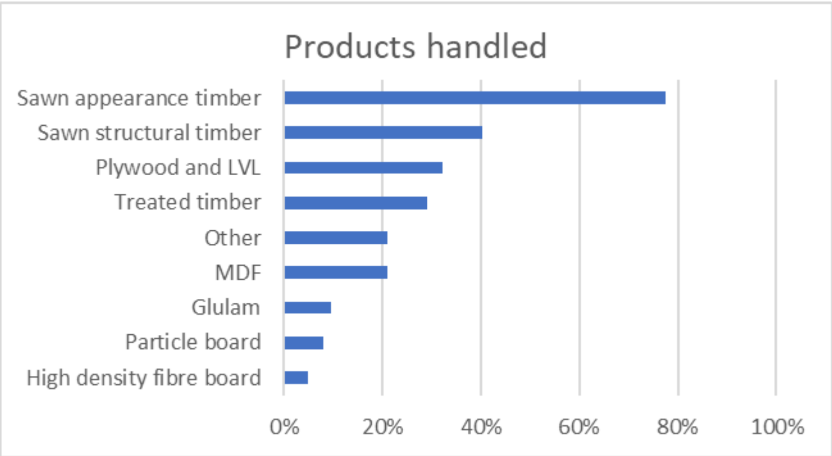


Figure 13: Timber product handled

Respondents could select three product types that accounted for most of their business. Their selected products included: Sawn appearance timber (77%); Sawn structural timber (40%), and plywood and LVL (32%); and. See Figure 13.

Importance of MC Management

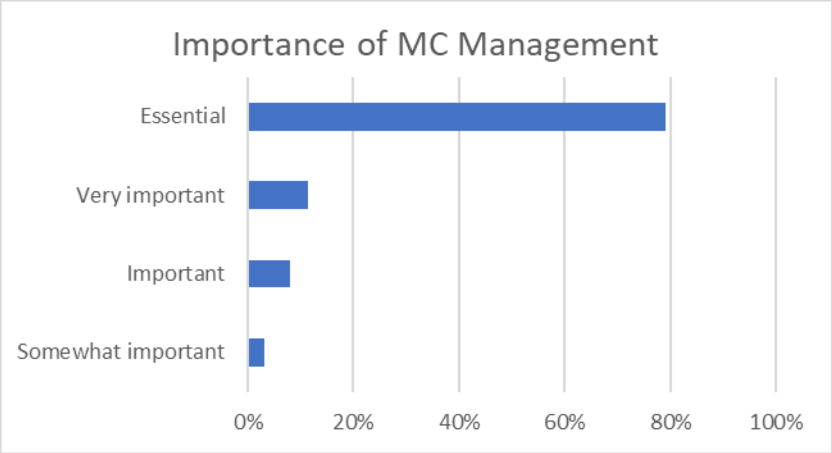


Figure 14: Importance of MC managemetn

79% of respondents rate MC management as 'Essential' in normal quality control processes. See Figure 14

Species handled

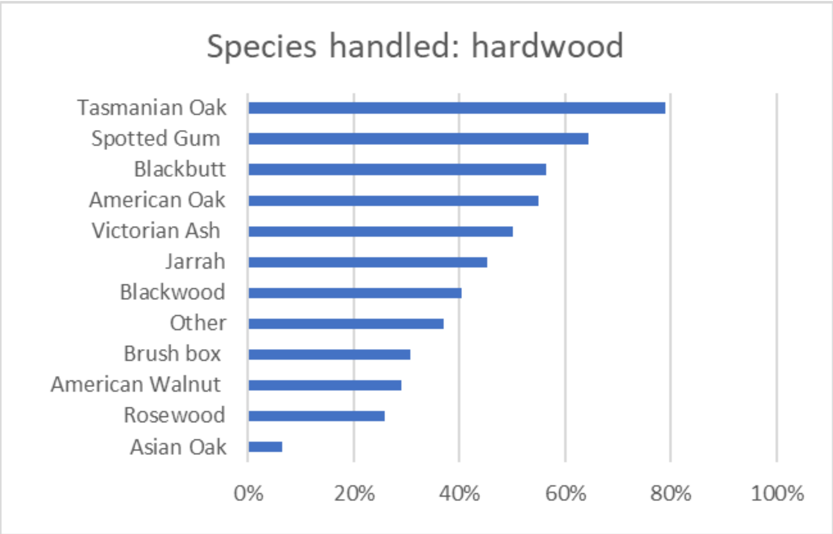


Figure 15: Hardwood species handled

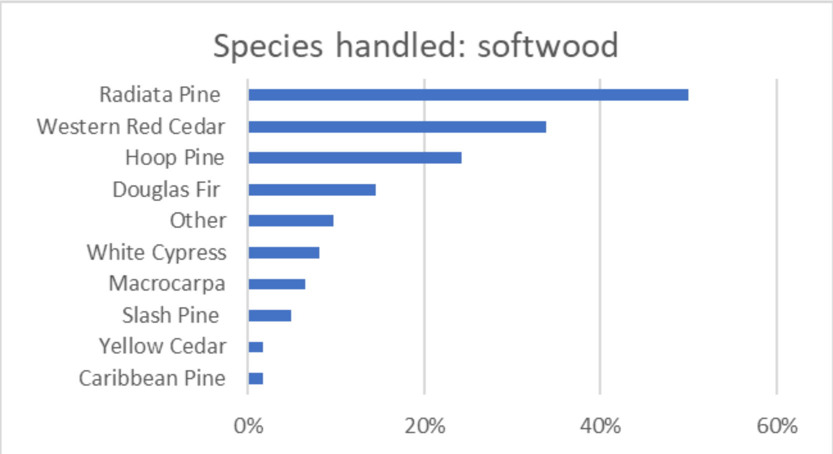


Figure 16: Softwood species handled

The common hardwoods that respondents handled were Tas Oak, Spotted Gum, American Oak, Blackbutt, and Victorian Ash. See Figure 15. The common softwoods handled were Radiata, Western Red Cedar, and Hoop Pine. See Figure 16

MC problems

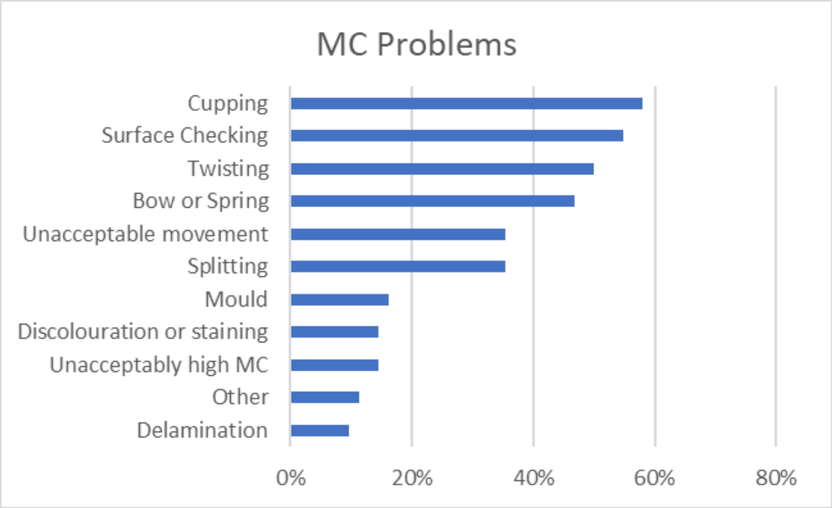


Figure 17: The MC problems that occur

Respondents could select up to three MC problems that occurred regularly. The MC problems most regularly reported were: Cupping (58%), Surface Checking (55%), Twisting, Bow or Spring (all approx. 48%), and Splitting and Unacceptable Movement (both approximately 35%). See Figure 17.

The occurrence of problems varies with state. NSW was prominent in cupping (85% of respondents) and bow and spring (69%), surface check is a significant issue in QLD (78%), while TAS has the highest reported incidence of splitting (60%)

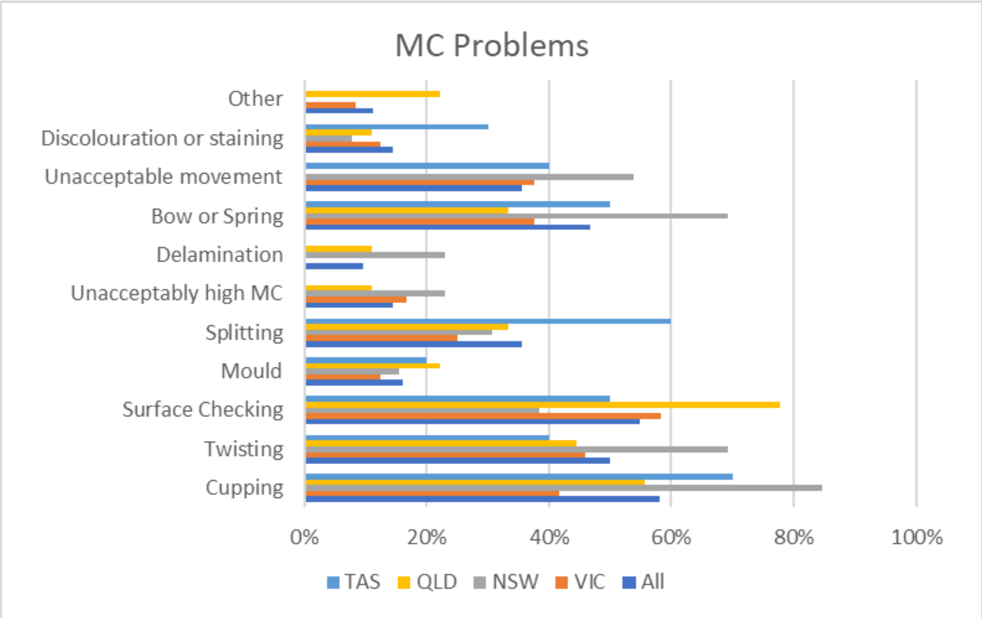


Figure 18: The MC problems that occur by state

Occurrence of MC issues

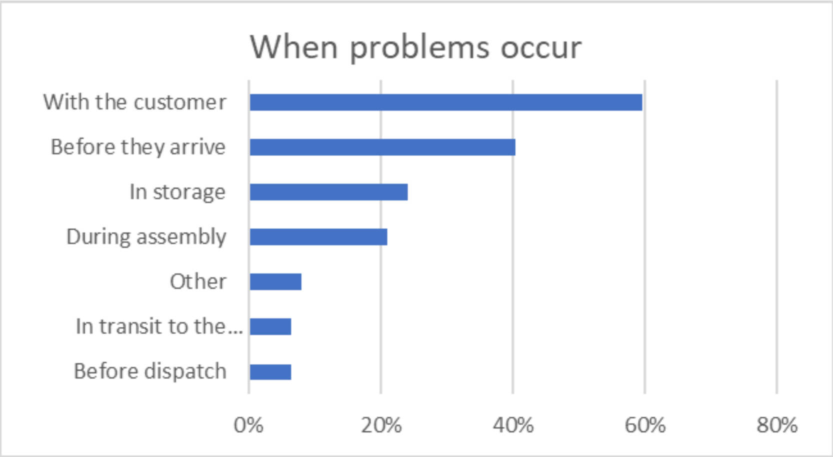


Figure 19: When the MC problems occur

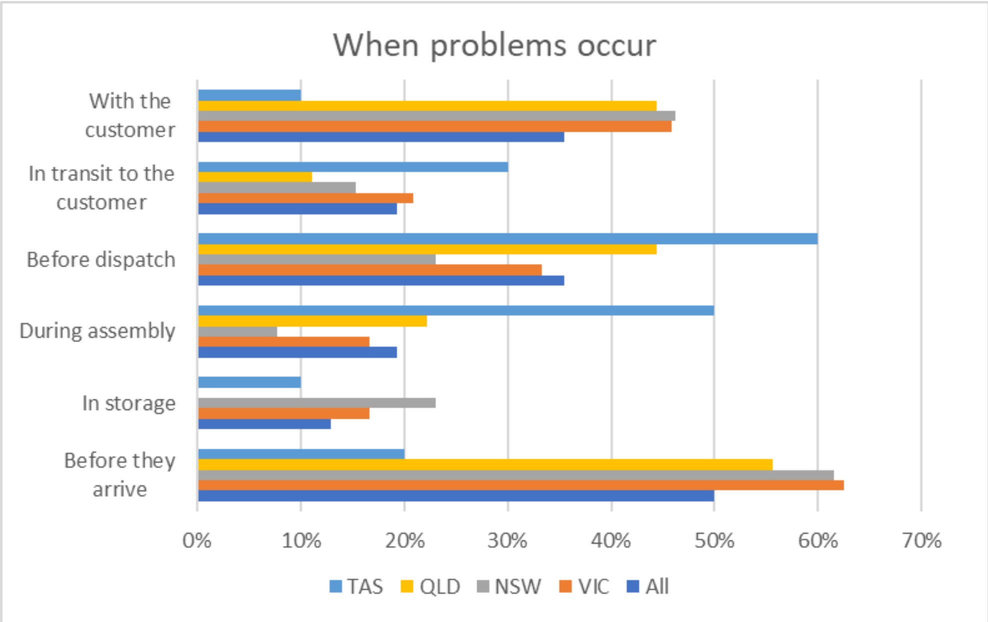


Figure 20: When the MC problems occur by state

Respondents felt that these MC issues most regularly occur with the customer; at the end of the supply chain (58%) and before the timber arrives at the start of the supply chain (45%). Regular problems were still reported in the business during storage and assembly (20% each). See Figure 19.

Seasonal impact on issues

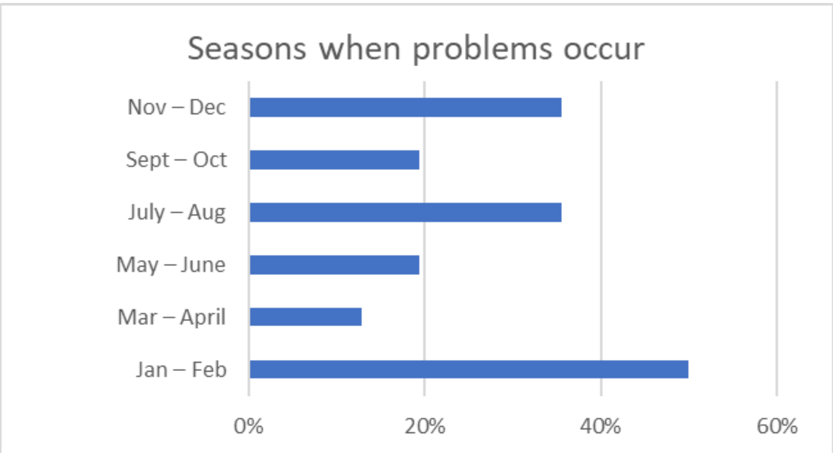


Figure 21: The seasons when problems most occur

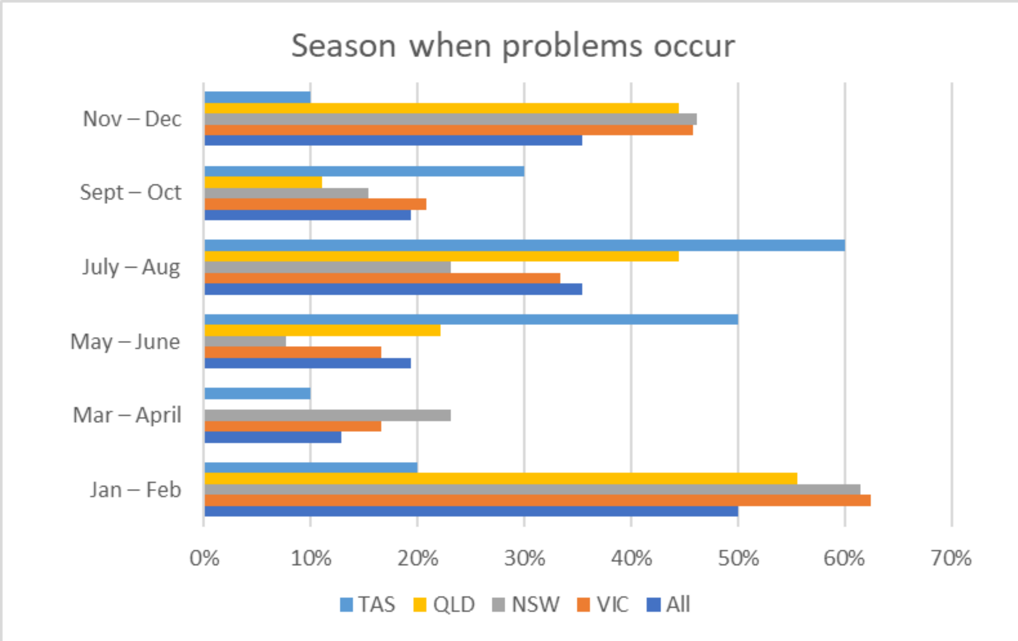


Figure 22: The seasons when problems most occur – by state

70% of respondents say seasonal changes impact the frequency of moisture content-related problems. Most moisture content-related issues were reported to occur: January – February (51%); July – August (32%); and November – December (38%). See Figure 21. While VIC, NSW and QLD have generally similar timing for problems, with most occurring in Nov – Dec, and Jan -Feb, TAS reports most in July – Aug.

Frequency of MC issues

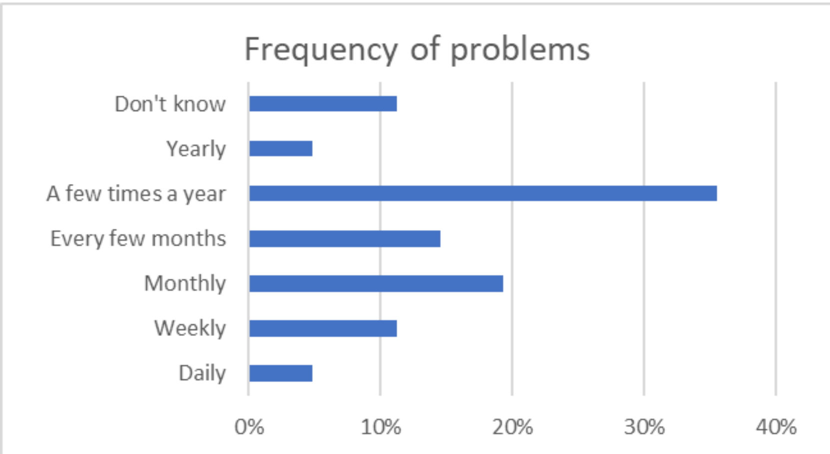


Figure 23: Frequency of MC problems

35% of respondents noted these issues generally occurred a 'few times a year'. See Figure 23

Amount of material affected by MC problems

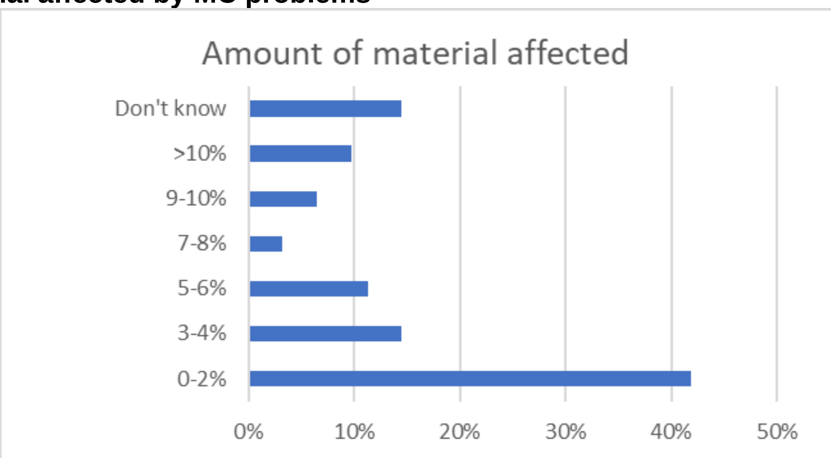


Figure 24: Amount of material affected

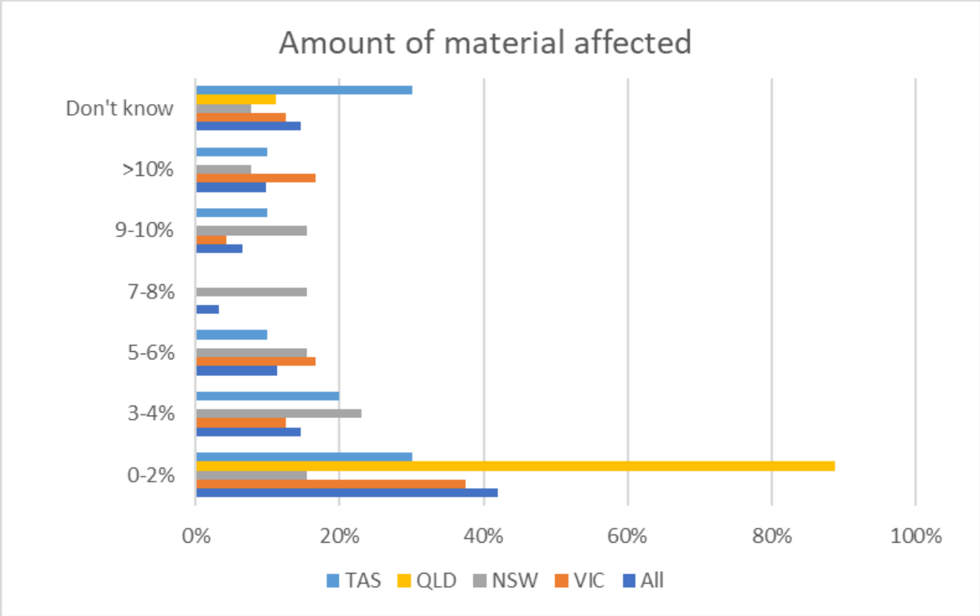


Figure 25: Amount of material affected – by state

The majority, 42%, of respondents noted that 0-2% of timber is affected by moisture content issues in their business. However, 12% noted experiencing 3-4% of timber affected while 12% have experienced 5-6% of timber affected. See Figure 24. Qld recognised the least material affected, with 89% opting for 0-2% of timber affected. VIC recognised the most material affected, with 17% opting for more than 10% of timber affected.

Detailed phone interview

Detailed phone interviews began in late 2019 but ceased in early 2020 due to industry lockdowns during the COVID-19 response. As the impacts of these lockdowns eased, interviews resumed, often informally and in connection with promotion of the open online survey. Key points from two of interviews are listed below. Appendix 1 includes fuller notes of these interviews.

- The measurement of moisture content in hardwoods is more problematic than outlined in the Australian Standards.
- Though the standard 24-hour oven drying procedure may work for softwoods, denser hardwoods like blackbutt and spotted gum may have continued moisture loss for a further 24 – 48 hours. It is not uncommon for the typical 24-hour oven dry sample to actually take 60 hours with these species.
- There is also significant variation found in the moisture content along the length of a single board of these higher density species.
- Companies find the variation in EMC at the location of use is far greater than their ability to control the MC of the product. Once the product leaves the factory, there is no longer control.
- An experiment in southern NSW with a major pine producer in 2011 identified that reducing the thickness of wrap from 100 to 50 microns exacerbated the condensation effect in wrapped packs.
- Heat and moisture build up inside the packs from moist timber would condense on the thin, cold layer of wrap creating moisture impacts to the timber inside.
- A 70-micron white and black wrap was developed that reflected heat through the white outside layer and drew heat outwards through the inside black layer. The slightly thicker wrap had more insulative value which had better outcomes for the stored product.
- One timber-wrap supplier developed an anti-fog additive for the black internal layer of their wrap that encourages vapour to form rather than droplets of moisture. An anti-fungal treatment in the wrap plastic is being considered.
- Anecdotally, most moisture content issues identified are with softwoods that still contain a high level of moisture.

- Damage to wrap in transport can occur through impacts in the environment, which can subsequently have moisture content impacts on the timber stored within. Forklifts and other equipment movement in storage can tear the wrap in the short-term. Over a long-term period, UV degradation can occur if packs are stored outside.

Appendix 1: Industry surveys

Online Survey

Slide 1:

Industry survey: Managing timber's moisture content (MC) in the supply chain, construction and in service

Welcome to this national timber industry survey on experiences of moisture content and moisture-related issues in the timber supply chain. As a timber and wood products worker, business owner or retailer, we would like to gauge your experience of the moisture content (MC) and moisture-related issues in your workplace.

This survey should take approximately 15 minutes to complete.

The survey's outcomes will be published by the University of Tasmania's Centre for Sustainable Architecture with Wood (CSAW). CSAW is leading this National Institute for Forest Products Innovation funded project. It is part of a research project that aims to provide evidence-based guidance to timber businesses on ways to minimise the loss of stock and revenue due to moisture-related issues in timber and wood products.

This survey is confidential, and all results will be deidentified to ensure that your responses cannot be linked to your business or products. All results will be general findings. You may withdraw at any time by following the instructions in our information sheet provided.

If you have concerns regarding your privacy while conducting this survey, or further questions, please contact: nikki.holdsworth@utas.edu.au before proceeding.

Please confirm below that you consent to proceeding with this survey, and you understand it is confidential and the results will not identify you or your business:

☐ Yes, I consent

Research team:

Discipline of Architecture and Design, University of Tasmania:

Prof. Gregory Nolan, Director, Centre for Sustainable Architecture with Wood (CSAW)

Ms. Nikki Nolan, NIFPI Research Project Officer, Centre for Sustainable Architecture with Wood (CSAW)

Project contact:

Email: nikki.holdsworth@utas.edu.au, Phone: (03) 6324 4470

Slide 2:

Please provide the location of your business, including postcode:

Business Location:

Post code:

Slide 3:

What type of business does your company do?

Select the best description below.

☐ Timber producer	☐ Timber wholesaler	☐ Timber retailer
☐ Fabricator	☐ Joiner	
☐ Builder	☐ Specialist installer	

Slide 4:

What type of timber products does your company manufacture, store, supply or handle?

Select the three product types that account for most of your business.

☐ Sawn appearance timber ☐ Sawn appearance timber ☐ Treated timber
☐ Plywood and LVL ☐ Glulam ☐ MDF
☐ Particle board ☐ High density fibre board ☐

Slide 5

How does your business rate the importance of moisture content (MC) management or other moisture issues in its normal quality control processes?

☐ Somewhat important ☐ Important ☐ Very important
☐ Essential

Slide 6

If your company handles hardwood, select the species you work with:

☐ Tasmanian Oak ☐ Victorian Ash ☐ Blackbutt
☐ Spotted Gum ☐ Brush box ☐ Jarrah
☐ Asian Oak ☐ American Walnut ☐ American Oak
☐ Blackwood ☐ Rosewood ☐

Other Hardwood Species (Please list)

If your company handles soft wood, please select the softwood species you work with:

☐ Radiata Pine ☐ Caribbean Pine ☐ Slash Pine
☐ Hoop Pine ☐ White Cypress ☐ Western Red Cedar
☐ Douglas Fir ☐ Yellow Cedar ☐ Macrocarpa
☐ ☐ ☐

Other Softwood Species (please list)

Slide 7:

What type of moisture-related problems has your company encountered with the timber products that it handles? Select up to three problems that regularly occur.

☐ Cupping ☐ Splitting ☐ Bow OR Spring
☐ Twisting ☐ Unacceptably high MC ☐ Unacceptable movement
☐ Surface Checking ☐ Delamination ☐ Discolouration or staining
☐ Mould

Other problems (please list)

Slide 8:

In your company, when do most regular moisture-related problems seem to occur in products? Select those that regularly occur.

☐ Before they arrive ☐ In storage ☐ During assembly
☐ Before dispatch ☐ In transit to the customer ☐ With the customer.

Other times (please list):

Slide 9:

Do seasonal changes impact the frequency of moisture-related problems in your business?

No ☐ Yes ☐

If you answered ‘Yes’, when do most moisture-related problems occur in your business?

Select up to two periods when problems regularly occur.

- ☐ Jan – Feb
- ☐ Mar – April
- ☐ May – June
- ☐ July – Aug
- ☐ Sept – Oct
- ☐ Nov – Dec

Slide 10:

How frequently do problems due to MC issues occur in your business?

- ☐ Daily
- ☐ Weekly
- ☐ Monthly
- ☐ Ever few months
- ☐ A few times a year
- ☐ Yearly
- ☐ Don't know

Slide 11:

What percentage of the timber and wood product are affected by moisture-related problems in your business?

- ☐ 0-2%
- ☐ 3-4%
- ☐ 5-6%
- ☐ 7-8%
- ☐ 9-10%
- ☐ >10%
- ☐ Don't know

Slide 12:

Thank you for your answers provided so far.

Before you submit your results, please indicate below if you would be willing to participate in a short follow up phone interview to discuss your experiences of moisture content and moisture-related issues in your workplace and with your products?

Participation in the phone interview stage is voluntary and you can withdraw from the research at any time. Research results will be generalised, and no findings will be identifiable to your business or products.

Would you like to participate in a follow up phone interview?

- ☐ Yes
- ☐ No

If no, please continue to submit your results.

If yes, please provide your contact information below and continue on to submit your results:

Name:	
Role/Title:	
Business name:	
Email address:	
Phone number:	

Slide 13:

Press SUBMIT to enter your answers to this survey.

Thank you for participating in this Industry Survey: 'Managing timber's moisture content in the supply chain, construction and in service'.

Qualitative Phone Interview Questions

Preamble

Good afternoon, may I speak with Mr./Ms./Mrs. X.

I am a NIFPI project officer with CSAW at the University of Tasmania. I am calling to undertake a phone interview with you as a follow up to the online survey 'Managing Timbers MC in the supply chain'.

This research is funded by the National Institute for Forest Products Innovation and is being led by the Centre for Sustainable Architecture with Wood from UTAS, in collaboration with local timber industry partners.

Thank you for completing the online survey. Both the online survey and this phone interview are voluntary and confidential. All the findings will be generalised so that neither your business and/or products can be identified. You are welcome to withdraw from the research at any time, even after this interview if you wish. Refer to our introductory email for details. When this research is published you will be emailed a link to the final paper for your information and guidance on moisture content issues.

If you have any questions or complaints about this study, please refer to our information sheet in the introductory email for the details of the Social Sciences Human Research Ethics Committee.

This conversation should be approx. 15 minutes and cover your experiences of moisture content issues in more detail. The answers you will provide will be stored securely on a University of Tasmania, password-protected server, accessible only to the research team.

Before we proceed, could I please get your verbal consent that you understand the project and you are happy for me to record your answers from this conversation?

Thank you,

Nikki Nolan

Phone questions

1. Could I please get your verbal consent that you understand the project and you are happy for me to record your answers from this conversation?
2. Where in the processing of the timber resource are moisture content problems most likely to occur? I.e. on receipt of the product from supplier; in house, during processing; or post-delivery of the timber resource.
3. Do you have any thoughts as to what caused the problems?
4. What QA procedures do you have in place to deal with problems?
5. Under what conditions is timber stored and processed?
6. Are you able to supply any images of the problems encountered?
   Please email these photos to nikki.holdsworth@utas.edu.au. These images will be coded to ensure confidentiality with a re-identifiable code. This will be in the format of which state your business is in, e.g. NSW1, Tas1.
7. Could I please confirm your consent to participate in this interview and for CSAW to include your answers in our research?

Thank you for your participation.

Appendix 2: Literature review

Introduction

As this project aims to establish an understanding of the moisture content (MC) variation of wood products in the supply chain, construction site and in-service condition, this literature review is covers:

- Wood MC basics
- Wood MC change after drying
- Wood and other materials in transit: containers
- MC assessment and protection on the building site.

Wood MC basics

the basics of wood's moisture content are documented in key references such as the Forest Products Laboratory's Wood handbook (2010). Timber and wood products in service contain water. The amount of water they contain at a particular time is known as its moisture content (MC).

Wood is hygroscopic and timber's MC will vary with its surrounding conditions. Once seasoned in production, timber and wood products lose or gain moisture to be in equilibrium with the surrounding atmosphere. As this moisture forms part of the wood matrix, timber will shrink when it loses moisture and expand as it absorbs moisture. This shrinkage or expansion occurs at different rates in each of the three principle wood grain directions: radially - across the growth rings, tangentially - around the growth rings and longitudinally - along the grain. Timber's EMC is the MC where timber neither gains nor loses moisture from the surrounding atmosphere. There are direct relationships between the wood's EMC, species (or product) properties, and the ambient temperature and relative humidity of a location. These are often expresses in charts such as Figure 26, that exclude the influence of species properties/

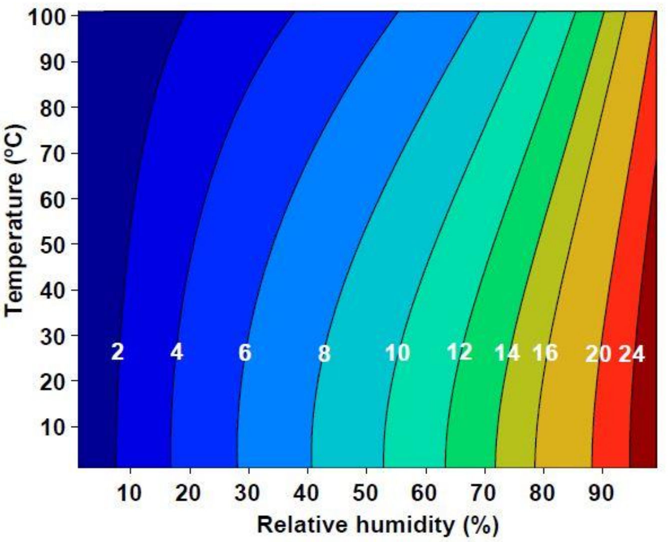


Figure 26: Equilibrium moisture content of wood (labelled contours) as a function of relative humidity and temperature (Wood Handbook Figure 4.1)

Ahmet et al. (1999) notes that these charts are often based on results amalgamated from a number of species and are not species specific. The noted that previous studies had shown that the EMC for a wide range of species conditioned in the same environment could vary substantially. He also noted that the EMC achieve for pieces of a single species would also vary dependent on the samples dimension and previous drying history.

Wood MC change after drying

Lumber was suggested to be stored in closed and heated space after the kiln or air drying (Simpson, 1991). According to Simpson et al. (1999), outdoor storage, open-shed storage and closed unheated storage used by manufacturers may result in different moisture absorption rate. Rietz (1978) suggested lumber may regain 1% of MC in an open shed and 0.3% in closed shed per month.

Zhang et al. (2006) monitored the moisture distribution of a package of kiln-dried red oak lumber stored in a high humidity condition over time using a wireless radio frequency MC sensor system. In their study, 1000 red oak lumber board in 2.4m length were first stacked and dried to 7% MC at 21.1℃ and 45% RH) for 3 months. Then, the boards were arranged into a package with 34 layers and 3 groups of sensors with 13 sensors each group were installed into the small pockets prepared from the boards. The arrangement of the group is identical and demonstrated in Figure 27. Two groups were installed 150mm away from each end of the package with another group placed in the middle of the package. After testing the performance of the sensors for the same condition (21.1℃ and 45% RH) for another 10 days, the condition of the chamber was changed to 21.1℃ and 80% RH, which could lead to an EMC of 12% during moisture absorption. Measurement of MC was taken every hour for 19 weeks (125000 readings).

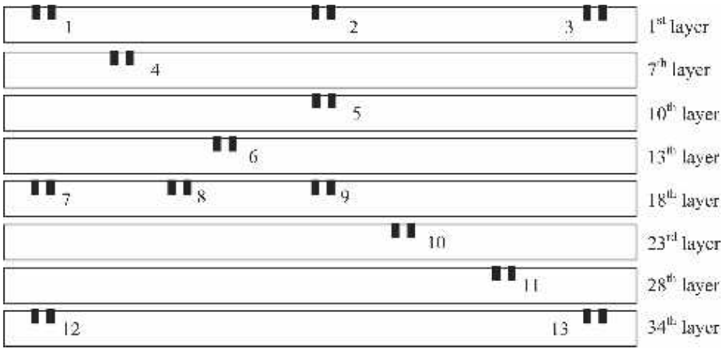


Figure 27: Cross section of a sensor arrangement (numbers represent sensor positions).

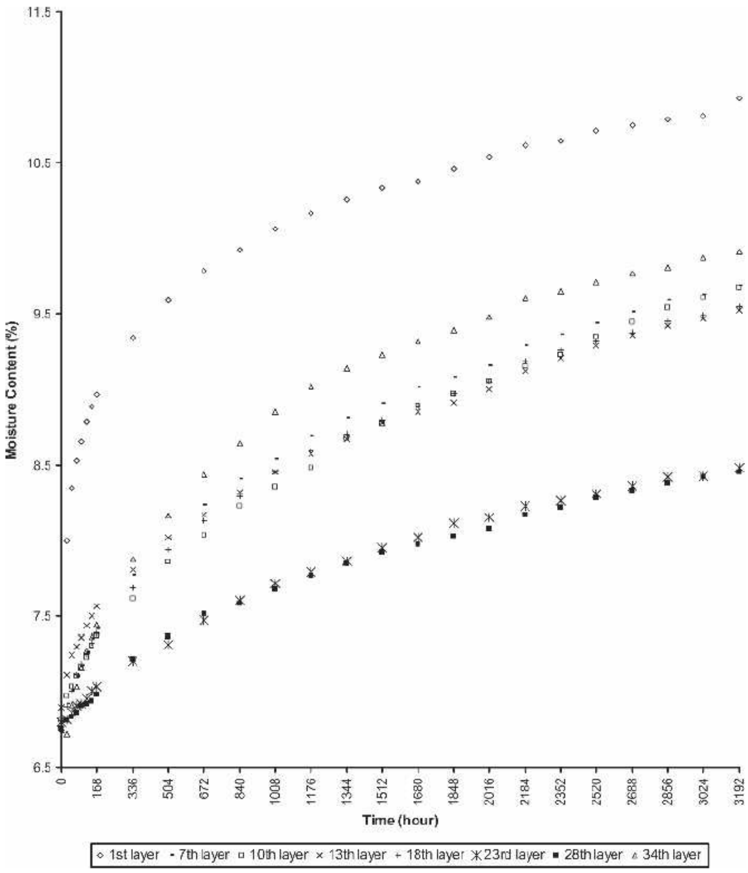


Figure 28: MC change by layer. (Zhang et al., 2006)

An overview of the distribution by layers was plotted in Figure 28. The mean MC for each layer was the average of readings from all sensors in that layer from the three groups. It was found that the top and bottom layers had the highest rate of moisture adsorption and the highest MC for top and bottom layers were 11.8% and 11.2%, respectively. The lowest MC was found from a range of 23rd to 28th layers, about 1/3 up from the bottom layer, with an average MC of 8.5%. The middle layer, 18th layer, reached an average MC of 9.6%.

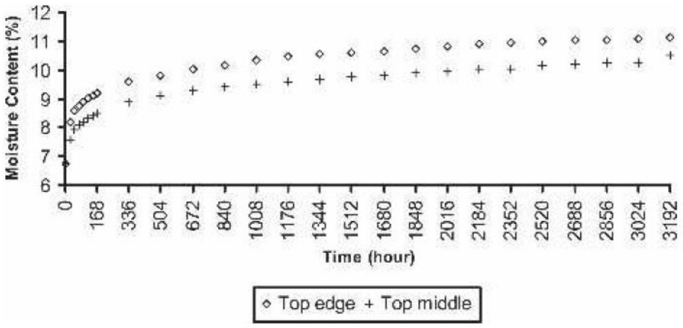


Figure 29: MC comparison between middle and edge boards of the first layer.

In Zhang et al. (2006), they also confirmed that, for the top layer, the middle boards with one face exposed to the environment, reached a lower MC (1% less) than those edge boards with two faces exposed, as can be seen in Figure 29. In Figure 10, a comparison was made between outside boards, with either a face or an edge exposed to the environment, and those inside board, with no surface directly exposed to the environment. It can be seen the outside boards had a faster MC change rate for the first week and then difference in change rate became constant.

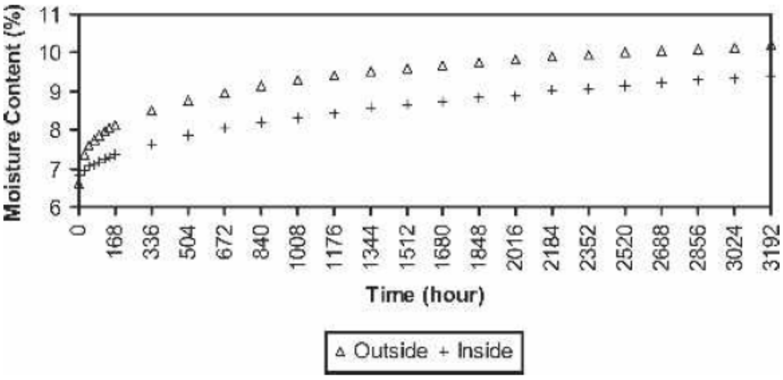


Figure 30: MC comparison between outside and inside boards.

Zhang et al. (2006) also proposed a simplified equation based on Fick's equation for diffusion into a slab or sheet to predict lumber package over time:

$$MC = a - b \times EXP(-\alpha \times t^\wedge\beta)$$

where MC = MC at time t; a, b, α and β are parameters given in Zhang et al. (2006).

Wood and other materials in transit: containers

Wood in containers

Espinoza et al. (2007) conducted a study in monitoring the equilibrium moisture content during storage, manufacturing and shipping of Bolivian wood products. After kiln-drying, the lumber will normally be stored in open sheds, and the EMC could change from 5% to 16% in different areas of Bolivia during different seasons. The Bolivian wood products are exported in containers, and their temperature and relative humidity can change drastically during transportation.

In Espinoza et al. (2007), the temperature and relative humidity (RH) of manufacturing plants in three cities of Bolivia (Santa Cruz, Cochabamba and La Paz) and in three containers. Nomad dataloggers were used to measure the temperature and RH, and these measurements were then used to calculate the equilibrium moisture content (EMC). The EMC is the MC of wood when it reaches equilibrium with the environment. The EMC is calculated using the equation provided by Ross (2010):

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

Where: where h is relative humidity (%) and W, K, K_1 and K_2 where K factors are diffusion coefficients and can be calculated using the following equations:

For temperature T in °C,

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

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

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

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

Three sensors were installed at each manufacturing plant, with one in the dry lumber storage area and two inside the plant. The measurement durations were 5 months in Santa Cruz and La Paz and 8 months in Cochabamba. According to Espinoza et al. (2007), 20 measurements of temperature and RH were taken each day. In addition, their study also used the above equation to generate data for 12 months of the year in 11 Bolivian cities through the use of historical weather data.

The results from Espinoza et al. (2007) found that when both storage and manufacturing areas used three-wall shed configuration, the MC of kiln-dried timber increased from 7% or 8% to 13-14% over 5-8 months. And the MC of timber in storage area was about less than 1% higher than those in the manufacturing area, see Figure 31 and Figure 32.

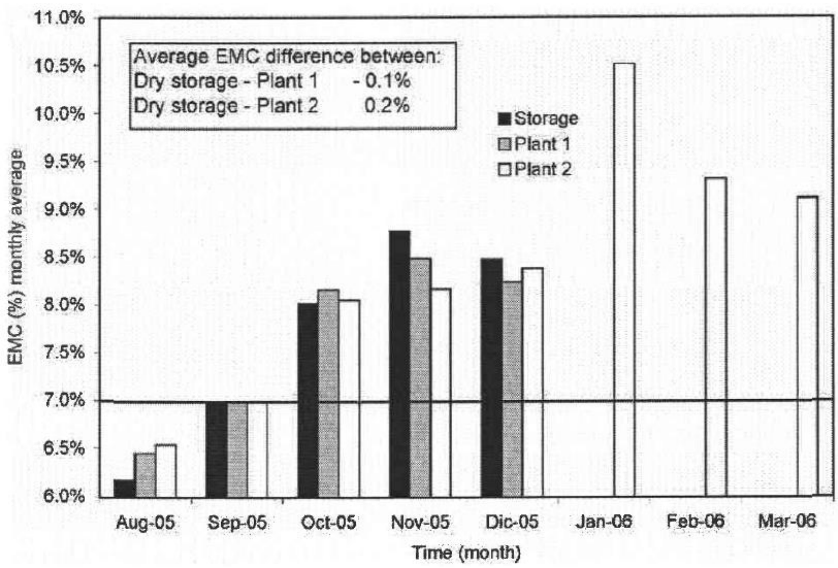


Figure 31: Monthly average EMC values for plant (three-walled shed configuration) in Cochabamba-Bolivia. August 2005 to March 2006. Horizontal line represents lumber MC after drying.

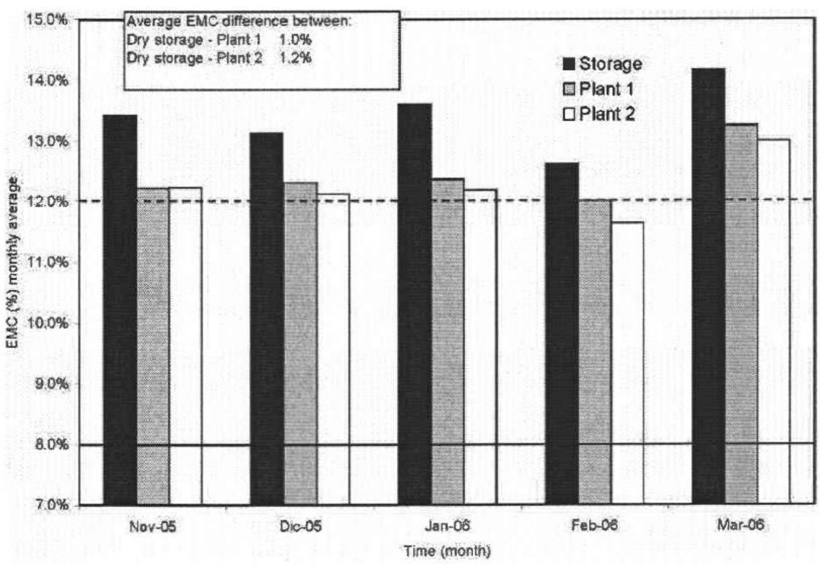


Figure 32: Monthly average EMC values for plant (three-walled shed configuration) in Santa Cruz-Bolivia. November 2005 to March 2006. Continuous and dashed horizontal lines represent respectively, lumber MC after drying for millwork (8%) and garden furniture (12%).

When the storage area was a shed opened at its four sides while the manufacturing area is in a close shed, the MC of the wood in the storage area increased from 7% to almost 14% at the highest and the MC of the wood in the manufacturing area increased from 7% to only 10% at the highest over 5 months, see Figure 33.

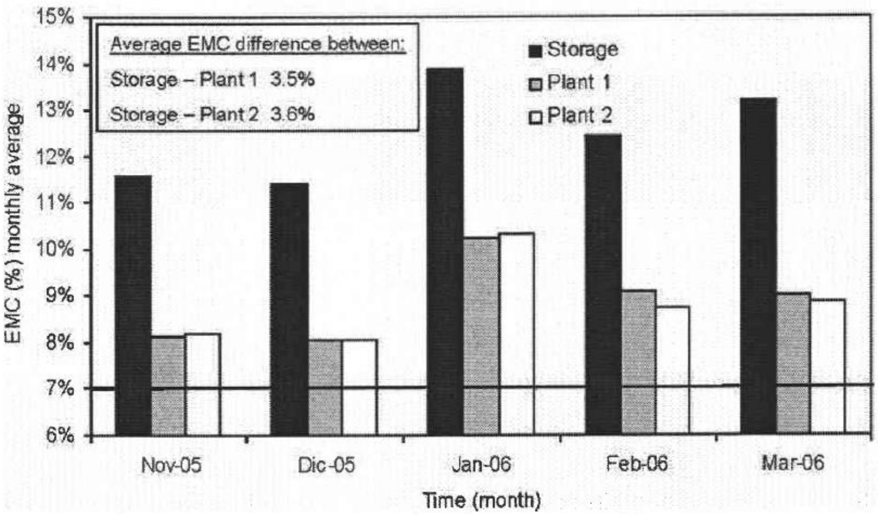


Figure 33: Monthly average EMC values for plant (storage in a shed opened at four sides, manufacturing area in a closed shed) in La Paz-Bolivia. November2005 to March 2006. Horizontal line represents lumber MC after drying.

The three containers were each in different shipments: two containing exterior doors from Cochabamba to Miami, Florida and one containing furniture parts from La Paz to Norfolk, Virginia. For each container, two sensors, one inside and another outside the package were installed, and 48 measurements were taken per day. All the products were wrapped in stretch-plastic, covered with corrugated cardboard and tied with plastic or metal straps. The first shipment did not have top and bottom wrapped with plastic (Espinoza et al., 2007).

The container shipment from Cochabamba to Miami was first transported in a truck to Arica port in Chile on 31 July 2005 and then arrived at Miami on 5 September 2005. It was found that the maximum temperature occurred when the ship passed the equator, and the lowest temperature occurred when the truck passed the Andean mountains at 15300 feet above sea level. The results from Espinoza et al. (2007) suggested the application of the stretch-plastic wrap was effective as a moisture barrier for some time, as indicated in Figure, the difference of EMC inside and outside the package reduced from 5.1% in the 43rd hour of shipping to below 1% on the 12th of shipping, see Figure 34. The low EMC at the beginning was explained to be due to the dry season (July-August).

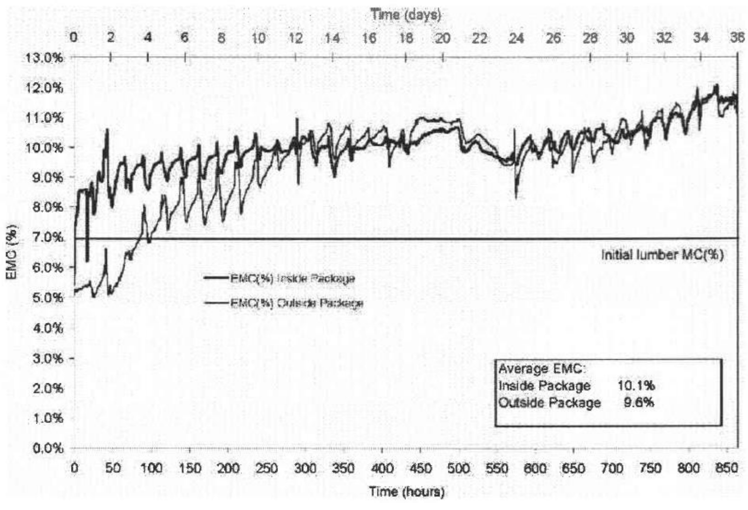


Figure 34: Hourly EMC values during first shipment of wood products from Cochabamba to Miami, Florida. The horizontal line represents lumber MC after drying.

The second shipment from Cochabamba to Miami was from January to February (a more humid season), so the initial EMC in Figure 35 was higher than those of the first shipment. However, as can be seen, the fluctuation of the EMC inside the package was smaller and smoother than the EMC outside the package. Espinoza et al. (2007) explained that the cargo for the second shipment was placed farther from the container walls and was in complete cover by the stretch-plastic while the first shipment was not covered on the top and bottom. The third shipment had similar results as the second one (see Figure 36); however, due to the damage to the datalogger outside the package, a comparison cannot be made.

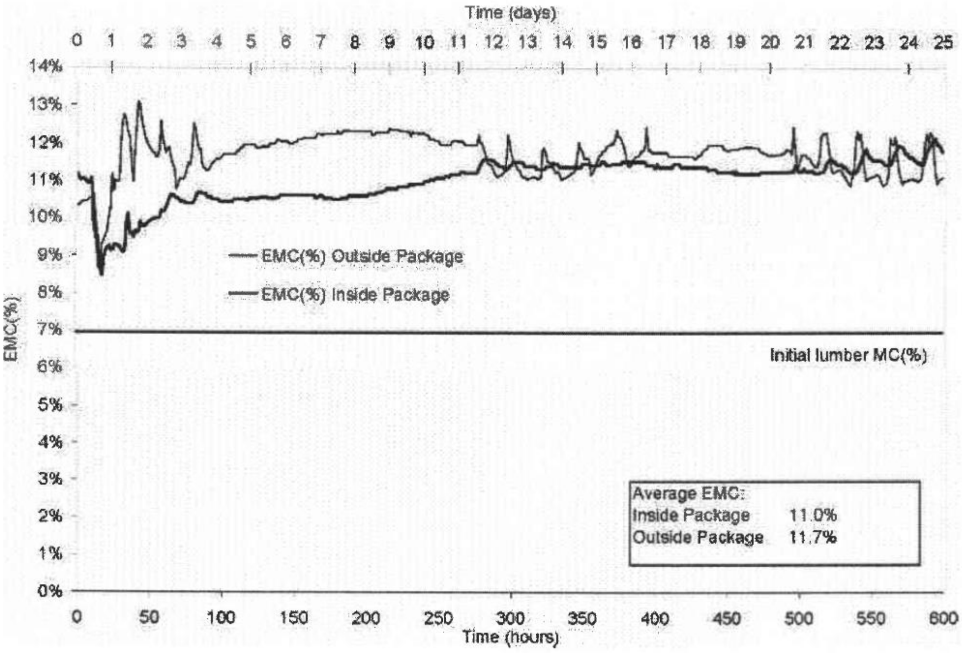


Figure 35: Hourly EMC values during second shipment of wood products from Cochabamba to Miami, Florida. The horizontal line represents lumber MC after drying.

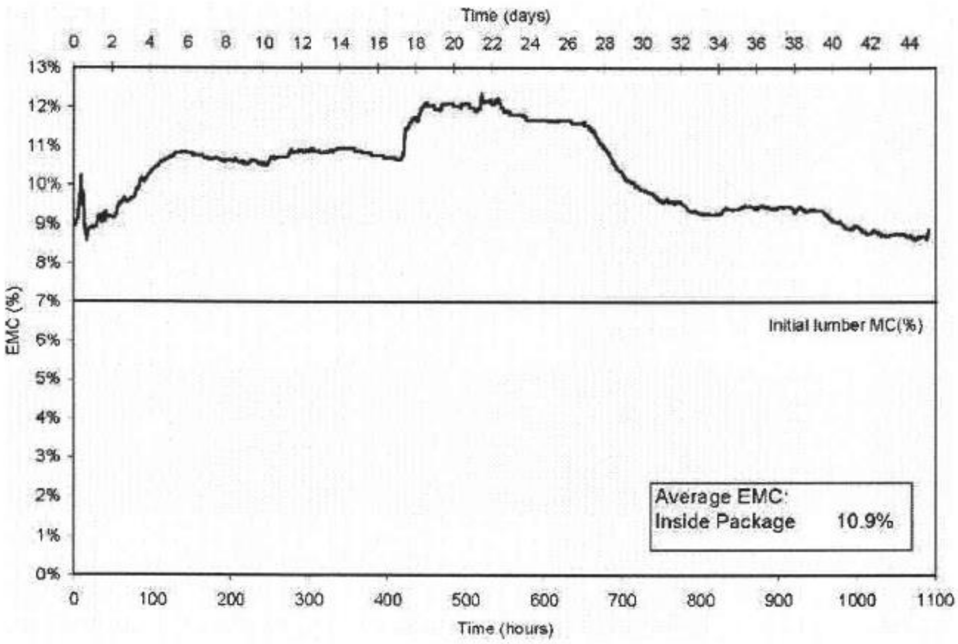


Figure 36: Hourly EMC values during shipment of wood products from La Paz to Norfolk, Virginia. The horizontal line represents lumber MC after drying.

Overall, the study by Espinoza et al. (2007) demonstrated the EMC of wood could change significantly after the kiln-dry process, the configuration of the storage shed and manufacturing area, the temperature and RH of the location and its geographical region are essential parameters worth considering for the timber industry. As suggested by Espinoza et al. (2007), a closed-shed facility with a design that controls the internal temperature to be higher than the outside is preferred to control the EMC of wood. In addition, during oceantransportation, using stretch-wrap plastic covering the entire package and placing the package away from container walls can help avoid condensation.

Other commodities in containers

The movement of moisture and its condensation on a cold surface can create damages to hygroscopic commodities, e.g. wood products, that are transported in containers. According to Sharp et al. (1979), cargo-sweat occurs when a cool cargo is shipped to a warm region and the moisture moves towards the load while container-sweat occurs when a warm cargo is shipped to a cool region and moisture moves to the walls of the container. The condensation will cause mould growth and damage the commodities.

Research investigating the prevention of condensation damage to cocoa beans transported in containers was conducted by Sharp et al. (1979). Similar to seasoned wood, the safe storage of cocoa is usually below 7.5% MC, and this corresponds to an equilibrium 80% RH. When condensation occurs to the ceiling of the container, moisture will fall onto the cargo, and mould growth can proceed and damage the cocoa beans. Sharp et al. (1979) commented that the use of ventilation could reduce the MC of the air inside; however, it requires permanent modification to the container. In addition, desiccant at that time was expensive, and a dehumidifier requires maintenance as well as an external power source. Therefore, Sharp et al. (1979) decided to insulate the container walls to maintain the temperature of the inner surfaces of the container above the dew point.

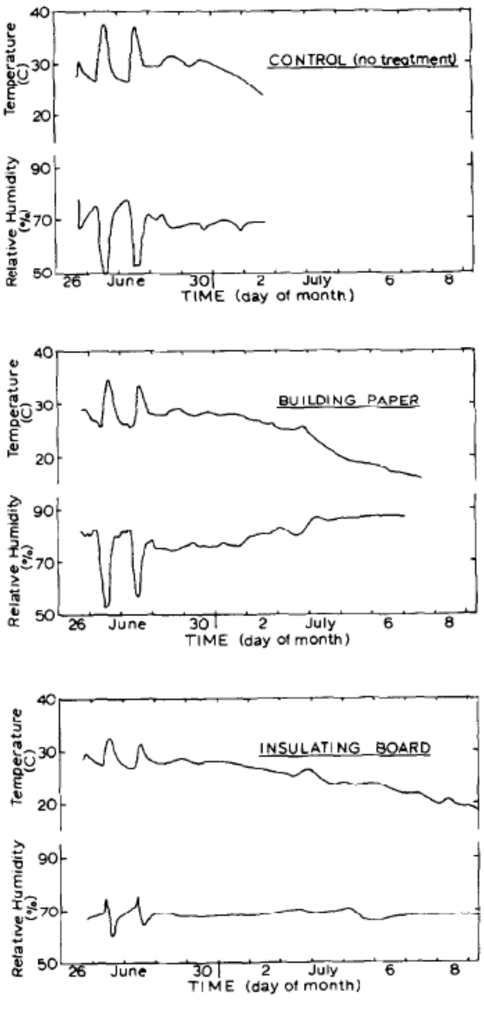


Figure 37: Temperature and humidity records: First trial. (Sharp et al., 1979)

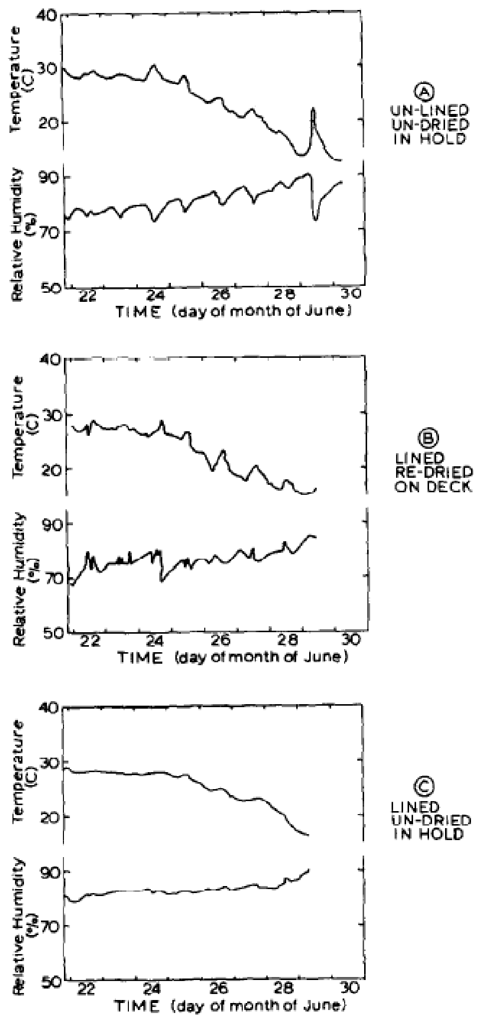


Figure 38: Temperature and humidity records: Second trial. (Sharp et al., 1979)

In the first trial of Sharp et al. (1979), three containers each loaded with 15t cocoa were transported below deck from Rabaul, Papua New Guinea to Sydney, Australia during winter. One of the containers was untreated as a control. The other two were lightly insulated on the ceiling. Among the two, one container had a lining of building paper faced on both sides with aluminium foil, fixed to a light wooden framework beneath the ceiling (Sharp et al., 1979). The foil was used as a radiation shield, and the air space between the building paper and the container was designed to provide insulation. Another container had a lining of 12mm thick insulation board nailed to a light wooden framework. During transportation, the containers were stuffed and stored covered to control the temperature variation. However, after unloading from the ship in Sydney, the container was left in the open for a few days before unstuffing; thus, leading to possible container-sweat. The entire duration from staffing to unstuffing was 16 days. Sharp et al. (1979) used a thermohygrograph to monitor the temperature and RH within the container. The moisture content of beans at 33 selected locations before stuffing and after unstuffing was determined by oven drying.

After inspection, no evidence of mould growth was found. However, due to the storage in the open space after unloading in Sydney, heavy condensation was discovered in all containers, and the one with insulation boards showed less condensate.

According to Sharp et al. (1979), insulation boards reduced the temperature and humidity fluctuations during the trip when compared with the results from building papers and the control group, see Figure 37.

Different from the first trial, the second trial conducted by Sharp et al. (1979) had one control (A) and two containers all with insulation boards on the ceiling as well as walls and doors. In addition, one insulated container (B) was placed on deck, and another insulated container (C) with control (A) were placed below deck.

Results showed that even with insulation, container B placed on deck showed similar temperature and RH history to the untreated container A placed below deck and B had greater daily fluctuation. As can be seen from Figure 38, insulated container C placed below deck demonstrated better temperature and RH stability when the ship travels from a warm region to a cold region. After unloading, the evidence of mould growth only occurred to the untreated container A. However, after being placed in a semi-covered location on the wharf for one or two days, inspection discovered heavy condensation on ceiling and walls in container A, and light condensation to the insulated containers B & C.

The study by Sharp et al. (1979) indicated that the use of insulation could help to minimise the temperature and RH variation inside the container. Furthermore, little or no condensation was found formed at sea when the container was transported from a warm region to a cold region. To avoid condensation, unstuffing should be conducted as soon as possible, or the containers should be stored in a ventilated building.

Navarro et al. (1988) examined the efficacy of calcium chloride to prevent condensation damage to groundnuts placed in containers for storage. In their study, shelled (initial MC 7.7%) and in-shell (initial MC 8.5%), groundnuts were loaded in 180 bags and placed in layers in the container. A total of four containers were used with calcium chloride of 0kg (control), 30kg, 60kg and 120kg, respectively. The temperatures of the metal roof and floor of the container and the bags at the upper and middle layers of the stack were measured using thermocouple cables. The air temperature and RH inside the container were measured by two thermohygrographs. After 3 weeks of storage, 21 samples of groundnuts were taken from each container to measure their MC.

The temperature variation of the control container for the first week was shown in Figure 39. The graph shows the temperature difference was significant when the container is placed in open space and condensation could occur.

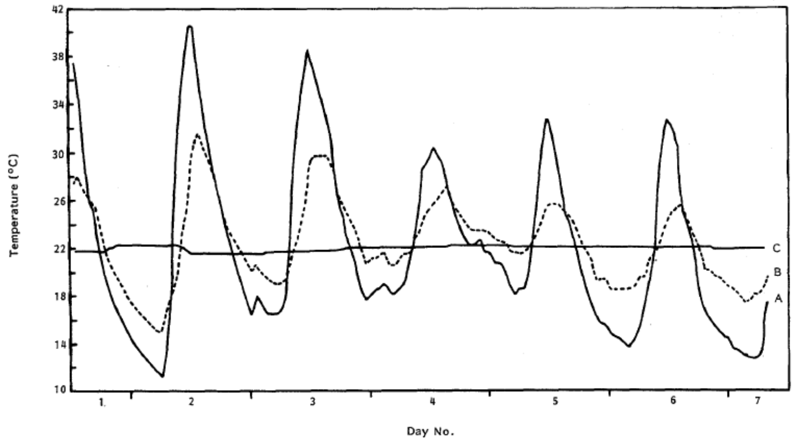


Figure 39: Changes in temperature recorded on the roof(A), upper layer of bags (B), and centre (C) of the control container during the first week of the trial. (Navarro et al., 1988)

The average maximum and minimum RH inside the containers were tabulated in Table 1. As can be seen, in general, the maximum RH dropped with an increasing amount of desiccant. With same maximum RH at headspace for the control group and container with 30kg of calcium chloride, groundnuts at different layers in the container with calcium chloride displayed lower MC, see Table 2.

It was found that the groundnuts in the lower layers of all the groups became drier, including those in the control group. And only the groundnuts in the upper layers of the control group exceeded their initial average MC. With the application of calcium chloride, the MC of the groundnuts were effectively controlled. The effectiveness of the desiccant can also be seen by comparing the in-shell and shelled groundnuts' MC. With more desiccant applied, the difference of MC between in-shell and shelled groundnuts increases, see Table 2. The inspection of the cargos after 3 weeks storage by Navarro et al. (1988) confirmed that mould growth only occurred to the upper layer of the control container.

Table 1: Average maximum and minimum RH (%) recorded during the trial in the headspace and on the floor of the containers. (Navarro et al., 1988)

		Calcium chloride per container (kg)			
		0	30	60	120
Headspace	Maximum	93	93	89	82
	Minimum	43	41	40	46
Floor	Maximum	94	83	86	75
	Minimum	54	53	47	42

Table 2: Average moisture content (± SE) of in-shell and shelled groundnuts taken from different locations in the containers at the end of the trial. (Navarro et al., 1988)

Position of bags in stack	Sampled layer of each individual bag		Calcium chloride per container (kg) 0	30	60	120
Upper layer	Upper	In-shell	10·2 ± 0·7	8·0 ± 0·2	8·0 ± 0·2	8·1 ± 0·2
		Shelled	9·9 ± 0·7	7·4 ± 0·2	7·2 ± 0·3	6·3 ± 0·2
	Lower	In-shell	9·9 ± 0·4	8·6 ± 0·2	7·7 ± 0·2	7·7 ± 0·2
		Shelled	8·7 ± 0·4	7·6 ± 0·4	6·9 ± 0·3	6·9 ± 0·3
Middle layer	Centre	In-shell	8·3 ± 0·3	8·5 ± 0·2	7·5 ± 0·3	7·5 ± 0·3
		Shelled	7·7 ± 0·2	7·2 ± 0·3	7·2 ± 0·2	7·2 ± 0·1
Lower layer	Centre	In-shell	7·5 ± 0·2	7·6 ± 0·1	7·1 ± 0·1	7·1 ± 0·1
		Shelled	6·7 ± 0·1	6·3 ± 0·2	6·0 ± 0·1	6·0 ± 0·1

Conclusion

The literature review provides some insights on the work in NIFPI 109. The use of historical weather data can help generate estimated EMC of wood and allowing researchers and the industry to know when and where there will be significant moisture variation in kiln-dried wood products. In addition, the information can help the industry to make a better decision on designing industrial facilities and packaging of wood products.

The investigation conducted by Sharp et al. (1979) demonstrated that insulation could help to minimise the temperature and RH fluctuation during transportation on the sea. However, after the vessel arrives at its destination, the container will be unloaded from the ship, and the container could be placed in different places before the cargo is discharged. During this period, the container is subjected to various temperature and humidity cycles. And condensation damage could occur. For NIF109, it would be worth comparing the temperature and RH fluctuation at different stages of transportation, e.g. on the sea and from unloading to discharge. To avoid product losses, it may be useful to shorten the period between unloading to discharge. If a delay is unavoidable, the containers could be stored covered in a ventilated building to minimise the risk of condensation damage.

The work done by Navarro et al. (1988) demonstrated the temperature and RH variation when a container was stored in open space. Such cases could be applied to containers loaded with wood products stored in the port area either waiting to be loaded to a ship or to be discharged. Condensation could cause damage to the hygroscopic commodities, and the application of desiccant such as calcium chloride could be a solution.

Study on monitoring the moisture distribution in the lumber package also offered a significant amount of information. The sensors arrangement and settings of the climate chamber could be used as a reference. The results from Zhang et al. (2006) also provided information on how the board's MC react at different locations of the package under humid condition. However, their study was based on fix condition at 21.1℃, 45% RH, the moisture distribution under climate variation was not included. In NIFPI109, the moisture distribution under random climate variation (during transportation) is of great interest to the industry. It may also be worth to begin from a controlled cyclic variation to investigate the pattern of MC change of lumber in a container.

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TR-2 Timber’s MC in the supply chain

Species behaviour and conditions in storage and service

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November 2022

NT045 / NIF109 Managing timber’s moisture content in the supply chain, construction and in service

Contents

Introduction

This technical report TR-P2 is part of the National Institute for Forest Products Innovation's (NIPFI) project: *NT045 / NIF109 Managing timber's moisture content (MC) in the supply chain, construction and in service*.

This project's objective is to generate and distribute informed industry guidance on best practice for the economic and effective MC control of timber and wood products in the Australian timber supply chain. It aims to identify regular problems and key influencing factors; build an initial knowledge base of equilibrium moisture content (EMC) conditions and timber's MC performance in the timber supply chain; and generate industry best practice guidance.

This report includes the results of the project's static sample monitoring component, designed to collect and assess first-generation information covering:

- Temperature and humidity conditions found in the Australian timber supply chain.
- MC responses of common species and wood products stored in those conditions.

Acknowledgement

This research was only possible through the generous participation and contribution of a range of timber industry producers and stockists, building companies, building owners and managers, and research collaborators in several states.

Methodology

The component's methodology involves:

- Design and manufacture of the static monitoring units.
- Unit distribution
- Data collection and assessment.

Static monitoring unit design and manufacture

To collect the required species and environmental information, static sensor and sample units were designed and fabricated. Variants were developed for use inside in sheltered storage facilities and buildings (Figure 1) and for weather-exposed building sites with possible occasional wetting (Figure 2). Each static unit included three components: a set of timber samples, a supporting or sheltering frame, and a data sensing and collection bundle.

Timber sample set

Each unit contained a set of generally nine timber or wood product samples of known species, size, weight, and MC, cut from standard seasoned commercial products. Each sample was 310 mm long, 80 mm wide and nominally 12 mm thick, except for the LVL which is 38 mm thick. This was the thinnest available standard product. As the samples were being prepared, MC samples were taken from each end and assessed for MC and density to AS1080. Table 1 list the samples in the set while Table 2 lists their densities and initial MC.

The grain direction across the depth of the pieces was recorded to the nearest 15 degrees. While pure quarter sawn or back sawn samples were preferred, this was not always possible. The sample surfaces were dressed and sanded but uncoated. To limit moisture uptake along the end grain, the ends and the last 10 mm of each face was finished with a bituminous sealant.

Table 1: Species

Species	Species	Species
Radiata pine *P. radiata*	Silver top ash *E. sieberi*	Blackbutt *E. pilularis*
Spotted gum *Corymbia maculata*	Tasmanian blue gum *E. globulus*	Weathertex high-density fibreboard
Messmate *E. obliqua*,	Plantation Shining gum *E. nitens*	LVL *P. radiata*

Brass pins were set into CNC routed holes in the front face of each sample. These were spaced 60 mm to the outside of the pins across the piece and 195 mm along the piece. The samples were grouped in sets, and each scribed with the species or product name and the set number. See Figure 3. Once fitted with a cup hook, the sample's final weight was recorded.

Table 2: Sample densities and initial MC

	Weathertex	***P. radiata***	***C. maculata***	***E. globulus***	***E. sieberi***	***E. obliqua***	***E. nitens***	***E. pilularis***	**LVL**
Density (kg/m^3)									
Average	1024	464	1086	974	876	666	607	901	655
Maximum	1075	520	1164	1077	970	798	753	992	695
Minimum	662	407	849	867	778	593	455	798	610
Initial MC (%)									
Average	5.9	11.4	11.5	13.4	13.4	11.7	11.4	13.0	9.1
Maximum	6.6	13.3	14.5	14.7	14.7	12.5	12.4	14.2	9.7
Minimum	5.6	10.0	8.1	11.4	11.4	11.1	10.6	11.3	8.4

Figure 1: An internal static sensor and sample unit.

Figure 2: A weather-protected static sensor and sample unit.

Figure 3: Pins fixed to the labelled sample's face.

Figure 4: A minnow sensor.

Supporting or sheltering frame

Fabricated from bent steel tube and braced with plywood, the supporting frames were designed to be easy to assemble and use, and withstand conditions expected in the supply chain. They featured a position for the sensor, and a top rail from which the timber samples were suspended and free to move. The assembled units were rigid and light enough to be stable on a bench and easy to move from place to place if required.

The weather-protected unit included a ply cover with sufficient ventilation holes to allow easy air movement. Their design assumed that they would be protected from driving rain but exposed to water splashes, wind, and similar site conditions.

Data sensing set

The option to include automatic weighting and telemetry systems in the static units was assessed but found to be overly complex and expensive. As a result, simper, robust Minnow temperature and humidity sensor were selected. See Figure 4. These sensors were available, relatively inexpensive, programable, had good data capacity and an effective 12 month battery life in operation. Their disadvantage was the data had to be downloaded manually. The units were fixed to the frame with Velcro. Before distribution, each Minnow was numbered and programmed to collect temperature and humidity at 10 minute intervals.

Unit distribution

For this component, at least 34 static monitoring unit were distributed to collaborator companies and other research groups in locations and operating businesses that broadly represent the range of conditions experienced in the timber supply chain. Useful data sets were recovered from 31 units. See Table 3.

As discussed in TR-S1, timber stored in the supply chain is exposed to a range of environmental conditions that vary with its geographical location, the product's general exposure at the location, and its immediate protection.

- Location determines the climate that drives an area's natural ambient conditions. In this component, locations are grouped by the climate zones (CZ) defined in the National Construction Code's (NCC) and listed in Table 4.
- The general level of protection that buildings or similar enclosures afford determines the stored timber's exposure to ambient conditions at a location. Table 5 lists the exposure conditions considered in this component and the number of static units deployed in each.
- The stored timber's immediate protection includes whether it is the product is grouped together in a pack (with or without wrap) or be an individual items (with or without coating) exposed to the surrounding environment. Given this range of this options, the timber's immediate protection was not considered in this component.

Table 3: Unit distribution by state

State	Number of units.
NSW	5
NT	0
QLD	6
SA	3
TAS	10
VIC	5
WA	2
Total	**31**

Table 4:Unit distribution by NCC climate zones

CZ	Description	Example locations	No of units
1	High humidity summer, warm winter	Cairns, Broome	0
2	Warm humid summer, mild winter	Brisbane, Byron Bay,	7
3	Hot dry summer, warm winter	Alice Springs	0
4	Hot dry summer, cool winter	Albury, Tamworth	0
5	Warm temperate	Sydney (coastal), Adelaide, Perth	7
6	Mild temperate	Melbourne, Mt Gambier	6
7	Cool temperate	Hobart, Launceston	11
8	Alpine	Thredbo, Tasmanian highlands.	0

Table 5: Unit distribution by exposure conditions

Exposure condition	Description	No. units
Fully exposed	Exposed to natural ambient conditions outside at a building site, storage area or building in service.	1
Sheltered	Under a roof at a building site or storage area.	2
In store	In an enclosed, ventilated building that has limited insulation, such as a timber store or joinery workshop. See Figure 5 to Figure 7.	20
In construction	A building site during construction and after envelope lock-up. See Figure 8.	2
In service: unconditioned	Generally, a building with an NCC-compliant envelope but without central heating, cooling, and ventilation systems. It may be heated in summer or have localised cooling in summer.	4
In service: conditioned	Generally, a conditioned office or accommodation space with active heating, cooling, and ventilation systems.	2

Figure 5: Static sensor and sample unit at a furniture fabricator in Melbourne.

Figure 6: Static sensor and sample unit at a timber store in Sydney.

Figure 7: Static sensor and sample unit at a dry mill Bridgewater.

Figure 8: Static unit at a multistorey construction site at Launceston.

In Tasmania, research staff generally delivered and installed the unit. Units sent to collaborator companies and groups outside Tasmania were usually mailed in a pack that contained the units, samples, sensor, and set-up instruction sheets. Industry members then assembled the units and installed them in suitable locations in their facilities. They were instructed to install the static station approximately 1m above floor level and 1.5m away from the closest wall or window. In an office building or home, they were asked to place the station on a desk or piece of joinery. Instruction and support documents are included in Appendix 2.

Data collection and assessment.

The static units' Minnow sensors allowed automatic collection of the ambient temperature and humidity while the samples' weight, and dimensions between fixed measuring pins was collected manually. The sensors were activated when units were dispatched. While they could collect data automatically for up to 12 months, they were generally download every three months. If download proved problematic for local operators, new sensors were posted to the site, and the original Minnows were returned in reply-paid envelopes.

Research assistants were engaged in several cities for the samples' manual assessment and provided with scientific scales, vernier calipers, an instruction set, training and access to an online phone application for data entry. In locations not serviced by research assistants, local staff were trained in sample measurement and data return. Ideally, samples were weighted and measured every ten to fourteen days and the results entered directly through a phone app into a central spreadsheet.

Over 820 sets of measurements of the nine samples were taken across the distributed sample sets and are reported below. A range of factors influenced the extent of data collection. These included:

- The start of sample measurement was staggered due to complications in unit distribution and recruitment of collaborator companies and research assistants.
- Human error in manual collection and recording of data.
- Impacts from the COVID response. Lockdowns significantly disrupted regular access and measurements, particularly in Melbourne, Brisbane, and Sydney.
- Some sites did not follow the setup instructions satisfactory while minor equipment issues were experienced. These had to be identified and rectified.
- Difficulties in managing the Minnow's data storage and service life. While data download and battery replacement were relatively simple tasks for a trained operator, it proved complicated for others.

Once received, sample measurements were cleaned, and checked for obvious recording error. Downloads from Minnows were saved and amalgamated into working sheets for each site. Temperature and humidity readings were then averaged to provide a single reading for each day.

Simpson's (1998) formula below was used to calculate daily EMCs from these averaged values.

$$\text{EMC} = \frac{1{,}800}{W}\left(\frac{Kh}{1-Kh} + \frac{K_1Kh + 2K_1K_2K^2h^2}{1 + K_1Kh + K_1K_2K^2h^2}\right)$$

For temperature in Celsius:

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

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

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

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

Where T is temperature, h is relative humidity (%/100), EMC is moisture content (%), and W, K, K1, and K2 are coefficients of an adsorption model developed by Hailwood and Horrobin (1946).

Monitored locations were characterised by climate zone and exposure condition and grouped. Species and condition results are then averaged across these sites. Groups with a single site was retained if they had data set of more than 15 readings, and provided interesting results.

To represent the timber's response to seasonal conditions, four key periods were identified: Summer: mid-January; Autumn: mid-April; Winter: mid-July; and Spring: mid-October. For each site, the average ambient conditions were calculated for one week in each period (12th to 18th of each month), and partnered with the results of nearest sample measurement. These were then averaged as part of the group calculations.

Results and discussion

The results and discussion below are presented in four sets, namely:

- As a single group of results from all monitored sites.
- In ten groups covering 28 monitored site in four climate zone (CZ2, CZ5, CZ6, and CZ7) and five exposure conditions (sheltered, in store, in construction, in service: unconditioned, and in service: conditioned)
- As comparisons across climate zones and service conditions.
- As individual site reports in Appendix 1.

Single group results

As set out in TR-1, the basics of wood's MC are documented in key references such as the Forest Products Laboratory's Wood handbook (2010). Timber and wood products in service contain water. The amount of water they contain at a particular time is known as its MC.

Wood is hygroscopic and timber's MC varies with its surrounding conditions. From the time timber leaves its primary production site as a seasoned product until it is eventually decommissioned from service, timber and other wood products are subject to a combination of general static environments in buildings or enclosures and dynamic environments in transit or on building sites. Each has a different and changing temperature and humidity profile. In each of these stages, the products can be packed (with or without wrap) or be an individual items exposed to the surrounding environment. In each of these environments, the MC of the timber or wood product changes as it loses or gains moisture to be in equilibrium with the surrounding atmosphere. As this moisture forms part of the wood matrix, timber will shrink when it loses moisture and expand as it absorbs moisture. This shrinkage or expansion occurs at different rates in each of the three principal wood grain directions: radially - across the growth rings, tangentially - around the growth rings and longitudinally - along the grain. Timber's EMC is the MC where timber neither gains nor loses moisture from the surrounding atmosphere. There are direct relationships between the wood's EMC, species (or product) properties, and the ambient temperature and relative humidity of a location.

While EMC estimates are regularly calculated from temperature and humidity conditions, as they have been in this project, the actual EMC for a wide range of species conditioned in the same environment can vary substantially (Ahmet et al. 1999). The EMC achieved for individual pieces of a single species can also vary dependent on the samples dimension and the piece's previous drying history.

Assessment of the readings of all sample in all locations assessed in this component confirms these basic understandings while providing quantitative details of conditions that occur in the Australian timber and wood products supply chain. They show that:

- The MC of timber and wood products change to be in equilibrium with the surrounding environment. In the supply chain, this occurs across location and seasons. This is reported in detail below.
- Species and products have individual EMCs. Engineered wood products (EWPs) generally have a lower EMC than solid timber species, with Weathertex lower than LVL and LVL lower than its constituent Radiata pine. Species EMC vary with the type of wood (hardwood and softwood) and other factors. See Figure 9.
- The average MC of species and wood products changes with climate zone and exposure conditions. See Figure 10. Timber in stores is driest in CZ6 (Melbourne) and wettest in CZ2 (Brisbane). Across exposure conditions, construction sites are generally the wettest while internal service environments are significantly drier than any other location in the supply chain.
- Species expand and contract with changes in MC. Unit movement as measured across six CZ7 storage sites is low longitudinally but higher across the width of the samples. Of the tested samples, Weathertex has the lowest movement overall. The extent of average movement of all species measured at these sites across the width was 0.76% across a 100 mm board.

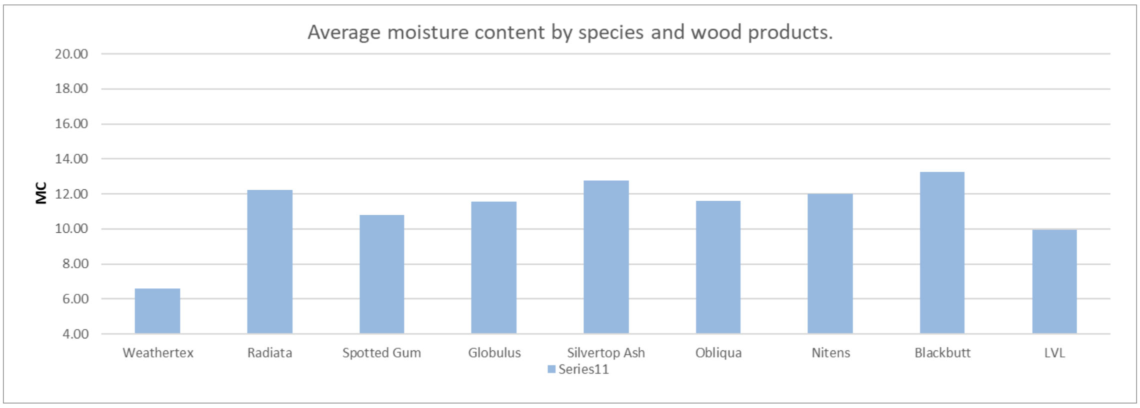

Figure 9: Average MC of all readings by species and product.

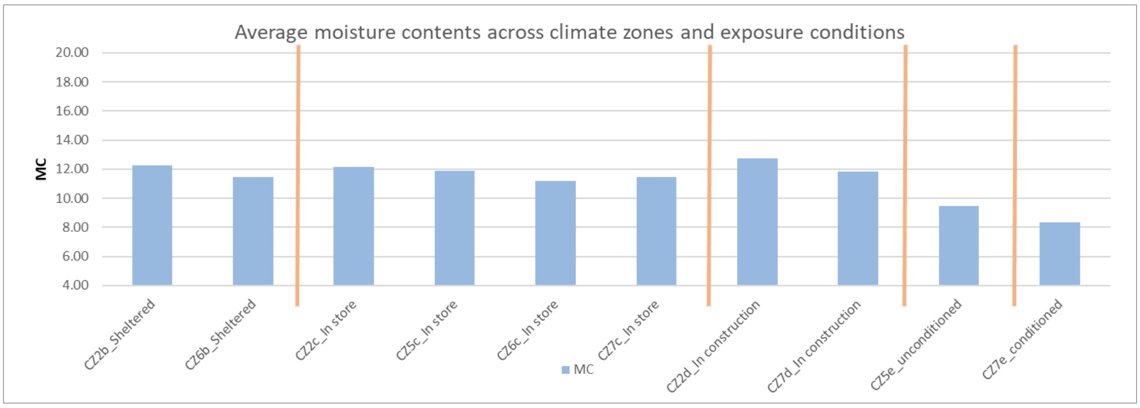

Figure 10: Average MC of all readings by climate zone and exposure condition.

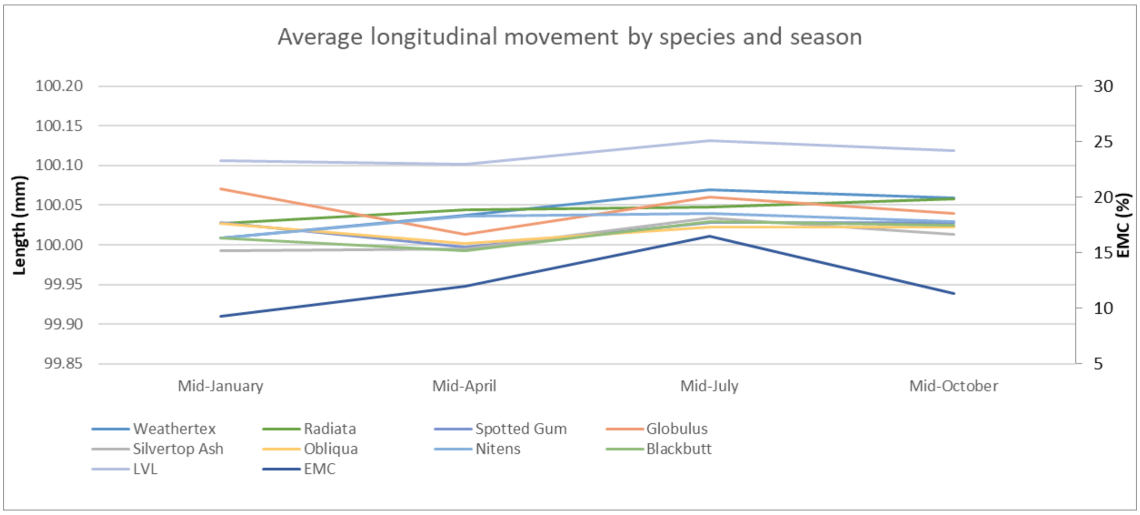

Figure 11: Average longitudinal movement in millimeters by species and season across six CZ7 sites. The seasonal EMC relates to the right axis.

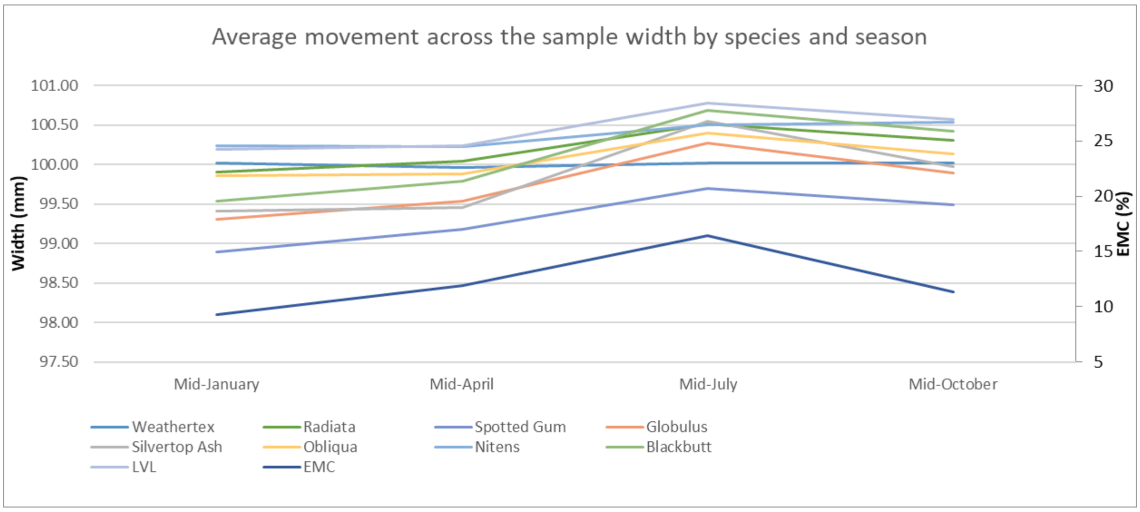

Figure 12: Average movement across sample width in millimeters by species and season across six CZ7 sites. The seasonal EMC relates to the right axis.

Climate zone and exposure condition groups

The discussion below covers the results of 28 monitored site in ten groups covering four climate zone and five exposure conditions. Generally, the groups are arranged initially by climate zone, from CZ7 to CZ2, and then by exposure condition from the most benign (in-service in a condition space) to notionally the most impactful (in a sheltered store).

As discussed above, the average MC of species and wood products changes with climate zone and exposure conditions. In the supply chain, the climate zone's influence on MC decreases as the timber exposure conditions improve. The climate zone's influence is most significant when the wood is directly exposed to natural conditions outside. Any type of building or shelter moderates the climate's most extreme conditions (direct sun and rainfall) but may have limited impact on climate-driven fluctuations in temperature and humidity. However, as a building's thermal performance improve and heating and cooling services are included, it can moderate temperature and humidity and improve the stored timber's exposure conditions to a point where the impacts of climatic difference are negligible.

Given this, the climate zone's influence is most impactful in exposed, sheltered and in store conditions. Its impact declines significantly in unconditioned residential and commercial buildings and is most benign in fully conditioned spaces. Ventilation, heating, and cooling systems in these spaces control temperature and humidity conditions within relatively narrow comfort bands acceptable for sedentary office workers.

Timber's exposure during construction is a special case, as climate and ambient conditions may be exaggerated by intermittent exposure to direct sun and rainfall, uncontrolled ventilation, partial insulation, unmoderated solar gain, and ponding water. Also, many construction activities such as concreting and plastering introduce moisture into the building site, and this can take significant time to dissipate.

While information about the timber's immediate protection was not collected in this study, this protection does influence comparisons between the measured condition of the timber samples and the MC or rate of MC change of the timber stored or in-service in the spaces. Considering the exposure conditions and product arrangements:

- In unconditioned and conditioned spaces in service, the measured condition in the timber samples is likely to closely reflect the MC of the space's timber joinery and furniture. While these elements may have protective coatings, they and the samples are directly exposed to ambient conditions.
- On construction sites, the MC condition and rate of MC change of stored timber may be similar to the conditions and rate of change measured in the timber samples.
- In storage spaces and workshops, the rate of change of timber stored in packs is likely to be slower and less extreme than change in conditions measured in the timber samples. Wrapped packs will have a lower rate of change than unwrapped packs.

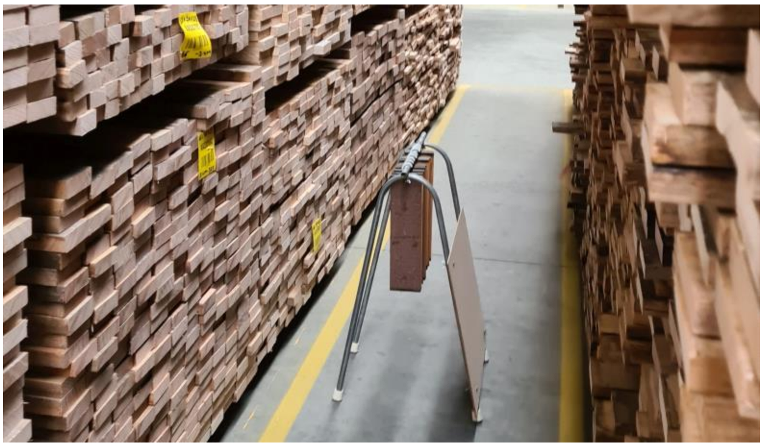

Figure 13: Static monitoring unit between unwrapped packsin CZ7.

Climate zone 7: Conditioned spaces

Two conditioned spaces were monitored in CZ7. See Figure 14. Table 6 lists the locations, the number of readings taken, and the boundary dates for these readings.

The measured conditions in the timber samples are likely to closely reflect the MC of the timber joinery and furniture elements in spaces. While these elements often have protective coatings, both they and the samples are directly exposed to ambient conditions.

Figure 14: Static monitoring in a conditioned office space in CZ7.

Table 6: Unit locations and sample readings

Unit locations	No. of readings	Initial reading	Last reading
CZ7_conditioned_Launceston	29	23/10/2020	10/01/2022
CZ7_conditioned_Hobart	36	23/03/2021	12/01/2022

The ambient conditions in the two spaces were generally very stable, as shown by the average temperature and humidity conditions across seasons. Periodic systems shutdowns during holidays and weekends probably accounts for the broader range of maximum and minimum conditions. The calculated EMC of 8% for the space is low against the range of product MC given in *AS2796 Timber—hardwood—sawn and milled products* and similar standards but expected given the buildings functions. See Table 7 and Figure 15.

Table 8 shows the boundary and average maximum and minimum MC readings across the sites. The range between the average conditions is generally less than 2%. Table 9 and Figure 16 shows the MC response of species and products across season. Their range of less than 1% MC indicating generally stable MC conditions across species during the monitored periods.

These stable conditions illustrate a regular pattern of species and products EMC that can be regarded as a performance baseline for later groups of site. They indicate that:

- Weathertex has a significantly lower MC than other products.
- Weathertex and LVL have the lowest range of MC values.
- LVL and Spotted gum, *C. maculata* have the lowest MC of the solid wood products.
- Radiata pine, Silvertop ash *E. sieberi* and Blackbutt *E. pilularis* have the highest MC.

Table 7: Ambient conditions: Average maximum, minimum and key seasons

	Temperature (°C)	Humidity (%)	EMC (%)
Maximum	23.93	60.21	11.02
Minimum	16.09	31.49	6.41
Range	7.84	28.72	4.62
Key seasons			
Summer: Mid-January	22.31	44.55	8.38
Autumn: mid-April	21.14	40.78	7.82
Winter: mid-July	21.00	43.22	8.19
Spring: mid-October	21.22	40.69	7.81

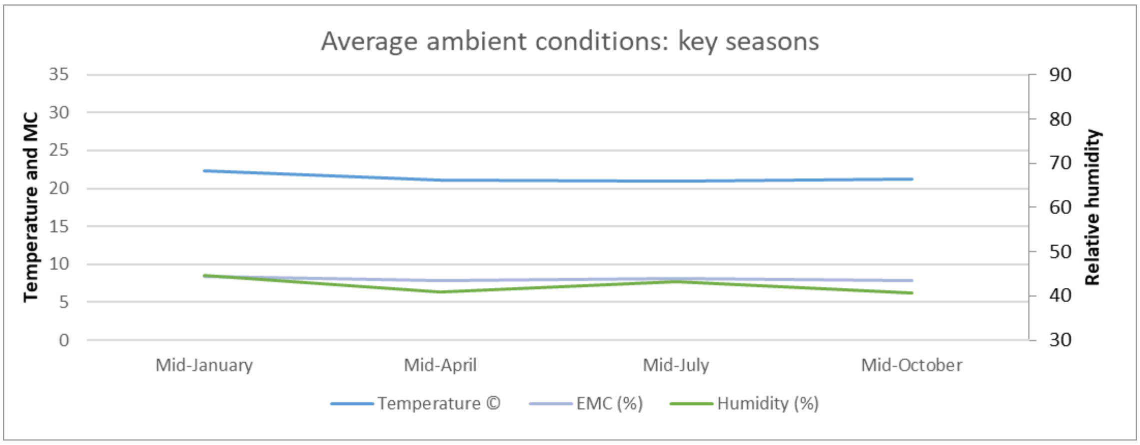

Figure 15: Average ambient conditions: key seasons

Table 8: MC responses of species and products: Maximum and minimum

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Boundary readings across sites									
Maximum	5.71	10.60	9.08	9.79	10.15	10.28	10.44	11.91	9.06
Minimum	4.50	7.62	6.05	7.10	7.90	7.84	7.77	9.21	7.54
Average readings across sites									
Maximum	5.55	10.03	8.88	9.42	9.85	9.85	9.96	11.55	8.80
Minimum	4.52	8.04	6.94	7.66	8.10	8.02	7.93	9.61	7.73
Range	1.03	1.99	1.95	1.75	1.75	1.83	2.03	1.95	1.07

Table 9: MC responses of species and products: Key seasons and range

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Summer	5.01	9.12	7.80	8.63	9.13	9.09	9.04	10.63	8.39
Autumn	4.95	8.95	7.71	8.53	9.08	9.04	9.02	10.64	8.30
Winter	4.90	8.97	7.39	8.20	8.73	8.68	8.67	10.27	8.14
Spring	4.76	8.50	7.12	8.00	8.58	8.62	8.38	10.00	8.05
Range	0.25	0.62	0.68	0.63	0.55	0.47	0.66	0.64	0.34

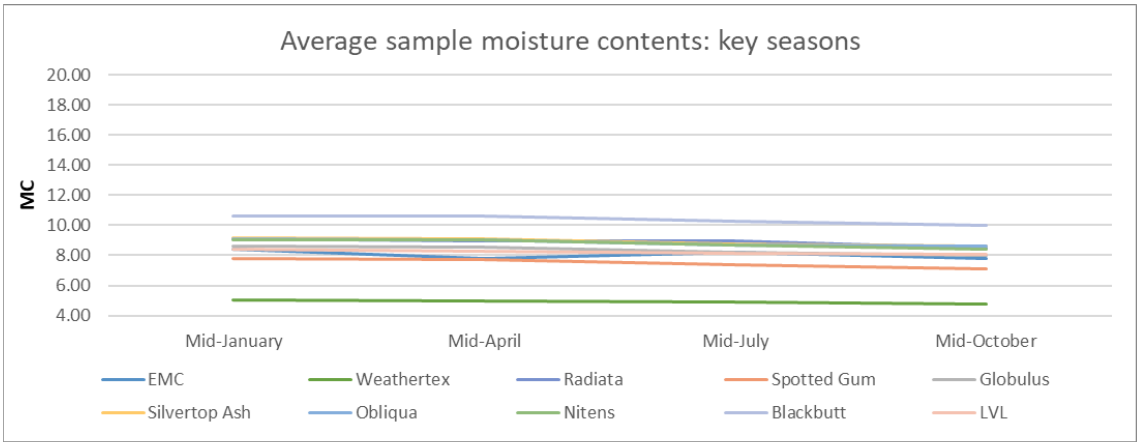

Figure 16: MC responses of species and products: key seasons

Climate zone 7: In construction

One construction site was monitored in CZ7, a three storey public building that had a conventional concrete frame structure, with a timber framed roof, and highly glazed façades. Monitoring began once the concrete frame was in place and continued to final fit out. See Figure 17 and Figure 18. Table 10 lists the location, the number of readings taken, and the boundary dates for these readings.

Figure 17: CZ7 construction – at frame stage

Figure 18: CZ7 construction – fitout

Table 10: Unit locations and sample readings

Unit locations	No. of readings	Initial reading	Last reading
CZ7_In construction_Launceston	37	10/03/2021	12/01/2022

The ambient conditions at the site were highly variable across all indicators. See Table 11 and Figure 19.The mid-winter conditions were extreme with an EMC condition well above the range of acceptable MC for timber elements in varied Australian standards. For structural hardwood products, 90% of the pieces being graded to AS2082 must have a MC not more than 15% with no piece having a MC of more than 18%. Seasoned softwood graded to AS2858 is supplied at a MC not exceeding 15%.

These adverse conditions result from the cold and wet winters common in CZ7 and probably the dissipation of moisture from the concrete structure and other building activity.

Table 11: Ambient conditions: Average maximum, minimum and key seasons

	Temperature (ºC)	Humidity (%)	EMC (%)
Maximum	18.94	84.94	18.32
Minimum	4.57	45.08	8.62
Range	14.37	39.86	9.70
Key seasons			
Summer: Mid-January	n/a	n/a	n/a
Autumn: mid-April	11.90	72.39	14.25
Winter: mid-July	8.86	84.44	18.16
Spring: mid-October	13.16	69.16	13.46

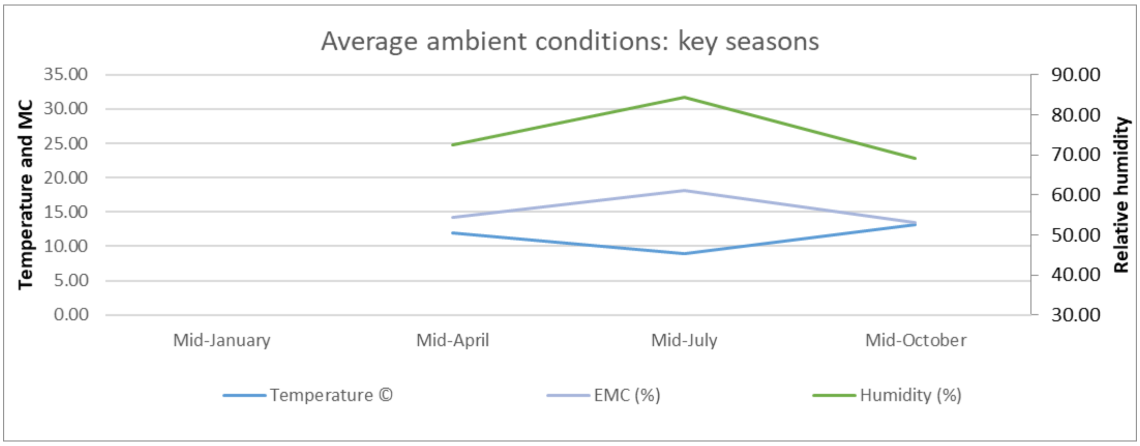

Figure 19: Average ambient conditions: key seasons

The MC response of products reflects the highly variable conditions during the construction process. Table 12 shows the boundary and average maximum and minimum MC readings. Table 13 and Figure 20 shows the MC response of species and products across seasons.

Species MC variability between Summer and Winter is high and regularly above 3%. As in the pattern described above, Weathertex with a significantly lower MC and range of MC than other products while Radiata pine, Silvertop ash and Blackbutt *E. pilularis* have high MC and range of MC.

Table 12: MC responses of species and products: Maximum and minimum

	Weathertex	***P. radiata***	***C. maculata***	***E. globulus***	***E. sieberi***	***E. obliqua***	***E. nitens***	***E. pilularis***	**LVL**
Maximum	9.02	16.80	14.68	15.32	16.35	16.52	16.25	18.31	n/a
Minimum	6.47	11.34	10.93	11.48	12.30	11.80	11.59	13.03	n/a
Range	2.54	5.45	3.74	3.84	4.05	4.72	4.66	5.28	n/a

Table 13: MC responses of species and products: Key seasons

	Weathertex	***P. radiata***	***C. maculata***	***E. globulus***	***E. sieberi***	***E. obliqua***	***E. nitens***	***E. pilularis***	**LVL**
Summer	7.74	12.66	11.62	12.20	13.11	12.78	12.77	14.13	n/a
Autumn	7.22	13.33	12.00	12.96	14.09	13.58	13.12	14.71	n/a
Winter	8.97	16.80	14.47	15.24	16.35	16.52	16.25	18.31	n/a
Spring	7.96	13.08	12.72	13.00	13.83	13.39	13.24	15.06	n/a
Range	1.75	4.13	2.85	3.04	3.24	3.74	3.48	4.18	n/a

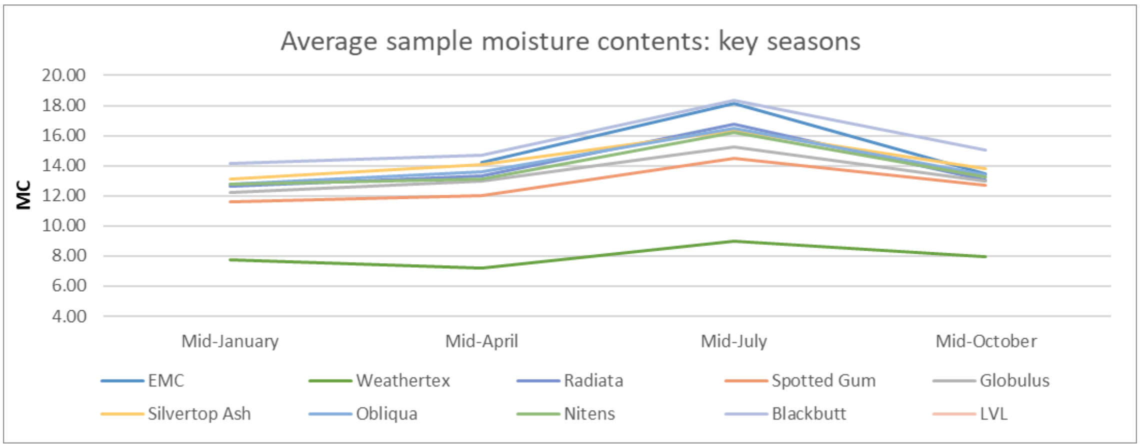

Figure 20: MC responses of species and products: key seasons

Climate zone 7: In store

Seven timber stores or workshop spaces were monitored in CZ7. Six were across northern and southern Tasmania and one store was in Midwest NSW. While the sites varied in their size and construction, all were relatively uninsulated structures, with good natural ventilation and little temperature control. The volume of timber in these types of stores influences the ambient conditions. Timber has a relatively high specific thermal capacity and open packs of timber can act to buffer temperature and humid fluctuations. See Figure 21 and Figure 22. Table 14 lists the locations, the number of readings taken, and the boundary dates for these readings at each site.

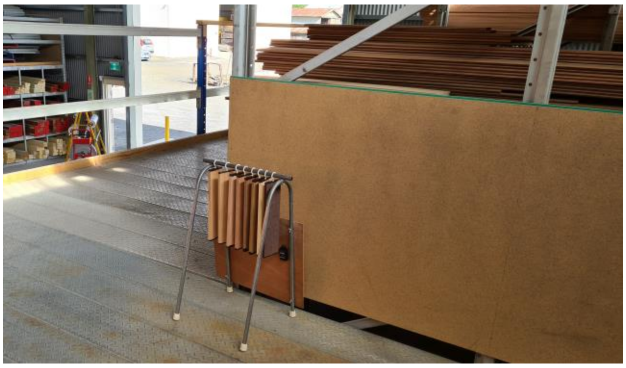

Figure 21: CZ7: Retail distribution store

Figure 22: CZ7: Timber store

Table 14: Unit locations and sample readings

Unit locations	No. of readings	Initial reading	Last reading
CZ7_In store_Hobart 01	40	20/09/2020	17/01/2022
CZ7_In store_Launceston	39	4/12/2020	12/01/2022
CZ7_In store_NSW	37	30/12/2020	8/12/2021
CZ7_In store_Hobart 02	36	20/09/2020	18/01/2022
CZ7_In store_Hobart 03	41	20/09/2020	17/01/2022
CZ7_In store_NWTas 01	35	26/03/2021	23/12/2021
CZ7_In store_NWTas 02	5	26/03/2021	26/05/2021

The ambient conditions in the spaces reflected the seasonal cool temperate conditions common in CZ7, with cold and wet winters and reasonably mild summers. See Table 15 and Figure 23. The EMC calculated from measured conditions in winter is quite high.

Table 15: Ambient conditions: Average maximum, minimum and key seasons

	Temperature (ºC)	Humidity (%)	EMC (%)
Maximum	24.28	82.33	17.39
Minimum	6.73	41.75	8.06
Range	17.55	40.58	9.32
Key seasons			
Summer: Mid-January	20.10	49.52	9.30
Autumn: mid-April	14.22	62.63	11.96
Winter: mid-July	9.64	79.20	16.47
Spring: mid-October	13.83	59.79	11.35

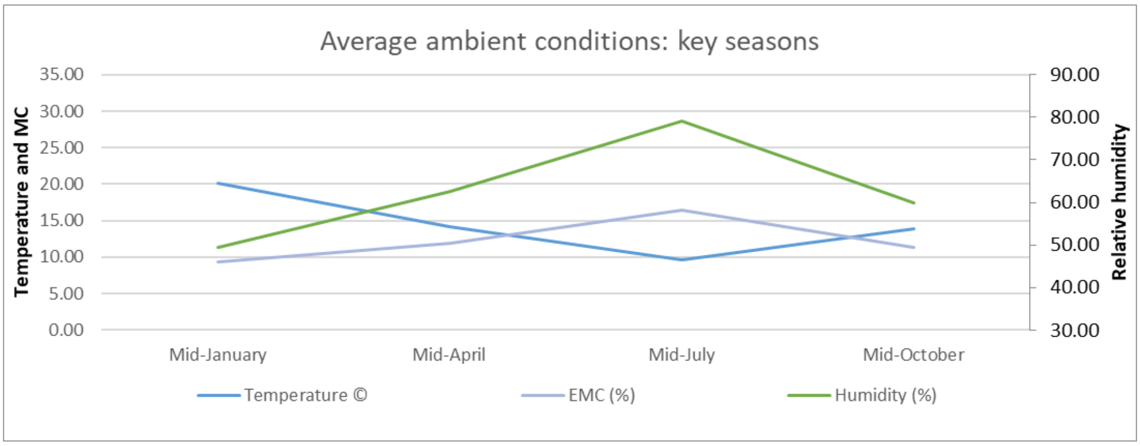

Figure 23: Average ambient conditions: key seasons

Table 16 shows the boundary and average maximum and minimum MC readings across the sites. The average maximum MC monitored across sites for several species is outside the AS2796 requirement for hardwood (14%) and just above the AS2858 requirement for structural pine (15%). Table 17 and Figure 24 shows the MC response of species and products across seasons, with the major Tasmanian oak species Messmate *E. obliqua* and others above 14% on average in winter.

The MC response of products in a sub-group of three CZ7 stores in southern Tasmania are shown in Table 18 and Figure 25, while results for three similar CZ7 stores in Northern Tasmania are shown in Table 19 and Figure 26. The pattern of MC change between seasons is similar between the two regional groups. The Northern Tasmanian sites had higher average MC across Autumn, Winter, and Spring in the monitored year than the southern sites, but this is likely to be well within the variation expected between regions and years.

Table 16: MC responses of species and products: Maximum and minimum

	Weathertex	***P. radiata***	***C. maculata***	***E. globulus***	***E. sieberi***	***E. obliqua***	***E. nitens***	***E. pilularis***	**LVL**
Boundary readings across sites									
Maximum	8.24	17.37	15.88	14.71	16.55	15.78	16.41	17.01	14.03
Minimum	5.00	8.79	5.86	9.14	7.95	9.23	9.43	10.06	8.32
Average readings across sites									
Maximum	7.57	15.29	12.88	13.36	14.81	14.34	13.92	15.52	12.51
Minimum	5.73	10.39	9.79	10.27	10.71	10.69	10.24	11.45	9.42
Range	1.84	4.90	3.10	3.09	4.10	3.65	3.68	4.08	3.09

Table 17: MC responses of species and products: Key seasons

	Weathertex	***P. radiata***	***C. maculata***	***E. globulus***	***E. sieberi***	***E. obliqua***	***E. nitens***	***E. pilularis***	**LVL**
Summer	6.11	10.84	9.58	10.60	11.25	11.08	10.65	11.71	9.97
Autumn	6.37	12.04	10.53	11.22	12.00	12.02	11.54	12.73	10.26
Winter	7.53	14.63	12.40	13.40	14.63	14.09	13.81	15.47	12.54
Spring	6.75	12.59	11.02	11.78	12.55	12.37	12.07	13.30	11.02
Range	1.42	3.79	2.82	2.80	3.38	3.01	3.15	3.76	2.57

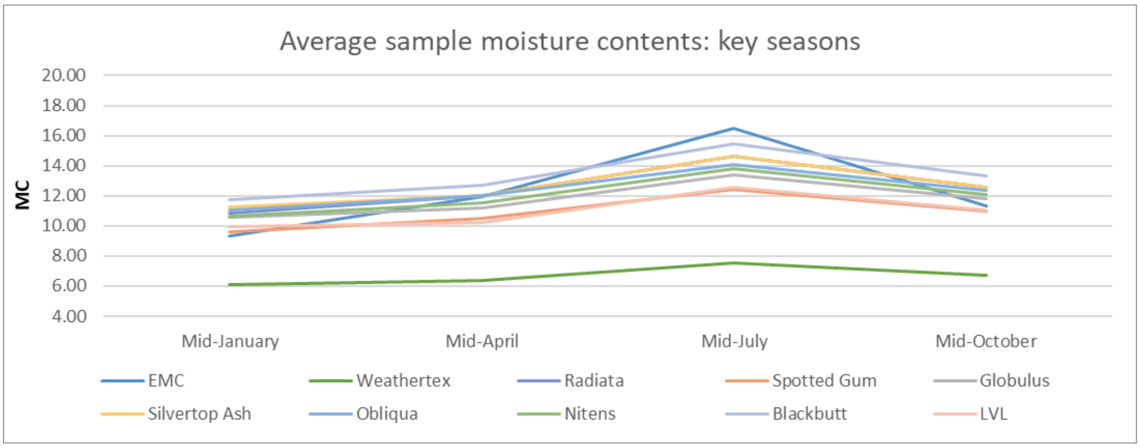

Figure 24: MC responses of species and products: key seasons

Table 18: MC responses of species and products: Key seasons – Hobart sites

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Summer	5.93	10.67	9.69	10.86	11.20	11.09	10.72	11.85	9.70
Autumn	6.23	11.50	9.79	11.28	11.79	11.69	11.43	12.28	9.87
Winter	7.61	14.81	12.61	14.11	15.22	14.42	14.06	15.54	12.84
Spring	6.65	12.44	10.90	12.02	12.73	12.36	11.94	13.00	10.75
Range	1.68	4.15	2.93	3.25	4.02	3.32	3.34	3.69	3.14

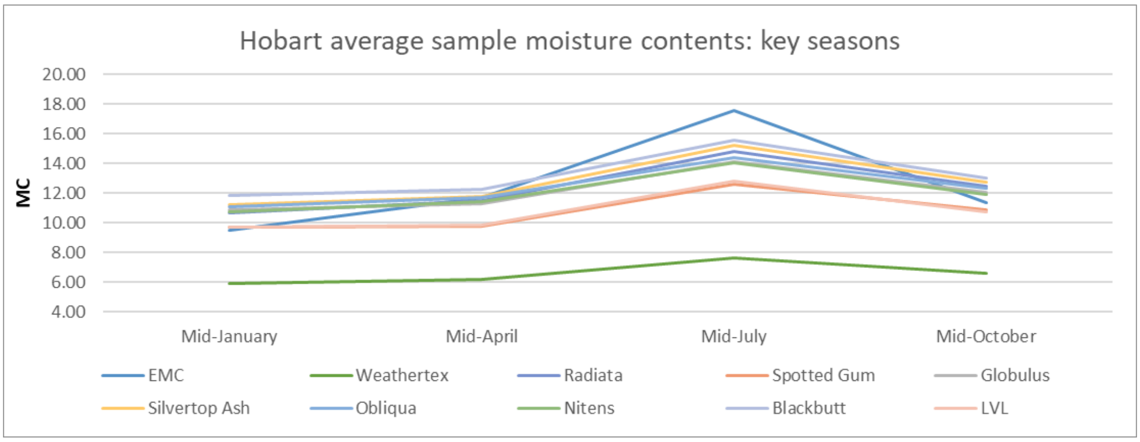

Figure 25: MC responses of species and products: key seasons

Table 19: MC responses of species and products: Key seasons - northern Tasmania sites

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Summer	6.39	11.11	9.41	10.21	11.33	11.06	10.55	11.49	10.78
Autumn	6.81	13.38	11.63	11.57	13.28	12.87	12.05	13.80	11.43
Winter	8.08	16.02	13.07	13.39	15.97	14.73	14.27	16.98	14.03
Spring	7.42	13.91	11.79	12.07	13.92	13.11	12.72	14.70	13.29
Range	1.69	4.91	3.66	3.18	4.65	3.68	3.72	5.49	3.25

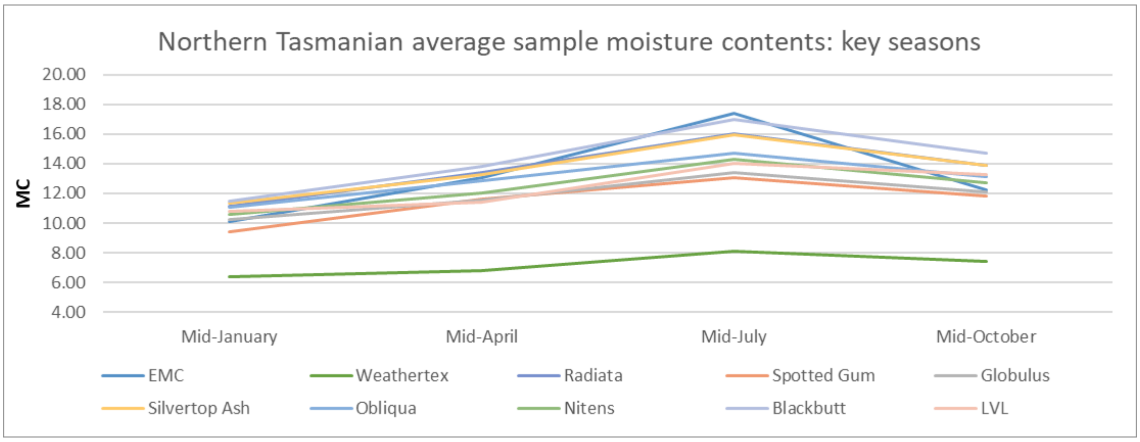

Figure 26: MC responses of species and products: key seasons

Climate zone 6: In store

Five stores or workshop spaces were monitored in CZ6. One was in Western Sydney, but the remainder were in Melbourne. See Figure 27 and Figure 28. Table 20 lists the locations, the number of readings taken, and the boundary dates for these readings at each site. While Minnow data was collected, COVID lockdowns affected sample measurement in Victorian sites in this climate Zone between August and October. In these cases, the first November reading was used for the Spring reading.

Figure 27: CZ6 timber store

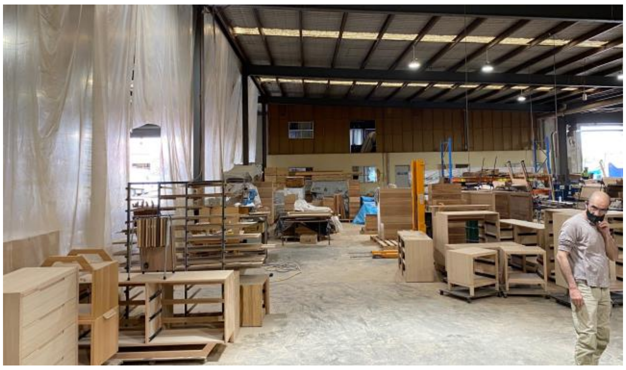

Figure 28:CZ6 furniture workshop.

Table 20: Unit locations and sample readings

Unit locations	No. of readings	Initial reading	Last reading
CZ6_In store_Melbourne 01	31	4/01/2021	21/12/2021
CZ6_In store_Melbourne 02	31	12/01/2021	21/12/2021
CZ6_In store_Melbourne 03	30	12/01/2021	21/12/2021
CZ6_In store_Melbourne 04	31	12/01/2021	21/12/2021
CZ6_In store_Sydney 01	14	25/03/2021	29/10/2021

The ambient conditions in the spaces reflected the seasonal mild temperate conditions common in CZ6, with cool but wet winters and mild to warm summers. See Table 21 and Figure 29:

Table 22 shows the boundary and average maximum and minimum MC readings across the sites. Generally drier than CZ7 sites, the average maximum MC monitored across sites for several species is near the AS2796 requirement for hardwood and just within the AS2858 requirement for structural pine. Table 23 and Figure 30 shows the MC response of species and products across seasons. Tasmanian oak species Messmate *E. obliqua* and most other species are on average in winter below the 14% MC limit for appearance products.

Table 21: Ambient conditions: Average maximum, minimum and key seasons

	Temperature (ºC)	Humidity (%)	EMC (%)
Maximum	26.95	79.96	16.26
Minimum	9.98	40.96	7.80
Range	16.98	39.01	8.46
Key seasons			
Summer: Mid-January	21.76	50.64	9.37
Autumn: mid-April	16.46	59.25	11.05
Winter: mid-July	12.19	74.03	14.60
Spring: mid-October	16.37	54.54	10.30

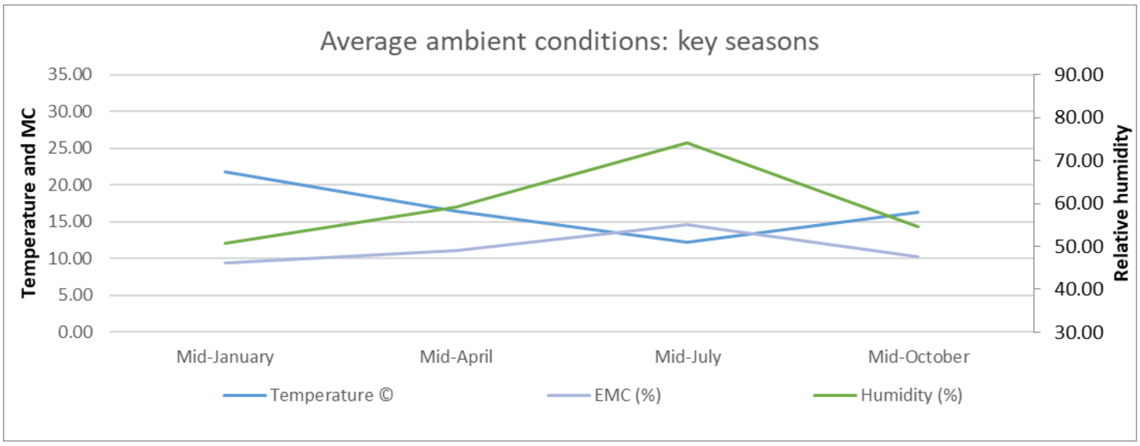

Figure 29: Average ambient conditions: key seasons

Table 22: MC responses of species and products: Maximum and minimum

	Weathertex	***P. radiata***	***C. maculata***	***E. globulus***	***E. sieberi***	***E. obliqua***	***E. nitens***	***E. pilularis***	**LVL**
Boundary readings across sites									
Maximum	7.48	15.38	13.74	13.96	15.87	14.32	15.09	15.77	12.48
Minimum	4.83	8.36	8.98	8.33	10.05	9.30	8.68	8.89	8.58
Average readings across sites									
Maximum	7.12	14.06	12.51	12.88	14.69	13.63	13.70	14.06	11.86
Minimum	5.54	10.17	9.80	10.30	11.30	10.49	10.50	10.99	9.23
Range	1.58	3.89	2.71	2.58	3.40	3.15	3.20	3.06	2.62

Table 23: MC responses of species and products: Key seasons

	Weathertex	***P. radiata***	***C. maculata***	***E. globulus***	***E. sieberi***	***E. obliqua***	***E. nitens***	***E. pilularis***	**LVL**
Summer	5.48	10.43	10.00	10.51	11.67	10.53	10.79	10.94	9.09
Autumn	6.37	12.06	11.12	11.61	12.93	11.95	12.09	12.50	10.48
Winter	6.95	13.42	12.12	12.60	14.32	13.16	13.20	13.68	11.65
Spring	6.33	11.80	10.89	11.38	12.77	11.81	11.86	12.32	10.46
Range	1.47	3.00	2.12	2.09	2.65	2.63	2.41	2.74	2.56

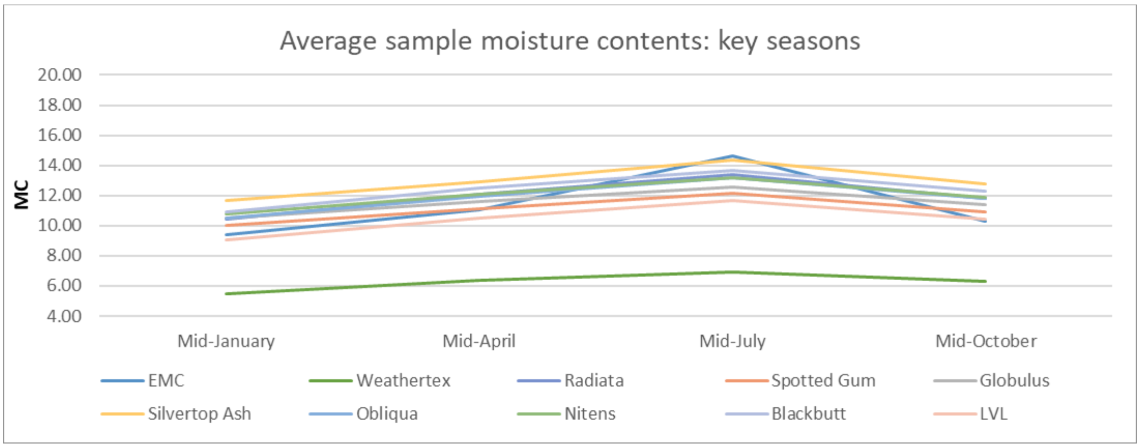

Figure 30: MC responses of species and products: key seasons

Climate zone 6: Sheltered

One sheltered space was monitored in CZ7, in the driveway and delivery area of a Melbourne furniture maker. The unit was positioned against the wall in a roofed area outside used for deliveries and short-term timber storage area. This and unit's proximity to a sunlit concrete driveway may also affect local ambient conditions compared to store buildings in the same climate zone. See Figure 31. Table 24 lists the location, the number of readings taken, and the boundary dates for these readings at each site.

Figure 31:CZ6 Sheltered timber storage area.

Table 24: Unit locations and sample readings

Unit locations	No. of readings	Initial reading	Last reading
CZ6_Sheltered_Melbourne	31	12/01/2021	21/12/2021

The ambient conditions are similar but more extreme than timber stores in this climate zone. In this sheltered location across seasons, temperatures are lower and humidity and calculated EMC are higher than those experienced in a similar enclosed timber store. See Table 25 and Figure 32.

Table 26 shows the boundary and average maximum and minimum MC readings at the site. Table 27 and Figure 33 shows the MC response of species and products across season. Results are similar to the timber stores in this climate zone but with some important difference, probably due to the increased ventilation outside. Summer and autumn MC are lower in this exposed location while winters and spring MC are higher. It also has a noticeably higher range of MC. Some hardwood species are outside the maximum MC for AS2796 in winter.

Table 25: Ambient conditions: Average maximum, minimum and key seasons

	Temperature (ºC)	Humidity (%)	EMC (%)
Maximum	32.15	84.71	18.25
Minimum	7.12	32.10	6.21
Range	25.04	52.61	12.04
Key seasons			
Summer: Mid-January	20.09	57.99	11.05
Autumn: mid-April	15.01	65.72	12.83
Winter: mid-July	11.46	78.24	16.02
Spring: mid-October	14.54	67.48	13.29

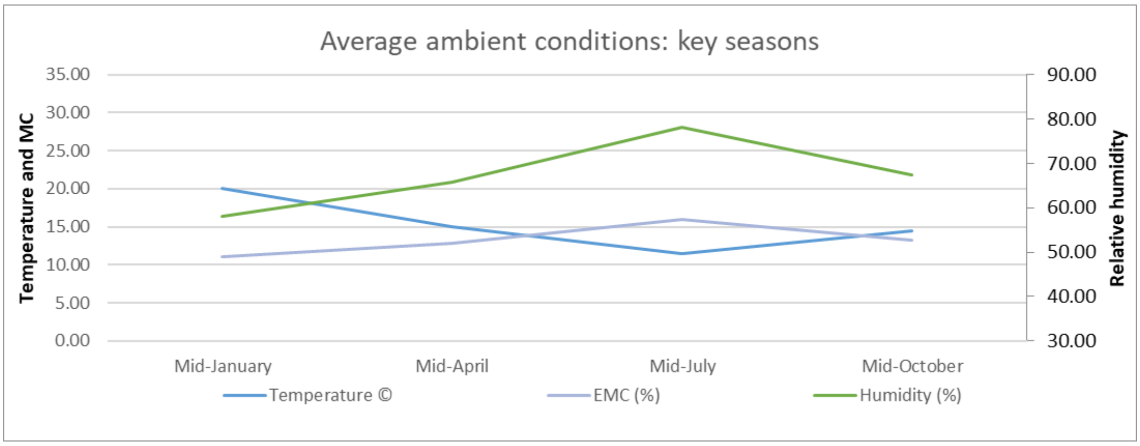

Figure 32: Average ambient conditions: key seasons

Table 26: MC responses of species and products: Maximum and minimum

	Weathertex	***P. radiata***	***C. maculata***	***E. globulus***	***E. sieberi***	***E. obliqua***	***E. nitens***	***E. pilularis***	**LVL**
Boundary readings across sites									
Maximum	7.73	16.78	12.32	13.91	14.26	14.49	14.86	15.56	14.15
Minimum	4.92	9.79	9.27	9.79	9.83	9.71	9.22	10.50	9.69
Average readings across sites									
Maximum	7.73	16.78	12.32	13.91	14.26	14.49	14.86	15.56	14.15
Minimum	4.92	9.79	9.27	9.79	9.83	9.71	9.22	10.50	9.69
Range	2.81	7.00	3.05	4.12	4.43	4.78	5.64	5.07	4.46

Table 27: MC responses of species and products: Key seasons

	Weathertex	***P. radiata***	***C. maculata***	***E. globulus***	***E. sieberi***	***E. obliqua***	***E. nitens***	***E. pilularis***	**LVL**
Summer	4.92	9.79	9.41	9.79	9.83	9.71	9.22	10.50	9.69
Autumn	5.97	11.23	10.13	11.20	11.57	11.69	11.51	12.46	11.03
Winter	7.64	15.74	12.18	13.70	14.22	14.38	14.51	15.26	13.91
Spring	7.14	14.05	10.93	12.29	12.66	12.90	13.04	13.55	12.33
Range	2.72	5.95	2.77	3.92	4.39	4.67	5.29	4.76	4.23

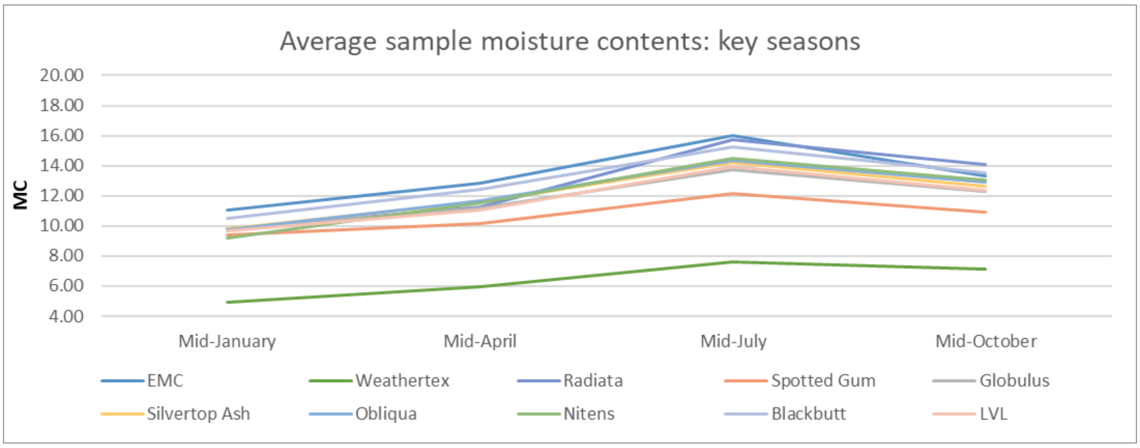

Figure 33: MC responses of species and products: key seasons

Climate zone 5: Unconditioned space

Two unconditioned space were monitored for limited periods in CZ5, both in Adelaide. See Figure 34. Table 28 lists the locations, the number of readings taken, and the boundary dates for these readings at each site.

Figure 34: CZ5 unconditioned space.

Table 28: Unit locations and sample readings

Unit locations	No. of readings	Initial reading	Last reading
CZ5_unconditioned_Adelaide 01	16	21/02/2021	28/06/2021
CZ5_unconditioned_Adelaide 02	6	11/03/2021	14/05/2021

The ambient conditions were monitored on one site between February and August and the results are shown in Table 29.

Table 29: Ambient conditions: Average maximum, minimum and key seasons

	Temperature (ºC)	Humidity (%)	EMC (%)
Maximum	31.59	81.13	16.76
Minimum	10.44	27.79	5.60
Range	21.15	53.34	11.16

Table 30 shows the boundary and average maximum and minimum MC readings across the two sites, while Table 31 and Figure 35 show the MC response of species and products across season. In each case, measured MC are relatively stable with a relatively low range of readings, particularly when compared to the timber storage buildings in the same climate zone.

Table 30: MC responses of species and products: Maximum and minimum

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Boundary readings across sites									
Maximum	6.56	12.20	8.65	11.57	12.86	12.34	12.70	13.16	10.69
Minimum	4.99	7.92	6.93	8.11	9.02	8.96	8.54	9.23	8.42
Average readings across sites									
Maximum	6.22	10.94	8.13	11.39	12.73	11.66	12.15	12.99	10.37
Minimum	5.00	8.17	7.11	9.25	10.26	9.68	8.88	10.31	8.71
Range	1.22	2.78	1.02	2.15	2.47	1.97	3.28	2.68	1.66

Table 31: MC responses of species and products: Key seasons

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Autumn	5.26	8.27	7.28	9.44	10.49	9.97	8.88	10.53	8.80
Winter	6.04	10.60	8.14	10.24	11.39	11.19	11.03	11.62	9.92

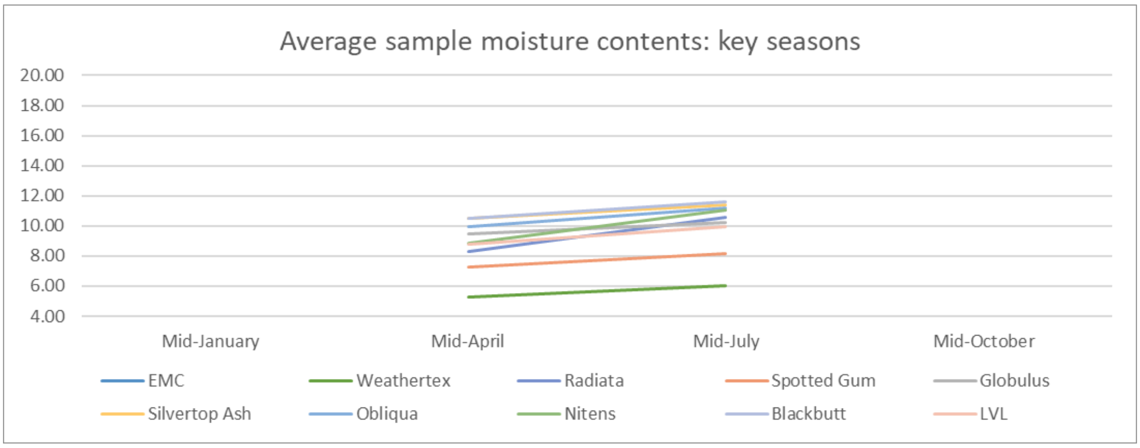

Figure 35: MC responses of species and products: key seasons

Climate zone 5: In store

Four timber storage spaces in regional areas across three states were monitored in CZ5. See Figure 36. Table 32 lists the locations, the number of readings taken, and the boundary dates for these readings at each site. Industry collaborators collected all readings in CZ5. The scattered number and boundary dates of readings reflects industry's understandable priority for their own tasks and the difficulty in organising casual staff to conduct regular monitoring outside of metropolitan areas.

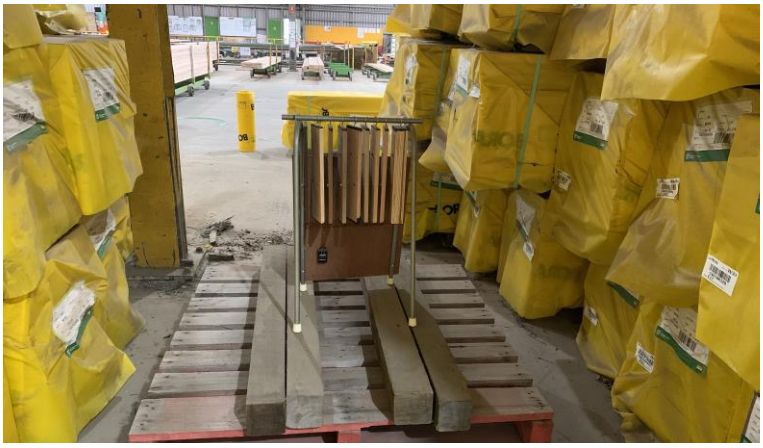

Figure 36: Monitoring unit in timber processing store in CZ5.

Table 32: Unit locations and sample readings

Unit locations	No. of readings	Initial reading	Last reading
CZ5_In store_NSW 01	11	12/05/2021	8/10/2021
CZ5_In store_SA 01	27	21/05/2021	14/01/2022
CZ5_In store_WA 01	9	12/03/2021	5/08/2021
CZ5_In store_WA 02	10	11/12/2020	29/07/2021

The ambient conditions in the spaces reflected the seasonal warm temperate conditions common in CZ5, with mild winters and warm to hot summers. See Table 33 and Figure 37. While the maximums and minimums experienced are not significantly different to timber stores in CZ6 and CZ7, the seasonal averages are notable warmer.

Table 34 shows the boundary and average maximum and minimum MC readings across the sites while Table 35 and Figure 38 shows the MC response of species and products across season. MC are generally lower in CZ5 stores than those in CZ6 and CZ7 in summer and autumn, but higher than CZ6 and similar to CZ7 stores in winters and spring, leading to a higher overall MC range.

The pattern of differences in species and product MC observed in the CZ7 conditions spaces generally continues, with Weathertex have significantly lower MC than other products, LVL and *C. maculata* having the lowest MC and MC range of the solid wood products, and Radiata pine, Blackbutt and Silvertop ash having the highest MC range.

Table 33: Ambient conditions: Average maximum, minimum and key seasons

	Temperature (ºC)	Humidity (%)	EMC (%)
Maximum	24.58	85.58	18.66
Minimum	9.50	35.49	6.98
Range	15.08	50.09	11.68
Key seasons			
Summer: Mid-January	25.28	41.21	7.82
Autumn: mid-April	18.54	63.89	12.01
Winter: mid-July	12.71	76.49	15.80
Spring: mid-October	18.51	55.47	10.49

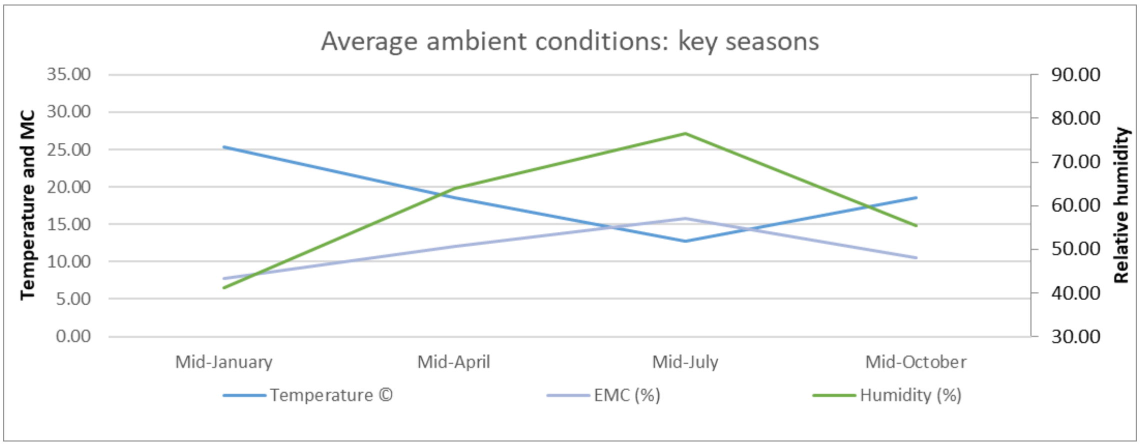

Figure 37: Average ambient conditions: key seasons

Table 34: MC responses of species and products: Maximum and minimum

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Boundary readings across sites									
Maximum	8.37	18.83	15.92	15.17	18.65	15.79	15.57	17.56	14.39
Minimum	4.85	8.87	7.90	8.88	9.33	8.91	8.64	9.27	7.84
Average readings across sites									
Maximum	7.40	15.67	13.10	13.83	16.00	14.33	14.51	16.18	12.96
Minimum	5.58	10.23	10.37	10.67	11.66	10.69	10.61	12.01	9.68
Range	1.82	5.44	2.74	3.16	4.35	3.64	3.89	4.17	3.28

Table 35: MC responses of species and products: Key seasons

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Summer	5.76	10.25	10.41	10.31	10.63	10.16	9.90	11.10	9.18
Autumn	6.17	10.78	10.01	11.05	11.98	11.08	11.12	12.39	9.44
Winter	7.32	14.84	13.03	13.64	15.82	14.03	14.22	16.01	12.88
Spring	6.42	12.66	12.30	12.44	13.61	12.51	12.40	13.93	11.70
Range	1.55	4.59	3.03	3.33	5.19	3.87	4.31	4.91	3.70

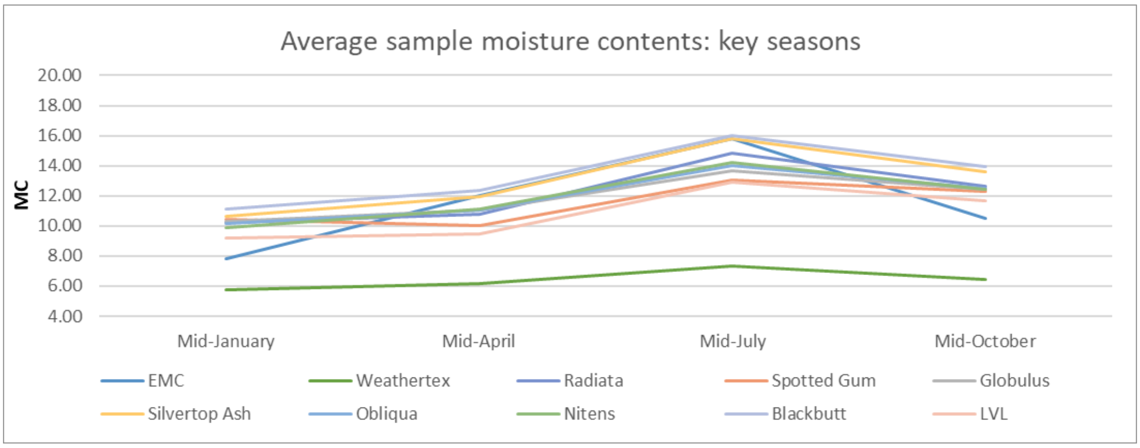

Figure 38: MC responses of species and products: key seasons

Climate zone 2: In construction

One residential construction site was monitored in CZ7. See Figure 39. Table 36 lists the locations, the number of readings taken, and the boundary dates for these readings at each site.

Figure 39: CZ.

Table 36: Unit locations and sample readings

Unit locations	No. of readings	Initial reading	Last reading
CZ2_In construction_Brisbane	30	23/04/2021	14/01/2022

The Minnow data collected for this site is limited, extending only from late August to mid—October. The ambient conditions recorded are summarised in Table 37.

Table 37: Ambient conditions: Average maximum, minimum and key seasons

	Temperature (ºC)	Humidity (%)	EMC (%)
Maximum	26.81	76.91	15.20
Minimum	17.66	36.56	7.19
Range	9.15	40.34	8.01
Key seasons			
Spring: mid-October	26.11	61.98	11.23

Sample monitoring was more extensive than ambient condition monitoring. Table 38 shows the average maximum and minimum MC readings at the site, while Table 39 and Figure 40 shows the MC response of species and products across season. The range of maximum and minimal readings and of seasonal readings are high, particularly in Radiata pine (9.5%) and LVL (7.35%). The significant seasonal MC change occurs between autumn and winter, while the seasonal change is higher on average than that experienced in the CZ7 construction site, and much higher for the Radiata pine (5.57% in CZ2 and 4.3% in CZ7).

Table 38: MC responses of species and products: Maximum and minimum

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Maximum	8.91	19.74	13.37	14.17	18.75	15.55	17.65	19.00	17.00
Minimum	5.79	10.25	9.81	10.19	11.74	11.04	10.81	12.72	9.65
Range	3.12	9.49	3.56	3.97	7.01	4.51	6.85	6.28	7.35

Table 39: MC responses of species and products: Key seasons

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Summer	6.95	11.61	9.91	10.66	12.16	11.70	11.57	12.89	11.43
Autumn	5.79	10.39	9.81	10.19	12.40	11.34	10.98	12.97	9.65
Winter	8.55	15.96	12.81	13.23	16.49	14.46	15.35	16.97	15.07
Spring	7.39	12.53	10.28	11.25	12.73	12.48	12.63	13.84	14.02
Range	2.76	5.57	3.00	3.04	4.33	3.13	4.37	4.09	5.41

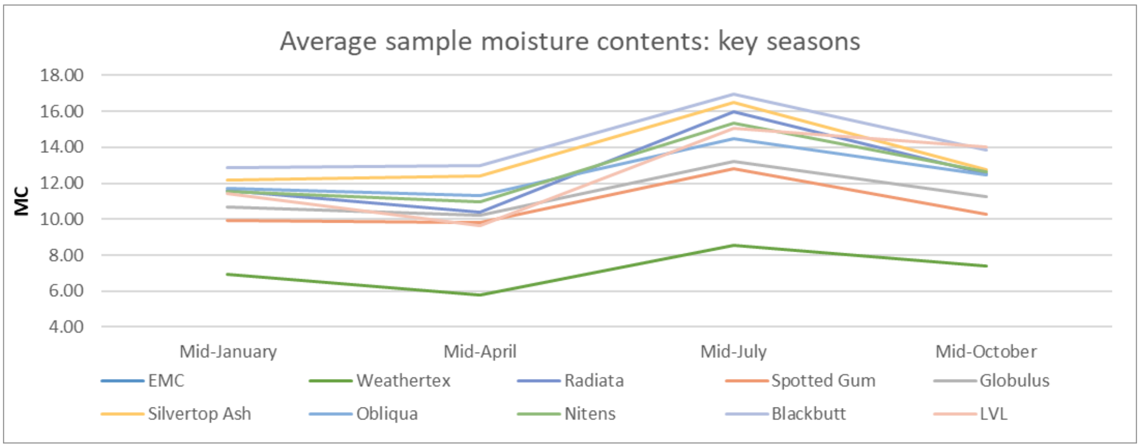

Figure 40: MC responses of species and products: key seasons

Climate zone 2: In store

Four timber stores were monitored in CZ2. Three were in Brisbane and one was in northern NSW. See Figure 41 and Figure 42. Table 40 lists the locations, the number of readings taken, and the boundary dates for these readings at each site.

Figure 41: CZ2 store building in Brisbane.

Figure 42:CZ2 store building in NSW

Table 40: Unit locations and sample readings

Unit locations	No. of readings	Initial reading	Last reading
CZ2_In store_Brisbane 01	38	7/04/2021	14/01/2022
CZ2_In store_Brisbane 02	18	19/01/2021	15/10/2021
CZ2_In store_Brisbane 03	35	7/04/2021	14/01/2022
CZ2_In store_NSW 01	33	14/04/2021	9/12/2021

The ambient and seasonal conditions are characteristic of CZ2 and show a warm to hot summer with temperatures declining to a mild winter (16.97 degrees C), relatively constant relative humidity internally and an increasing EMC from autumn to spring. See Table 41 and Figure 43.

Table 41: Ambient conditions: Average maximum, minimum and key seasons

	Temperature (ºC)	Humidity (%)	EMC (%)
Maximum	26.46	86.45	18.92
Minimum	13.62	41.48	7.93
Range	12.84	44.98	10.99
Key seasons			
Summer: Mid-January	25.57	64.11	11.70
Autumn: mid-April	21.77	63.15	11.70
Winter: mid-July	16.97	67.82	13.30
Spring: mid-October	21.42	68.91	13.55

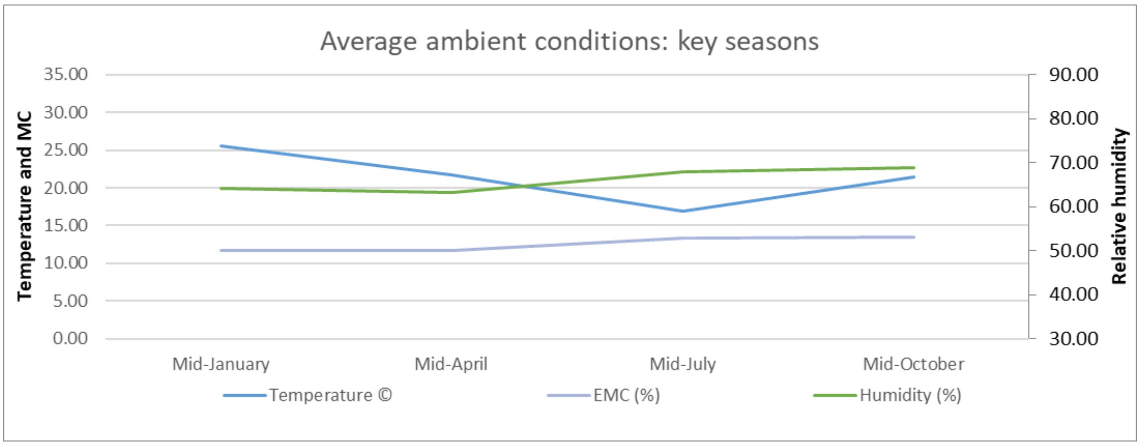

Figure 43: Average ambient conditions: key seasons

Table 42 shows the boundary and average maximum and minimum MC readings across the sites while Table 43 and Figure 44 shows the MC response of species and products across season. MC are generally higher in CZ2 stores than those in all other climates zones but the ranges across seasons are lower. For example, the measured seasonal range for Radiata pine is 2.18% in CZ2 site, 4.59% in CZ5, 3.0% in CZ6 and 3.79% in CZ7 stores.

Table 42: MC responses of species and products: Maximum and minimum

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Boundary readings across sites									
Maximum	9.13	16.43	13.45	13.89	15.38	14.76	15.77	17.10	13.66
Minimum	4.65	9.47	8.88	9.37	11.35	9.86	9.90	11.87	8.96
Average readings across sites									
Maximum	8.22	15.52	12.38	13.02	15.07	14.25	14.69	15.87	12.80
Minimum	6.09	10.92	9.91	10.42	12.12	10.78	11.14	12.57	9.97
Range	2.13	4.60	2.47	2.61	2.94	3.47	3.55	3.30	2.82

Table 43: MC responses of species and products: Key seasons

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Summer	7.14	12.88	10.80	11.44	13.28	12.02	12.39	13.64	11.27
Autumn	7.03	13.13	11.28	11.83	13.61	12.68	12.89	14.33	11.29
Winter	7.93	15.05	12.08	12.82	14.84	13.79	14.37	15.58	12.56
Spring	7.82	14.56	11.25	12.45	14.32	13.42	13.69	14.89	11.97
Range	0.90	2.18	1.28	1.37	1.56	1.77	1.98	1.93	1.29

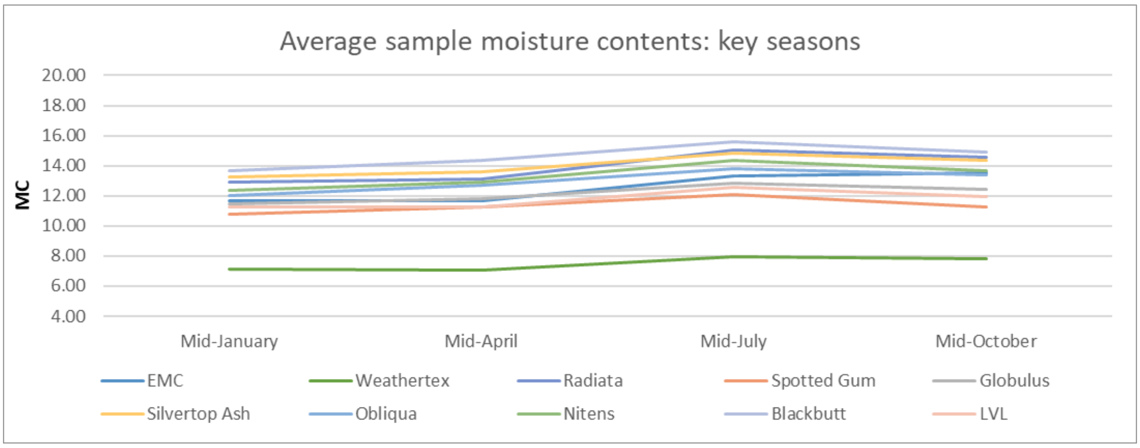

Figure 44: MC responses of species and products: key seasons

Climate zone 2: Sheltered

One sheltered site in Brisbane was monitored in CZ2. See Figure 45. Table 44 lists the locations, the number of readings taken, and the boundary dates for these readings at each site.

Figure 45: Sheltered site in an open sided store in CZ2.

Table 44: Unit locations and sample readings

Unit locations	No. of readings	Initial reading	Last reading
CZ2_Sheltered_Brisbane	19	19/01/2021	15/10/2021

The ambient conditions reflect the warm humid summer and mild winter characteristic of CZ2. See Table 45 and Figure 46. The maximum and minimum and seasonal conditions are broadly similar to stores in CZ2, but the EMC conditions are marginally higher.

Table 45: Ambient conditions: Average maximum, minimum and key seasons

	Temperature (ºC)	Humidity (%)	EMC (%)
Maximum	27.06	84.71	18.05
Minimum	13.43	46.43	8.85
Range	13.63	38.28	9.20
Key seasons			
Summer: Mid-January	25.53	68.69	12.83
Autumn: mid-April	20.72	65.12	12.24
Winter: mid-July	16.48	69.41	13.82

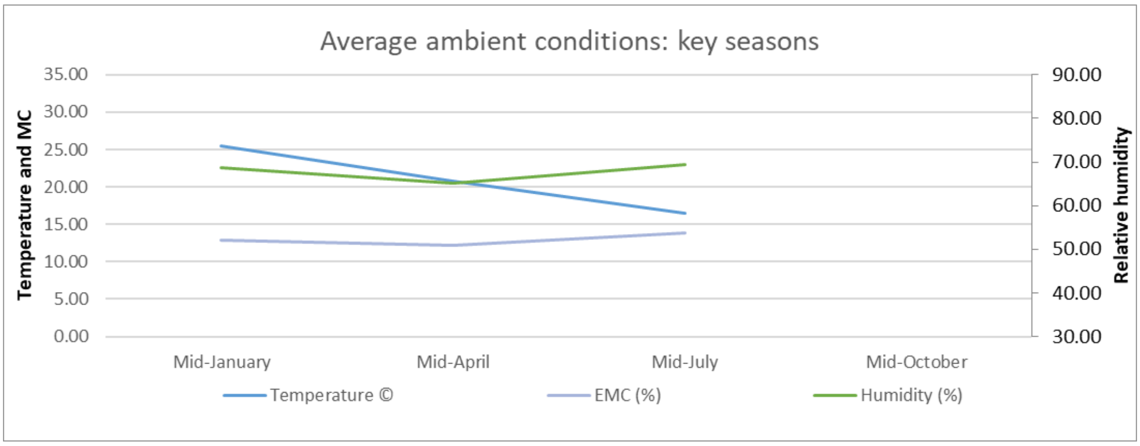

Figure 46: Average ambient conditions: key seasons

Table 46 shows the boundary and average maximum and minimum MC readings across the sites while Table 47 and Figure 47 shows the MC response of species and products across season.

While the maximum and minimum ranges are similar to CZ2 stores, the seasonal ranges are generally lower. Also, while the average product MC in the CZ2 sheltered store are higher than other site group (except construction zones), they are consistent across the season and the measured range between season is lower than any other recorded groups except the conditioned spaces in CZ7.

Table 46: MC responses of species and products: Maximum and minimum

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Maximum	8.36	16.43	13.44	15.48	15.45	14.48	14.94	16.74	13.03
Minimum	6.81	11.31	11.13	11.93	12.68	11.57	11.35	13.29	10.42
Range	1.56	5.12	2.31	3.55	2.77	2.91	3.59	3.44	2.62

Table 47: MC responses of species and products: Key seasons

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
Summer	7.37	12.78	11.84	12.62	13.50	12.44	12.23	14.32	11.01
Autumn	7.67	12.96	11.85	13.01	13.46	12.49	12.57	14.16	11.57
Winter	8.09	13.95	12.77	14.44	14.35	13.37	13.54	15.36	12.62
Spring	8.02	14.21	11.78	13.42	13.76	13.10	13.18	14.20	11.79
Range	0.71	1.43	0.99	1.82	0.89	0.94	1.31	1.20	1.61

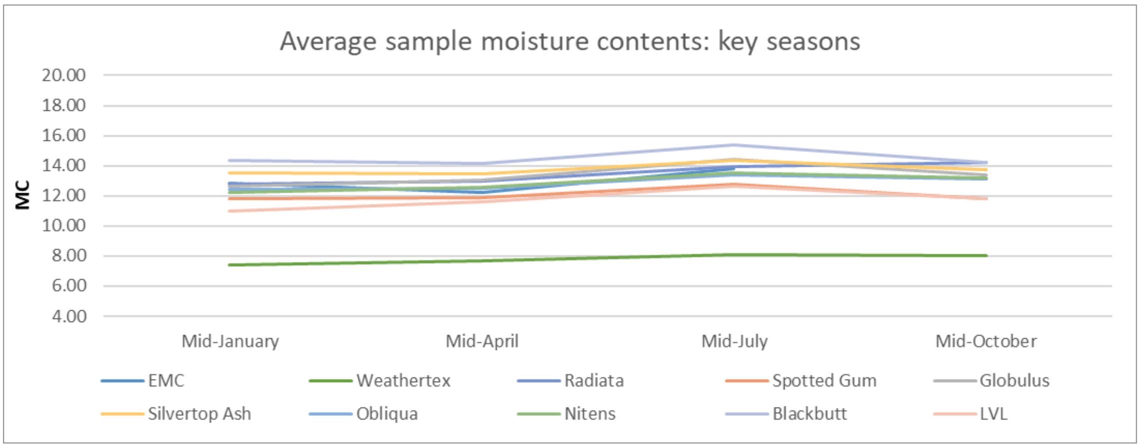

Figure 47: MC responses of species and products: key seasons

Comparisons across climate zone and service conditions

The risks of MC change and product damage can occur across seasons in a storage facility or workshop but occur more regularly when products are moved in the supply chain from the EMC conditions in one location to those in another. This section explores three scenarios, namely moving product in particular seasons:

- Across storage facilities in CZ7, CZ6, CZ5 and CZ2.
- From a store across exposure conditions in CZ7
- From a store across exposure conditions in CZ2.

In these comparisons, it is assumed that products move from the stores to either another store, a building site or to a building in service, either as packs or finished products.

The level of potential risks is assessed by comparing the measured species MC at the store to the next likely location in the supply chain in the same season. Generally,

- A mild risk reflects an MC difference in between 2 and 3%.
- A medium risk reflects an MC difference between 3 and 4%.
- A high risk reflects an MC difference above 4%.

As described above, the timber's immediate protection will affect potential risk:

- In unconditioned and conditioned spaces in service, the samples' measured MC is likely to closely reflect the EMC of timber elements placed into the space.
- On construction sites, the MC condition and rate of MC change of stored timber may be similar to the conditions and rate of change measured in the timber samples.
- In storage spaces and workshops, the rate of change of timber stored in packs is likely to be slower and less extreme than change in conditions measured in the timber samples. Wrapped packs will have a lower rate of change than unwrapped packs.

Comparisons of timber stores across climate zones

Timber and wood products are regularly moved between timber stores across climate zones. The following charts and tables compare the ambient conditions and measured species responses between sites for:

- Summer: Mid-January.
    - See Table 49 and Figure 48 for the ambient conditions while Table 49 and Figure 49 show the species and products MC response across seasons.
- Autumn: mid-April.
    - See Table 50 and Figure 50 for the ambient conditions while Table 51 and Figure 51 show the MC response of species and products.
- Winter: mid-July.
    - See Table 52 and Figure 52 for the ambient conditions while Table 53 and Figure 53 show the MC response of species and products.
- Spring: mid-October.
    - See Table 54 and Figure 54 for the ambient conditions while Table 55 and Figure 55 show the MC response of species and products

Only mild potential risks are evident for material moving between stores and include product moved:

- in January, with Radiata pine, Silvertop ash and Blackbutt transported between CZ5 and CZ2.
- in April, with Radiata pine transported between CZ5 and CZ2.
- in October with Radiata pine, Silvertop ash and Blackbutt transported between CZ5 and CZ6 to CZ2.

Summer: Mid-January

Table 48: Ambient conditions: January across regions

	Temperature (°C)	Humidity (%)	EMC (%)
CZ7_In store_Tasmania	20.10	49.52	9.30
CZ6_In store_Melbourne	21.76	50.64	9.37
CZ5_In store_various	25.28	41.21	7.82
CZ2_In store_Brisbane	25.57	64.11	11.70

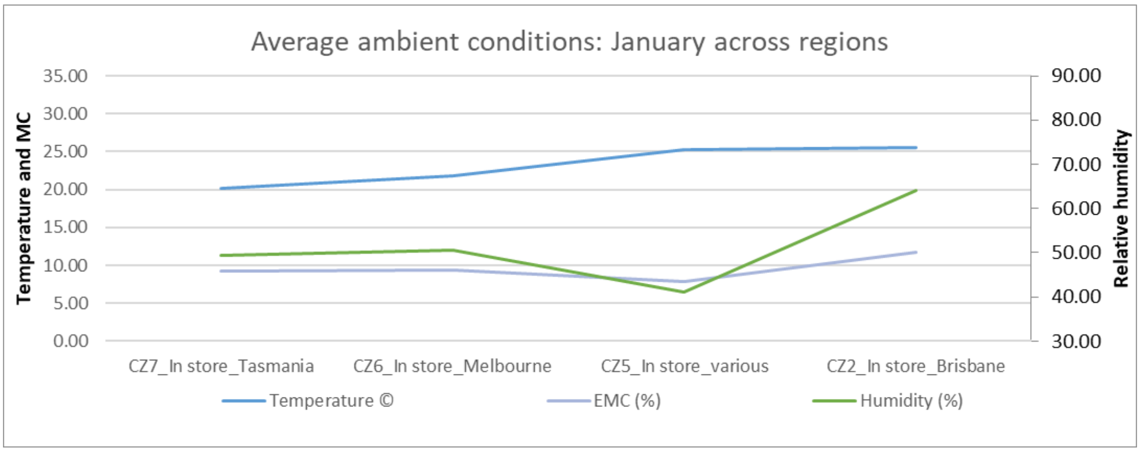

Figure 48: Average ambient conditions: January across regions

Table 49: MC responses of species and products: January across regions

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
CZ7_store	6.11	10.84	9.58	10.60	11.25	11.08	10.65	11.71	9.97
CZ6_store	5.48	10.43	10.00	10.51	11.67	10.53	10.79	10.94	9.09
CZ5_store	5.76	10.25	10.41	10.31	10.63	10.16	9.90	11.10	9.18
CZ2_store	7.14	12.88	10.80	11.44	13.28	12.02	12.39	13.64	11.27

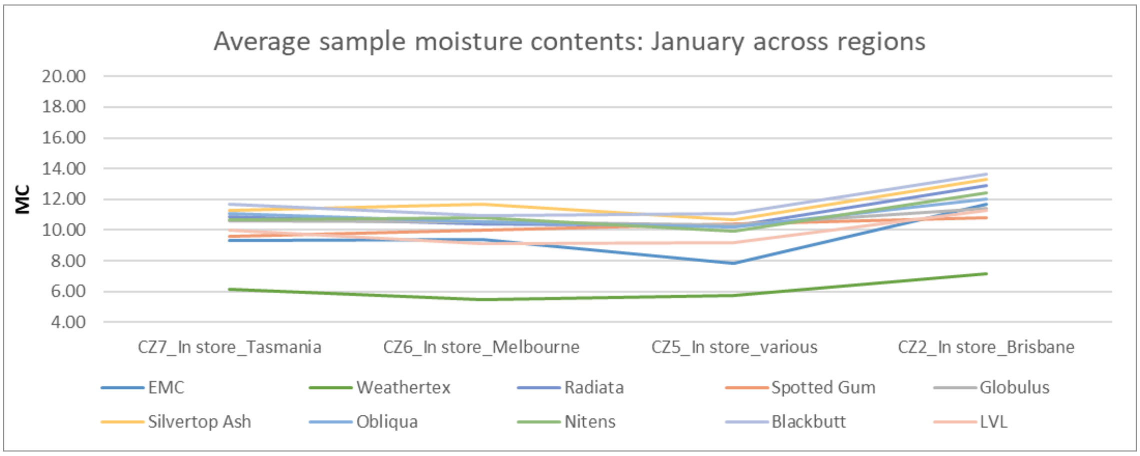

Figure 49: MC responses of species and products: January across regions

Autumn: mid-April

Table 50: Ambient conditions: April across regions

	Temperature (ºC)	Humidity (%)	EMC (%)
CZ7_In store_Tasmania	14.22	62.63	11.96
CZ6_In store_Melbourne	16.46	59.25	11.05
CZ5_In store_various	18.54	63.89	12.01
CZ2_In store_Brisbane	21.77	63.15	11.70

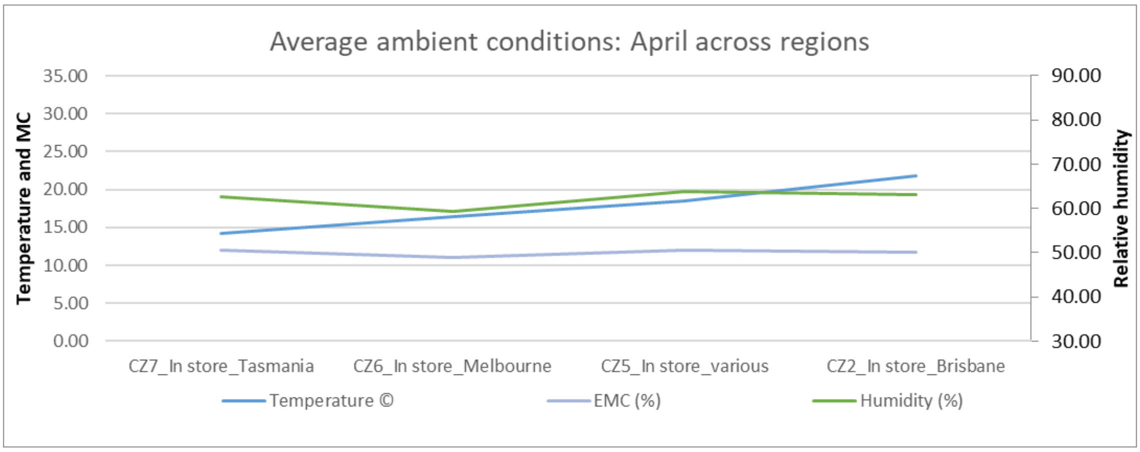

Figure 50: Average ambient conditions: April across regions

Table 51: MC responses of species and products: April across regions

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
CZ7_store	6.37	12.04	10.53	11.22	12.00	12.02	11.54	12.73	10.26
CZ6_store	6.37	12.06	11.12	11.61	12.93	11.95	12.09	12.50	10.48
CZ5_store	6.17	10.78	10.01	11.05	11.98	11.08	11.12	12.39	9.44
CZ2_store	7.03	13.13	11.28	11.83	13.61	12.68	12.89	14.33	11.29

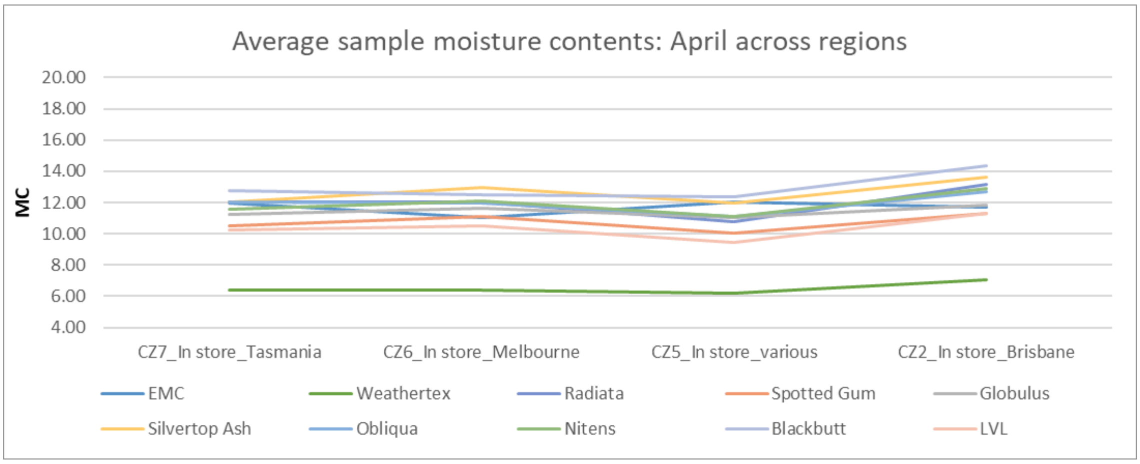

Figure 51: MC responses of species and products: April across regions

Winter: mid-July

Table 52: Ambient conditions: July across regions

	Temperature (ºC)	Humidity (%)	EMC (%)
CZ7_In store_Tasmania	9.64	79.20	16.47
CZ6_In store_Melbourne	12.19	74.03	14.60
CZ5_In store_various	12.71	76.49	15.80
CZ2_In store_Brisbane	16.97	67.82	13.30

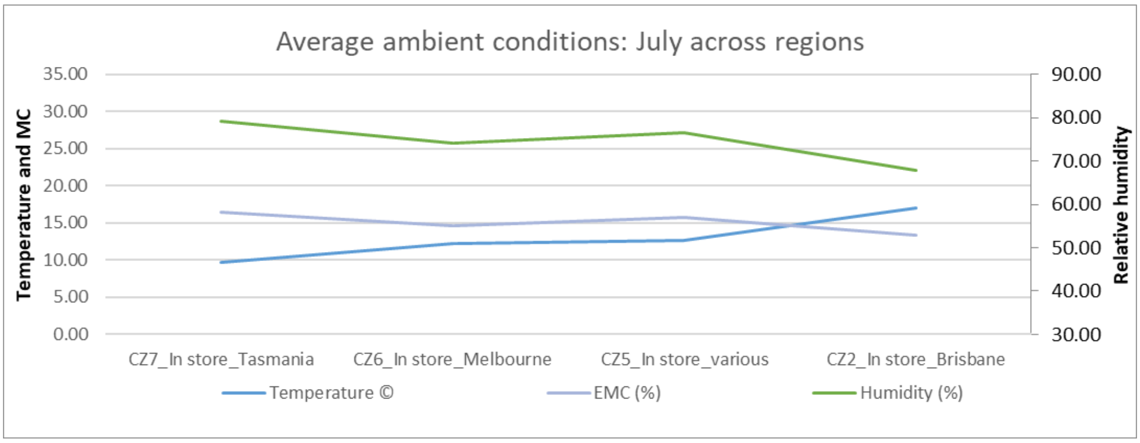

Figure 52: Average ambient conditions: July across regions

Table 53: MC responses of species and products: July across regions

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
CZ7_store	7.53	14.63	12.40	13.40	14.63	14.09	13.81	15.47	12.54
CZ6_store	6.95	13.42	12.12	12.60	14.32	13.16	13.20	13.68	11.65
CZ5_store	7.32	14.84	13.03	13.64	15.82	14.03	14.22	16.01	12.88
CZ2_store	7.93	15.05	12.08	12.82	14.84	13.79	14.37	15.58	12.56

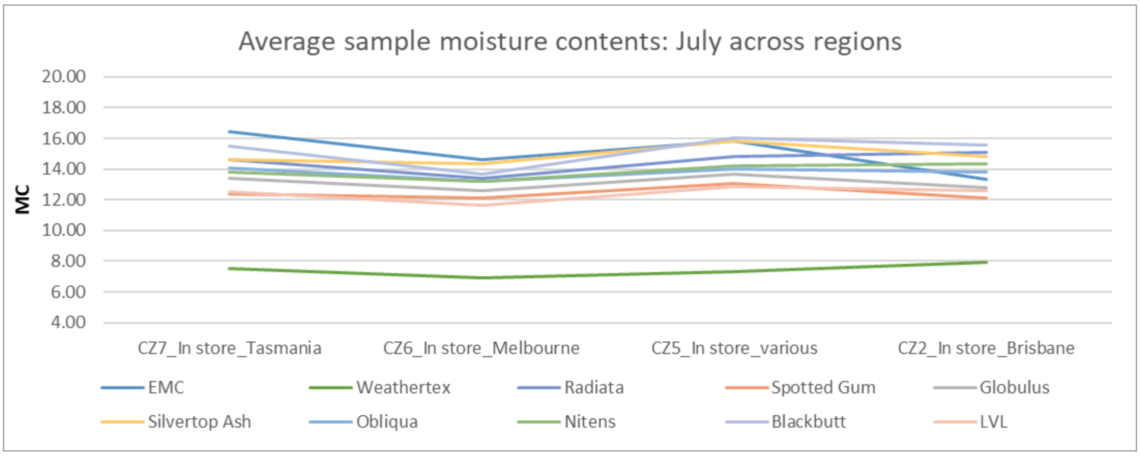

Figure 53: MC responses of species and products: July across regions

Spring: mid-October

Table 54: Ambient conditions: October across regions

	Temperature (°C)	Humidity (%)	EMC (%)
CZ7_In store_Tasmania	13.83	59.79	11.35
CZ6_In store_Melbourne	16.37	54.54	10.30
CZ5_In store_various	18.51	55.47	10.49
CZ2_In store_Brisbane	21.42	68.91	13.55

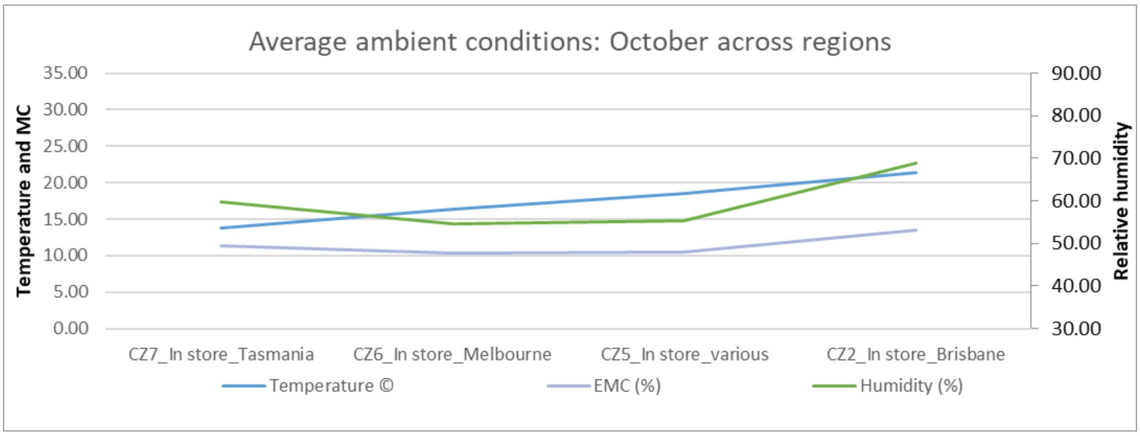

Figure 54: Average ambient conditions: October across regions

Table 55: MC responses of species and products: October across regions

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
CZ7_store	6.75	12.59	11.02	11.78	12.55	12.37	12.07	13.30	11.02
CZ6_store	6.33	11.80	10.89	11.38	12.77	11.81	11.86	12.32	10.46
CZ5_store	6.42	12.66	12.30	12.44	13.61	12.51	12.40	13.93	11.70
CZ2_store	7.82	14.56	11.25	12.45	14.32	13.42	13.69	14.89	11.97

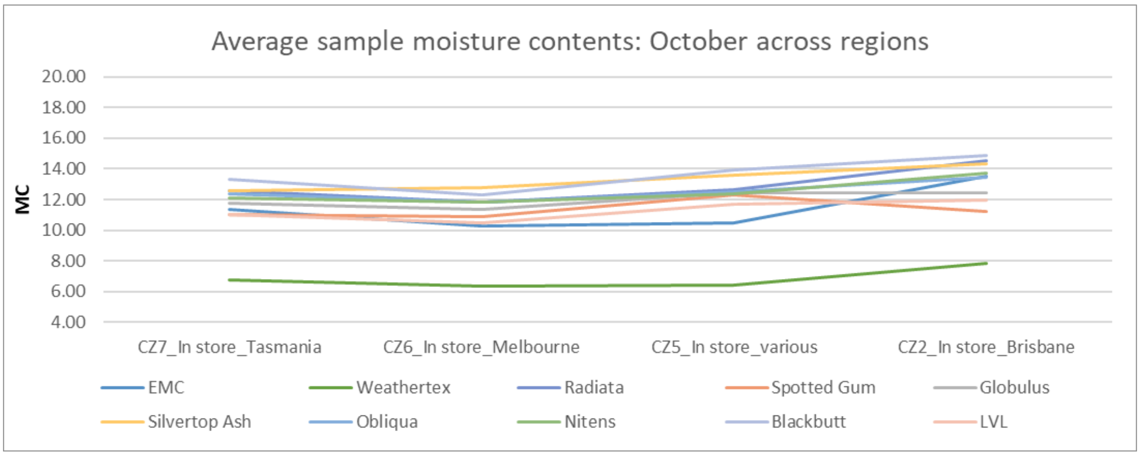

Figure 55: MC responses of species and products: October across regions

Comparisons across exposure conditions in CZ7

Timber and wood products regularly move from timber stores to workshops and construction site and directly or indirectly to unconditioned or conditioned spaces. The following charts and tables compare the ambient conditions and species responses between stages of the CZ7supply chain for:

- Summer: Mid-January.
  - See Table 56 for the ambient conditions while Table 57 and Figure 56 show the species and products MC response across seasons.
- Autumn: mid-April.
  - See Table 58 and Figure 57 for the ambient conditions while Table 59 and Figure 58 show the MC response of species and products.
- Winter: mid-July.
  - See Table 60 and Figure 59 for the ambient conditions while Table 61 and Figure 60 show the MC response of species and products.
- Spring: mid-October.
  - See Table 62 and Figure 61 for the ambient conditions while Table 63 and Figure 62 show the MC response of species and products

Potential risks evident from the results include:

- Medium risks occurring when product is moved:
  - In January, with all species moving from construction to in service in a conditioned space.
  - In April and October, with all species moving from the store or workshop to service.
- High risk occurring when product is moved
  - In April, July and October, with all species moving from construction to in-service conditions.
  - In July, with all species moving from the store or workshop to service.

Summer: Mid-January

Table 56: Ambient conditions: January across exposure conditions

	Temperature (ºC)	Humidity (%)	EMC (%)
CZ7_In store_Tasmania	20.10	49.52	9.30
CZ7_In construction	n/a	n/a	n/a
CZ7_conditioned	22.31	44.55	8.38

Table 57: MC responses of species and products: January across exposure conditions

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
CZ7_Store	6.11	10.84	9.58	10.60	11.25	11.08	10.65	11.71	9.97
CZ7_Constr.	7.74	12.66	11.62	12.20	13.11	12.78	12.77	14.13	
CZ7_Condit	5.01	9.12	7.80	8.63	9.13	9.09	9.04	10.63	8.39

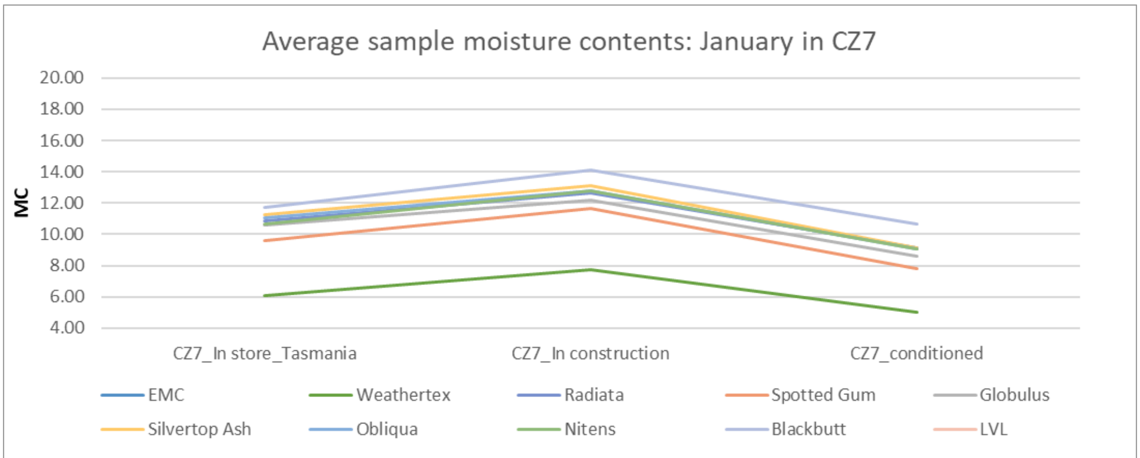

Figure 56: MC responses of species and products: January across exposure conditions

Autumn: mid-April

Table 58: Ambient conditions: April across exposure conditions

	Temperature (ºC)	Humidity (%)	EMC (%)
CZ7_In store_Hobart	14.22	62.63	11.96
CZ7_In construction	11.90	72.39	14.25
CZ7_conditioned	21.14	40.78	7.82

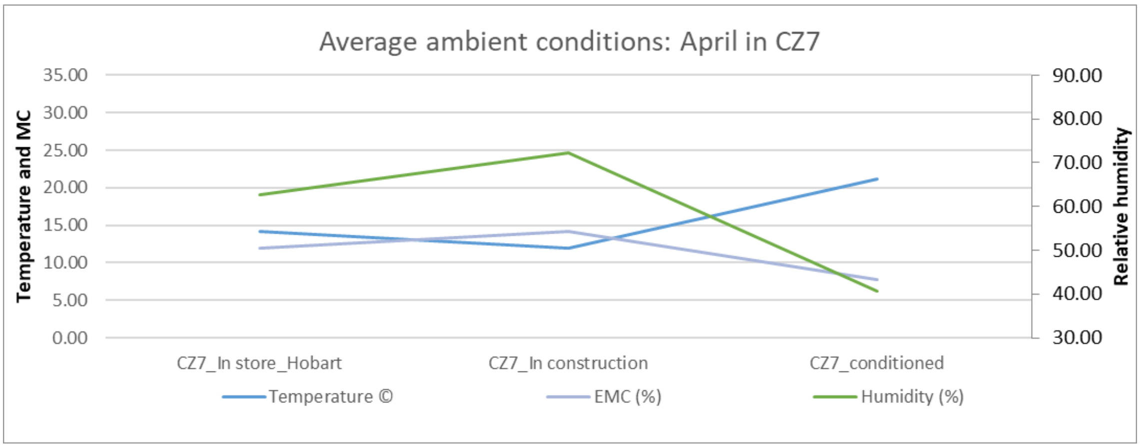

Figure 57: Average ambient conditions: April across exposure conditions

Table 59: MC responses of species and products: April cross exposure conditions

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
CZ7_Store	6.37	12.04	10.53	11.22	12.00	12.02	11.54	12.73	10.26
CZ7_Constr.	7.22	13.33	12.00	12.96	14.09	13.58	13.12	14.71	
CZ7_Condit	4.95	8.95	7.71	8.53	9.08	9.04	9.02	10.64	8.30

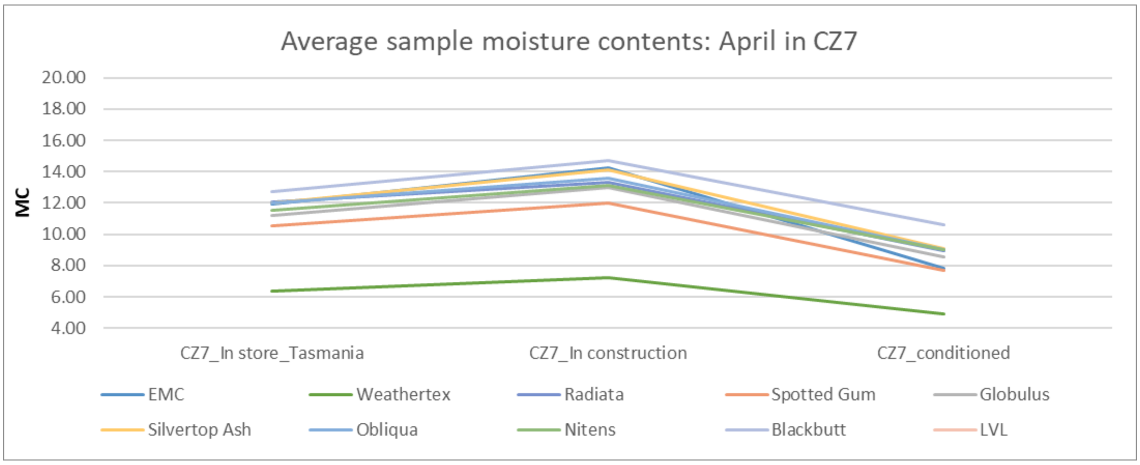

Figure 58: MC responses of species and products: April across exposure conditions

Winter: mid-July

Table 60: Ambient conditions: July across exposure conditions

	Temperature (ºC)	Humidity (%)	EMC (%)
CZ7_In store_Hobart	9.64	79.20	16.47
CZ7_In construction	8.86	84.44	18.16
CZ7_conditioned	21.00	43.22	8.19

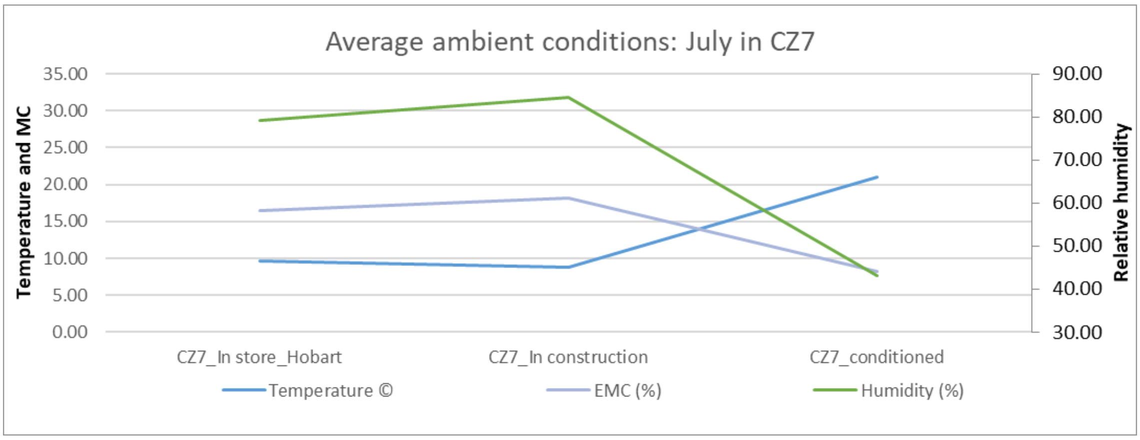

Figure 59: Average ambient conditions: July across exposure conditions

Table 61: MC responses of species and products: July across exposure conditions

	Weathertex	***P. radiata***	***C. maculata***	***E. globulus***	***E. sieberi***	***E. obliqua***	***E. nitens***	***E. pilularis***	**LVL**
CZ7_Store	7.53	14.63	12.40	13.40	14.63	14.09	13.81	15.47	12.54
CZ7_Constr.	8.97	16.80	14.47	15.24	16.35	16.52	16.25	18.31	
CZ7_Condit	4.90	8.97	7.39	8.20	8.73	8.68	8.67	10.27	8.14

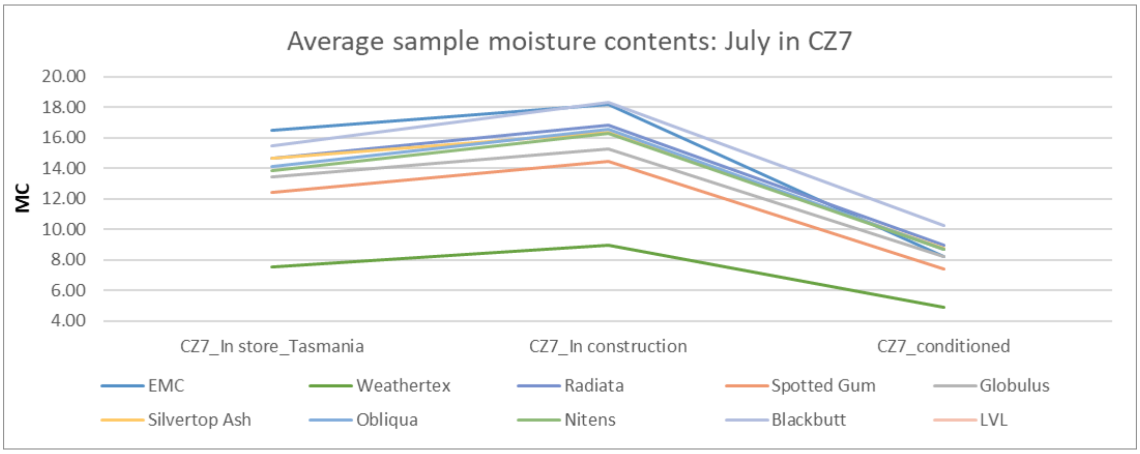

Figure 60: MC responses of species and products: July across exposure conditions

Spring: mid-October

Table 62: Ambient conditions: October across exposure conditions

	Temperature (ºC)	**Humidity (%)**	**EMC (%)**
CZ7_In store_Hobart	13.83	59.79	11.35
CZ7_In construction	13.16	69.16	13.46
CZ7_conditioned	21.22	40.69	7.81

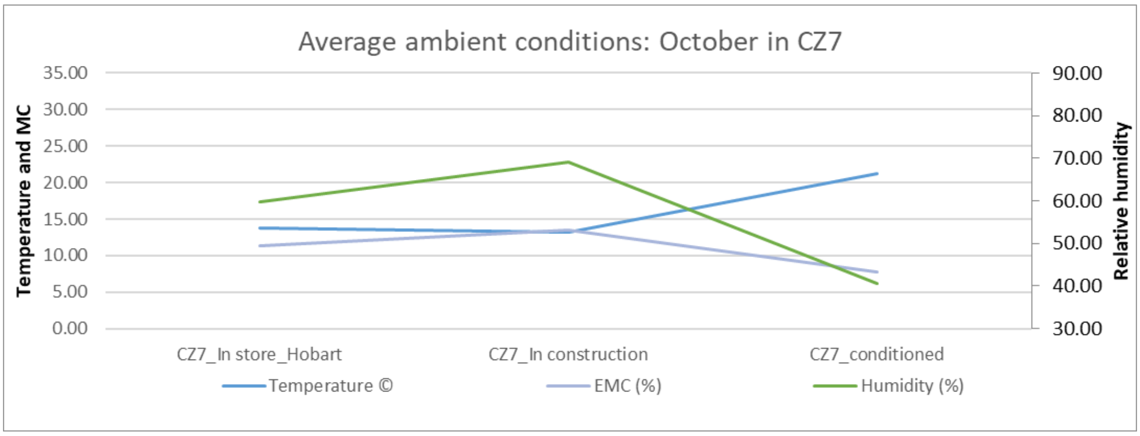

Figure 61: Average ambient conditions: October across exposure conditions

Table 63: MC responses of species and products: October across exposure conditions

	Weathertex	***P. radiata***	***C. maculata***	***E. globulus***	***E. sieberi***	***E. obliqua***	***E. nitens***	***E. pilularis***	**LVL**
CZ7_Store	6.75	12.59	11.02	11.78	12.55	12.37	12.07	13.30	11.02
CZ7_Constr.	7.96	13.08	12.72	13.00	13.83	13.39	13.24	15.06	
CZ7_Condit	4.76	8.50	7.12	8.00	8.58	8.62	8.38	10.00	8.05

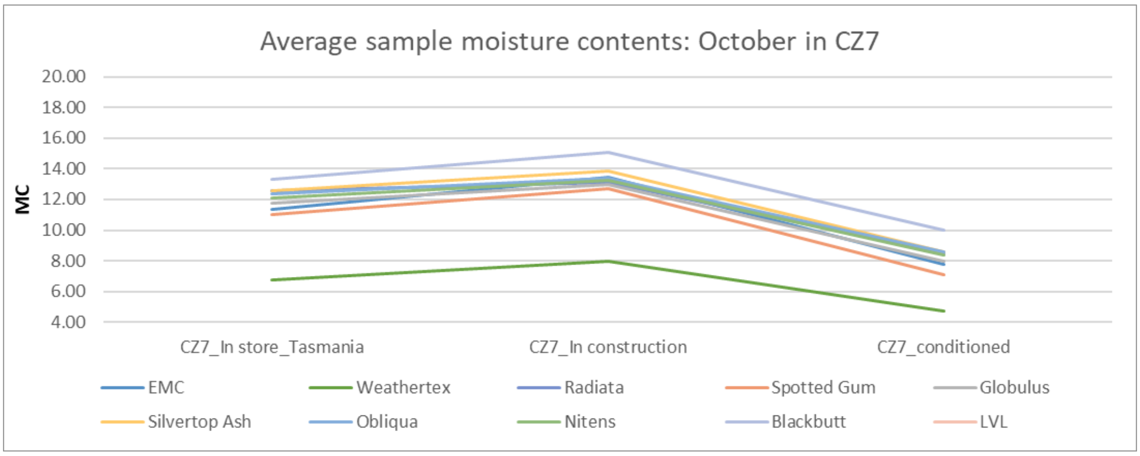

Figure 62: MC responses of species and products: October across exposure conditions

Comparisons across conditions in CZ2

As discussed above, timber and wood products regularly move from timber stores and directly or indirectly to unconditioned or conditioned spaces. The following charts and tables compare the ambient conditions and species responses in the CZ2 supply chain for:

- Summer: Mid-January.
  - See Table 64 for the ambient conditions while Table 65 and Figure 63 show the species and products MC response across the season.
- Autumn: mid-April.
  - See Table 66 for the ambient conditions while Table 67 and Figure 64 show the MC response of species and products.
- Winter: mid-July.
  - See Table 68 for the ambient conditions while Table 69 and Figure 65 show the MC response of species and products.
- Spring: mid-October.
  - See Table 70 for the ambient conditions while Table 71 and Figure 66 show the MC response of species and products.

In this, the measured conditions in the CZ7 conditioned space are likely to be very similar to equivalent spaces in CZ2. Potential risks evident from the results include:

- Mild risk occurring when product is moved:
  - In January, with all species moving from a timber store or workshop, or construction to in service in a conditioned space.
  - In April, with most species moving from construction to a conditioned space.
- Medium risk occurring when product is moved:
  - In April, with most species moving from a timber store or workshop to a conditioned space.
  - In October, with most species moving from construction to a conditioned space.
- High risk occurring when product is moved:
  - In July, with most species moving from a timber store or workshop, or construction to a conditioned space.
  - In October with most species moving from a timber store or workshop to a conditioned space.

Summer: Mid-January

Table 64: Ambient conditions: January across exposure conditions

	Temperature (ºC)	Humidity (%)	EMC (%)
CZ2_In store	25.57	64.11	11.70
CZ7_conditioned	22.31	44.55	8.38

Table 65: MC responses of species and products: January across exposure conditions

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
CZ2_Store	7.14	12.88	10.80	11.44	13.28	12.02	12.39	13.64	11.27
CZ2_Constr.	6.95	11.61	9.91	10.66	12.16	11.70	11.57	12.89	11.43
CZ7_Condit	5.01	9.12	7.80	8.63	9.13	9.09	9.04	10.63	8.39

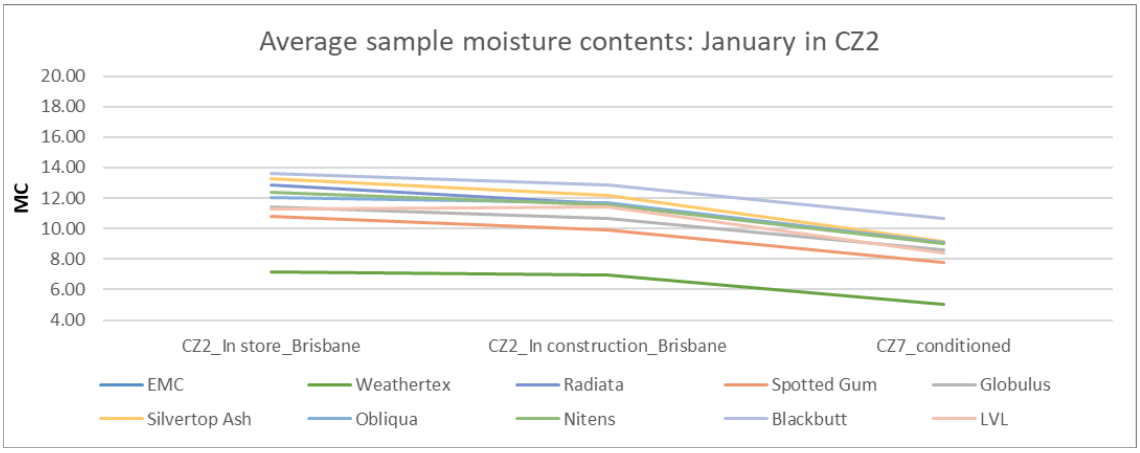

Figure 63: MC responses of species and products: January across exposure conditions

Autumn: mid-April

Table 66: Ambient conditions: April across exposure conditions

	Temperature (ºC)	Humidity (%)	EMC (%)
CZ2_In store	21.77	63.15	11.70
CZ7_conditioned	21.14	40.78	7.82

Table 67: MC responses of species and products: April across exposure conditions

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
CZ2_Store	7.03	13.13	11.28	11.83	13.61	12.68	12.89	14.33	11.29
CZ2_Constr.	5.79	10.39	9.81	10.19	12.40	11.34	10.98	12.97	9.65
CZ7_Condit	4.95	8.95	7.71	8.53	9.08	9.04	9.02	10.64	8.30

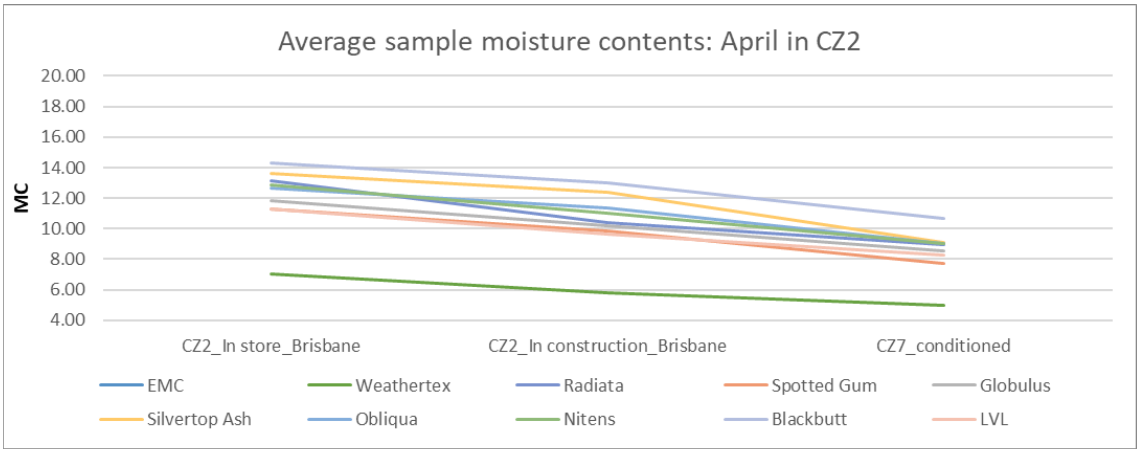

Figure 64: MC responses of species and products: April across exposure conditions

Winter: mid-July

Table 68: Ambient conditions: July across exposure conditions

	Temperature (ºC)	Humidity (%)	EMC (%)
CZ2_In store	16.97	67.82	13.30
CZ7_conditioned	21.22	40.69	7.81

Table 69: MC responses of species and products: July across exposure conditions

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
CZ2_Store	7.93	15.05	12.08	12.82	14.84	13.79	14.37	15.58	12.56
CZ2_Constr.	8.55	15.96	12.81	13.23	16.49	14.46	15.35	16.97	15.07
CZ7_Condit	4.76	8.50	7.12	8.00	8.58	8.62	8.38	10.00	8.05

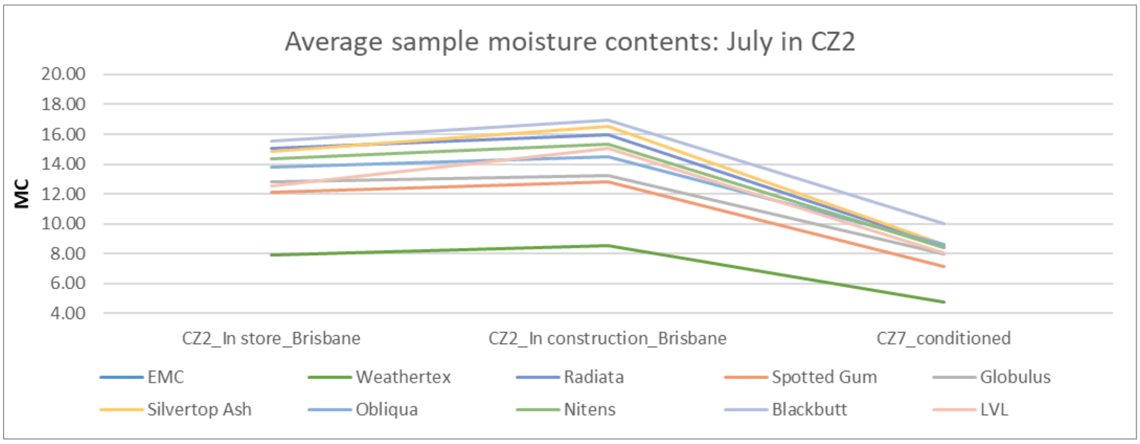

Figure 65: MC responses of species and products: July across exposure conditions

Spring: mid-October

Table 70: Ambient conditions: October across exposure conditions

	Temperature (ºC)	Humidity (%)	EMC (%)
CZ2_In store	16.97	67.82	13.30
CZ7_conditioned	11.90	72.39	14.25

Table 71: MC responses of species and products: October across exposure conditions

	Weathertex	*P. radiata*	*C. maculata*	*E. globulus*	*E. sieberi*	*E. obliqua*	*E. nitens*	*E. pilularis*	LVL
CZ2_Store	7.82	14.56	11.25	12.45	14.32	13.42	13.69	14.89	11.97
CZ2_Constr.	7.39	12.53	10.28	11.25	12.73	12.48	12.63	13.84	14.02
CZ7_Condit	4.76	8.50	7.12	8.00	8.58	8.62	8.38	10.00	8.05

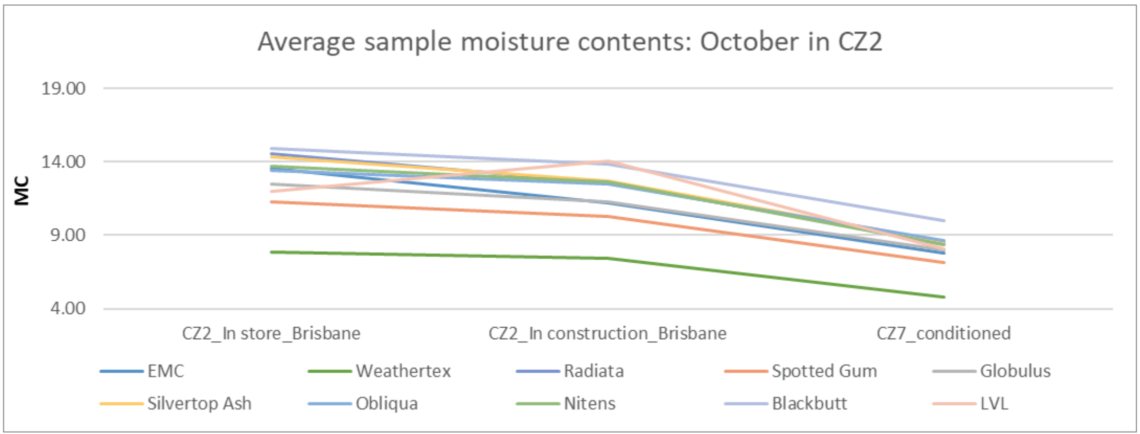

Figure 66: MC responses of species and products: October across exposure conditions

Conclusion

The project's static sample monitoring component was designed to collect and assess first-generation information covering the temperature and humidity conditions found in the Australian timber supply chain and the MC responses of common species and wood products stored in those conditions.

In this component, 31 sets of data were collected from static monitoring units across four climate zones, recording the temperature and humidity conditions and the MC responses of timber species and wood products.

Each full data set has value as it informs timber suppliers of likely conditions in their own facility and in facilities or location to who they supply product. The assessment of averaged results informs industry decision making, as they demonstrate that:

- The MC of timber and wood products change to be in equilibrium with the surrounding environment. In the supply chain, this occurs across location and seasons.
- Species and products have individual EMC. Engineered wood products (EWP) generally have a lower EMC than solid timber species, with Weathertex lower that LVL and LVL lower than its constituent Radiata pine. Species EMC vary with the type of wood (hardwood and softwood) and other factors.
- The average MC of species and wood products changes with climate zone and exposure conditions. Timber in stores is driest in CZ6 (Melbourne) and wettest in CZ2 (Brisbane). Across exposure conditions, construction sites are generally the wettest while internal service environments are significantly drier than any other location in the supply chain.
- Species expand and contract with changes in MC. Unit movement as measured across six CZ7 storage sites is low longitudinally but higher across the width of the samples. Of the tested samples, Weathertex has the lowest movement overall. The extent of average movement of all species measured at these sites across the width was 0.76% across a 100 mm board.

The component's results provide quantitative detail of the conditions found in the Australian timber and wood products supply chain. This can inform:

- Risk management, as areas of high risk can now be defined and the level of risk between site quantified.
- The review of existing construction and MC control processes. For example, the highly variable results documented from construction sites indicates that equilibration of seasoned timber on a building site prior to installation may be counter-production.
- Industry understanding of the duration of exposure times in particular environmental conditions that can result in unacceptable change in timber MC. This type of knowledge can be used to ensure timber components are detailed to accommodate predictable MC-induced movement and timber's MC is maintained to suit context specific building applications.

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TR-2 Appendix 1 Timber's MC in the supply chain

Species behaviour and conditions in storage and service

Professor Gregory Nolan

Dr Nathan Kotlarewski

December 2022

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

These reports show how environmental conditions change in the timber supply chain and the MC response of major timber species and products. Figure 1 shows the measured environmental conditions and the calculated EMC for the listed facility. Figure 2 shows the measured MC response to those conditions of static timber samples stored in it.

Climate zone 7: Conditioned spaces

Site name: CZ7 _ conditioned _ Launceston

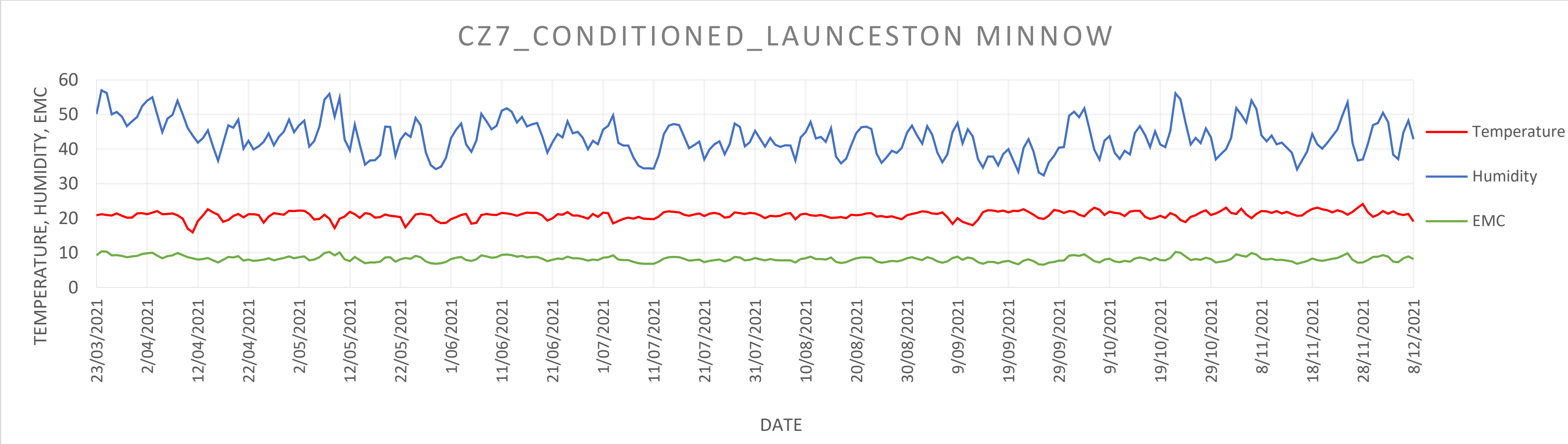


Figure 1. Temperature, Humidity, and calculated EMC

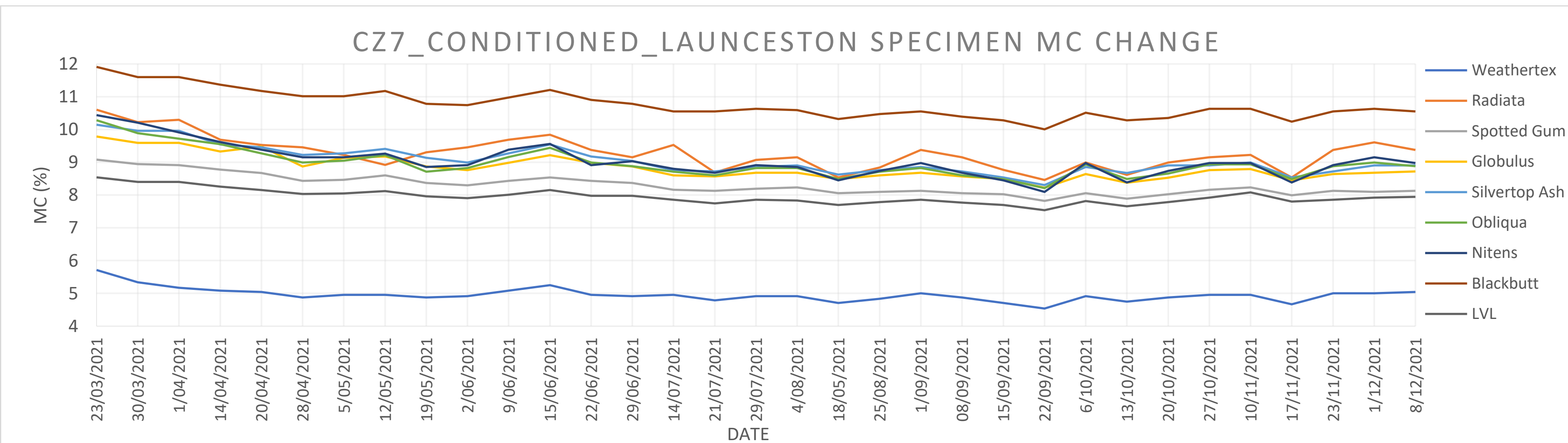


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ7_ conditioned _ Hobart

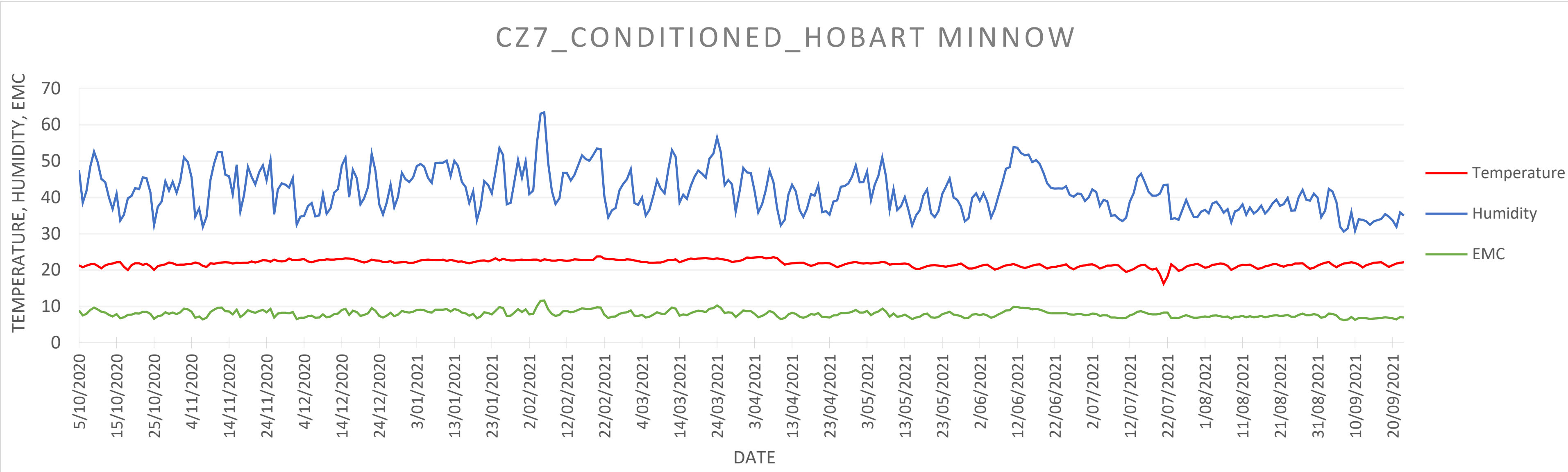


Figure 1. Temperature, Humidity, and calculated EMC

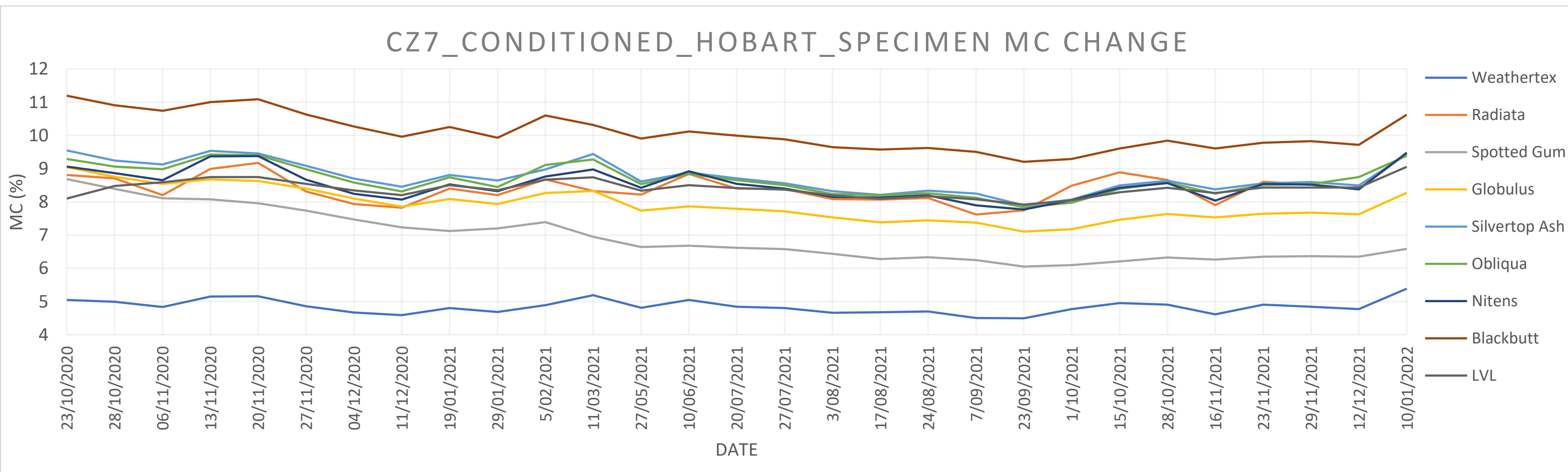


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Climate zone 7: Unconditioned spaces

Site name: CZ7 _ unconditioned _ Hobart

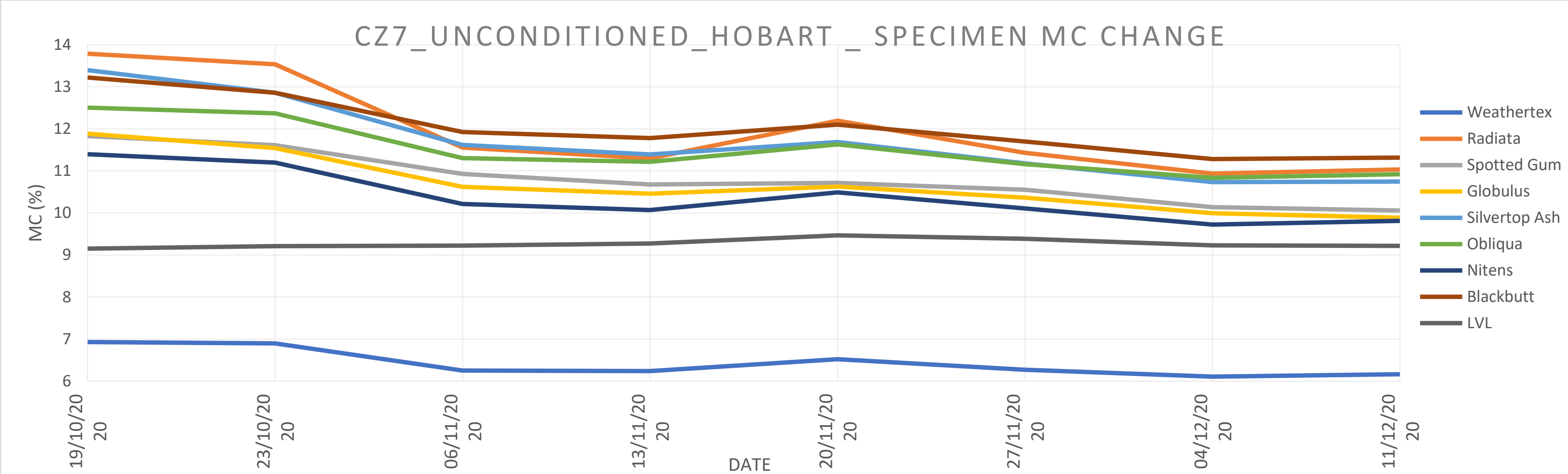


Figure 1. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Climate zone 7: In construction

Site name: CZ7 _ In construction _ Launceston

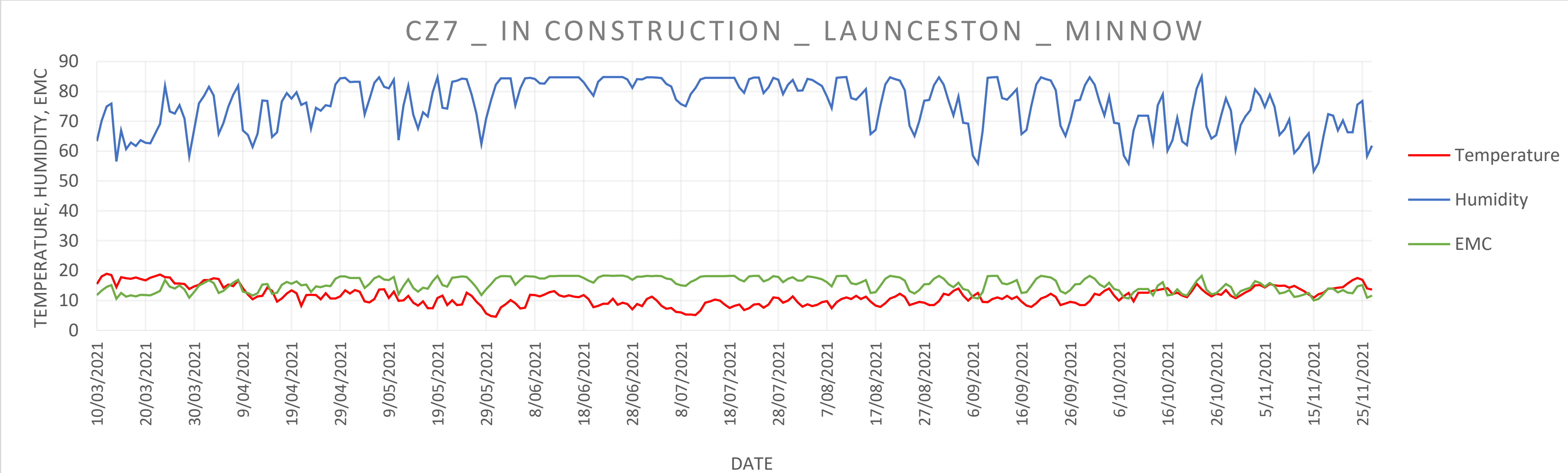


Figure 1. Temperature, Humidity, and calculated EMC

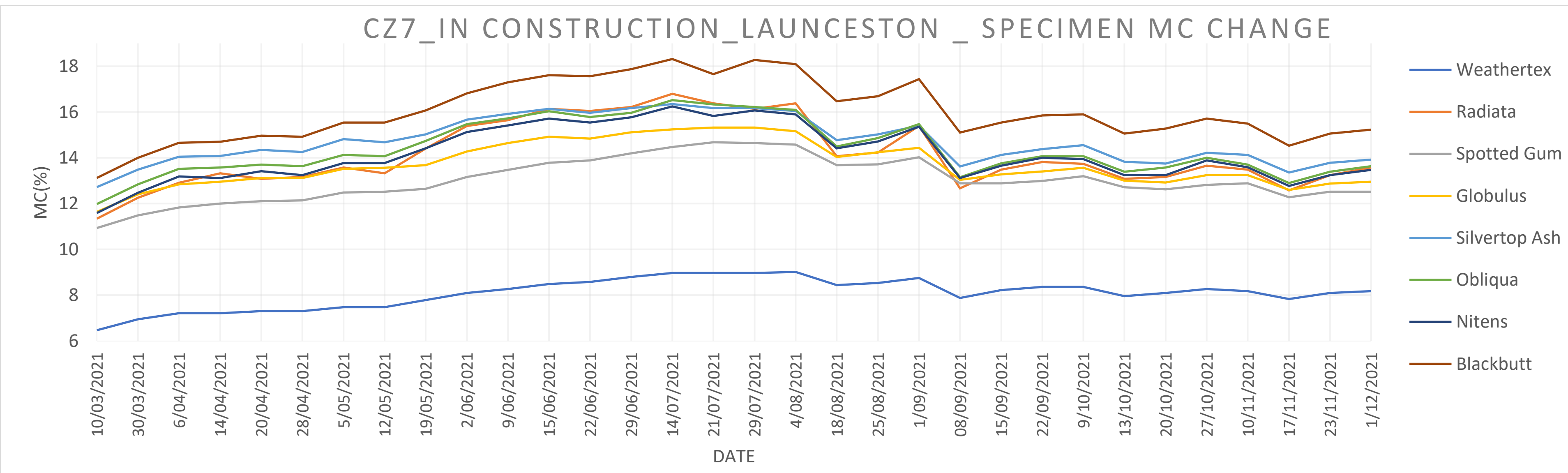


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Climate zone 7: In store

Site name: CZ7 _ In store _ Hobart 01

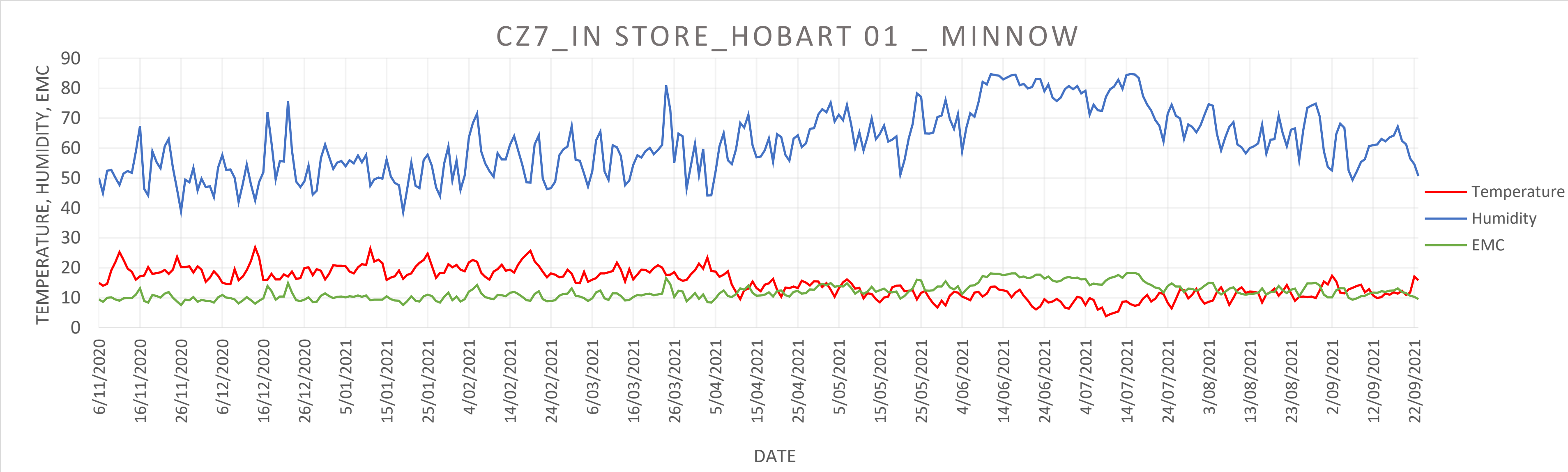


Figure 1. Temperature, Humidity and calculated EMC

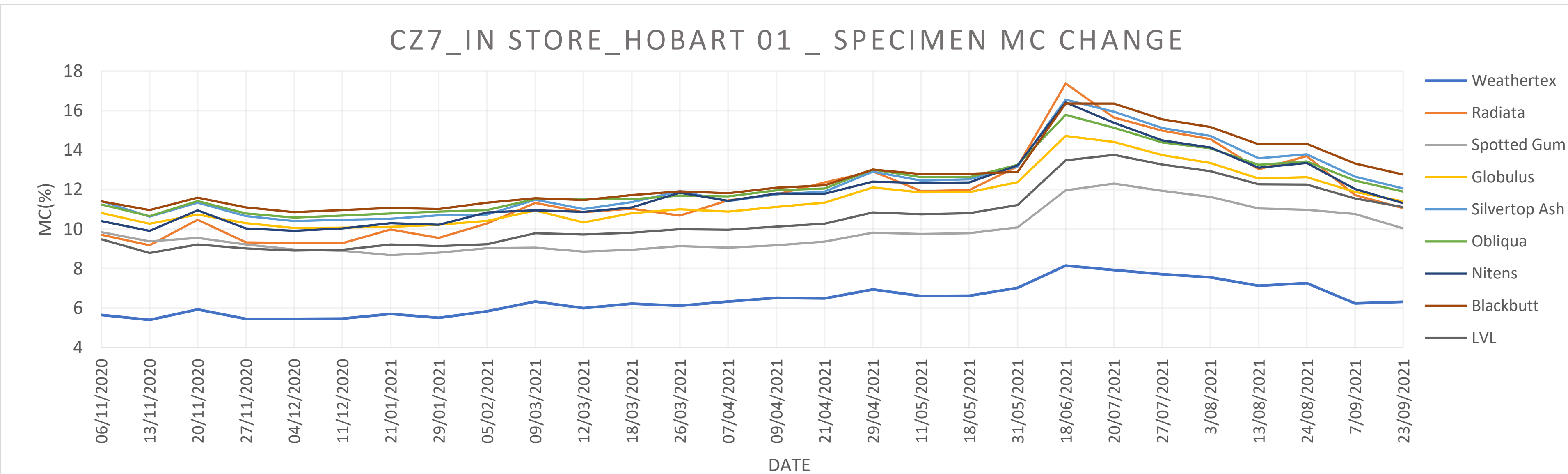


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ7 _ In store _ Launceston

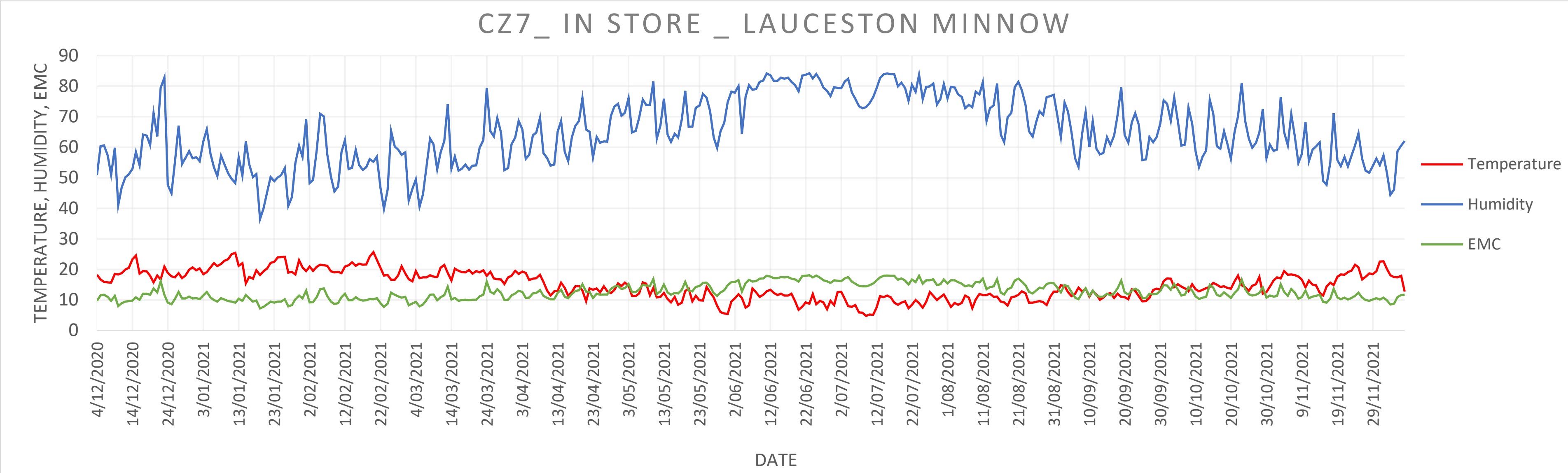


Figure 1. Temperature, Humidity and calculated EMC

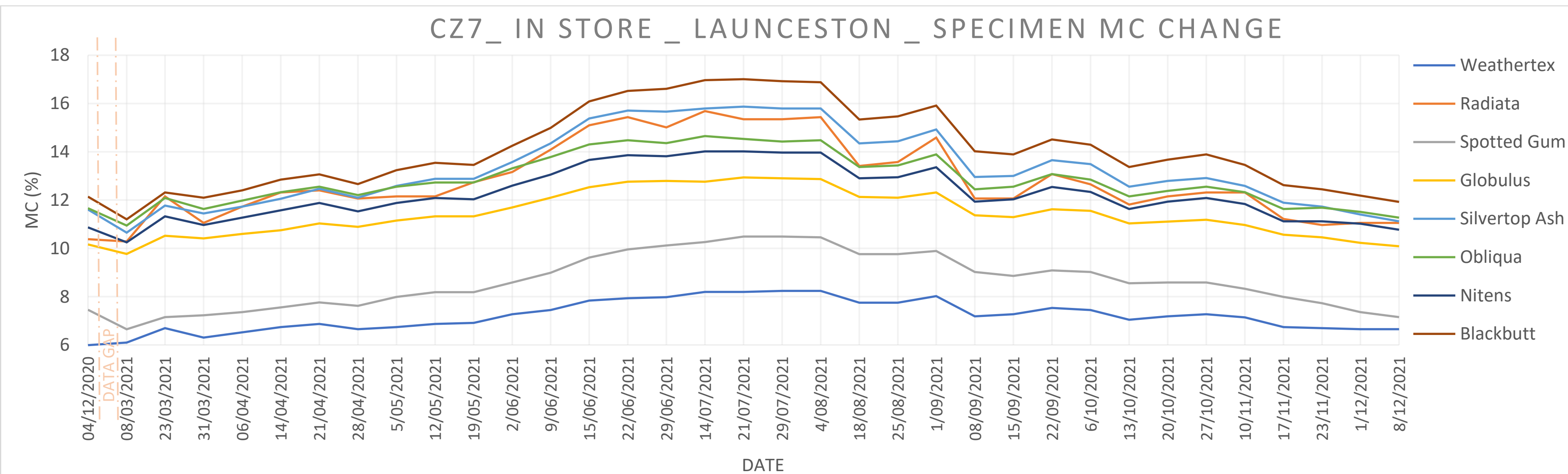


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ7_In store_NSW

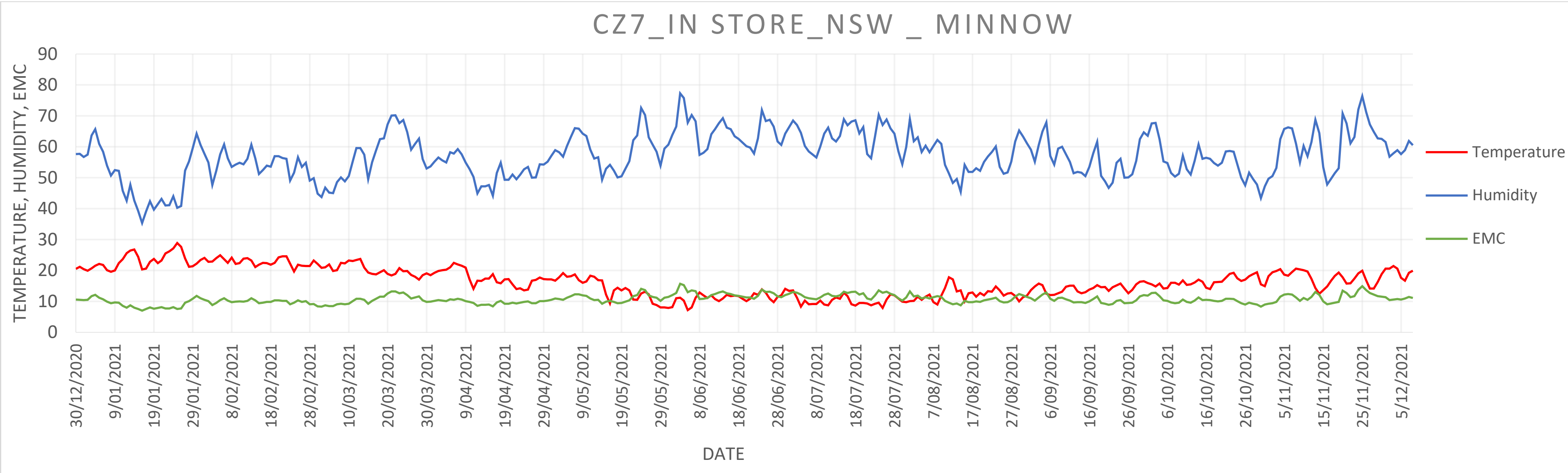


Figure 1. Temperature, Humidity, and calculated EMC

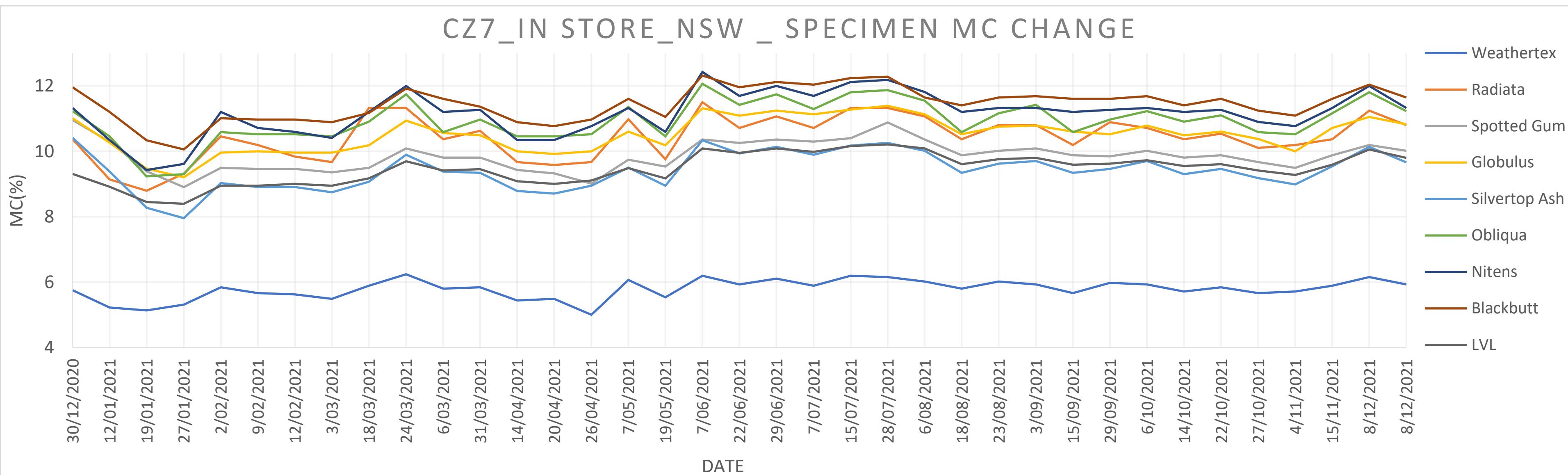


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ7 _ In store _ Hobart _ 02

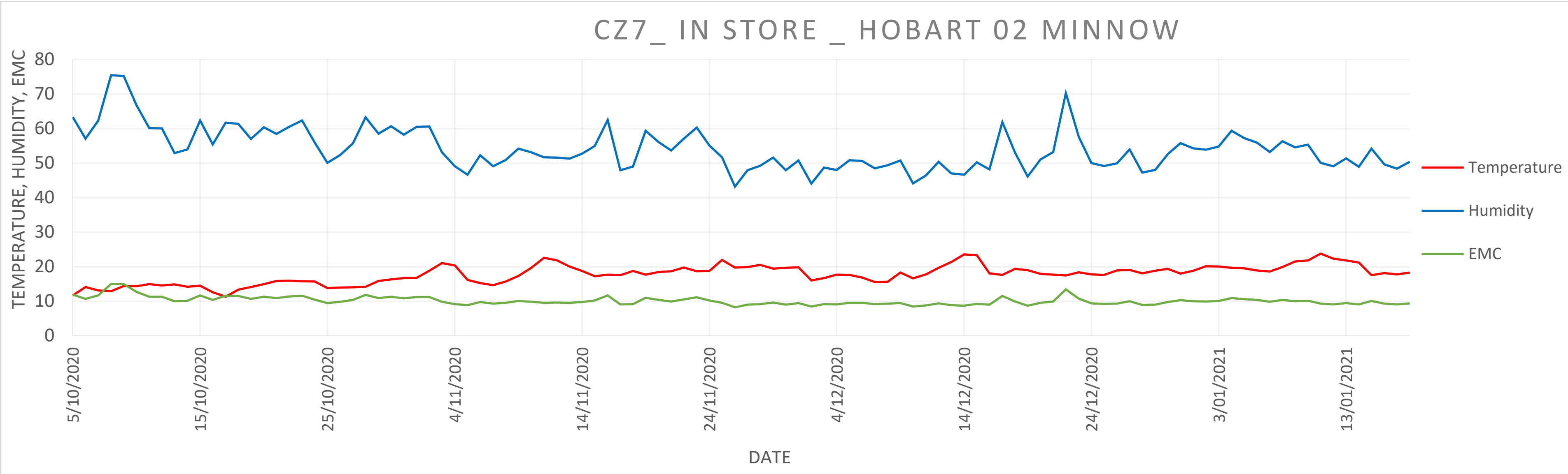


Figure 1. Temperature, Humidity, and calculated EMC

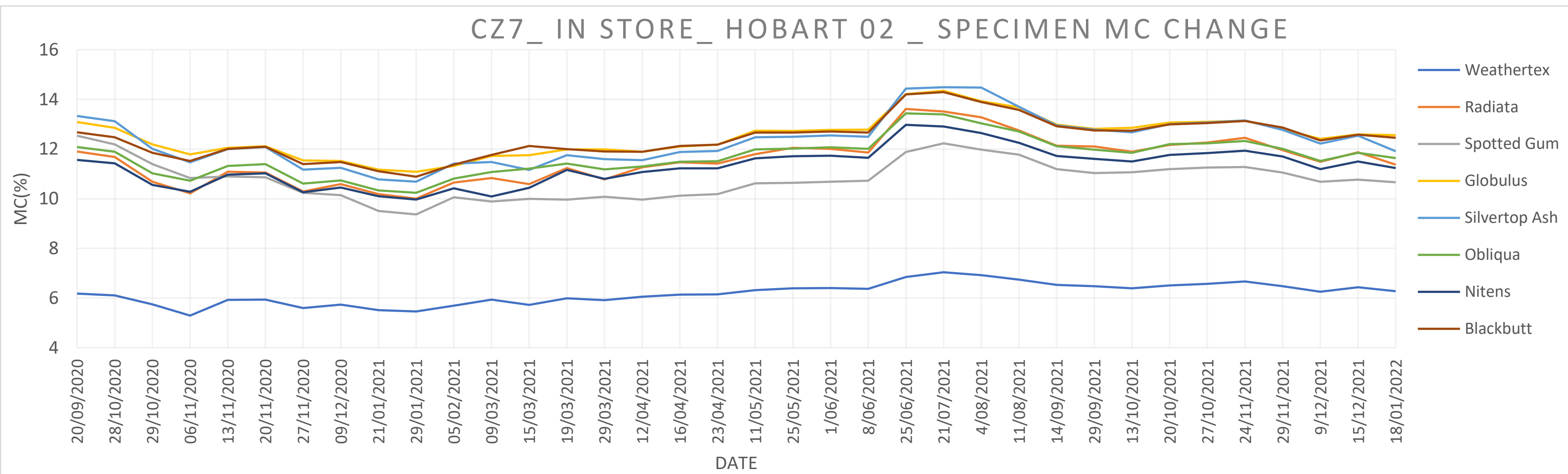


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ7 _ In store _ Hobart 03

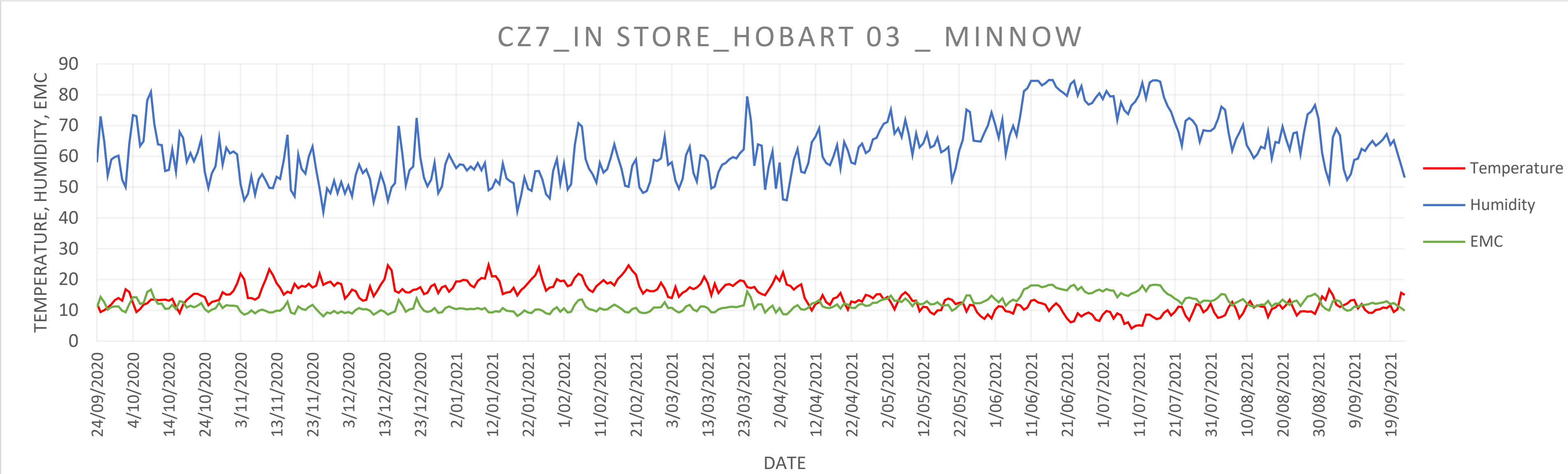


Figure 1. Temperature, Humidity, and calculated EMC

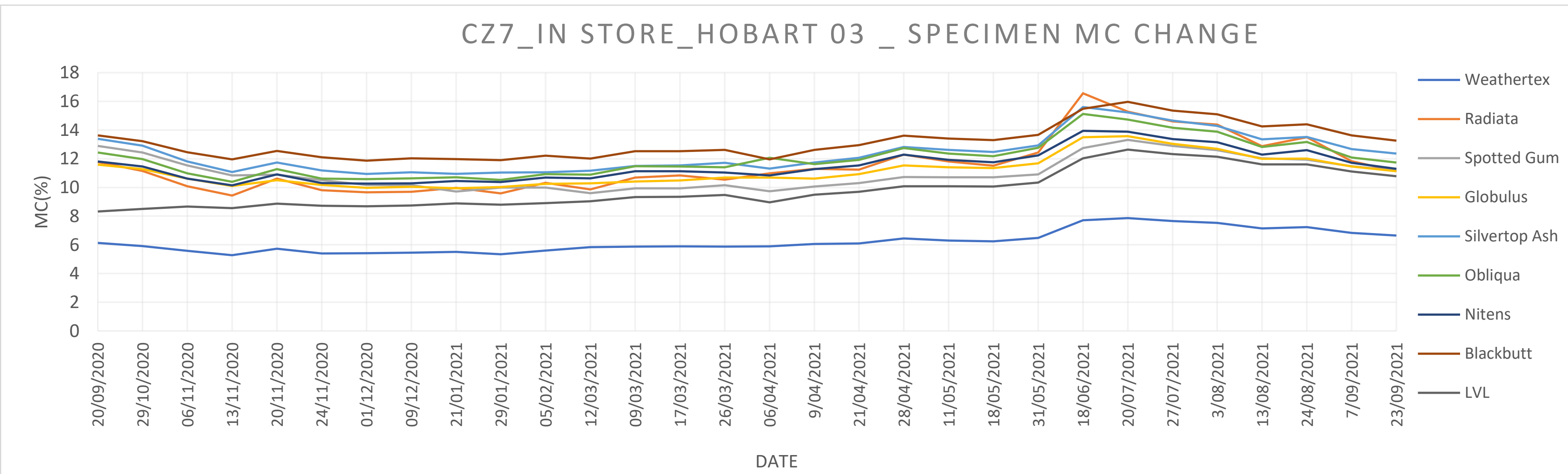


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ7 _ In store _ NWTas 01

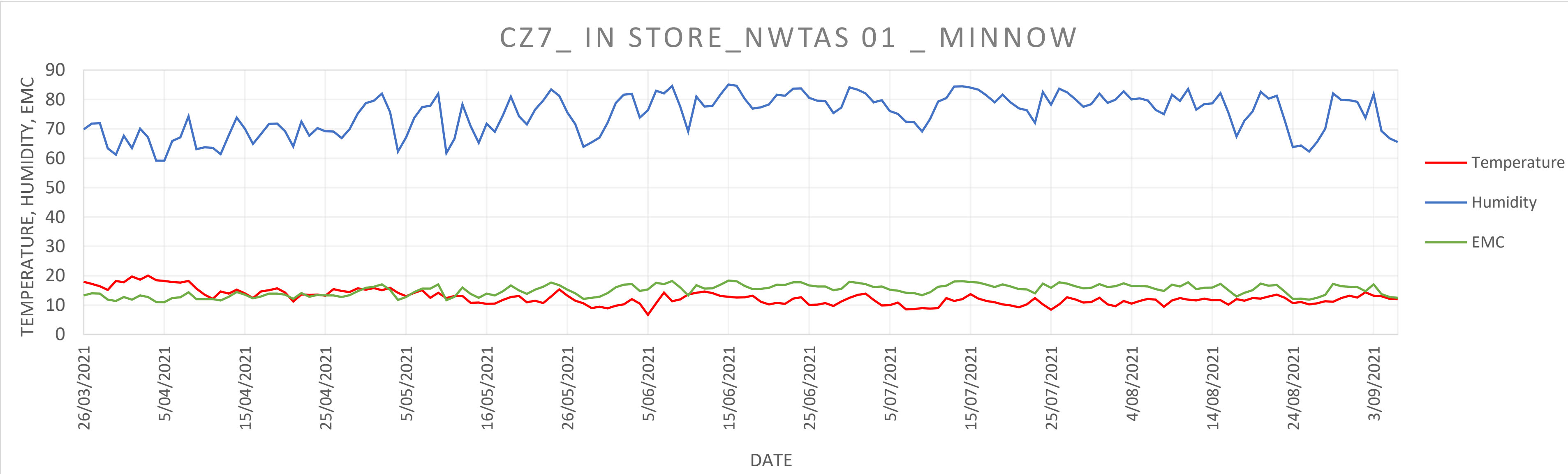


Figure 1. Temperature, Humidity, and calculated EMC

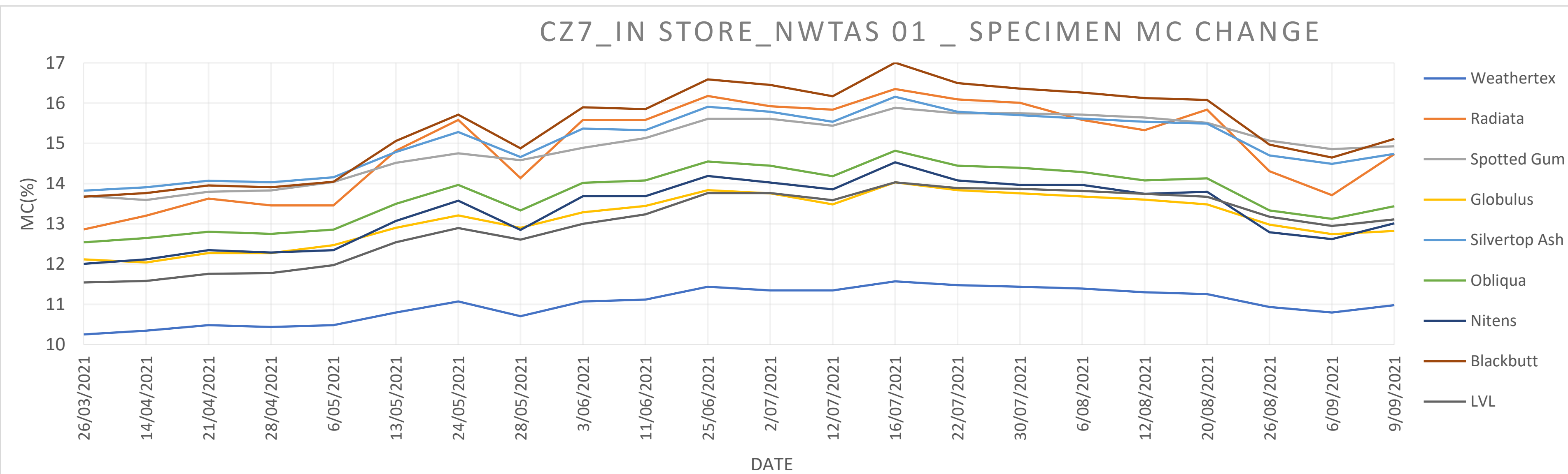


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Climate zone 6: In store

Site name: CZ6 _ In store _ Melbourne 01

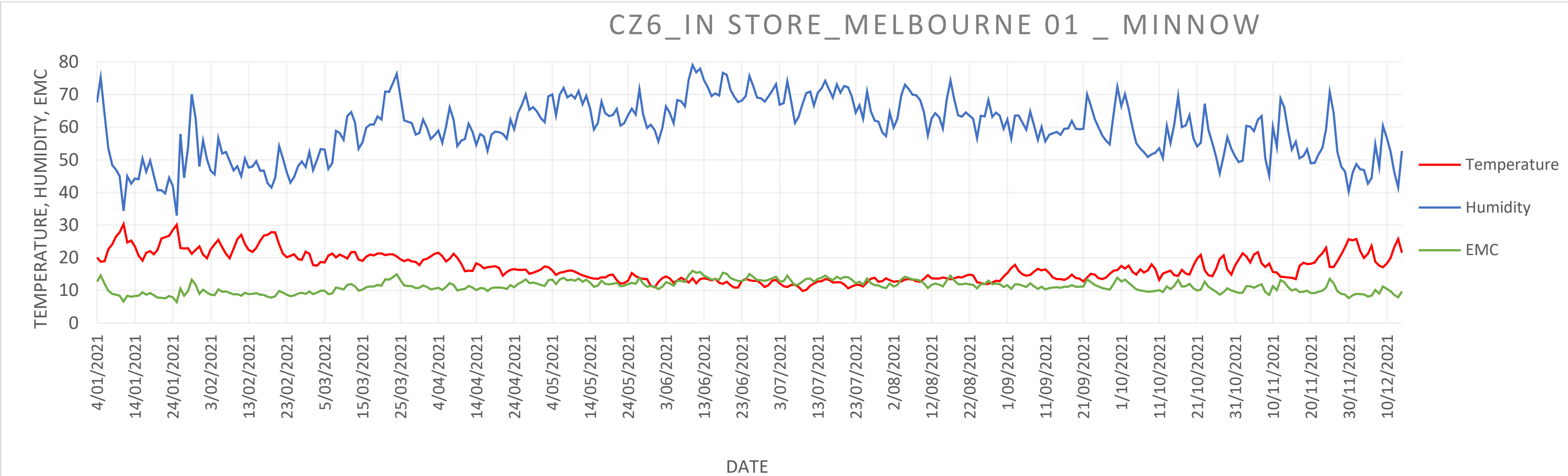


Figure 1. Temperature, Humidity, and calculated EMC

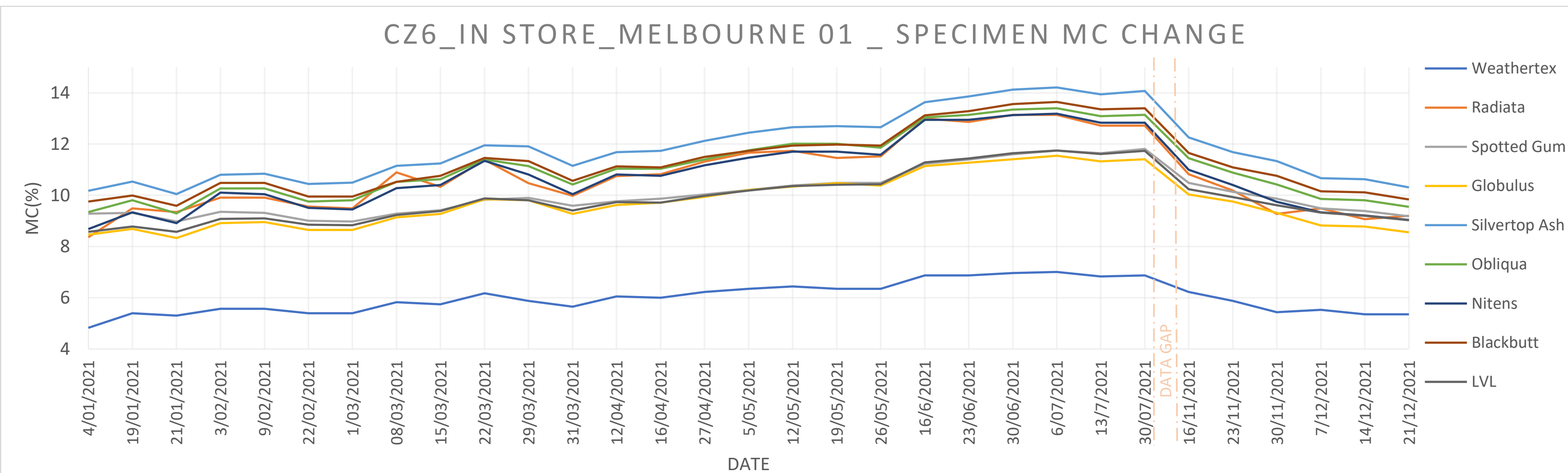


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ6_In store _ Melbourne 02

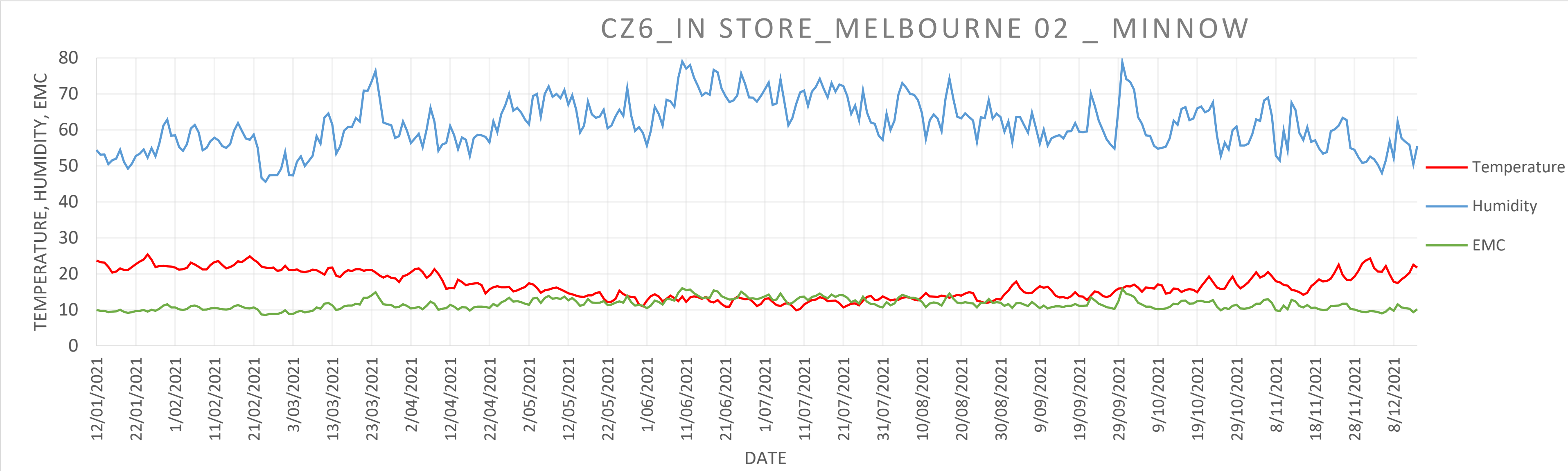


Figure 1. Temperature, Humidity and calculated EMC

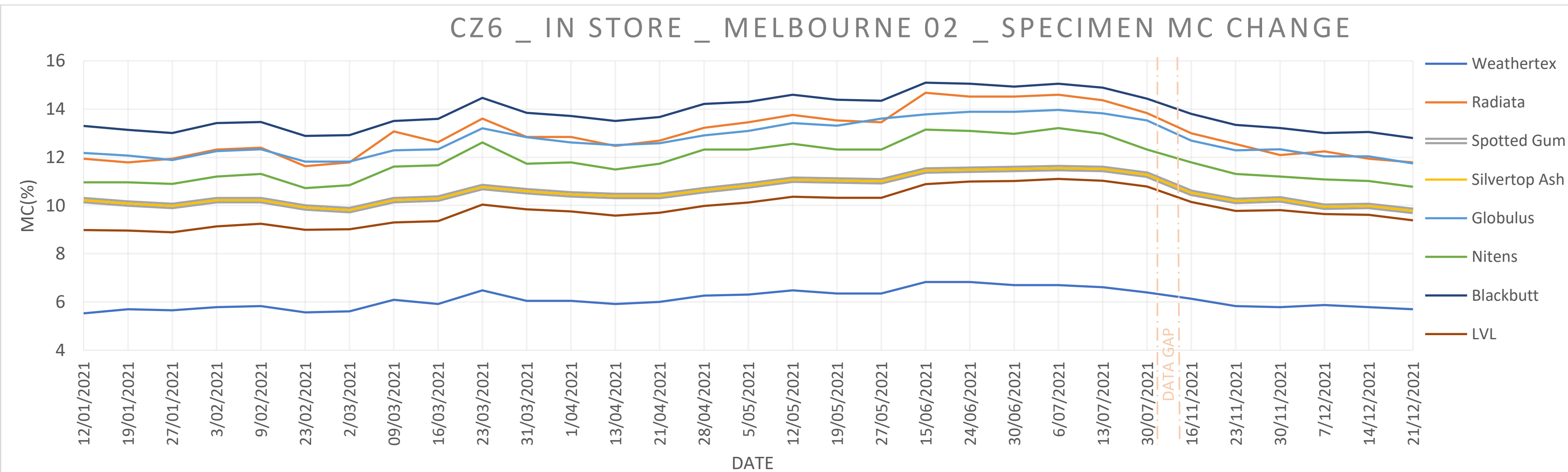


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ6 _ In store _ Melbourne 03

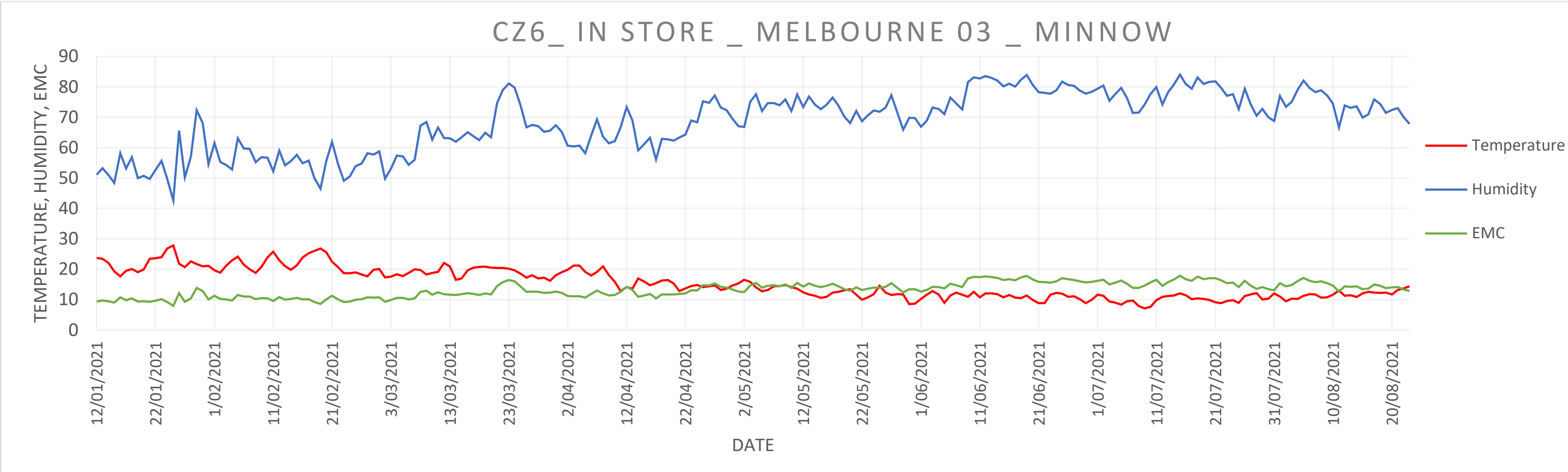


Figure 1. Temperature, Humidity, and calculated EMC

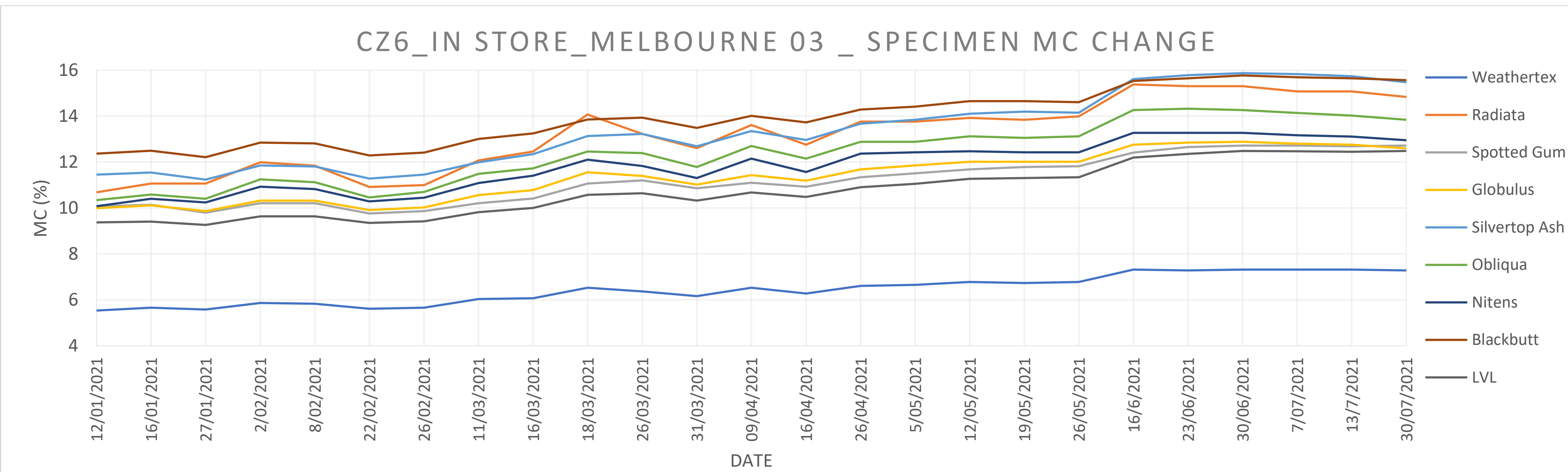


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ6_In store_Melbourne 04

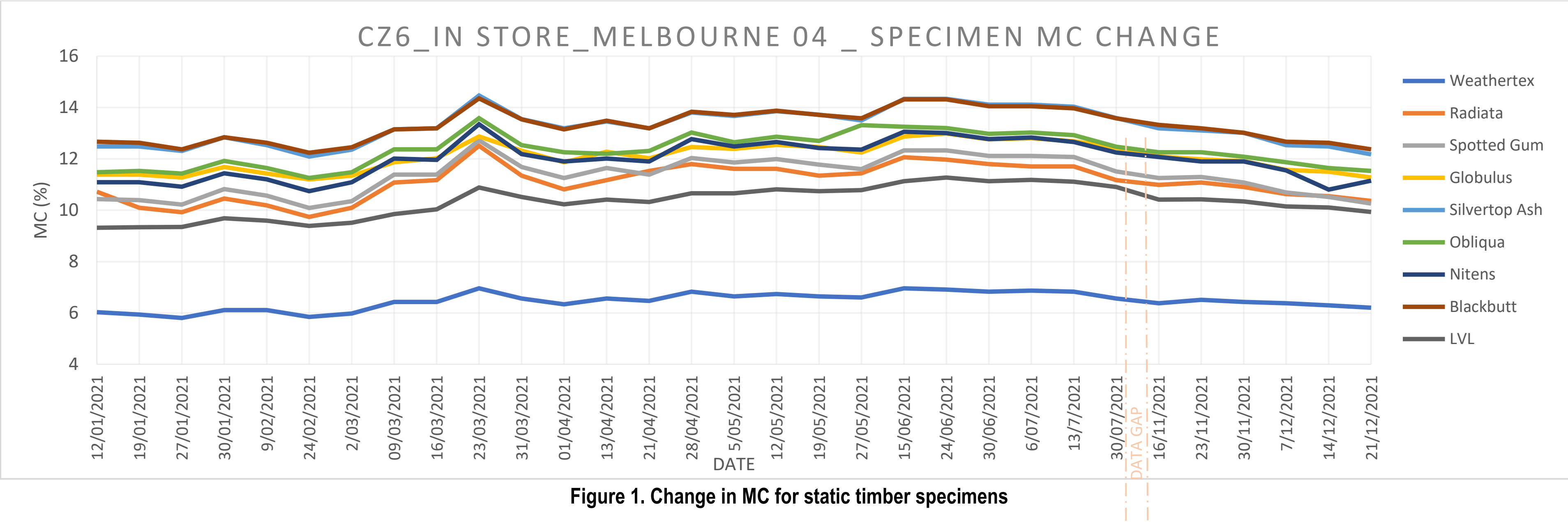


Figure 1. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ6_In store_Sydney 01

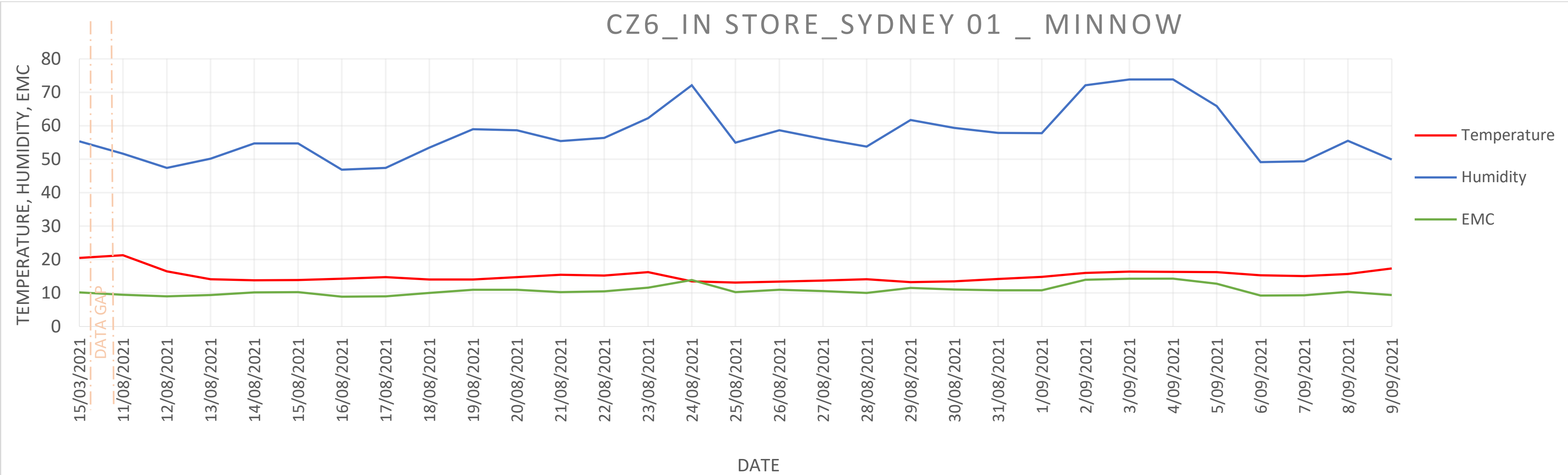


Figure 1. Temperature, Humidity, and calculated EMC

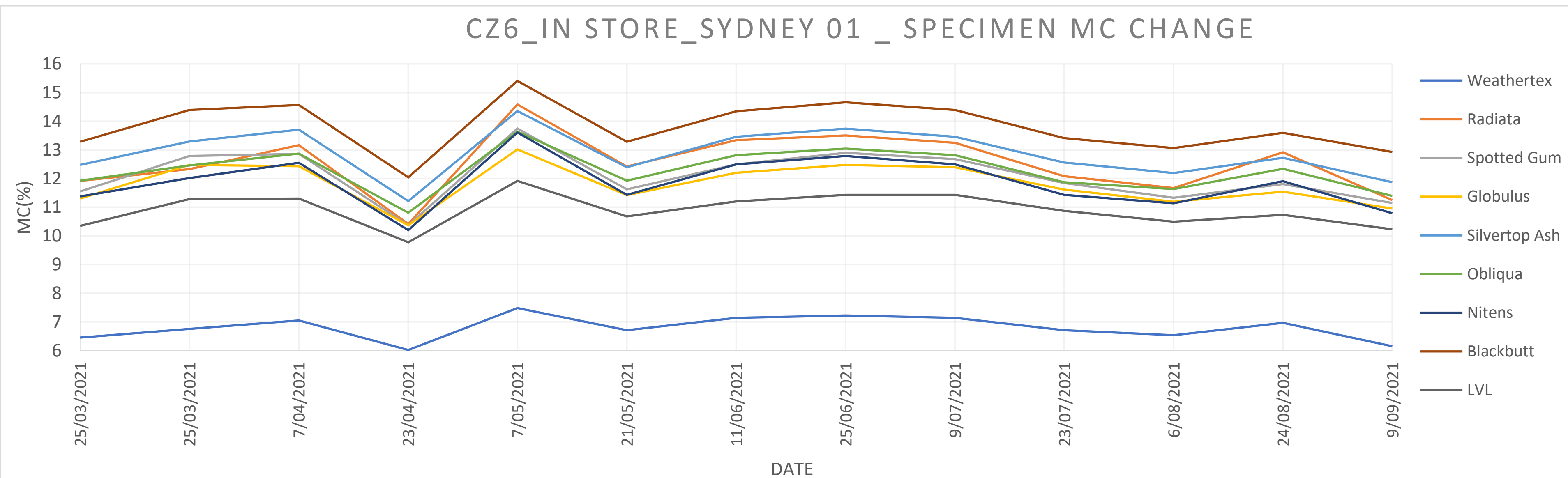


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Climate zone 6: Sheltered

Site name: CZ6 _ Sheltered _ Melbourne

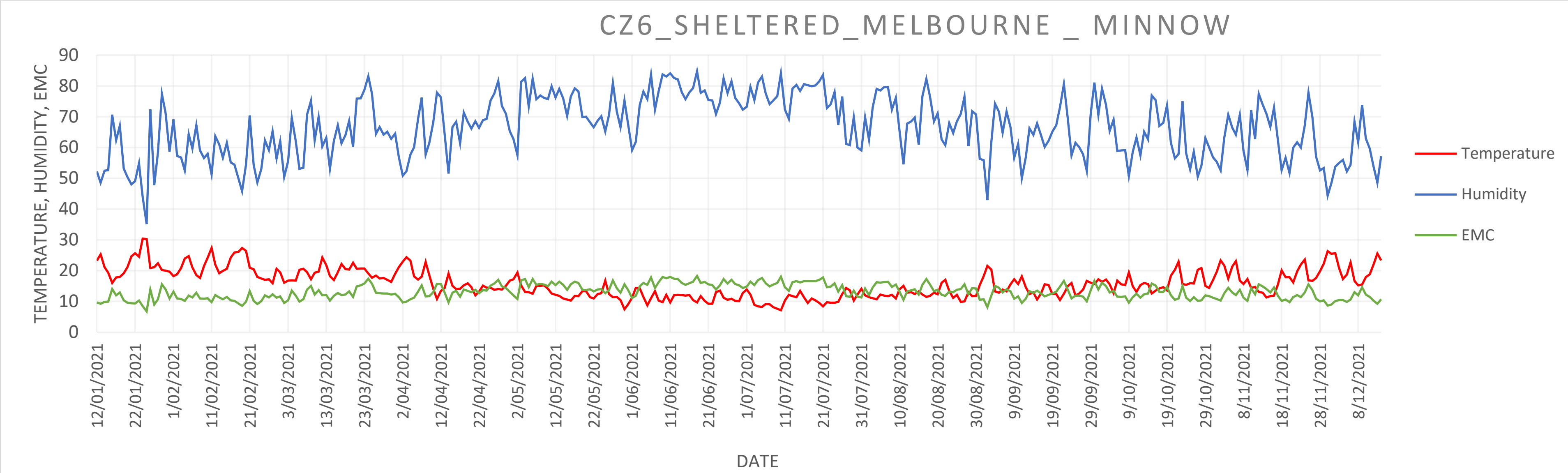


Figure 1. Temperature, Humidity and calculated EMC

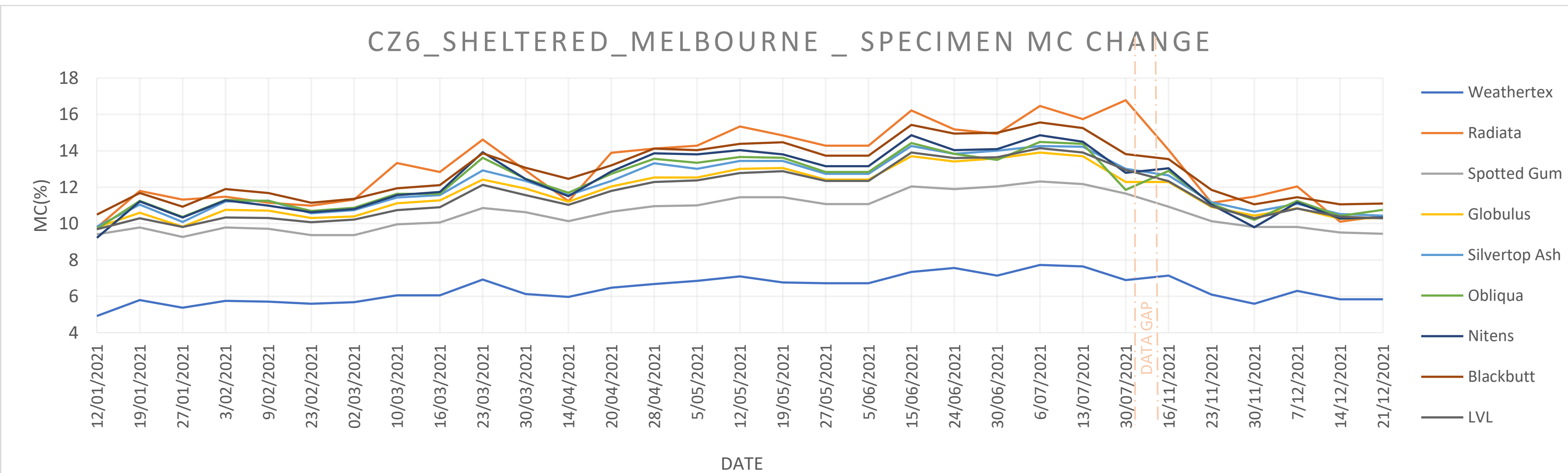


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Climate zone 5: Unconditioned space

Site name: CZ5_unconditioned_Adelaide 01

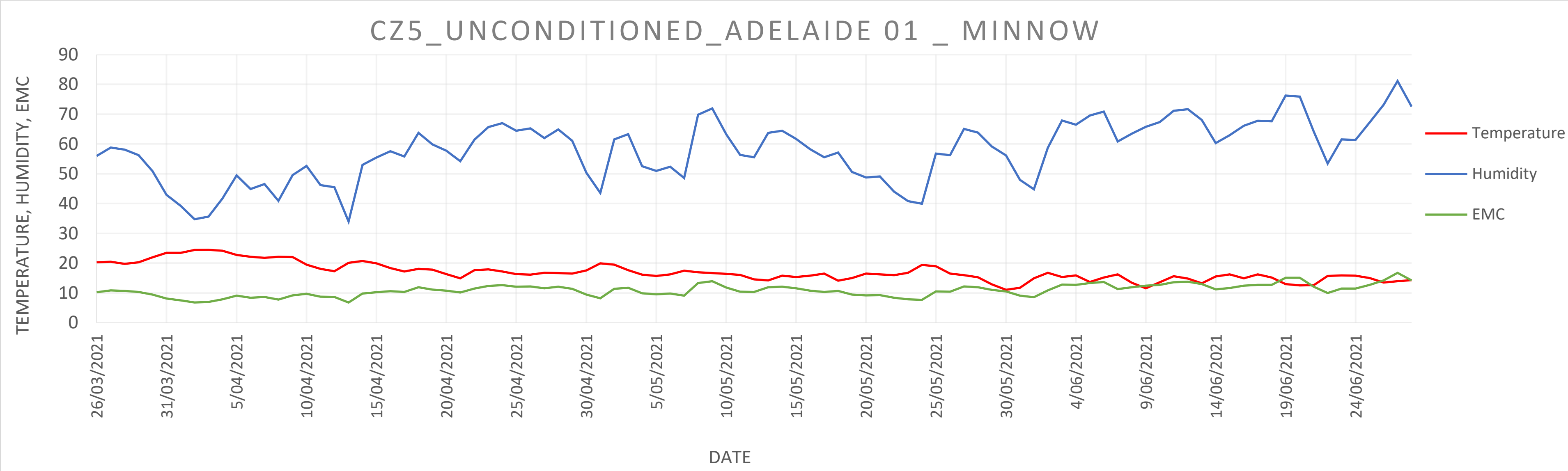


Figure 1. Temperature, Humidity and calculated EMC

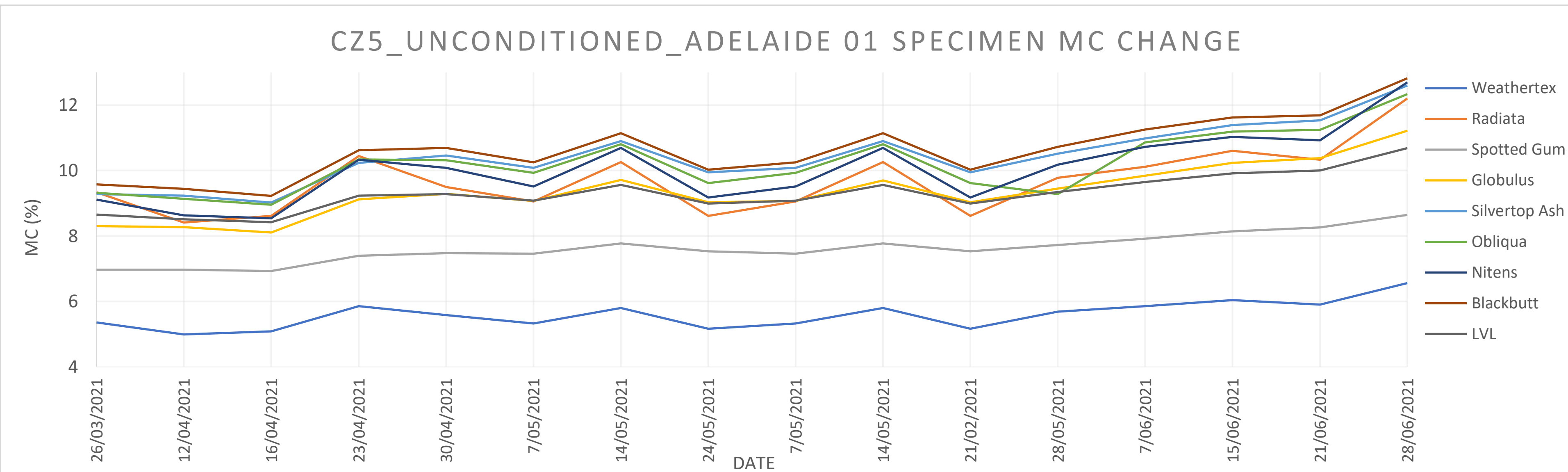


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ5_unconditioned_Adelaide 02

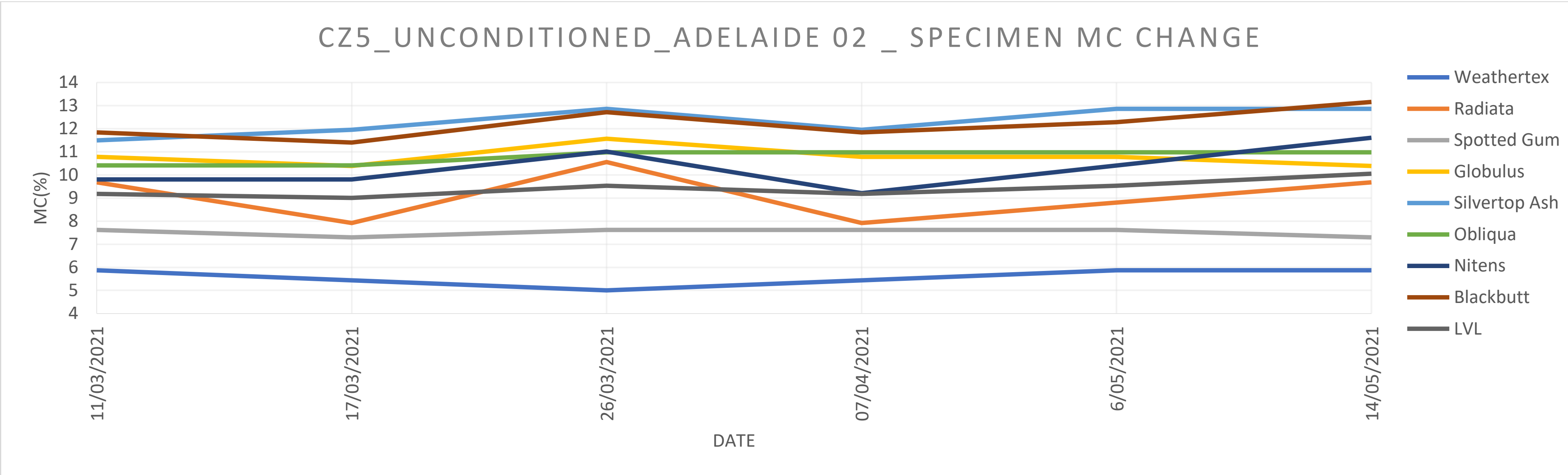


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Climate zone 5: In store

Site name: CZ5_In store_NSW 01

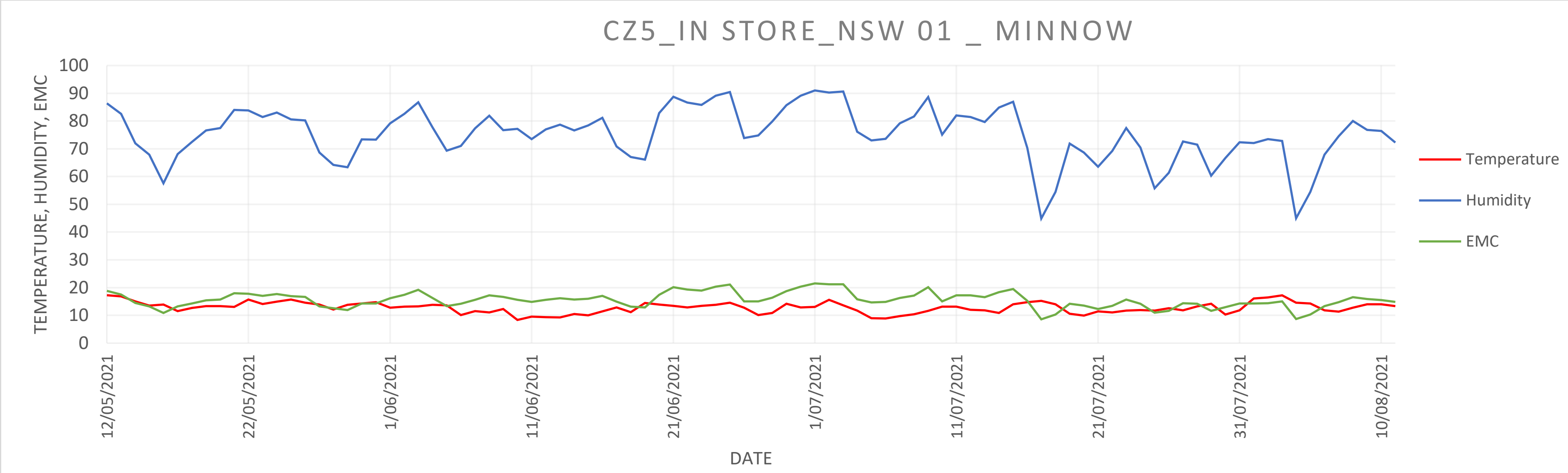


Figure 1. Temperature, Humidity, and calculated EMC

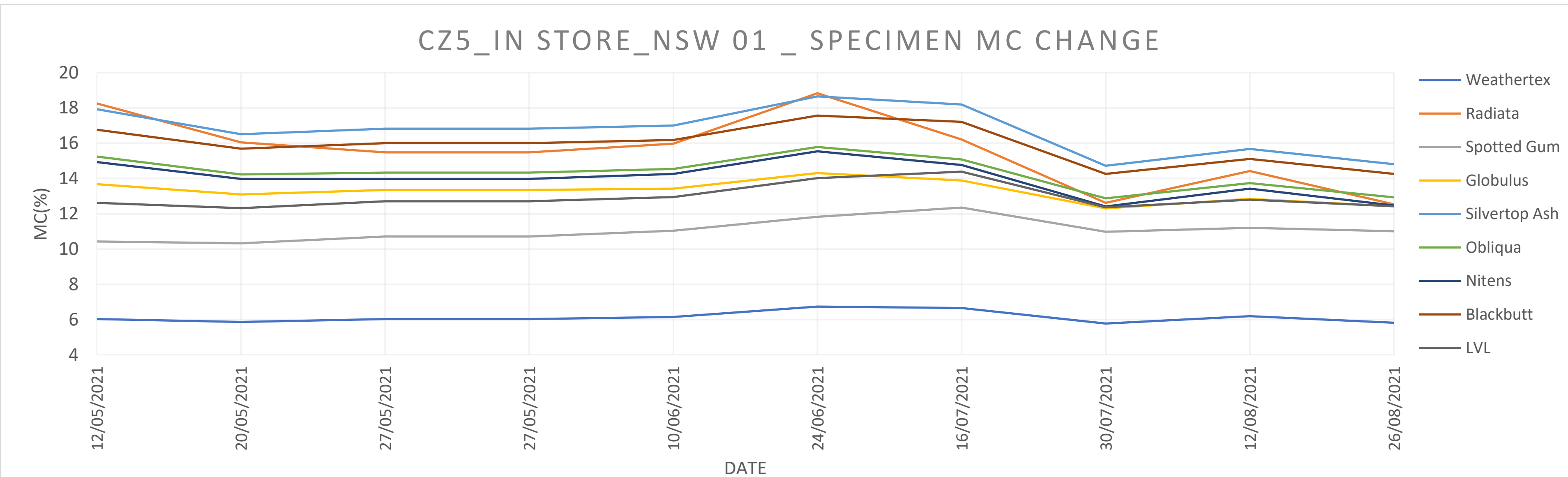


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ5_In store_SA 01

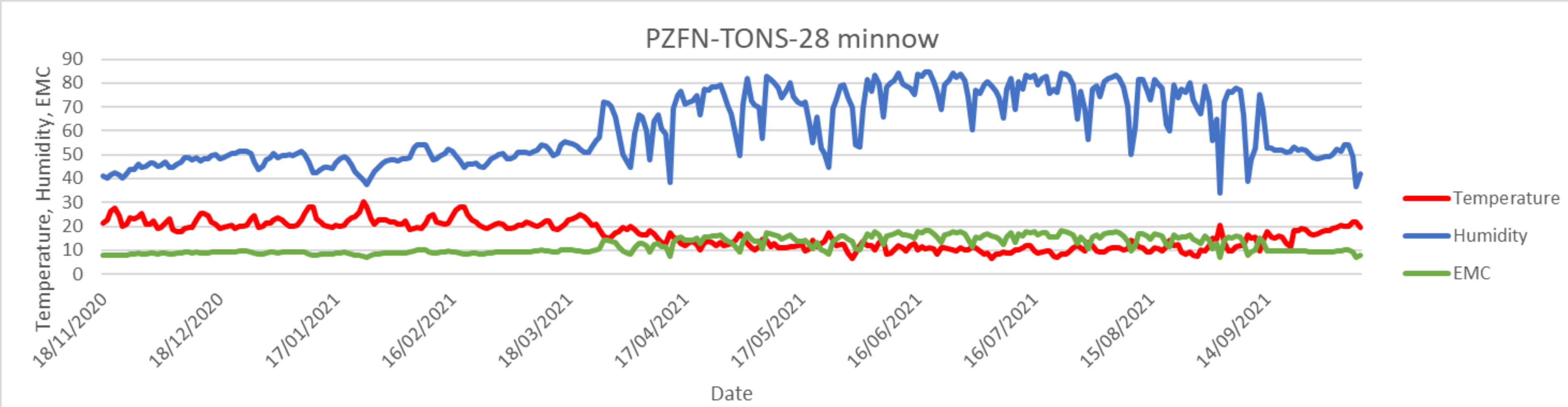


Figure 1. Temperature, Humidity and calculated EMC

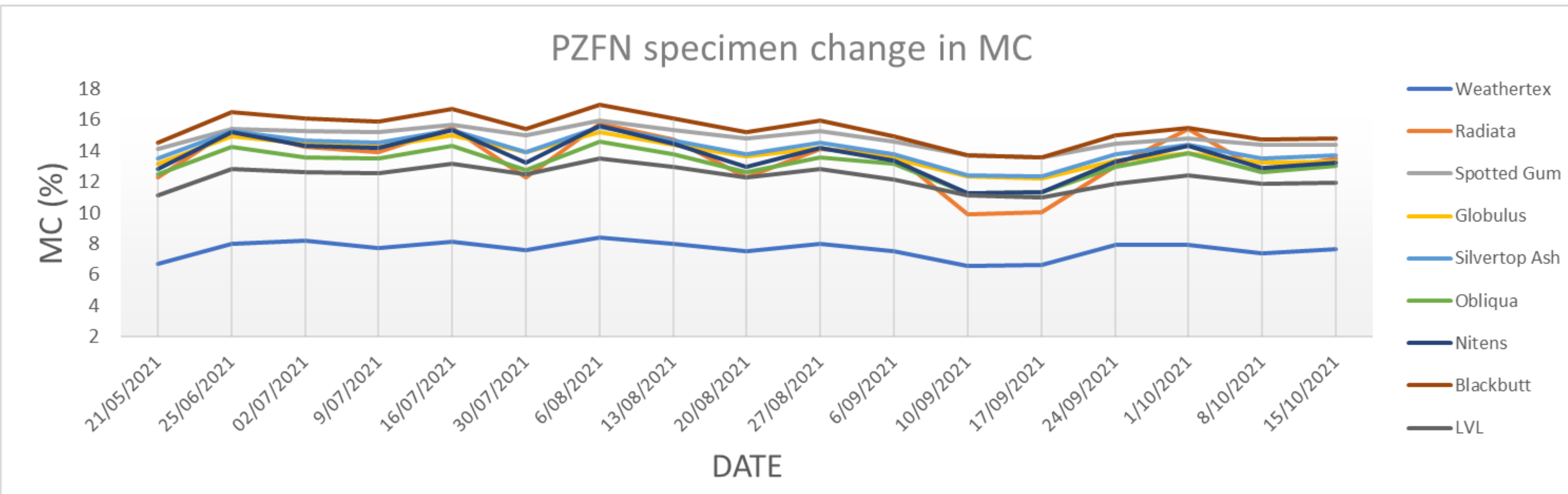


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ5_In store_WA 01

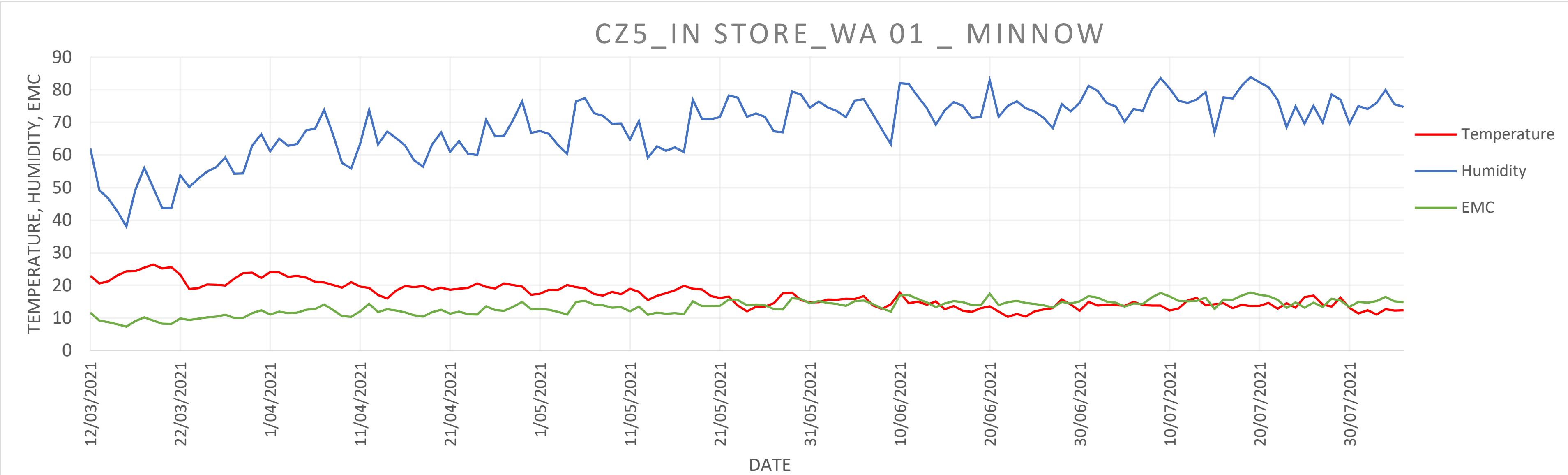


Figure 1. Temperature, Humidity, and calculated EMC

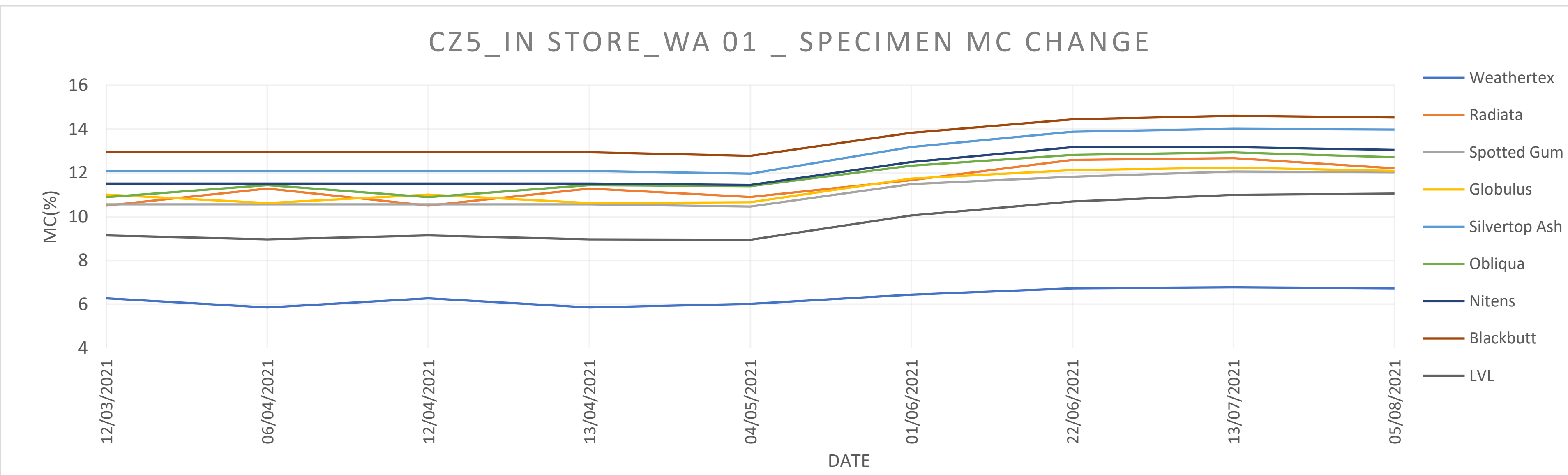


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ5_In store_WA 02

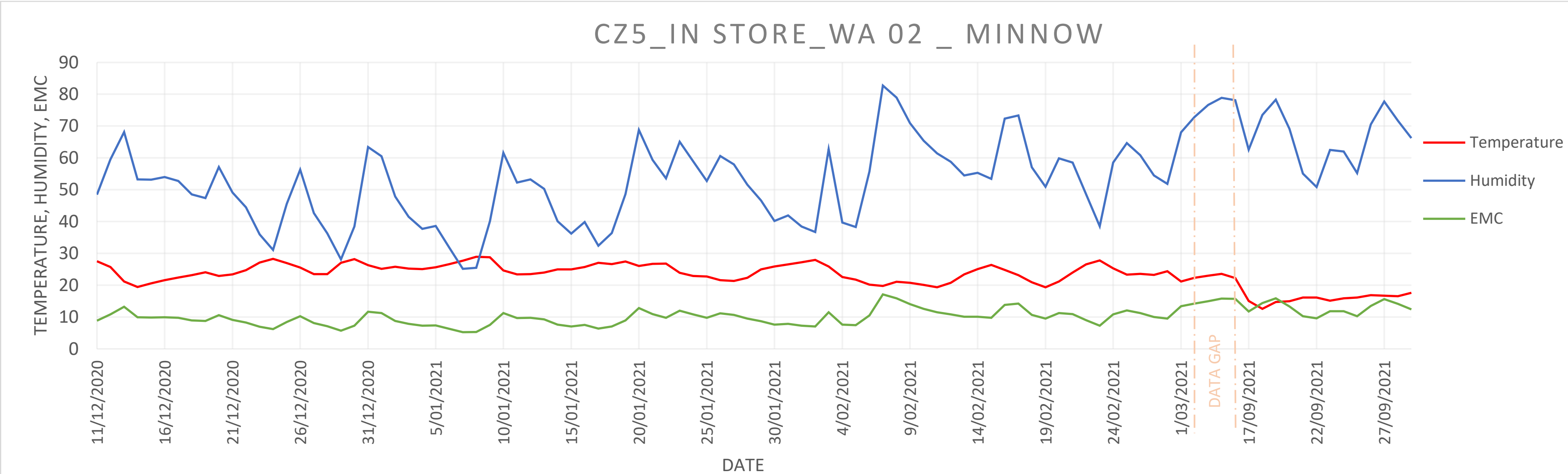


Figure 1. Temperature, Humidity, and calculated EMC

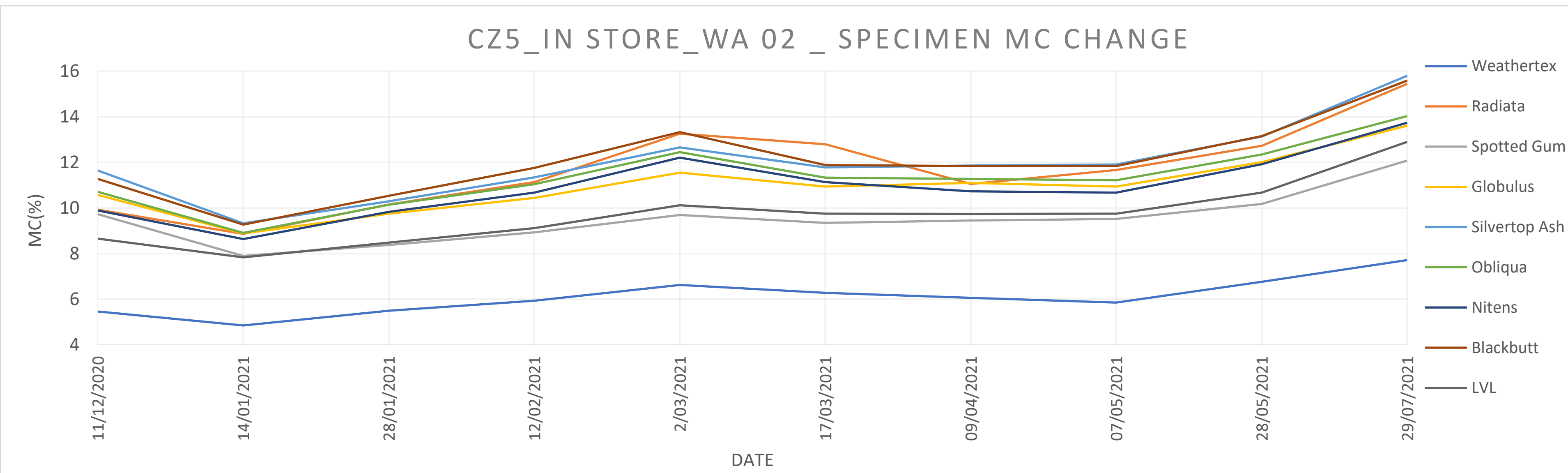


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Climate zone 5: Exposed

Site name: CZ5_Exposed_NSW 01

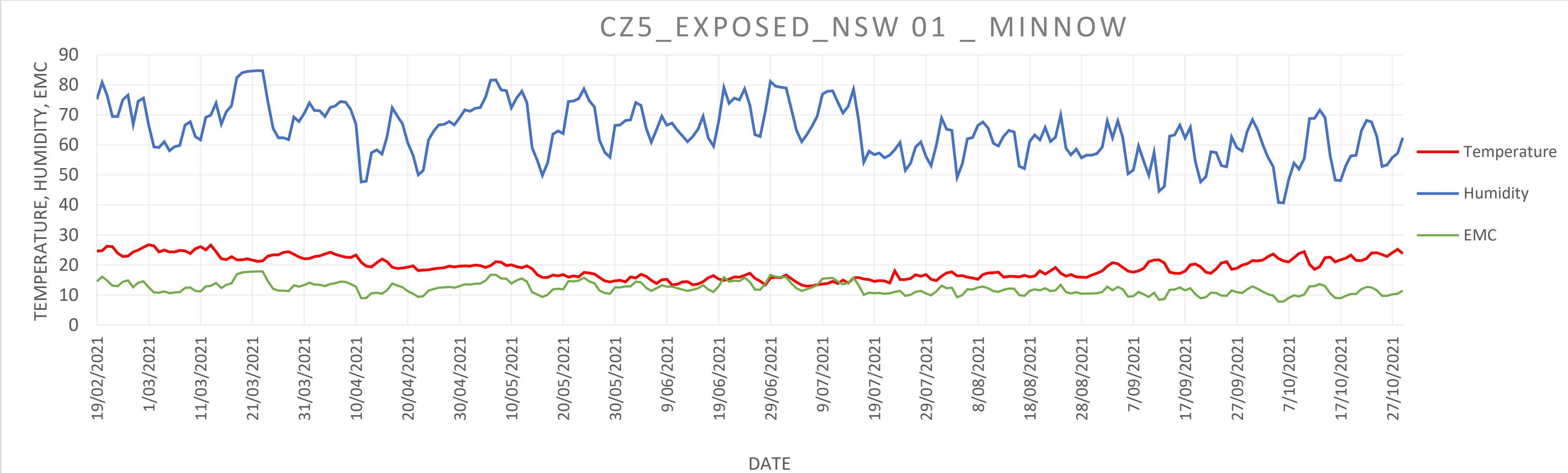


Figure 1. Temperature, Humidity, and calculated EMC

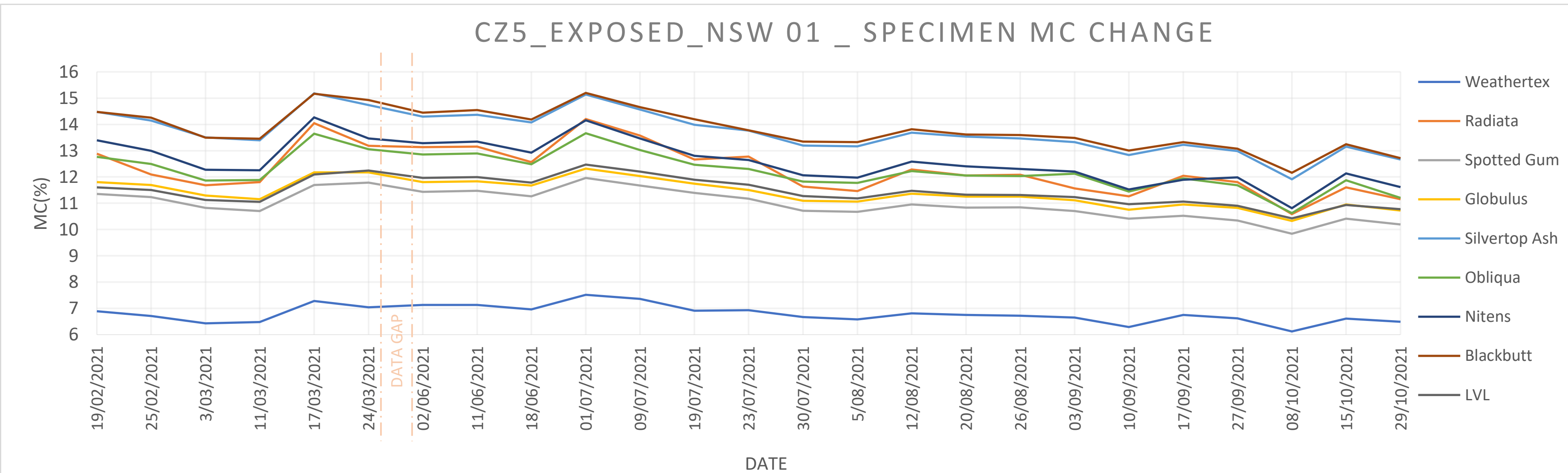


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Climate zone 2: In construction

Site name: CZ2_In construction_Brisbane

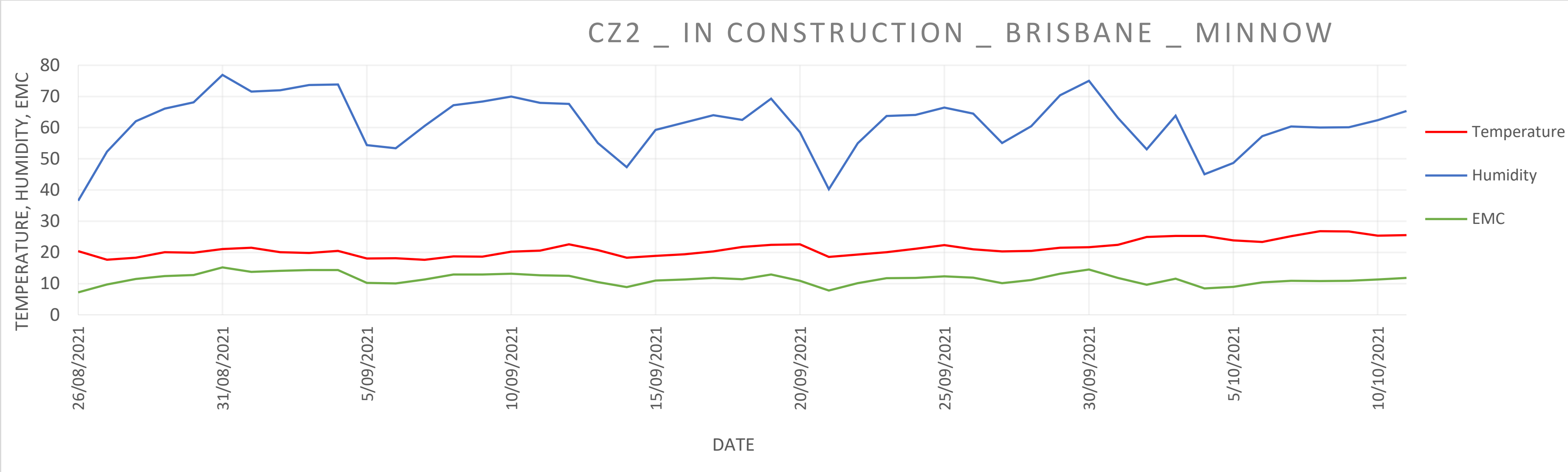


Figure 1. Temperature, Humidity, and calculated EMC

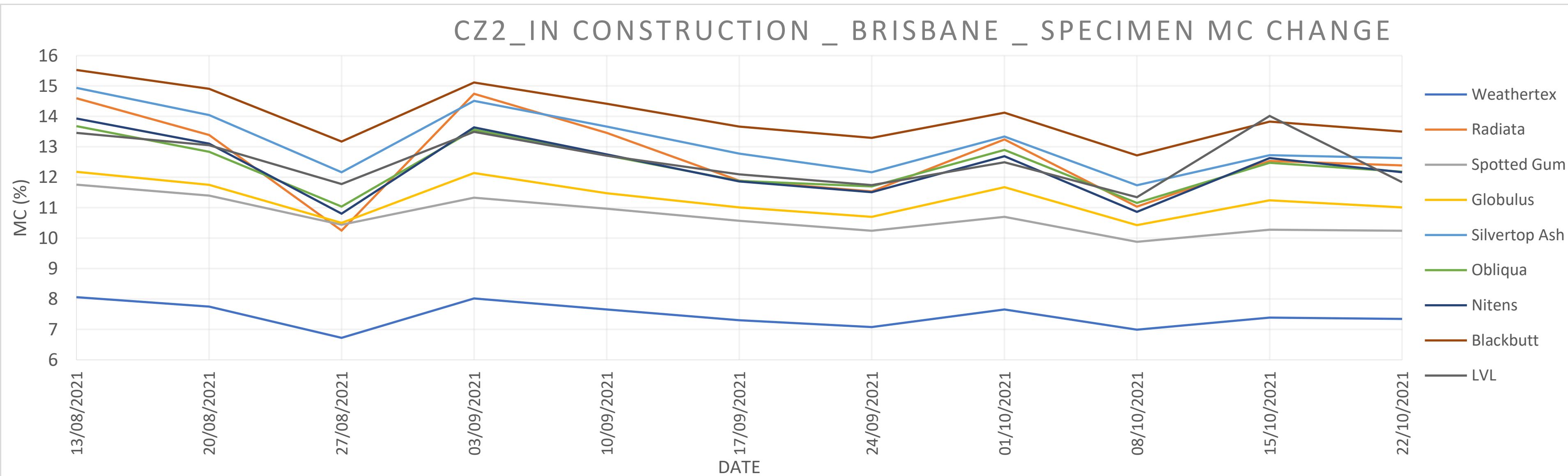


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Climate zone 2: In store

Site name: CZ2_In store_Brisbane 01

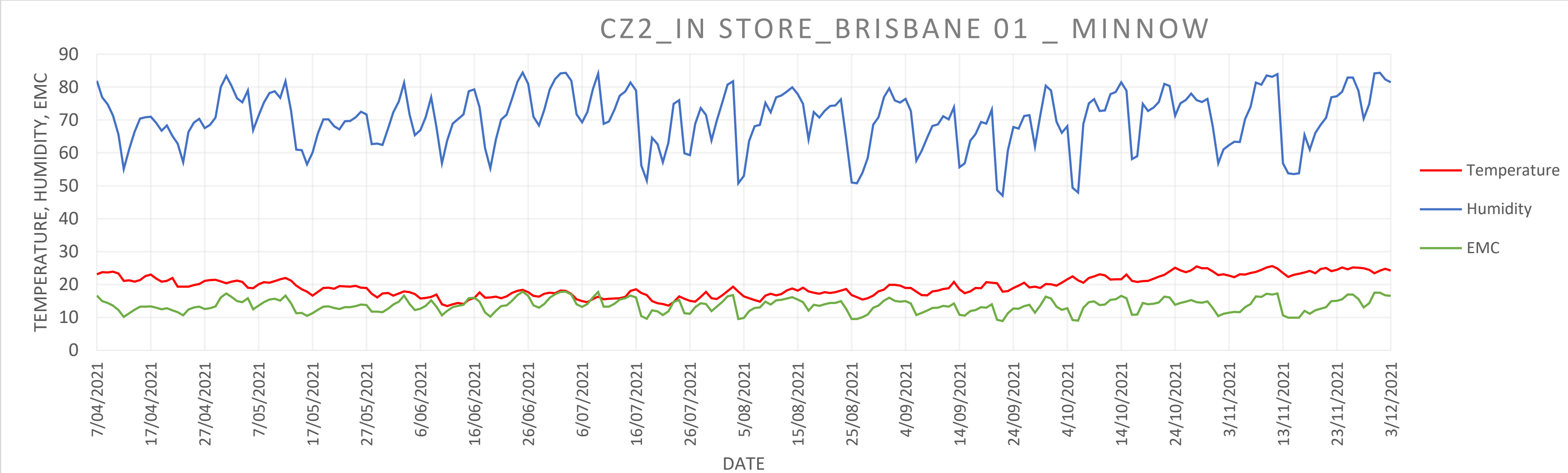


Figure 1. Temperature, Humidity, and calculated EMC

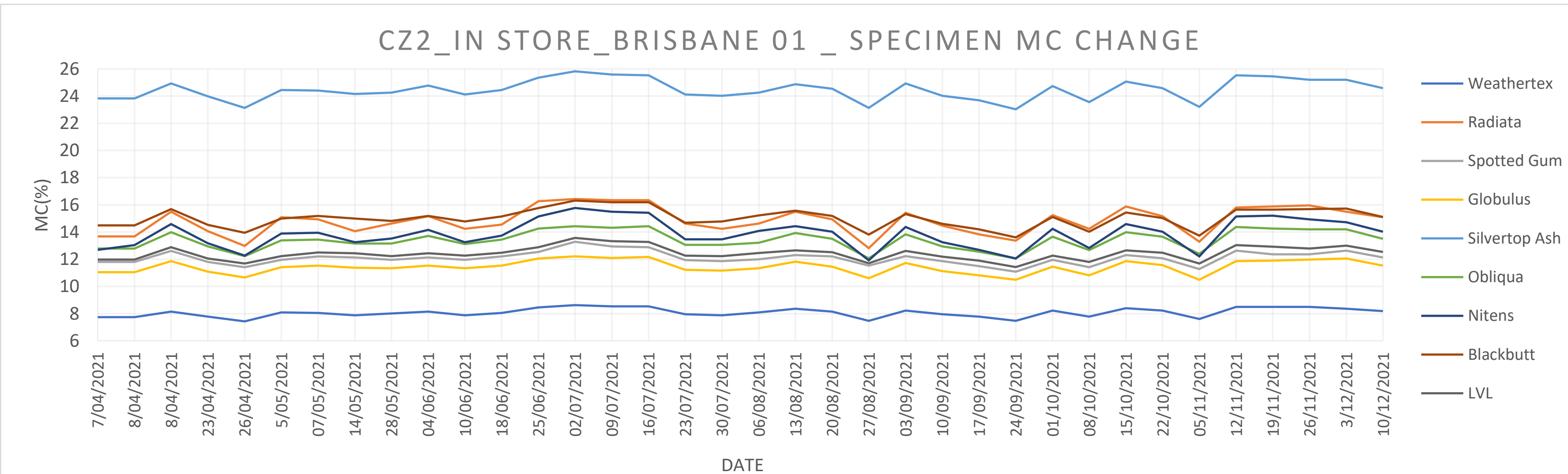


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ2_In store_Brisbane 02

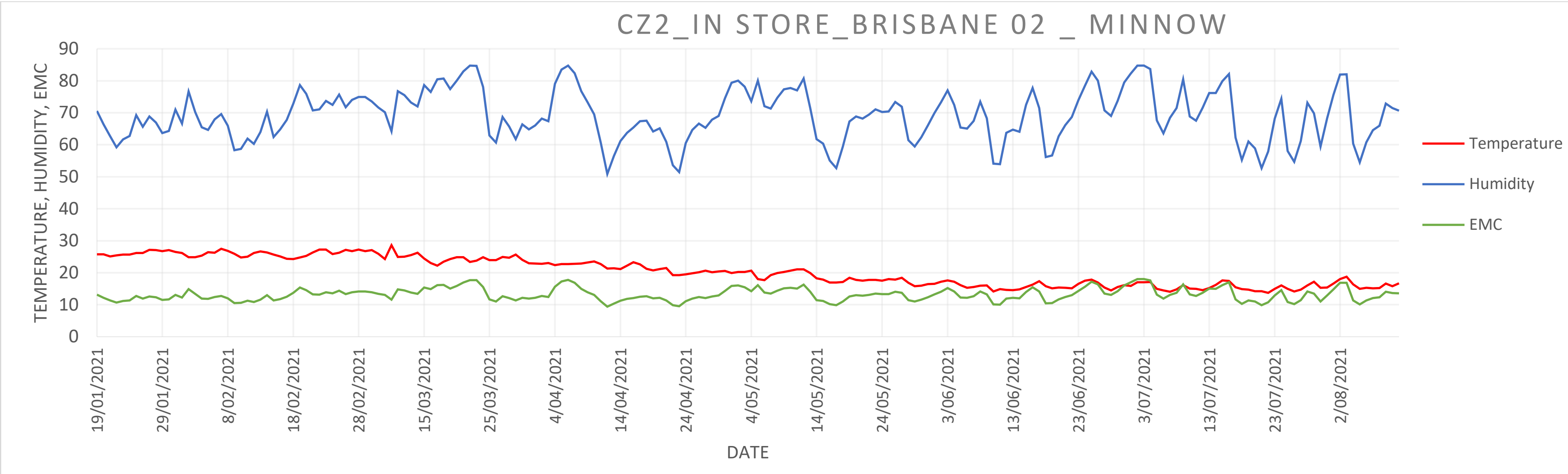


Figure 1. Temperature, Humidity, and calculated EMC

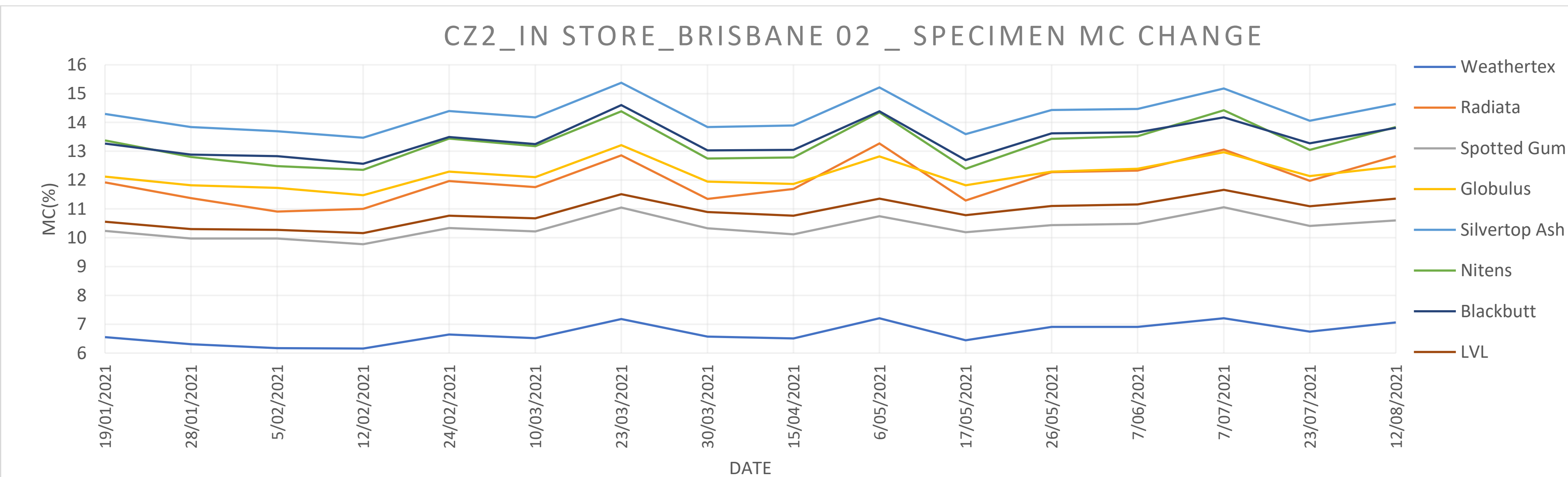


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ2_In store_Brisbane 03

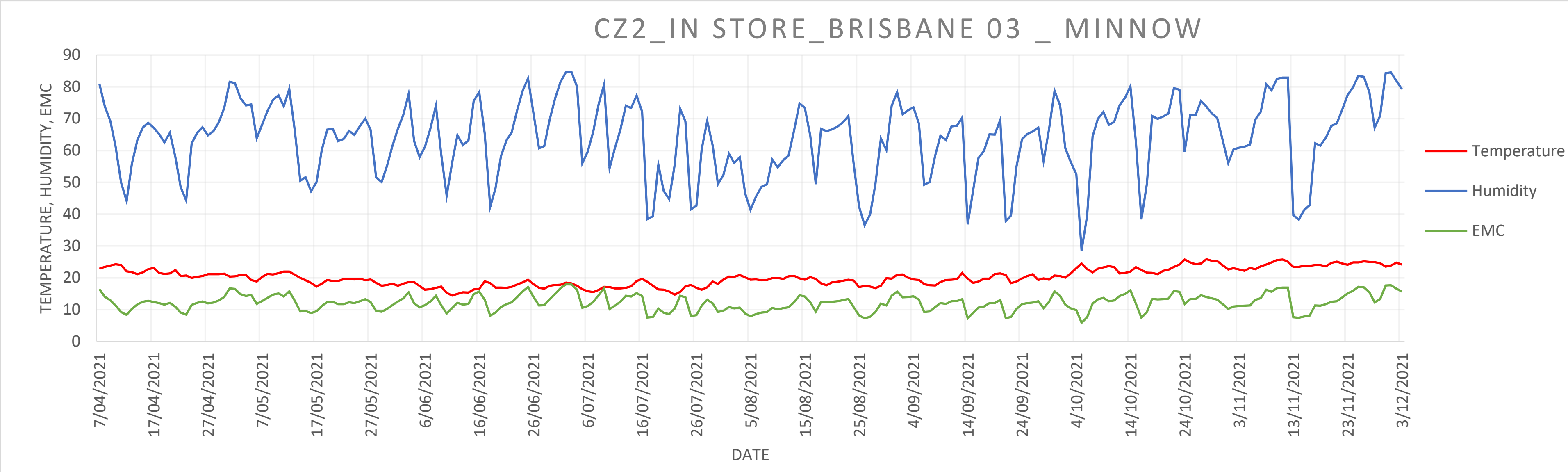


Figure 1. Temperature, Humidity and calculated EMC

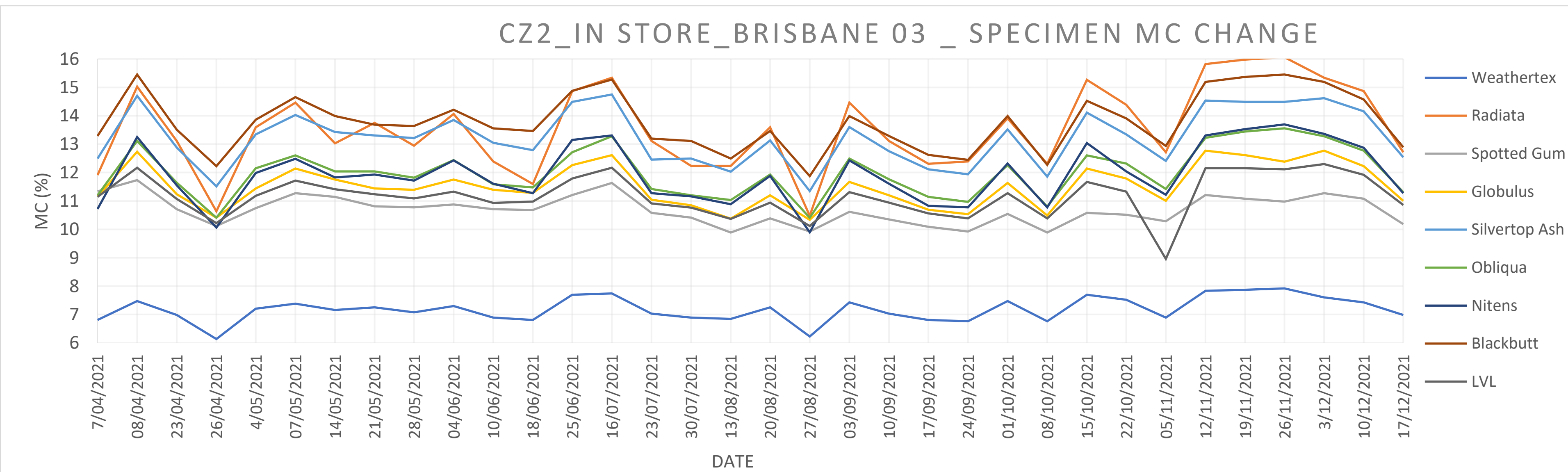


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Site name: CZ2_In store_NSW 01

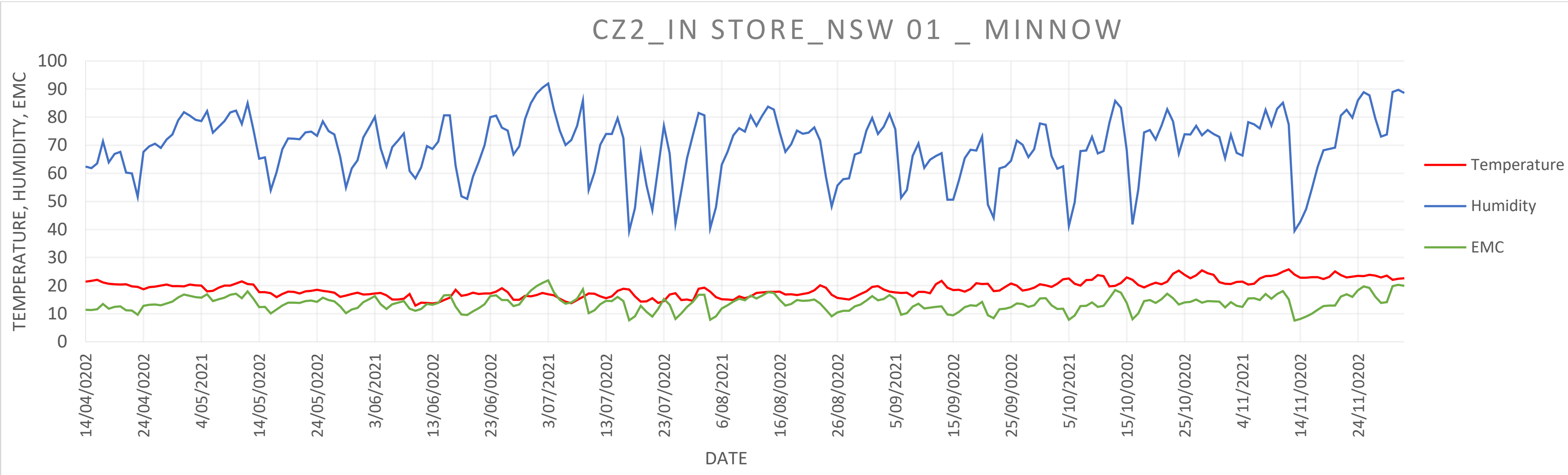


Figure 1. Temperature, Humidity, and calculated EMC

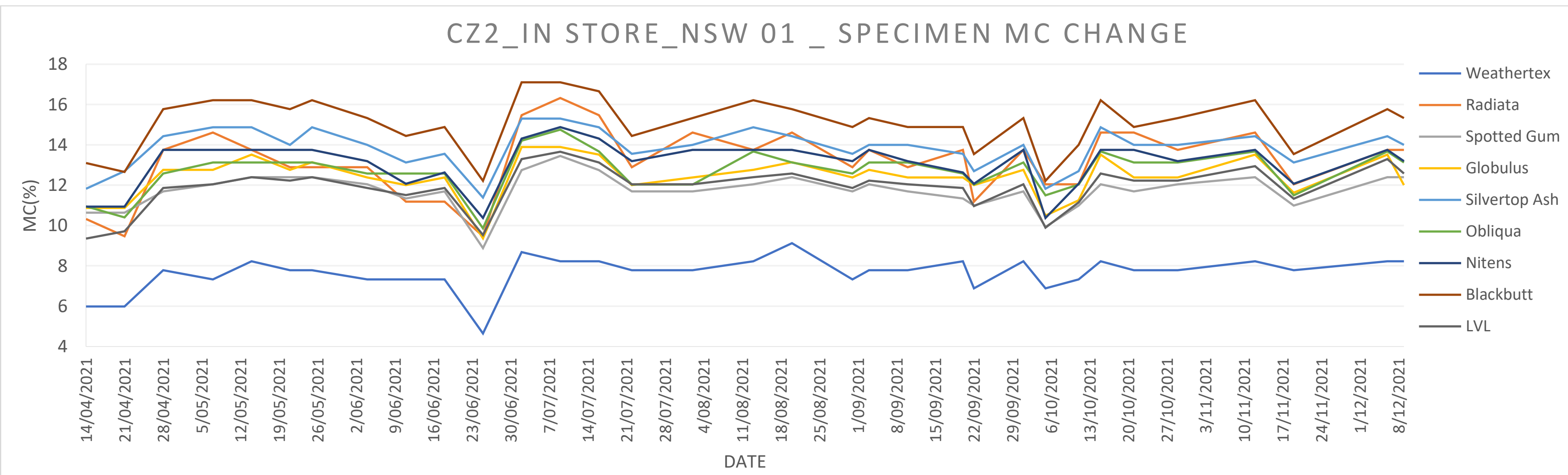


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

Climate zone 2: Sheltered

Site name: CZ2_Sheltered_Brisbane

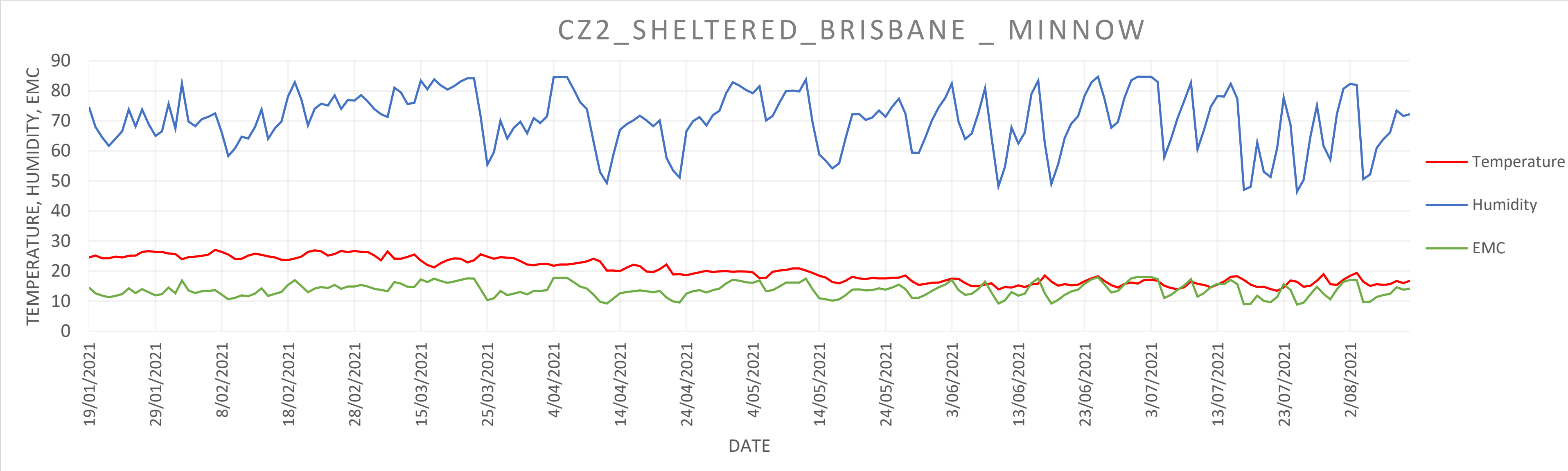


Figure 1. Temperature, Humidity, and calculated EMC

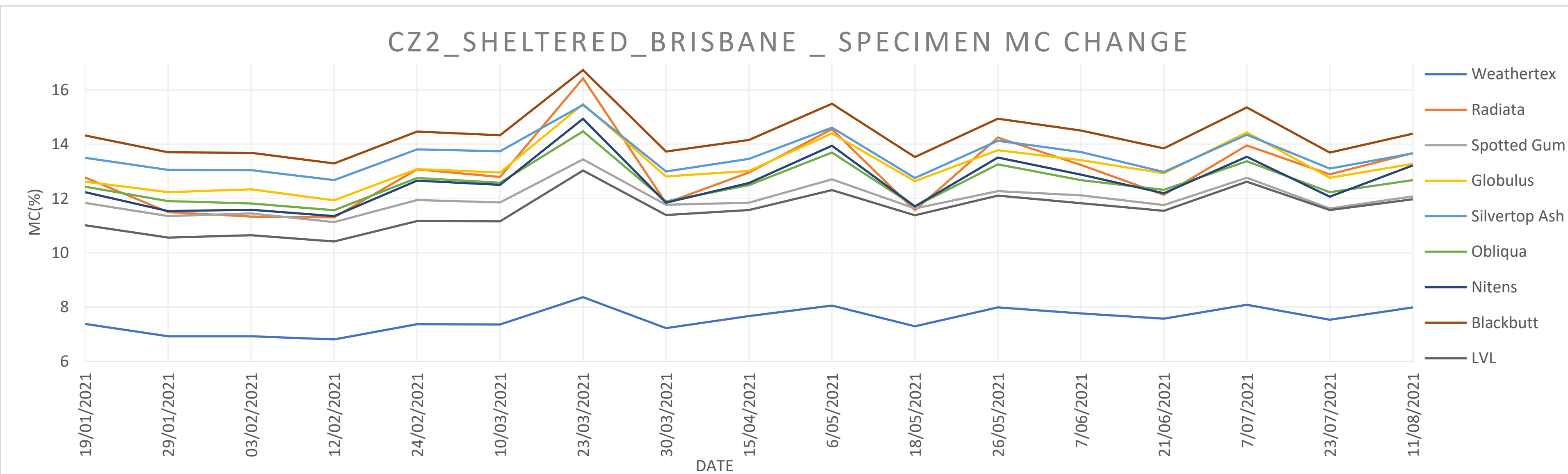


Figure 2. Change in MC for static timber specimens

Note: Minor misalignments may exist in the dates between Figure 1 and Figure 2.

TR-P3 Timber's MC in the supply chain

MC behaviour of wrapped packs in storage

Dr Nathan Kotlarewski

Professor Gregory Nolan

December 2022

NT045 / NIF109 Managing timber's moisture content in the supply chain, construction and in service

UNIVERSITY of TASMANIA

centre for sustainable architecture with wood
CSAW

NATIONAL INSTITUTE FOR FOREST PRODUCTS INNOVATION

Contents

Introduction

This technical report TR-P3 is part of the National Institute for Forest Products Innovation's (NIPFI) project: *NT045 / NIF109 Managing timber's moisture content (MC) in the supply chain, construction and in service*.

This project's objective is to generate and distribute informed industry guidance on best practice for the economic and effective MC control of timber and wood products in the Australian timber supply chain. It aims to identify regular problems and key influencing factors; build an initial knowledge base of equilibrium moisture content (EMC) conditions and timber's MC performance in the timber supply chain; and generate industry best practice guidance.

This report includes the results of the project's monitoring of timber's MC content in the supply chain under varying wrapping conditions. This component aimed to establish useful correlations between observable site conditions, means for protecting wood products in the supply chain and the risk to product serviceability due to its MC behaviour and actual exposure conditions in storage, in transit, and in building under construction and in service. Its results are being used to predict changes to timber MC caused by different storage techniques and identify associated risks.

Additional understandings of the temperature and humidity conditions that timber and wood products are subjected to in the Australian supply chain (from the producer to their position in service) needs to be developed. In building these understanding, the supply chain can be usefully separated into the four stages: in storage and transit in the wood distribution network; the construction phase, and in service.

Timber's EMC is the MC where timber neither gains nor loses moisture from the surrounding atmosphere. There are direct relationships between the wood's EMC, species (or product) properties, the ambient temperature and relative humidity of a location. These ambient conditions change constantly in the supply chain at rates moderated by methods of packing and wrapping the products and its protection in shelters.

As discussed in TR-S1 and above, timber stored and in transit in the supply chain is exposed to a range of environmental conditions that vary with its geographical location, the product's general exposure at the location, and its immediate protection.

- Location determines the climate that drives an area's natural ambient conditions. In this component, locations are grouped by the climate zones (CZ) defined in the National Construction Code's (NCC). The Tasmanian site falls within CZ7, while the Queensland site is in CZ2.
- The general level of protection that buildings or similar enclosures afford determines the stored timber's exposure to ambient conditions at a location. The exposure conditions considered in this project are listed in TR-S1. The two conditions considered in this component are:
    - Fully exposed: Exposed to natural ambient conditions outside.
    - In store: In an enclosed, ventilated building that has limited insulation, such as a timber store or joinery workshop.
- The stored timber's immediate protection includes whether it is the product is grouped together in a pack (with or without wrap) or be an individual items (with or without coating) exposed to the surrounding environment. In this component, the immediate protection provided is listing in Table 1.

Materials and Method

This research trial included the monitoring of the ambient conditions of identical timber packs of plantation-grown Shining gum *Eucalyptus nitens* with three different levels of immediate protection, stored at sites in two different climate zones (CZ7 and CZ2), and in two exposure conditions, and the timber's MC response to these ambient and protection conditions.

This trial ran over the summer of 2021-22 and collected evidence of the temperature and humidity conditions that timber packs are exposed to during transit and in storage. The packs were assembled in Tasmania at the Centre for Sustainable Architecture (CSAW) Newnham workshop and distributed to their allocated sites early in December 2021. See Figure 3.

Packs, their protection, and condition monitoring

Each pack was nominally 600 wide x 600 high x 1200 mm long and assembled from nominally 25 mm board. They incorporated three temperature and humidity sensors for monitoring environmental conditions on the top, east and west side of each pack. Each of the three sensors was located 400 mm from the end the pack and centred to the face or side of the pack. Two types of sensors were used in this project; Minnow-1.0TH (top) and IC_EL_CC_2_001 (east and west). Each pack also consisted of five sample boards. These were marked with paint at each end and positioned in:

- the middle of the pack in the top row of boards (top middle).
- the centre row on the west side of the pack (west).
- the middle of the centre row (middle).
- the centre row on the west side of the pack (east).
- the middle of the pack in the bottom row of boards (bottom middle)

The sample board's provided the initial MC conditions of the timber in the assembled pack and were used to determine the change in MC at the trial's end. Figure 1 shows a timber pack being prepared for dispatch and Figure 2 illustrates the allocated MC specimens in the sample boards for use at the start and end of the trial.

Three types of wrapping were tested in this project. Table 1 details the wrapping arrangement of each pack. Industry provided all the plastic wrapping for the trial.

Figure 1: Timber pack with sensors and chosen sample boards.
Orange paint highlights sample boards; top middle, west, middle, east and bottom middle.

Figure 2 Allocated MC specimens in the sample boards

Table 1: Pack protection

Item	Description
Poorly wrapped	Opaque blue plastic: - previously used wrap recycled for this trial. - the wrap was randomly slashed with cuts approximately 250 mm in length on top, side and ends of the pack. - exposed, unwrapped base
Fully wrapped - opaque	Opaque plastic, white external, black internal: - plastic was brand new - wrapped base - top wrap layer over bottom lap to exclude water pooling with overlapping wrap on the ends and both sides. - tapped ends to prevent water penetration
Fully wrapped - clear	Clear plastic: - plastic was brand new - wrapped base - top wrap layer over bottom lap to exclude water pooling with overlapping wrap on the ends and both sides. - tapped ends to prevent water penetration

Figure 3: Three types of wrapping trailed in this sub-program. Poorly wrapped (left), fully wrapped - opaque (middle) and fully wrapped clear (right).

Exposure sites and conditions

Five packs were produced and exposed at sites at:

- An industry facility at Mowbray, a northern suburb of Launceston in CZ7.
- the Queensland Department of Agriculture and Fisheries (QDAF) facility at Salisbury, Brisbane in CZ2.

Each site included an internal storage area and an exterior yard, which were largely open to ambient conditions. See Figure 6. Of the five packs for each site, three packs were placed in the exterior yard and oriented north-south and two packs were stored in the interior area. See Figure 4 and Figure 5. The three exterior packs were poorly wrapped, clear wrapped and opaque wrapped. The interior packs were poorly wrapped and clear wrapped.

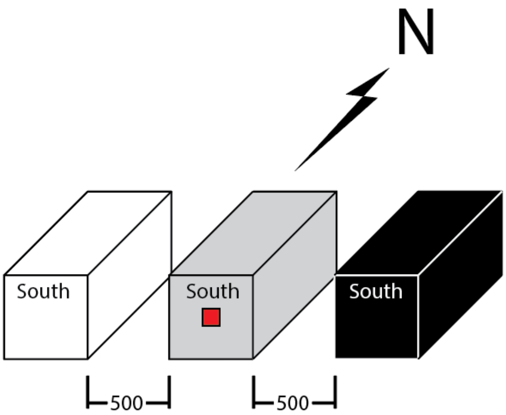


Figure 4 Location for each pack in exterior environment. Red square represents additional environment sensor facing south

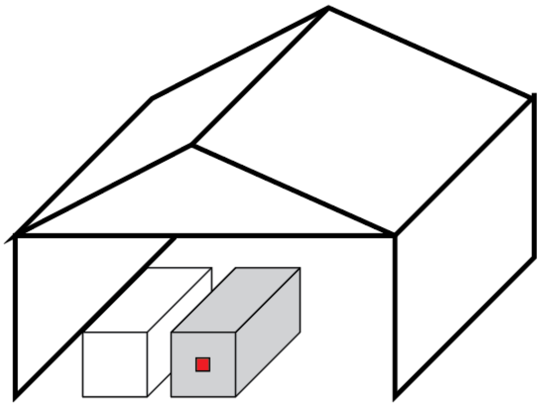
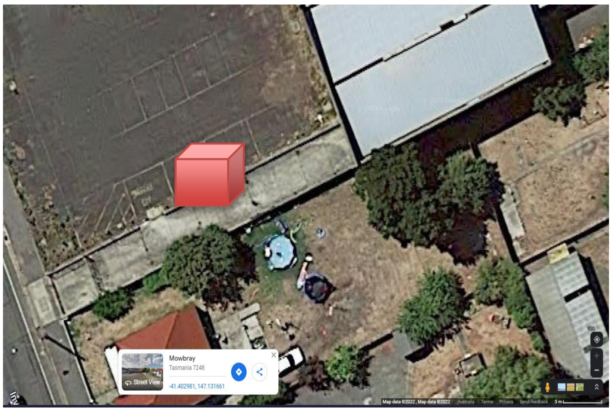
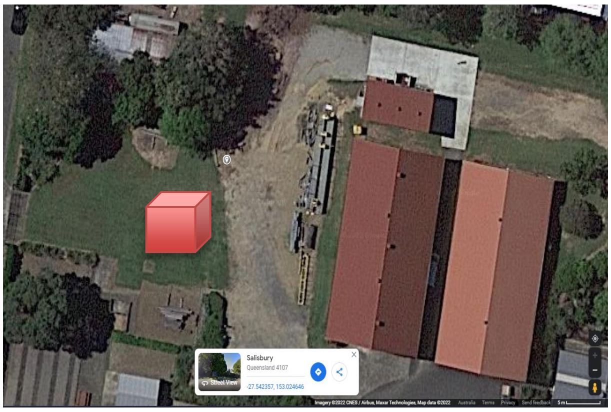


Figure 5 Location for each pack in interior environment. Red square represents additional environment sensor



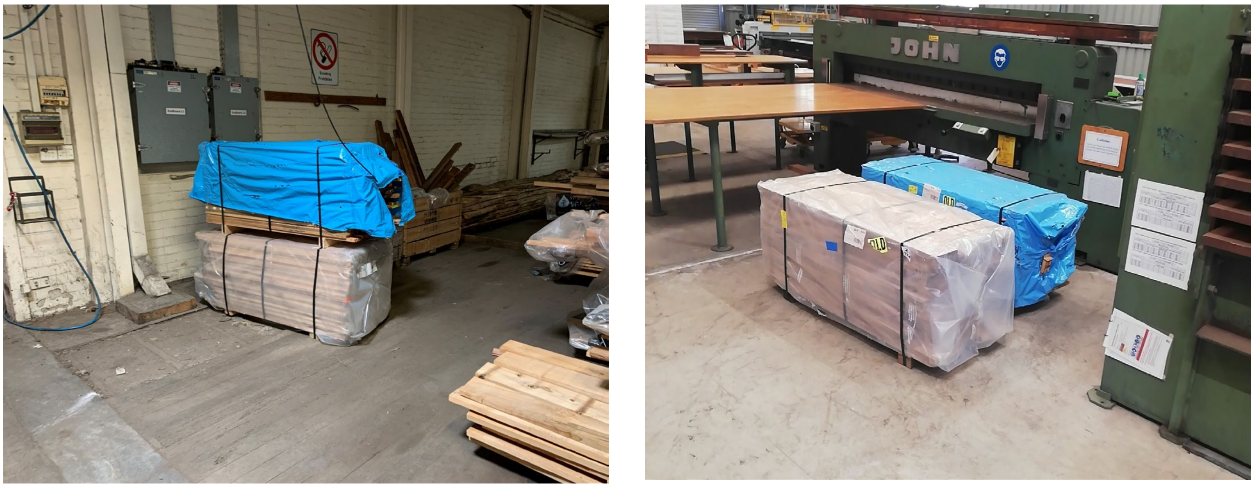
Tasmanian CZ7 site



Queensland CZ2 site

Tasmanian CZ7 exterior

Queensland CZ2 exterior



Tasmanian CZ7 interior Queensland CZ2 interior

Figure 6 Industry site, Tasmania and QDAF site, Queensland

The Queensland packs were dispatched from CSAW's Newnham workshop on December 7, 2021, and arrived at QDAF on January 5, 2022. Additional sensors were installed to the dispatched packs (exterior to the wrapping) to monitor the environmental conditions during transit.

The pack were exposed on each site from 14/12/21 in Tasmania and 5/01/22 at Salisbury, and remained exposed to 9/05/22 and 5/05/22 respectively. The Tasmanian packs were then broken down at CSAW's Newnham workshop, while QDAF recovered and processed the sample boards at Salisbury, Qld. All MC assessment was done using the oven dry method according to AS/NZS 1080.1:2012.

Queensland sensors were returned via return mail to CSAW and the data was recovered from the sensors and assessed.

There were several issues with monitoring the conditions of the test samples throughout this project. The most obvious was the reliability of the environment sensors and human error. Two types of sensors were used in this project. A Minnow-1.0TH and IC_EL_CC_2_001. Some Minnow's failed to collect data for unknown reasons, the battery would fail and or the settings on the device were incorrectly set up meaning there was a lost opportunity to collect data over several months. The accuracy of the device (+/-2^{O}C) is optimal between +5^{O}C to +60^{O}C which in some cases the conditions of the trial exceeded. There was also obvious water damage caused by interior packaging sweating and early signs of corrosion to the hardware. The other type of sensor was a single use data collection which was essentially fail proof and could operate at a wider temperature range between -30^{O}C to +70^{O}C.

Results

Timber in transit

The following graph illustrates the environmental conditions of the timber packs in transit from CSAW Tasmania, on December 7 2021, to QDAF Queensland, on January 5 2022.

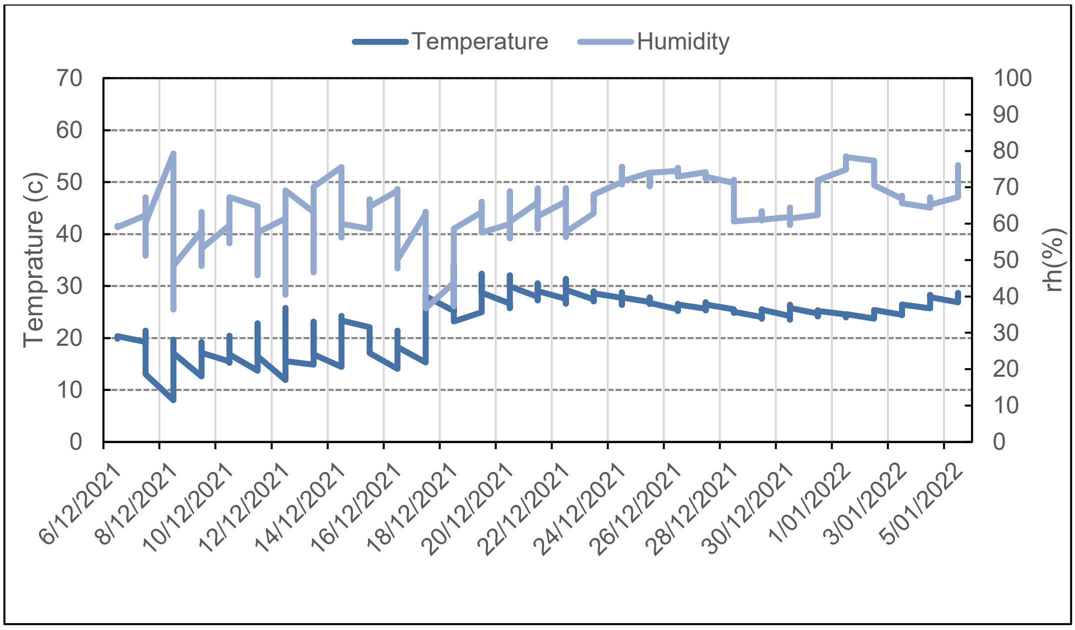


Figure 7. Ambient conditions experience by timber packs dispatched from CSAW 7/12/2021 to arrival at QDAF 5/01/2022

Whilst in transit to Queensland, there is an obvious increase in ambient temperature beyond the December 16, 2021. Prior to this, the packs were stored in Tasmania prior to departure across Bass Strait and onwards to Queensland. The exact location of the packs in transit over this timeline was unknown.

Poorly wrapped: exterior

The following tables and associated graphs illustrate the overall change in MC and the environmental conditions over the 2021-2022 summer across a Tasmanian and Queensland site for poorly wrapped timber packs in an exterior environment.

Tasmanian site

Table 2 highlights the initial and post-trail MC and associated change in MC for the Tasmanian site. Figure 8, Figure 9 and Figure 10 present the environmental conditions over several months for sensors located on the north facing top middle, east facing middle and west facing middle of the timber pack. Figure 11 presents detailed data collected over a 24-hour period on January 15, 2022.

Table 2 MC change in a poorly wrapped timber pack in Tasmania (exterior)

Tasmania, Poorly wrapped, exterior			
Position in pack	**Initial MC (%)**	**Post-trial MC (%)**	**Change in MC (%)**
Top middle	11.2	19.9	8.8
West	10.9	11.4	2.2
Middle	11.3	11.6	0.3
East	11.1	13.3	0.5
Bottom middle	11.3	11.9	0.6
(average)	(11.2)	(13.6)	(2.5)

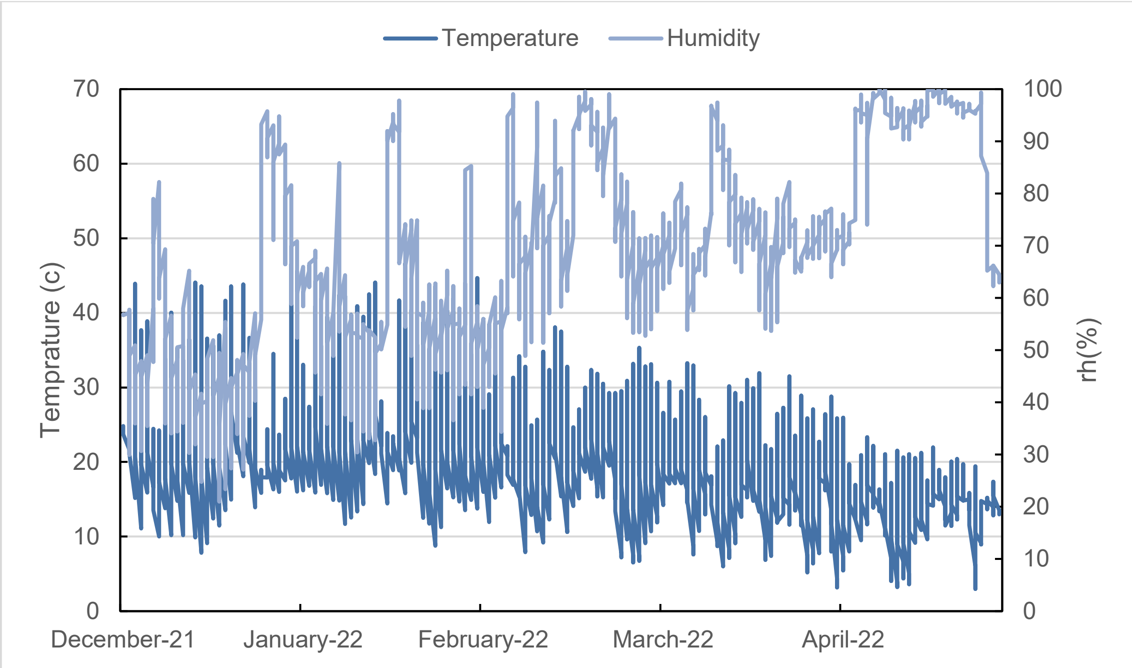


Figure 8 Measured environmental conditions in a CZ7 pack. Sensor - north facing top middle

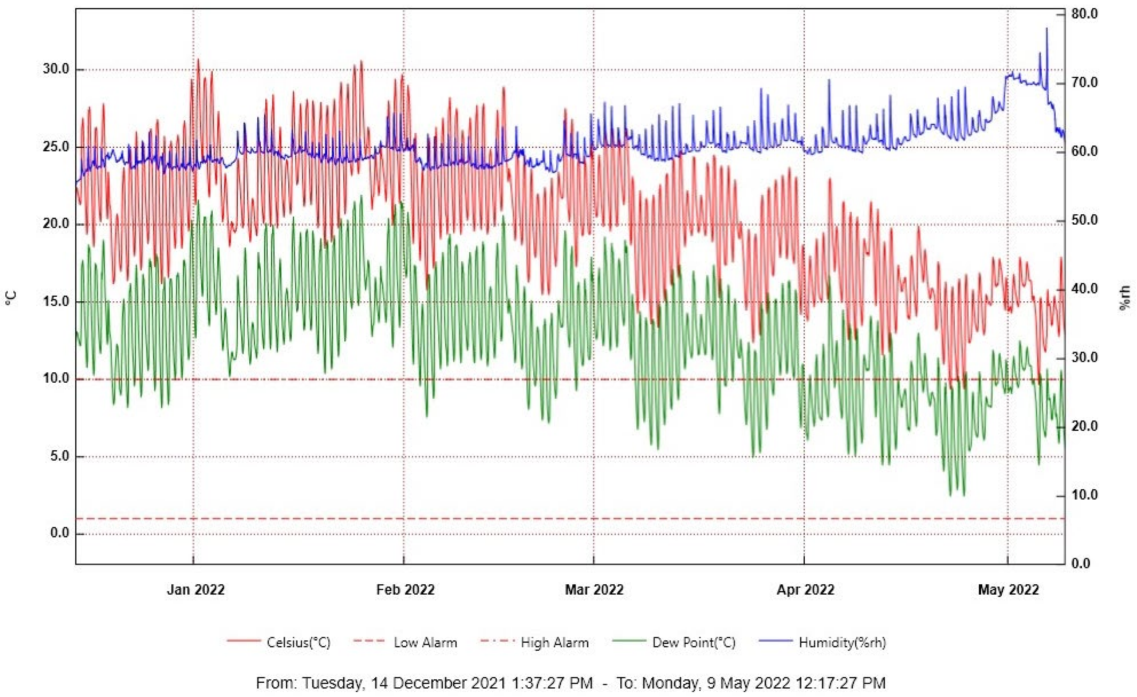


Figure 9 Measured environmental conditions in a CZ7 pack. Sensor - east facing middle

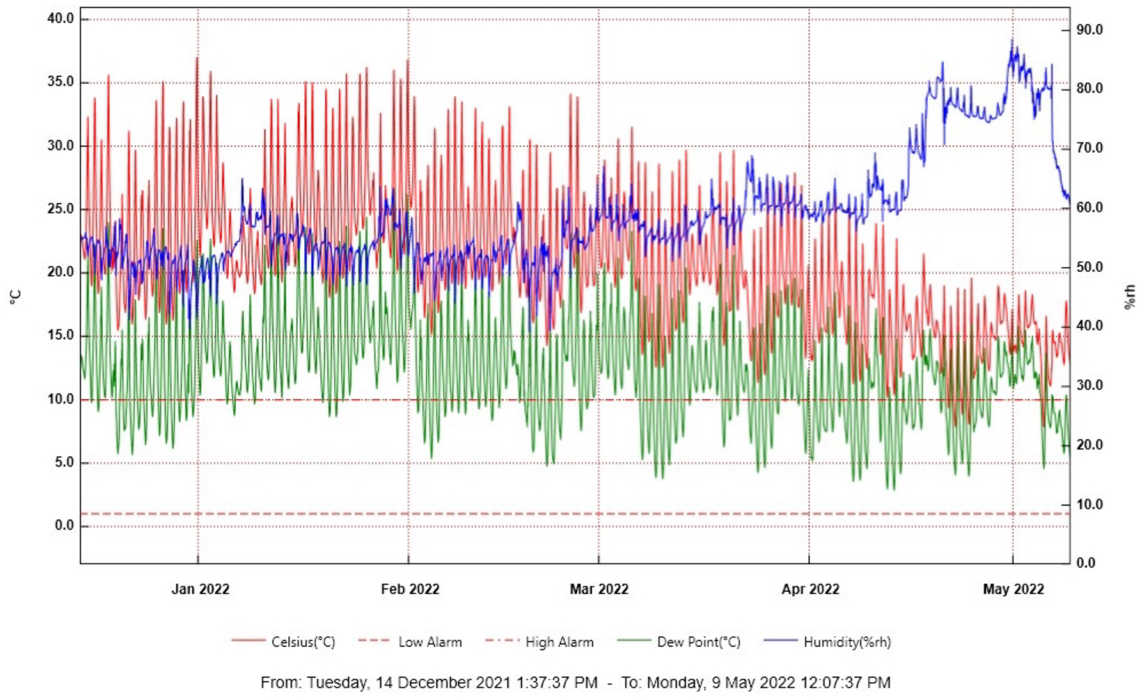


Figure 10 Measured environmental conditions in a CZ7 pack. Sensor - west facing middle

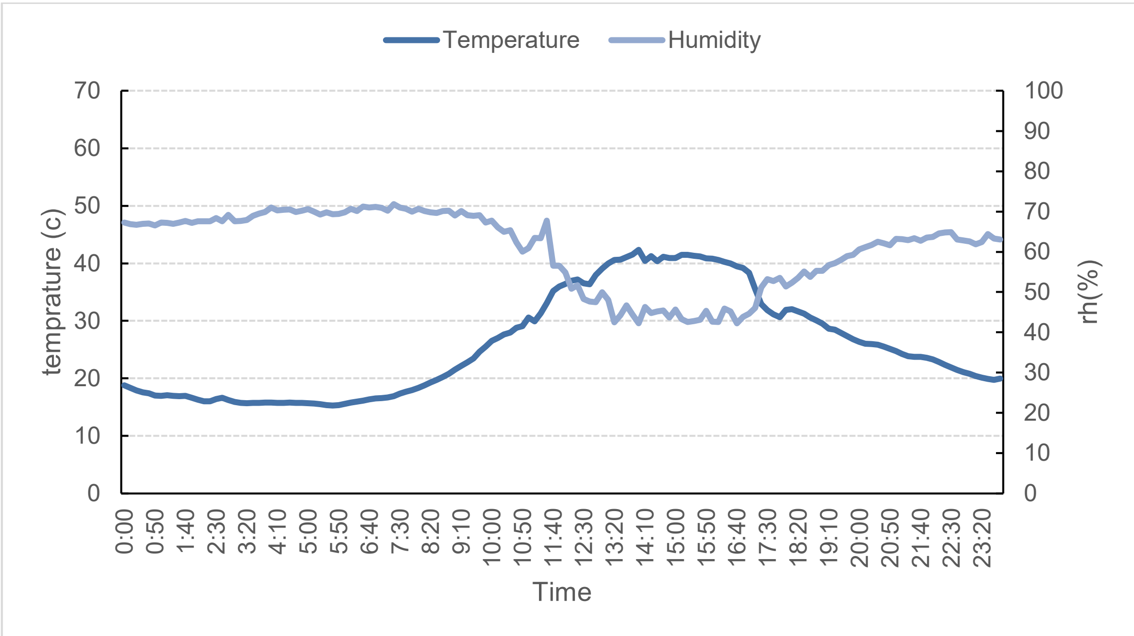


Figure 11 Measured environmental conditions in an exterior poorly wrapped CZ7 pack on January 15, 2022. Sensor - north facing top middle

Queensland site

Table 3 highlights the initial and post-trail MC and associated change in MC for the Queensland site. Figure 12, Figure 13 and Figure 14 present the environmental conditions over several months for sensors located on the north facing top middle, east facing middle and west facing middle of the timber pack. Figure 15 presents detailed data collected over a 24-hour period on January 15, 2022.

Table 3 MC change in a poorly wrapped timber pack in Queensland (exterior)

Queensland, Poorly wrapped, exterior			
Position in pack	**Initial MC (%)**	**Post-trial MC (%)**	**Change in MC (%)**
Top middle	11.6	22.5	10.9
West	12.3	28.6	16.3
Middle	11.5	22.5	10.9
East	11.5	24.5	13.0
Bottom middle	12.2	20.5	8.4
(average)	(11.8)	(23.7)	(11.9)

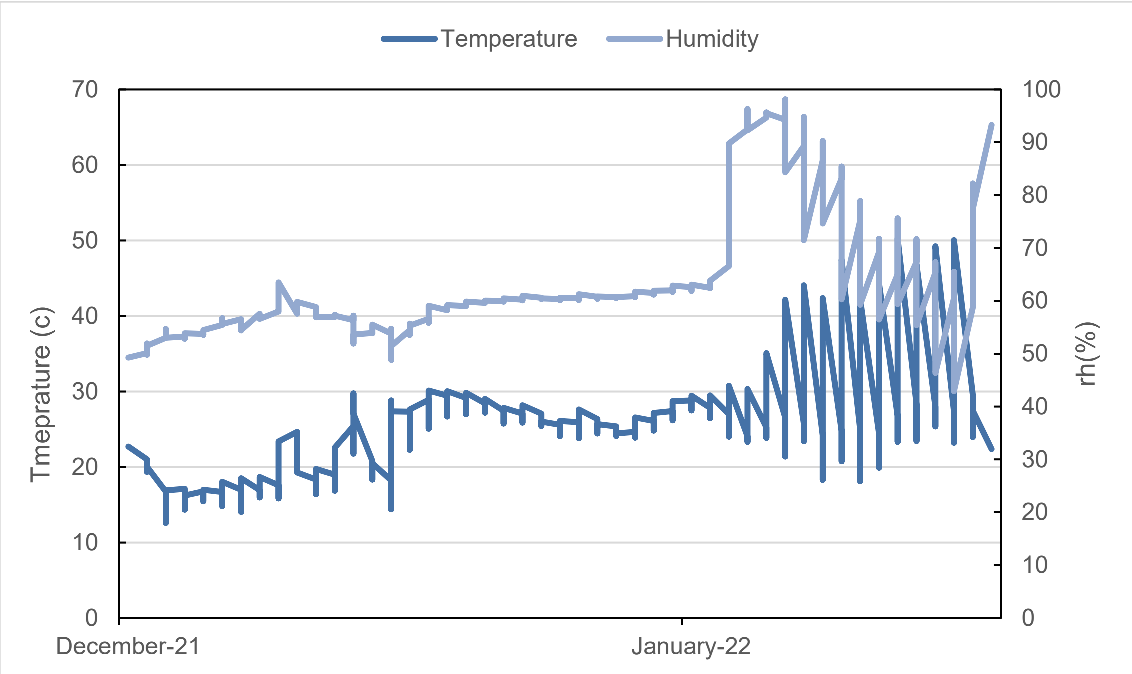


Figure 12 Measured environmental conditions in a CZ2 pack. Sensor - north facing top middle

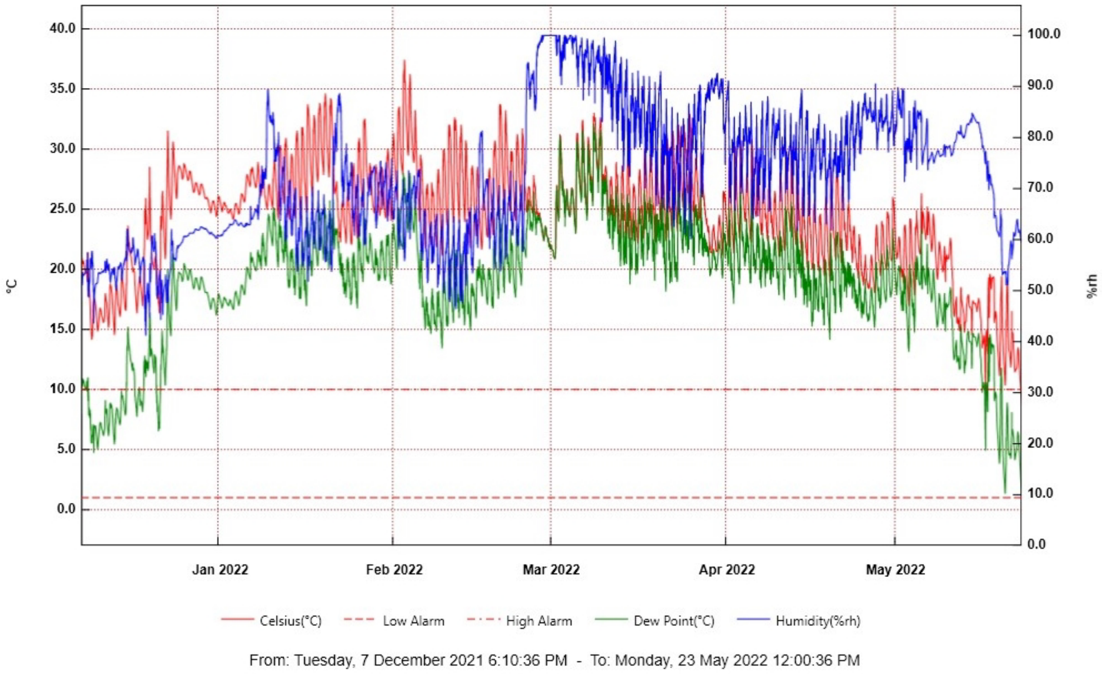


Figure 13 Measured environmental conditions in a CZ2 pack. Sensor - east facing middle

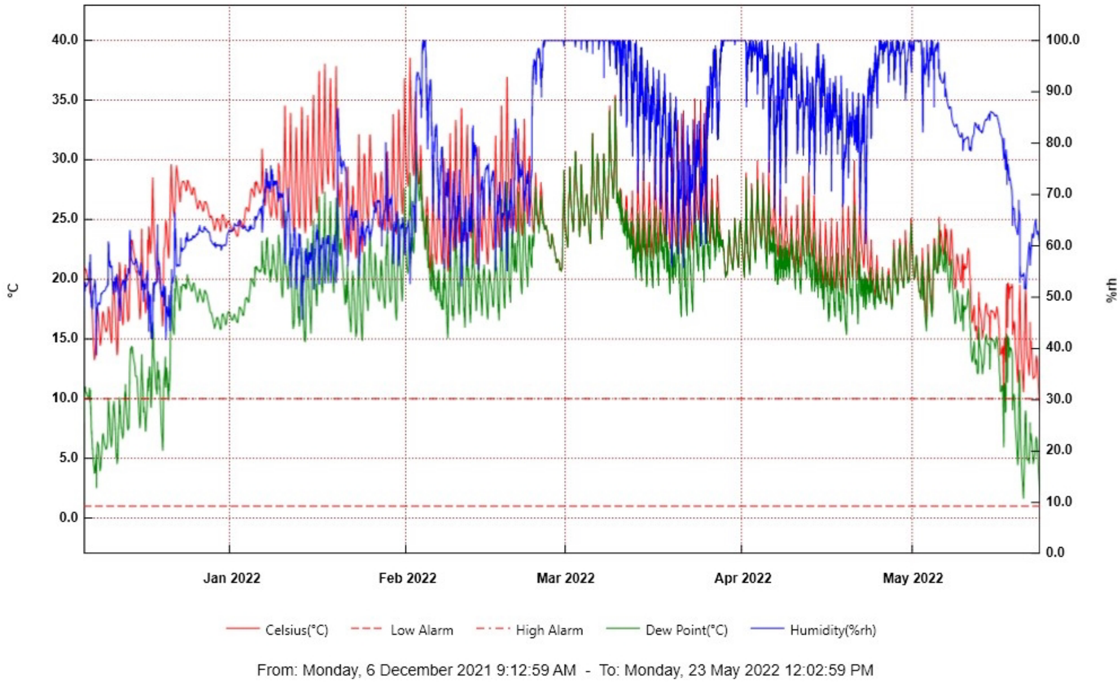


Figure 14 Measured environmental conditions in a CZ2 pack. Sensor - west facing middle

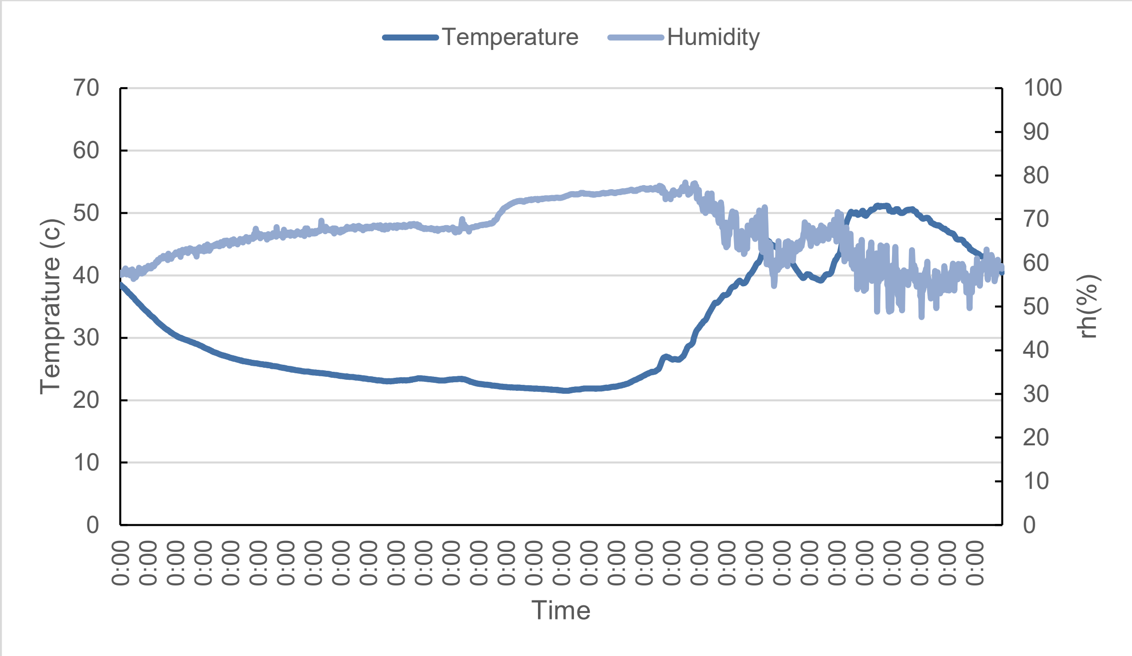


Figure 15 Measured environmental conditions in an exterior poorly wrapped CZ2 pack on January 15, 2022. Sensor - north facing top middle <check chart axis>

Fully wrapped – opaque: exterior

Tasmanian site

The following tables and associated graphs illustrate the overall change in MC and the environmental conditions over the 2021-2022 summer across a Tasmanian and Queensland site for fully wrapped - opaque timber packs in an exterior environment. Table 4 highlights the initial and post-trail MC and associated change in MC for the Tasmanian site. Figure 16, Figure 17 and Figure 18 present the environmental conditions over several months for sensors located on the north facing top middle, east facing middle and west facing middle of the timber pack. Figure 19 presents detailed data collected over a 24-hour period on January 15, 2022.

Table 4 MC change in a fully wrapped - opaque timber pack in Tasmania (exterior)

Tasmania, opaque wrapped, exterior			
Position in pack	**Initial MC (%)**	**Post-trial MC (%)**	**Change in MC (%)**
Top middle	11.3	20.0	8.7
West	11.6	11.5	-0.1
Middle	11.7	11.6	-0.1
East	11.7	12.7	1.0
Bottom middle	11.3	12.2	0.9
(average)	(11.5)	(13.6)	(2.1)

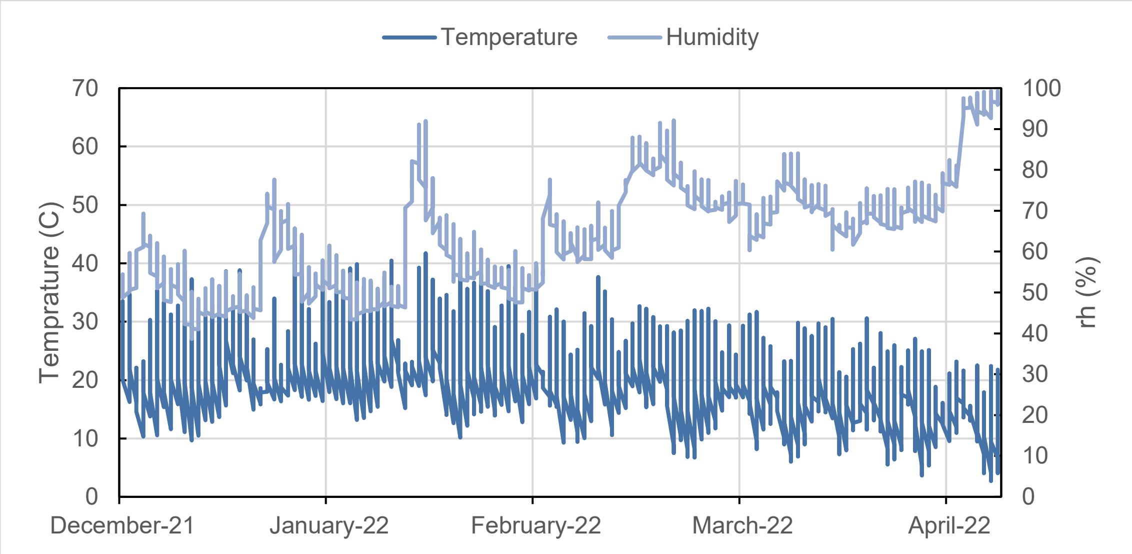


Figure 16 Measured environmental conditions in a CZ7 pack. Sensor north facing top middle

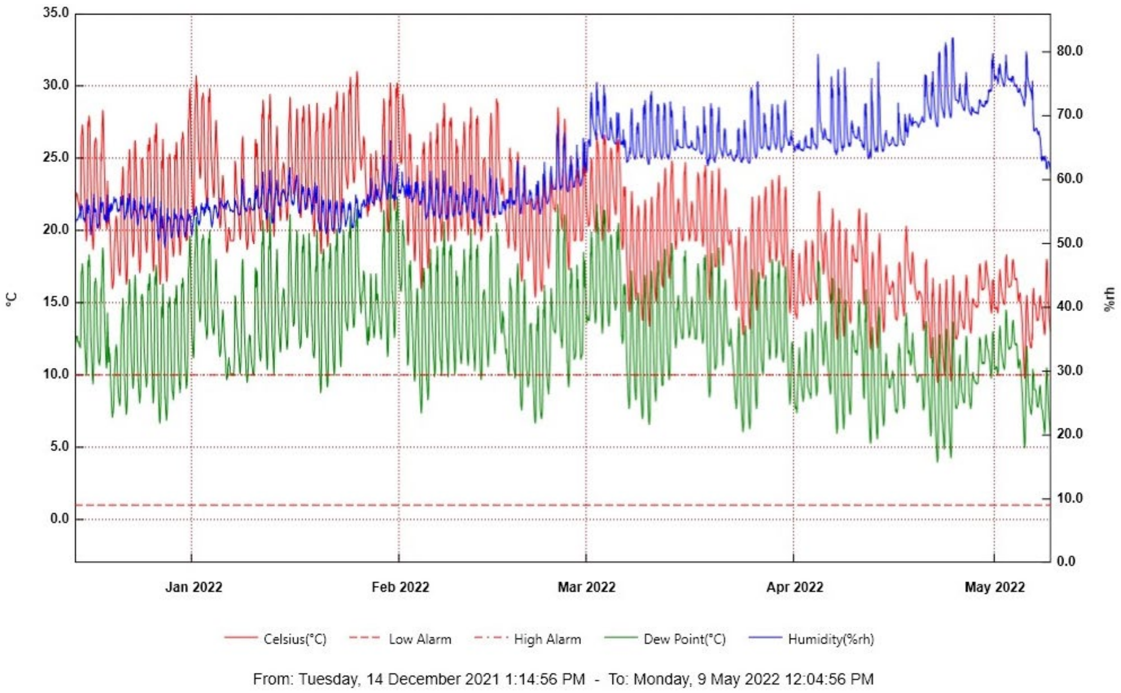


Figure 17 Measured environmental conditions in a CZ7 pack. Sensor - east facing middle

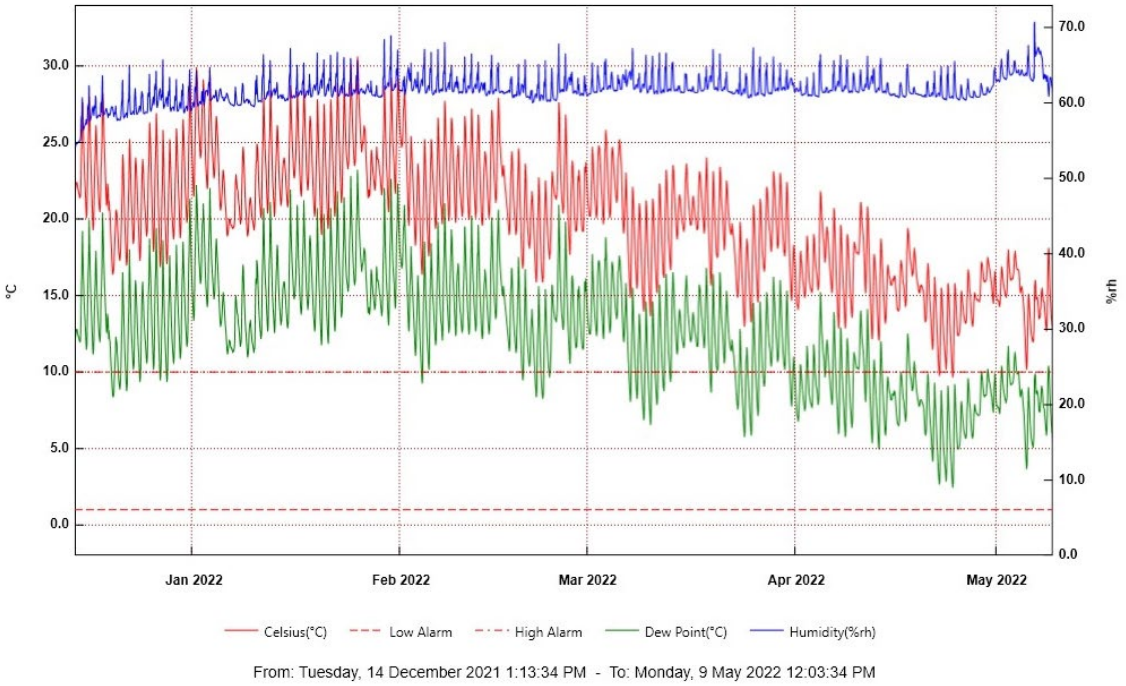


Figure 18 Measured environmental conditions in a CZ7 pack. Sensor - west facing middle

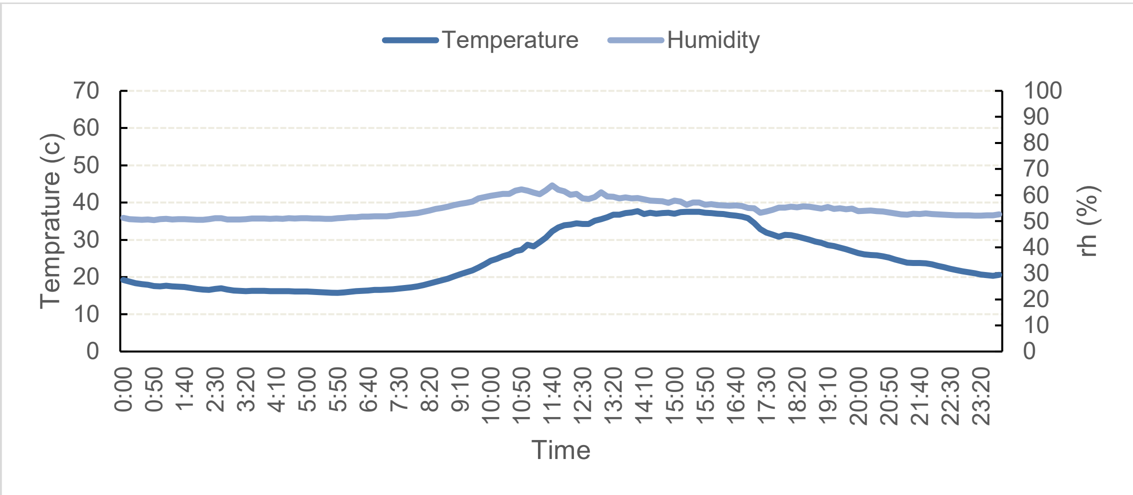


Figure 19 Measured environmental conditions in an exterior fully wrapped - opaque CZ7 pack on January 15, 2022. Sensor - north facing top middle

Queensland site

Table 5 highlights the initial and post-trail MC and associated change in MC for the Queensland site. Figure 20, Figure 21 and Figure 22 present the environmental conditions over several months for sensors located on the north facing top middle, east facing middle and west facing middle of the timber pack. Figure 23 presents detailed data collected over a 24-hour period on January 15, 2022.

Table 5 MC change in a fully wrapped - opaque timber pack in Queensland (exterior)

Queensland, opaque wrapped, exterior			
Position in pack	**Initial MC (%)**	**Post-trial MC (%)**	**Change in MC (%)**
Top middle	11.5	37.7	26.2
West	11.3	17.2	5.9
Middle	11.4	19.9	8.5
East	12.1	19.9	7.8
Bottom middle	11.7	16.0	4.2
(average)	(11.6)	(22.1)	(10.5)

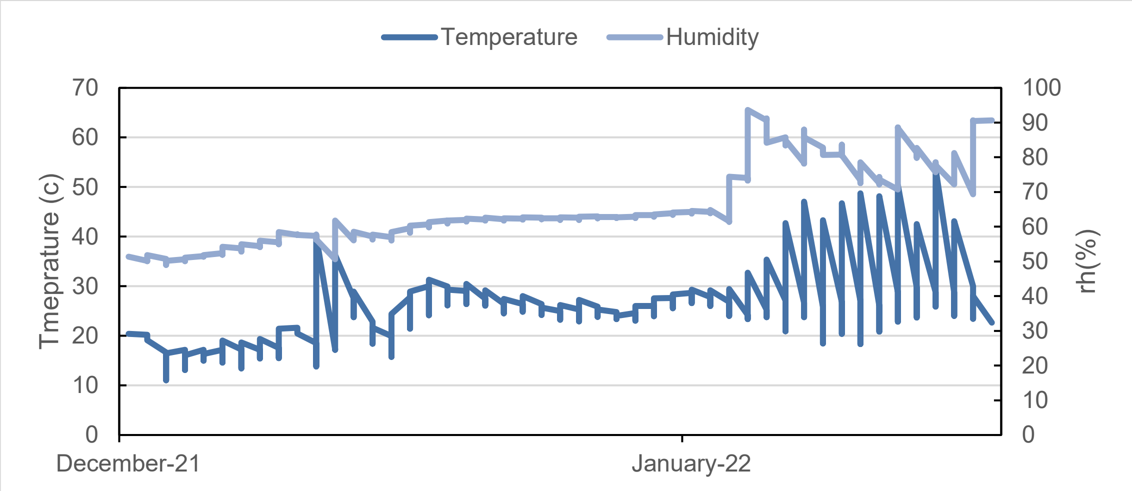


Figure 20 Measured environmental conditions in a CZ2 pack. Sensor - north facing top middle

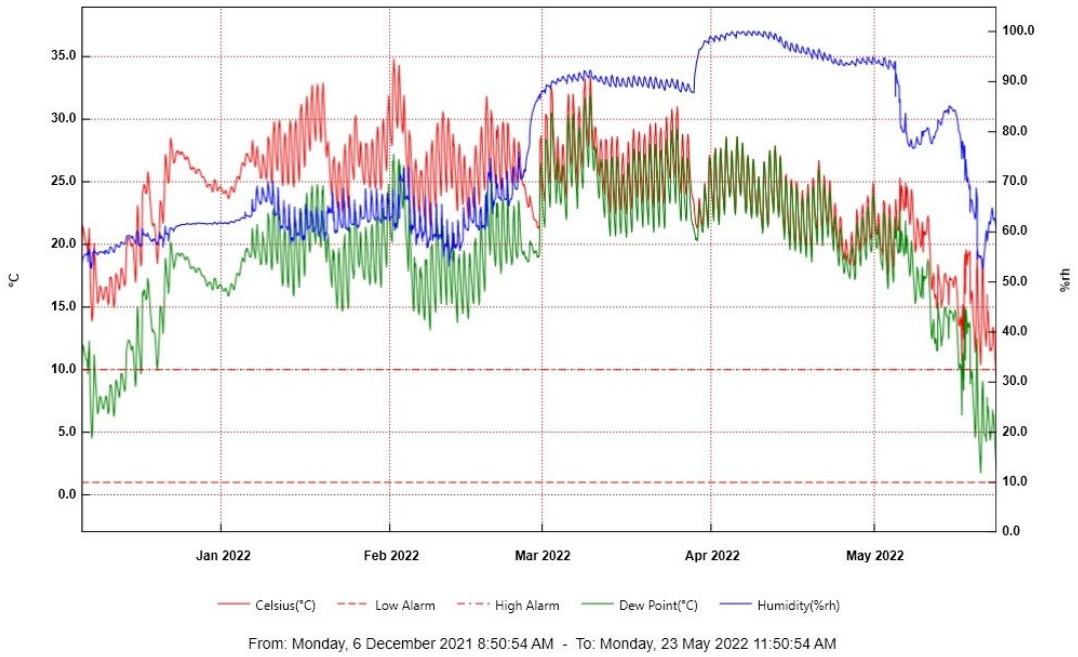


Figure 21 Measured environmental conditions in a CZ2 pack. Sensor - east facing middle

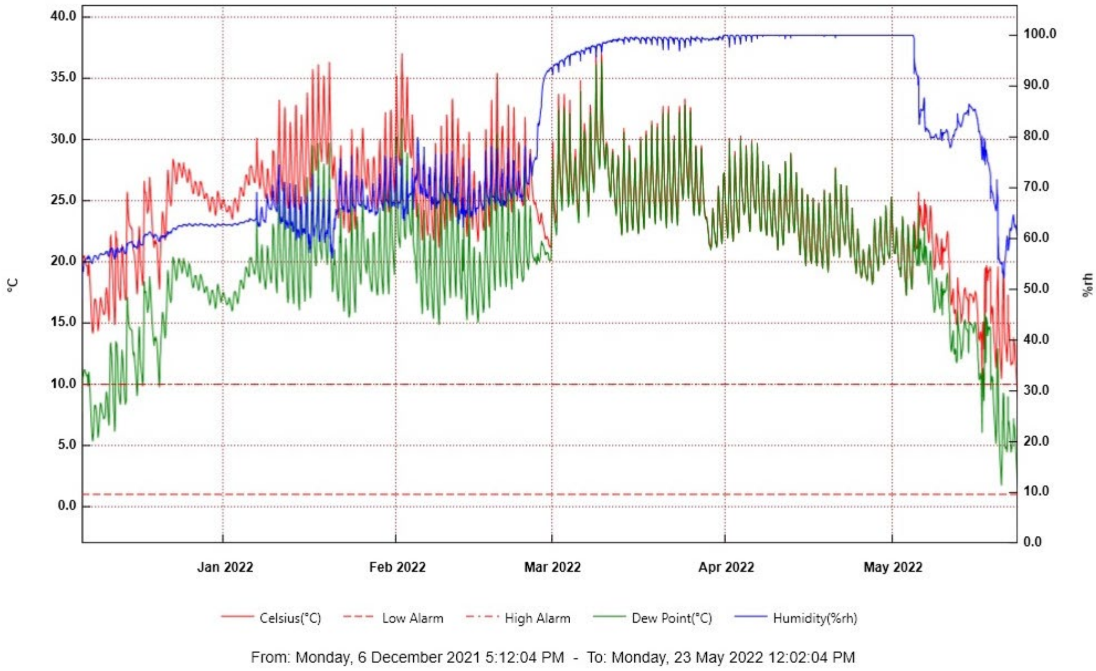


Figure 22 Measured environmental conditions in a CZ2 pack. Sensor - west facing middle

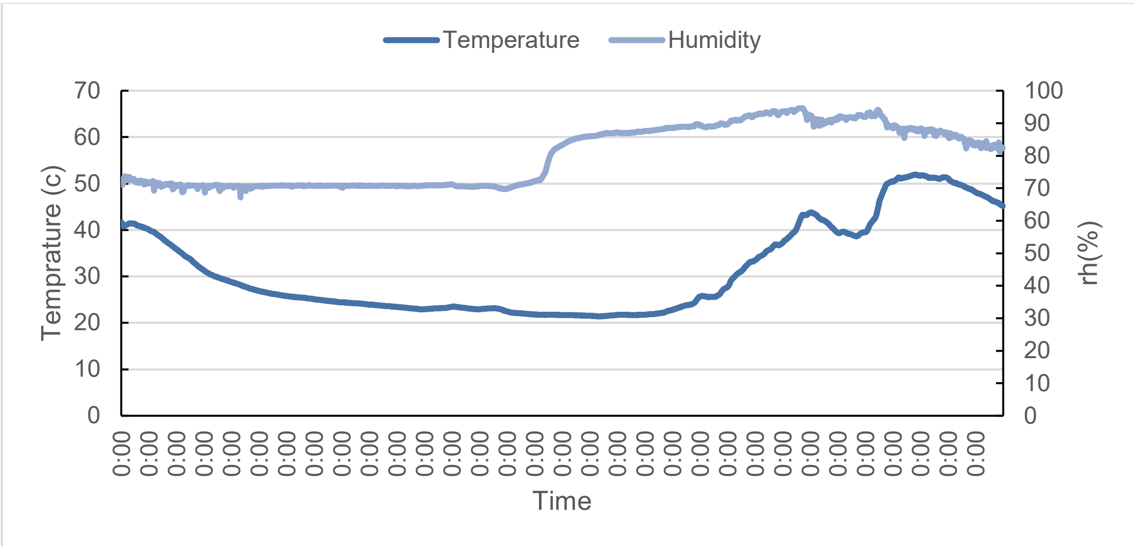


Figure 23 Measured environmental conditions in an exterior fully wrapped - opaque CZ2 pack on January 15, 2022. Sensor - north facing top middle

Fully wrapped – clear: exterior

Tasmanian site

The following tables and associated graphs illustrate the overall change in MC and the environmental conditions over the 2021-2022 summer across a Tasmanian and Queensland site for fully wrapped - clear timber packs in an exterior environment. Table 6 highlights the initial and post-trail MC and associated change in MC for the Tasmanian site. Figure 24, Figure 25 and Figure 26 present the environmental conditions over several months for sensors located on the north facing top middle, east facing middle and west facing middle of the timber pack. Figure 27 presents detailed data collected over a 24-hour period on January 15 2022.

Table 6 MC change in a fully wrapped - clear timber pack in Tasmania (exterior)

Tasmania, clear wrapped, exterior			
Position in pack	**Initial MC (%)**	**Post-trial MC (%)**	**Change in MC (%)**
Top middle	11.4	32.1	20.6
West	11.6	11.0	-0.7
Middle	11.8	11.8	0.0
East	11.9	11.4	-0.5
Bottom middle	11.4	11.5	0.1
(average)	(11.7)	(15.5)	(3.9)

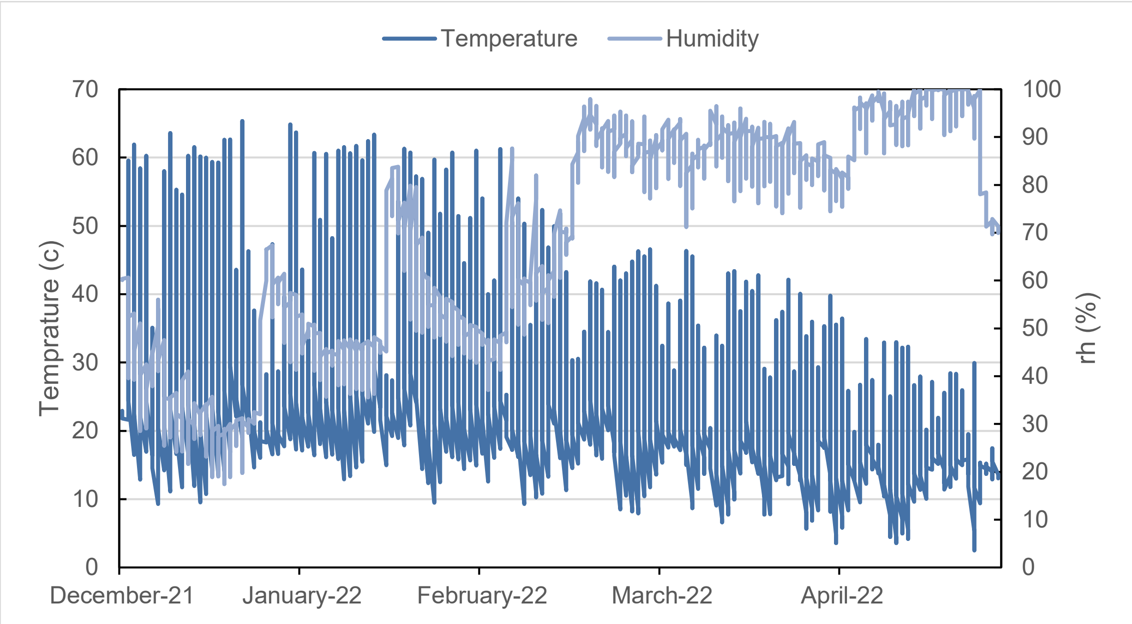


Figure 24 Measured environmental conditions in a CZ7 pack. Sensor - north facing top middle

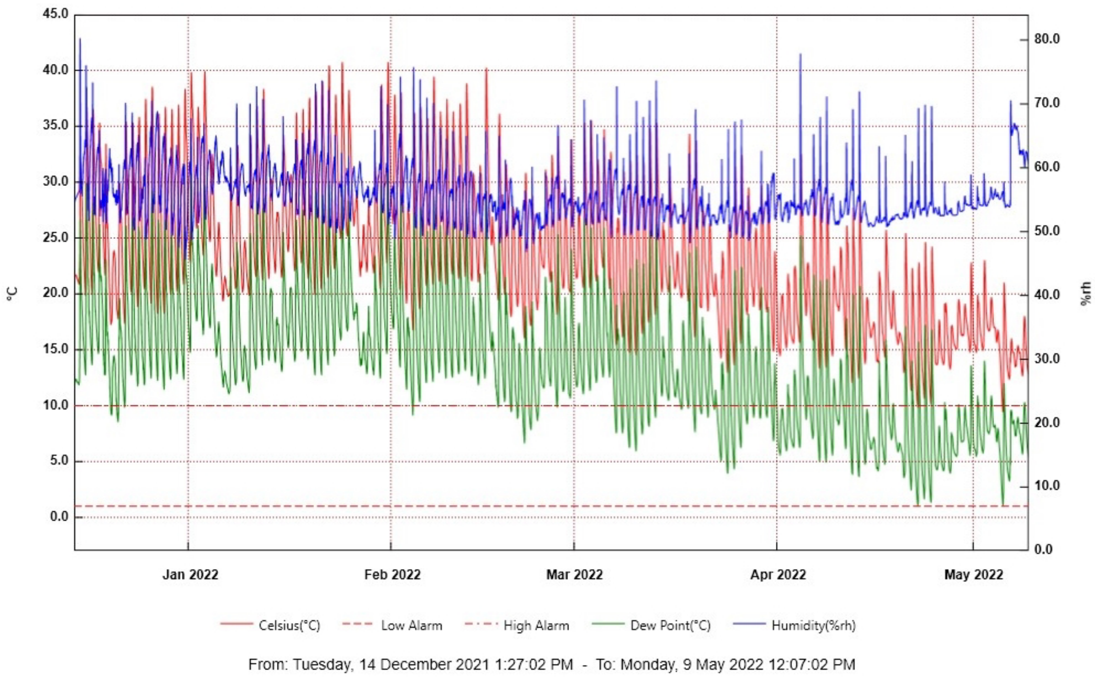


Figure 25 Measured environmental conditions in a CZ7 pack. Sensor - east facing middle

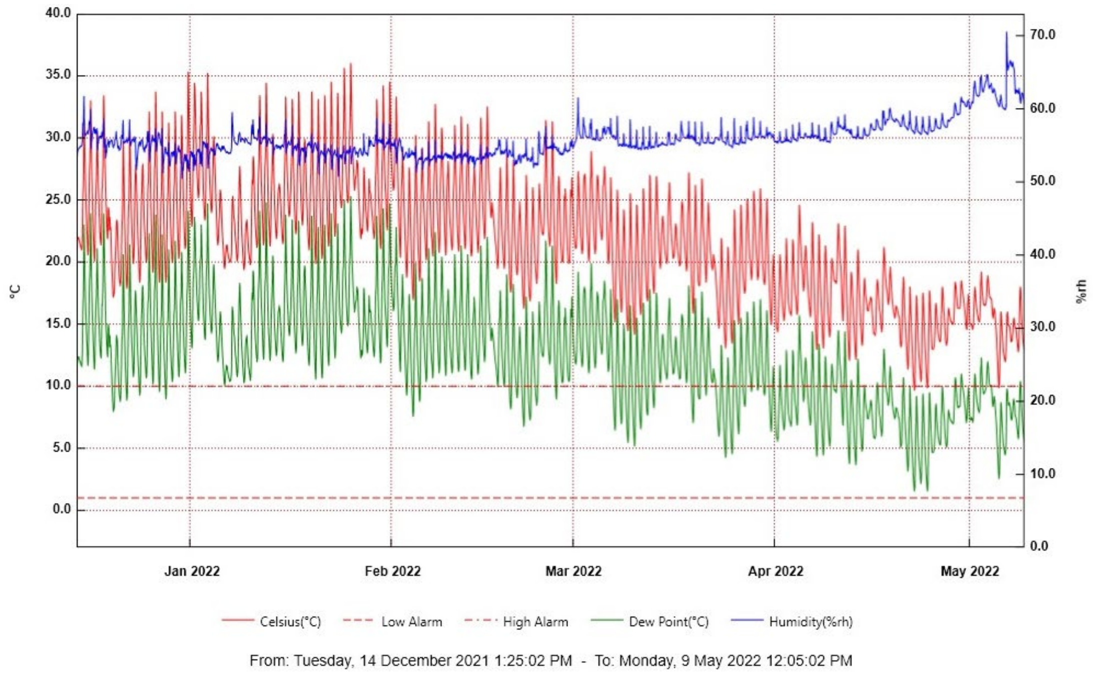


Figure 26 Measured environmental conditions in a CZ7 pack. Sensor - west facing middle

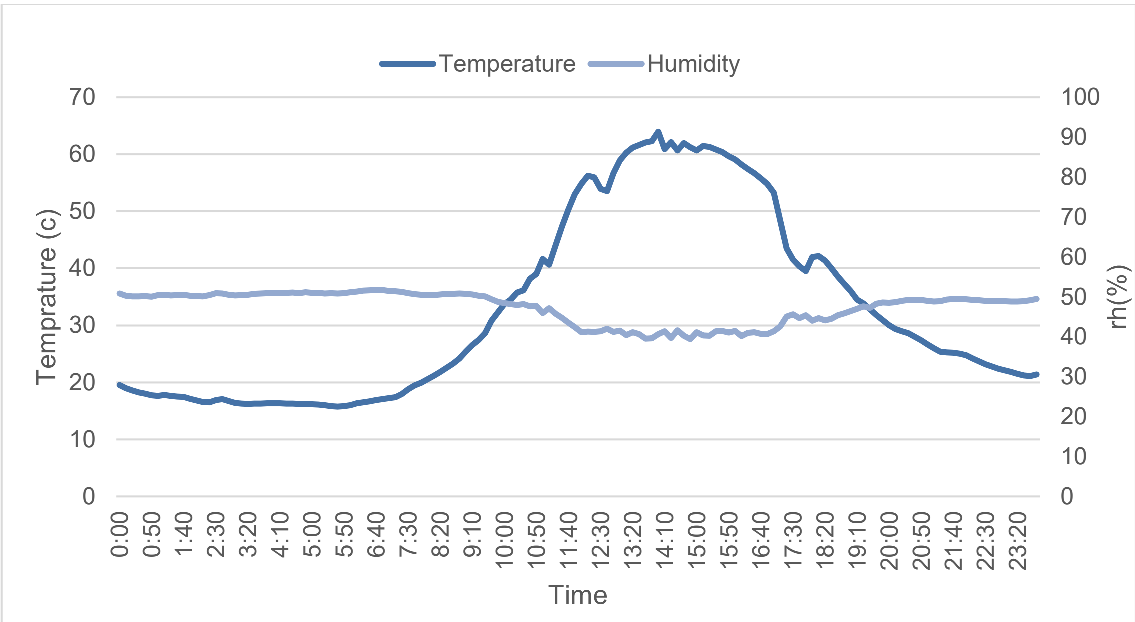


Figure 27 Measured environmental conditions in an exterior fully wrapped - clear CZ7 pack on January 15, 2022. Sensor - north facing top middle

Queensland site

Table 7 highlights the initial and post-trail MC and associated change in MC for the Queensland site. Figure 28, Figure 29 and Figure 30 present the environmental conditions over several months for sensors located on the north facing top middle, east facing middle and west facing middle of the timber pack. Figure 31 presents detailed data collected over a 24-hour period on January 15 2022.

Table 7 MC change in a fully wrapped - clear timber pack in Queensland (exterior)

Queensland, clear wrapped, exterior			
Position in pack	**Initial MC (%)**	**Post-trial MC (%)**	**Change in MC (%)**
Top middle	11.3	39.0	27.7
West	12.0	20.3	8.3
Middle	12.0	21.4	9.4
East	11.5	15.9	4.4
Bottom middle	11.6	16.1	4.5
(average)	(11.7)	(22.5)	(10.9)

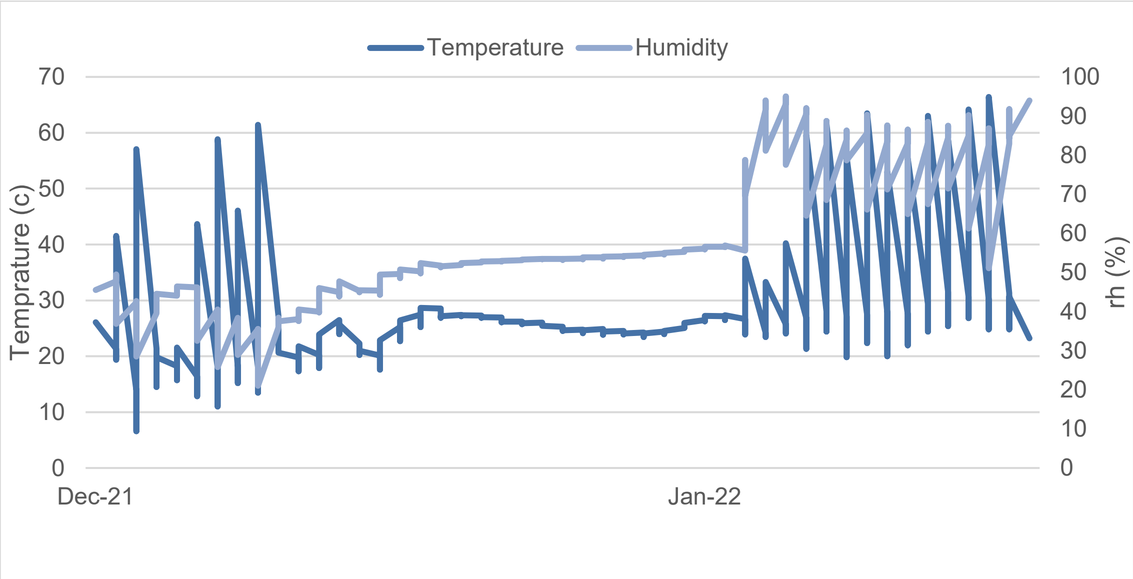


Figure 28 Measured environmental conditions in a CZ2 pack. Sensor - north facing top middle

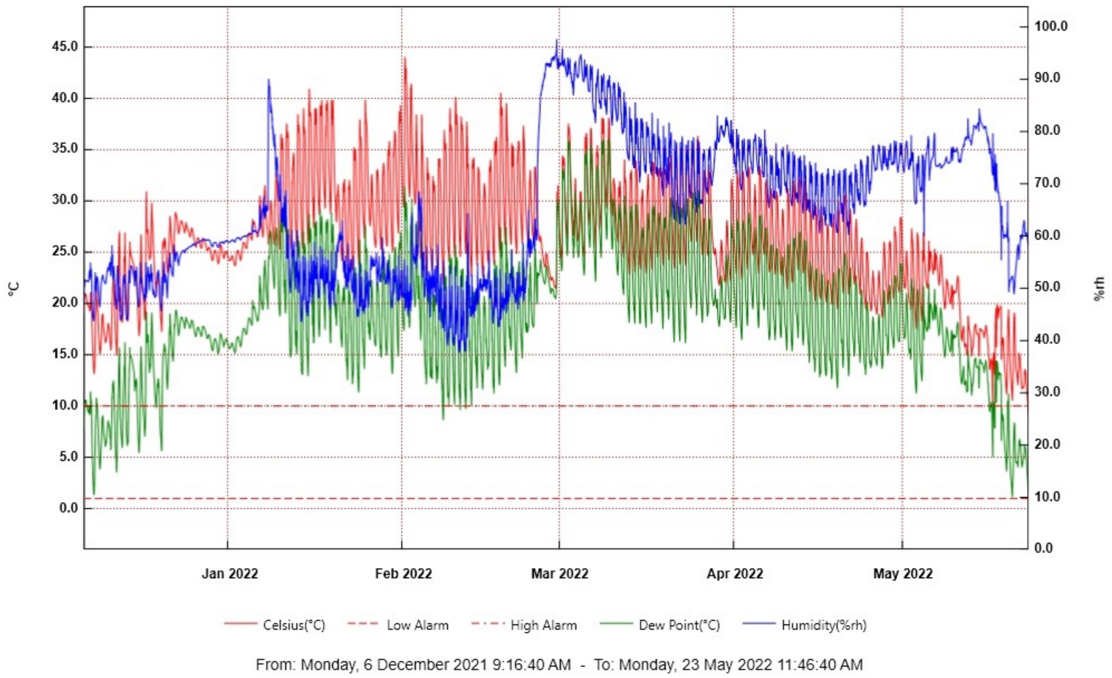


Figure 29 Measured environmental conditions in a CZ2 pack. Sensor - east facing middle

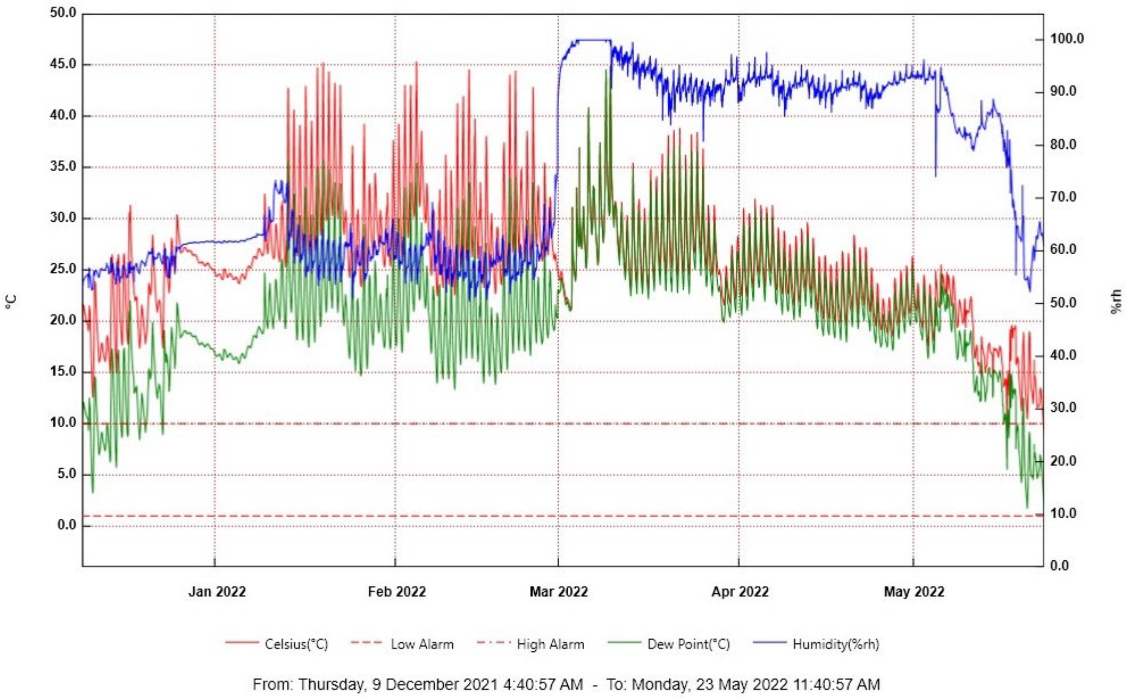


Figure 30 Measured environmental conditions in a CZ2 pack. Sensor - west facing middle

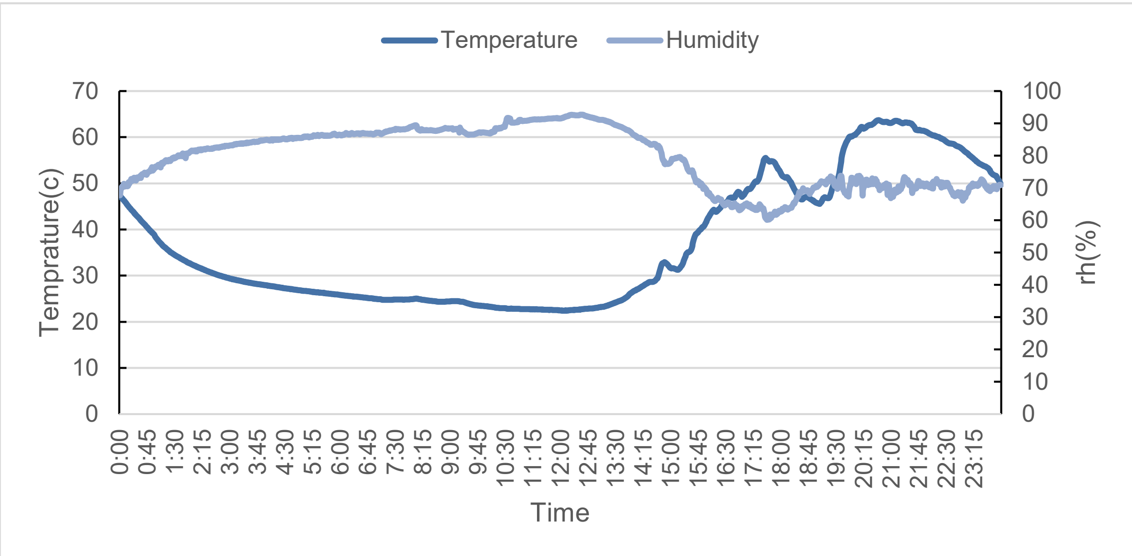


Figure 31 Measured environmental conditions in an exterior fully wrapped - clear CZ2 pack on January 15, 2022. Sensor - north facing top middle

Poorly wrapped: interior

Tasmanian site

The following tables and associated graphs illustrate the overall change in MC and the environmental conditions over the 2021-2022 summer across a Tasmanian and Queensland site for poorly wrapped timber packs in an interior environment. Table 8 highlights the initial and post-trail MC and associated change in MC for the Tasmanian site. Figure 32, Figure 33 and Figure 34 present the environmental conditions over several months for sensors located on the north facing top middle, east facing middle and west facing middle of the timber pack. Figure 35 presents detailed data collected over a 24-hour period on January 15 2022.

Table 8 MC change in a poorly wrapped timber pack in Tasmania (interior)

Tasmania, Poorly wrapped, interior			
Position in pack	**Initial MC (%)**	**Post-trial MC (%)**	**Change in MC (%)**
Top middle	11.6	11.4	-0.2
West	11.9	11.4	-0.5
Middle	11.9	11.2	-0.7
East	11.8	11.6	-0.3
Bottom middle	12.0	11.4	-0.6
(average)	(11.9)	(11.4)	(-0.5)

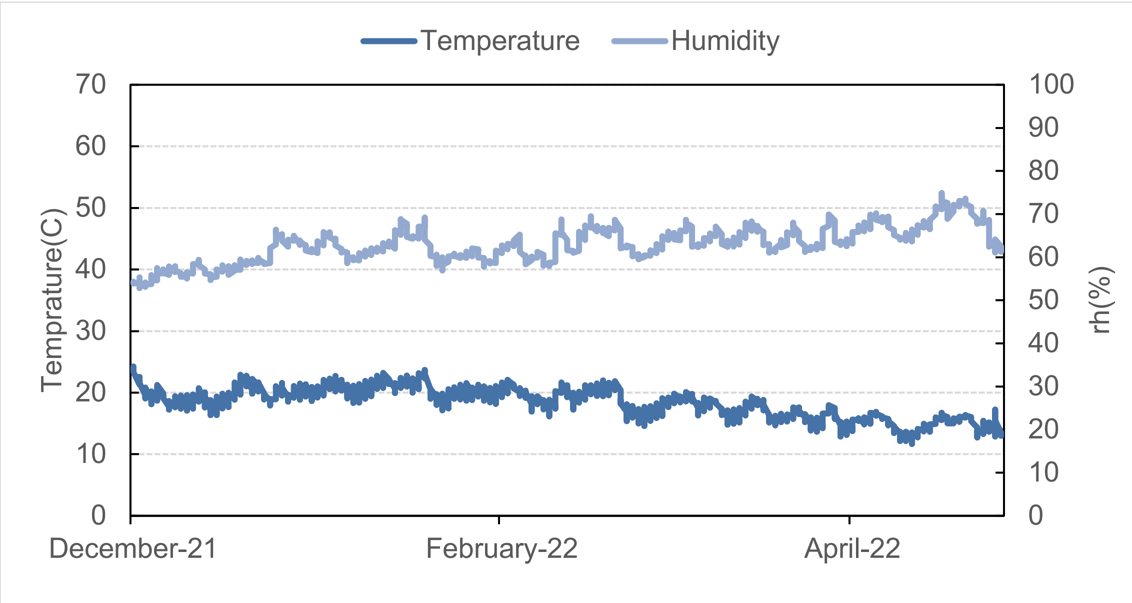


Figure 32 Measured environmental conditions in a CZ7 pack. Sensor - north facing top middle

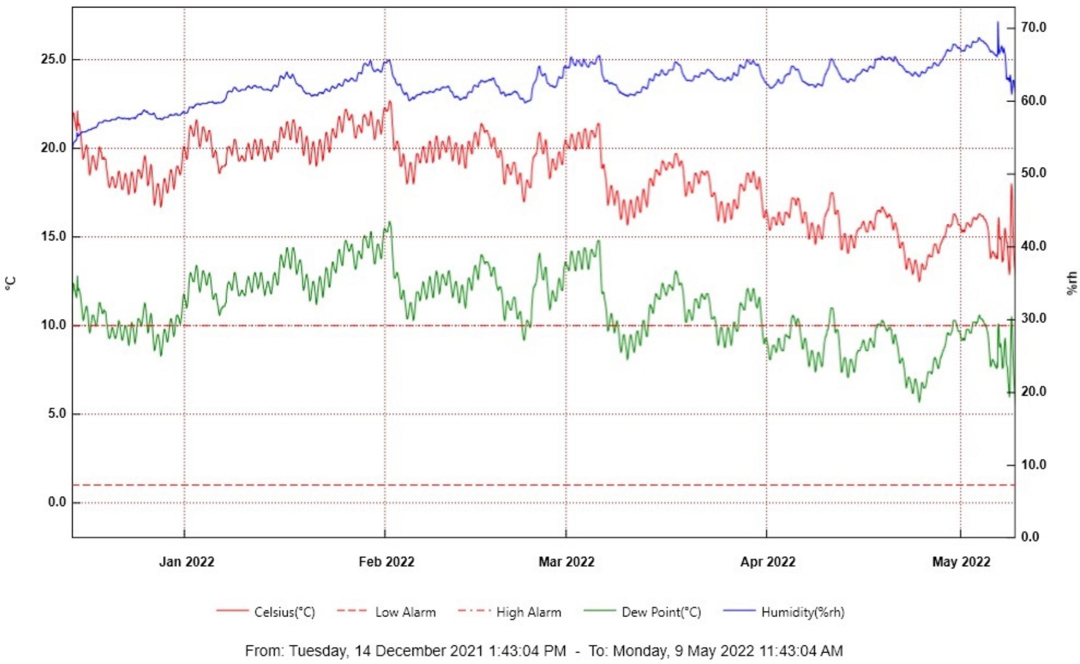


Figure 33 Measured environmental conditions in a CZ7 pack. Sensor - east facing middle

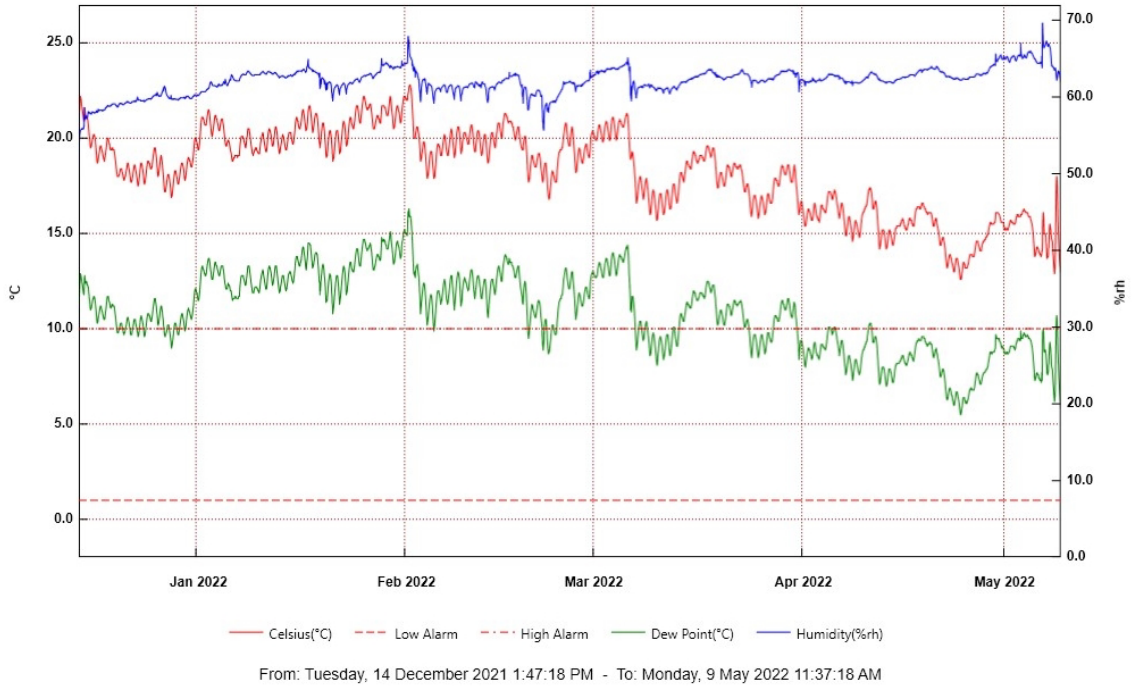


Figure 34 Measured environmental conditions in a CZ7 pack. Sensor - west facing middle

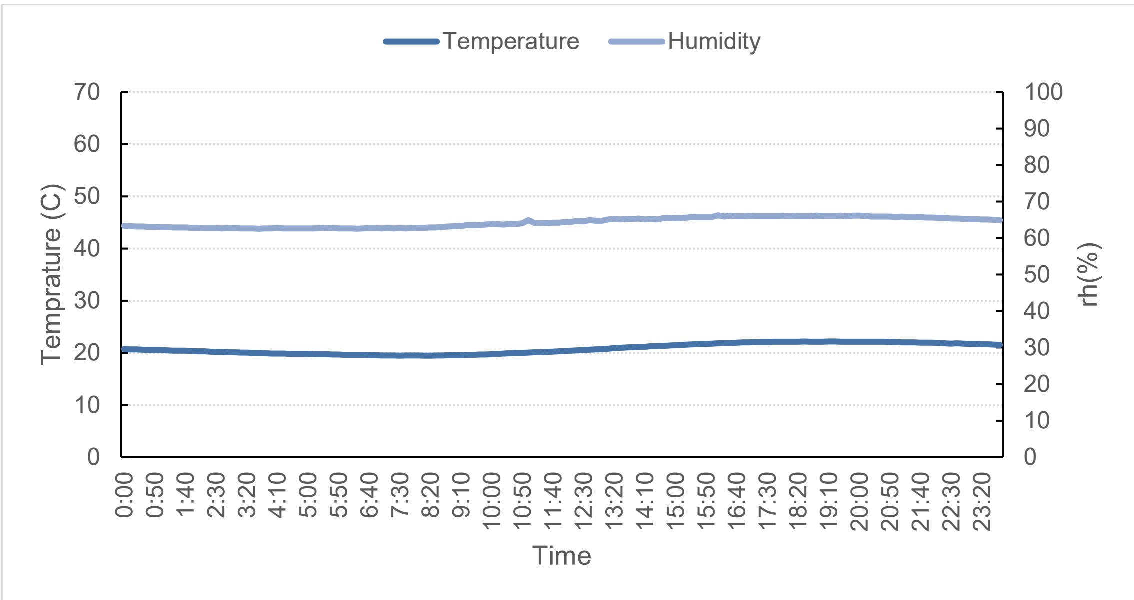


Figure 35 Measured environmental conditions in a CZ7 pack on January 15, 2022. Sensor - north facing top middle

Queensland site

Table 9 highlights the initial and post-trail MC and associated change in MC for the Queensland site. Figure 36, Figure 37 and Figure 38 present the environmental conditions over several months for sensors located on the north facing top middle, east facing middle and west facing middle of the timber pack. Figure 39 presents detailed data collected over a 24-hour period on January 15, 2022.

Table 9 MC change in a poorly wrapped timber pack in Queensland (interior)

Queensland, Poorly wrapped, interior			
Position in pack	**Initial MC (%)**	**Post-trial MC (%)**	**Change in MC (%)**
Top middle	11.0	11.1	0.2
West	11.4	11.6	0.2
Middle	11.1	11.5	0.4
East	11.3	11.6	0.3
Bottom middle	11.5	11.9	0.4
(average)	(11.9)	(11.5)	(0.3)

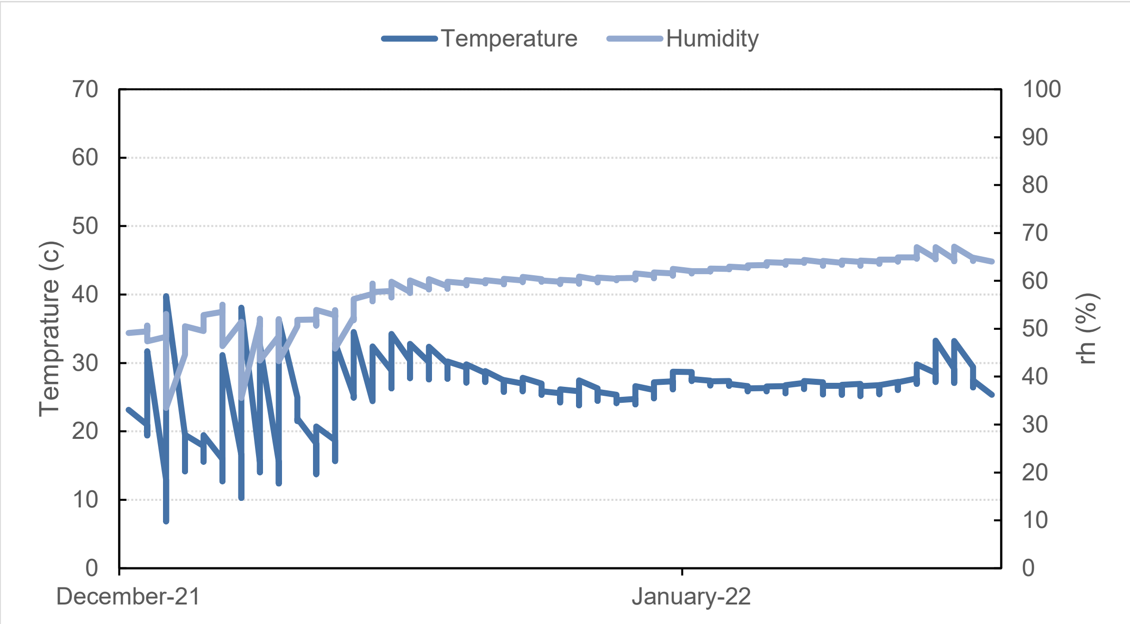


Figure 36 Measured environmental conditions in a CZ2 pack. Sensor - north facing top middle

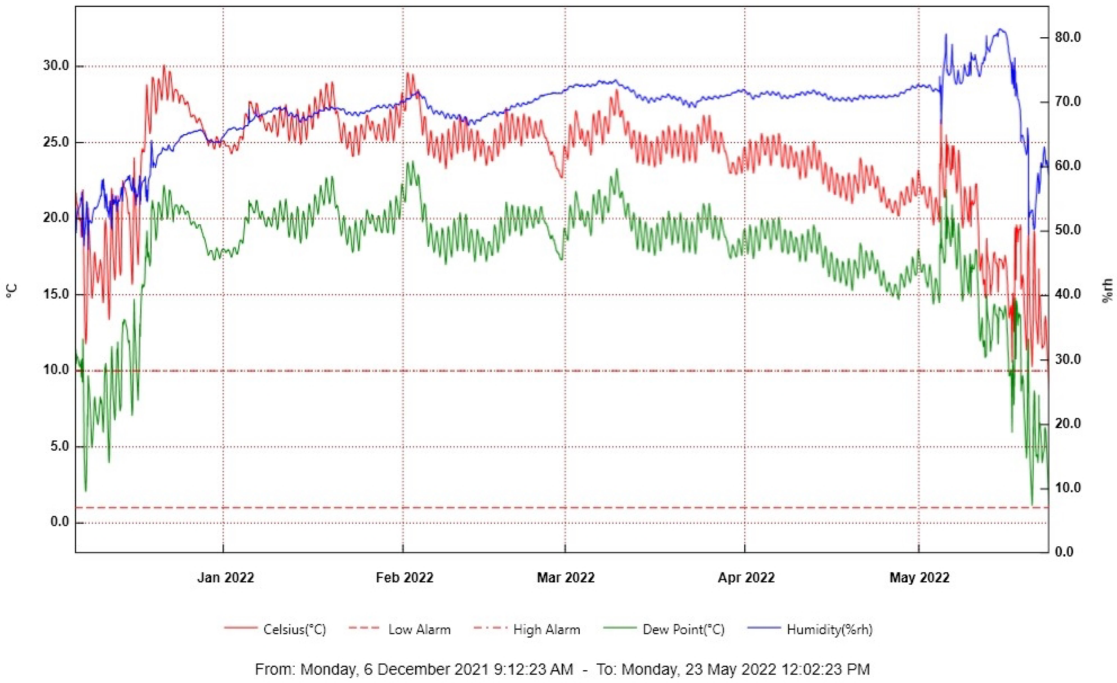


Figure 37 Measured environmental conditions in a CZ2 pack. Sensor - east facing middle

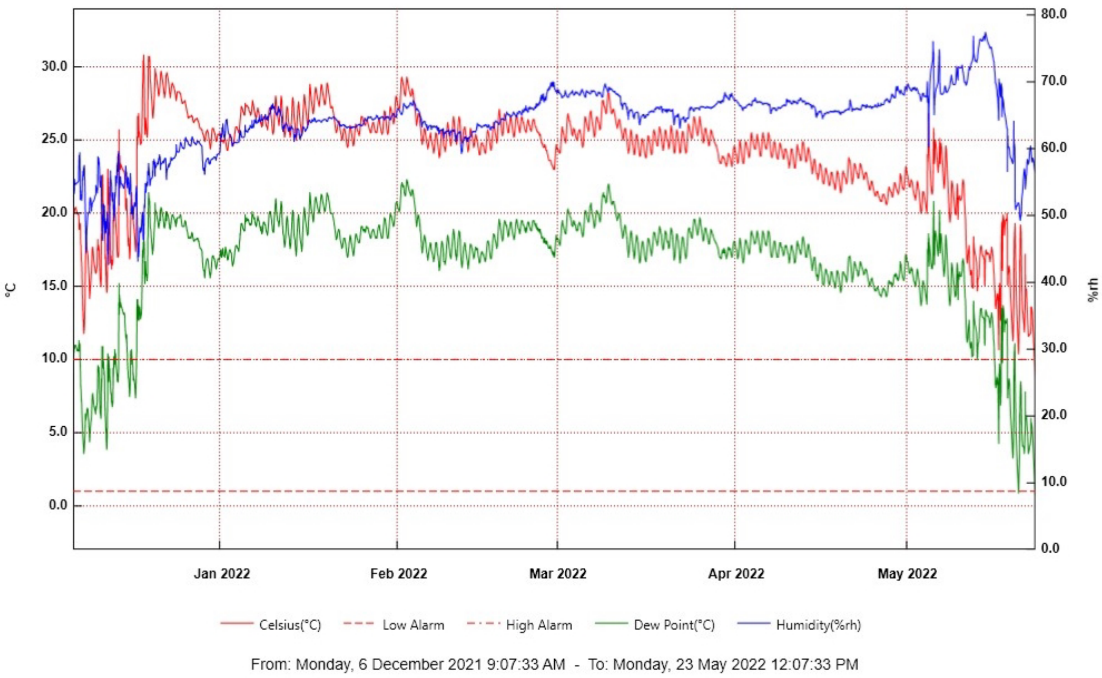


Figure 38 Measured environmental conditions in a CZ2 pack. Sensor - west facing middle

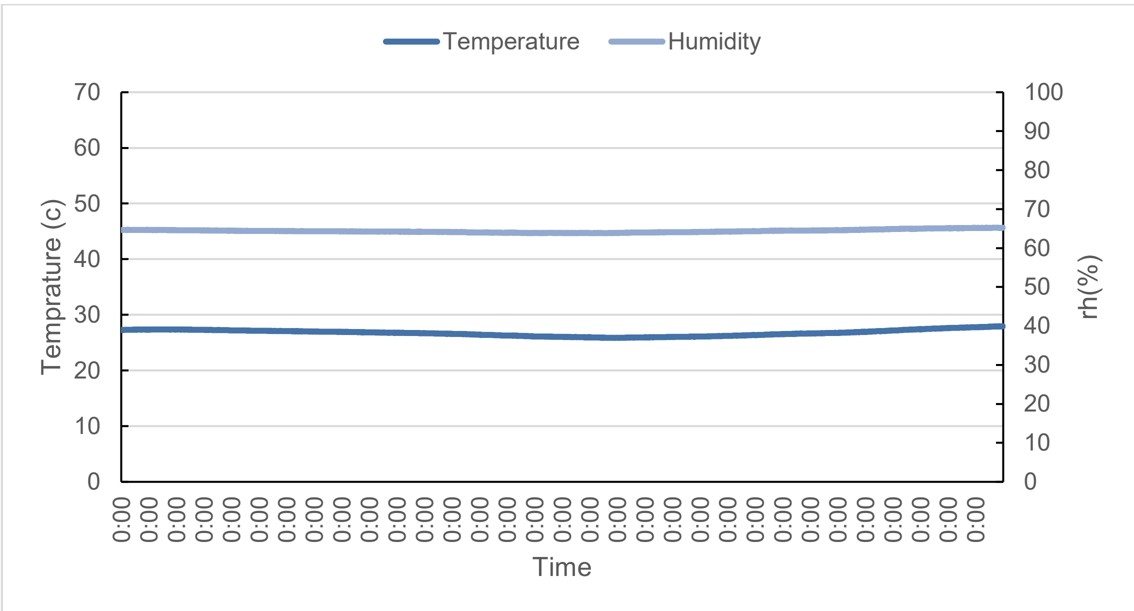


Figure 39 Measured environmental conditions in a CZ2 pack on January 15, 2022. Sensor - north facing top middle

Fully wrapped - clear interior

Tasmanian site

The following tables and associated graphs illustrate the overall change in MC and the environmental conditions over the 2021-2022 summer across a Tasmanian and Queensland site for fully wrapped - clear timber packs in an interior environment. Table 10 highlights the initial and post-trail MC and associated change in MC for the Tasmanian site. Figure 40, Figure 41 and Figure 42 present the environmental conditions over several months for sensors located on the north facing top middle, east facing middle and west facing middle of the timber pack. Figure 43 presents detailed data collected over a 24-hour period on January 15, 2022.

Table 10 MC change in a fully wrapped - clear timber pack in Tasmania (interior)

Tasmania, clear wrapped, interior			
Position in pack	**Initial MC (%)**	**Post-trial MC (%)**	**Change in MC (%)**
Top middle	11.5	11.4	-0.1
West	11.8	11.4	-0.4
Middle	11.7	11.5	-0.2
East	11.6	10.9	-0.7
Bottom middle	11.1	11.1	0.0
(average)	(11.5)	(11.3)	(-0.3)

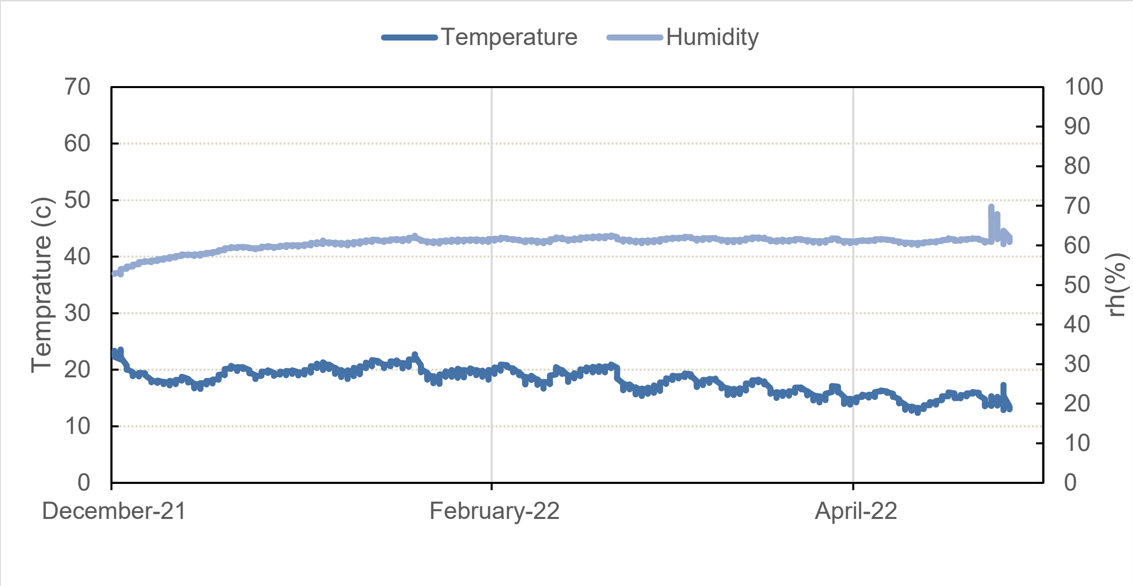


Figure 40 Measured environmental conditions in a CZ7 pack. Sensor - north facing top middle

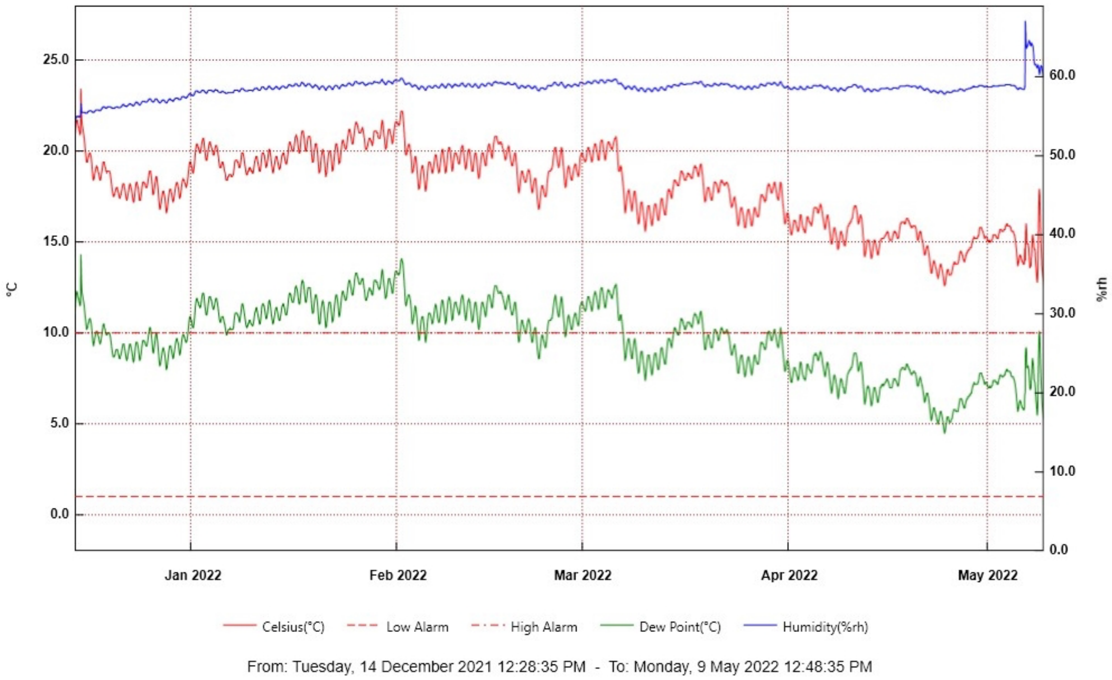


Figure 41 Measured environmental conditions in a CZ7 pack. Sensor - east facing middle

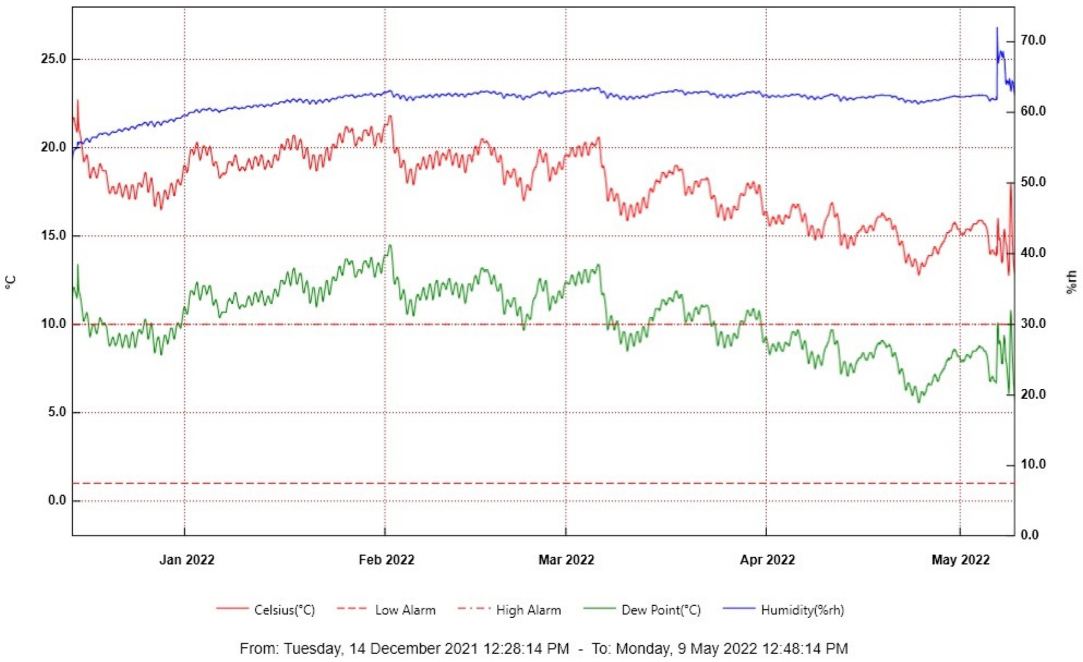


Figure 42 Measured environmental conditions in a CZ7 pack. Sensor - west facing middle

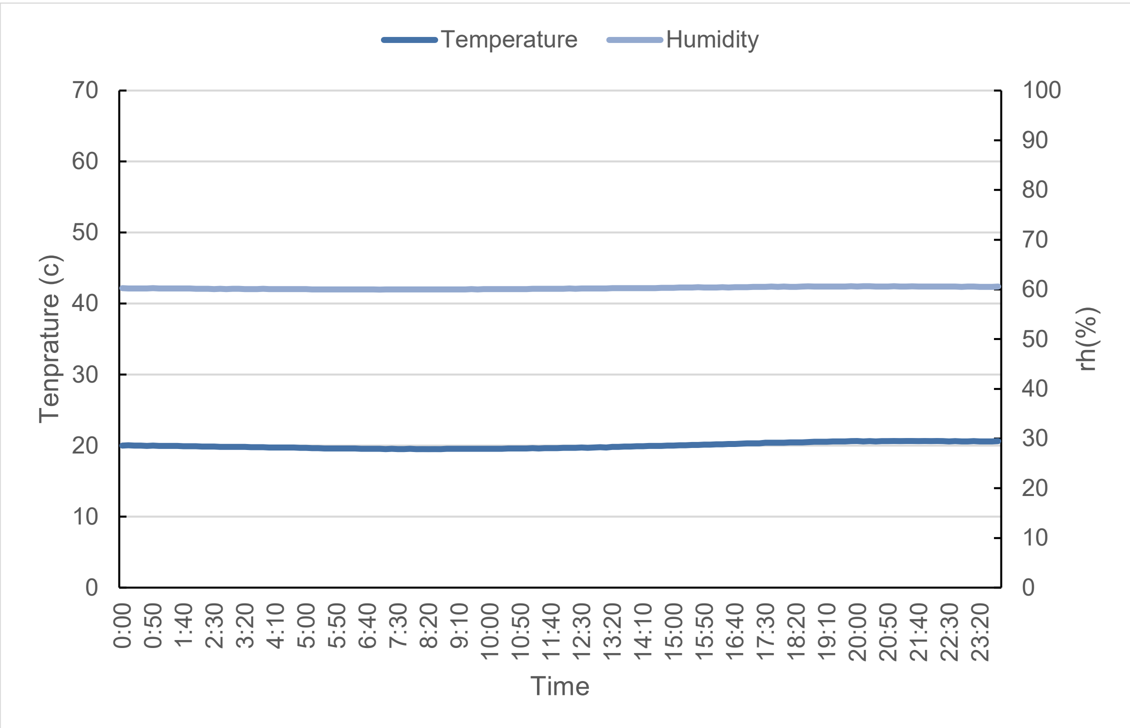


Figure 43 Measured environmental conditions in a CZ7 pack on January 15, 2022. Sensor - north facing top middle

Queensland site

Table 11 highlights the initial and post-trail MC and associated change in MC for the Queensland site. Figure 44, Figure 45 and Figure 46 present the environmental conditions over several months for sensors located on the north facing top middle, east facing middle and west facing middle of the timber pack. Figure 47 presents detailed data collected over a 24-hour period on January 15, 2022.

Table 11 MC change in a fully wrapped - clear timber pack in Queensland (interior)

Queensland, clear wrapped, interior			
Position in pack	**Initial MC (%)**	**Post-trial MC (%)**	**Change in MC (%)**
Top middle	11.1	10.7	-0.3
West	11.1	11.3	0.3
Middle	11.1	11.2	0.2
East	11.1	11.4	0.3
Bottom middle	10.8	11.4	0.6
(average)	(11.0)	(11.2)	(0.2)

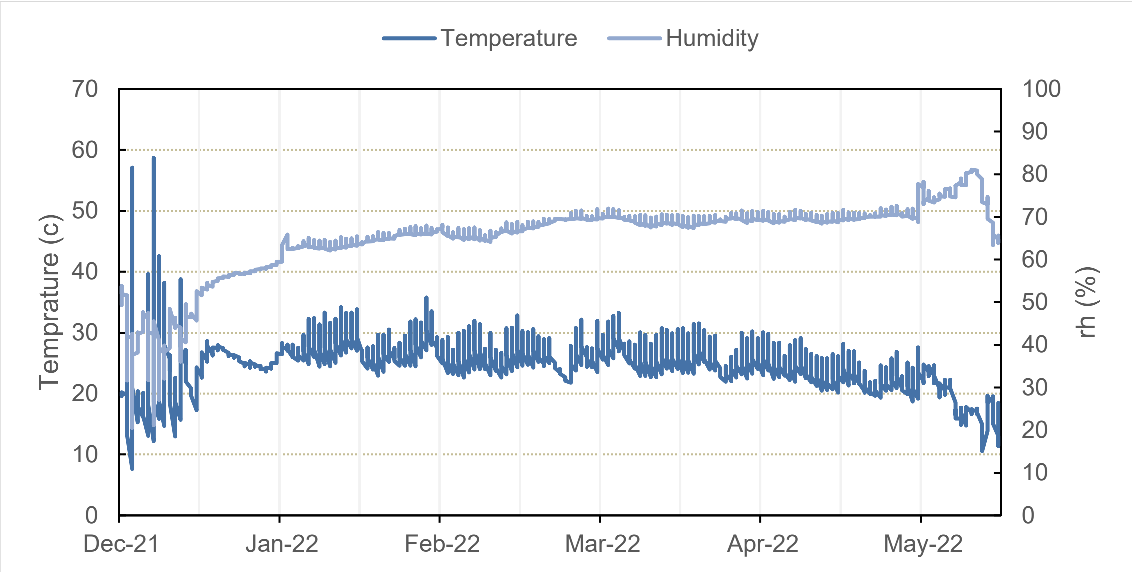


Figure 44 Measured environmental conditions in a CZ2 pack. Sensor - north facing top middle

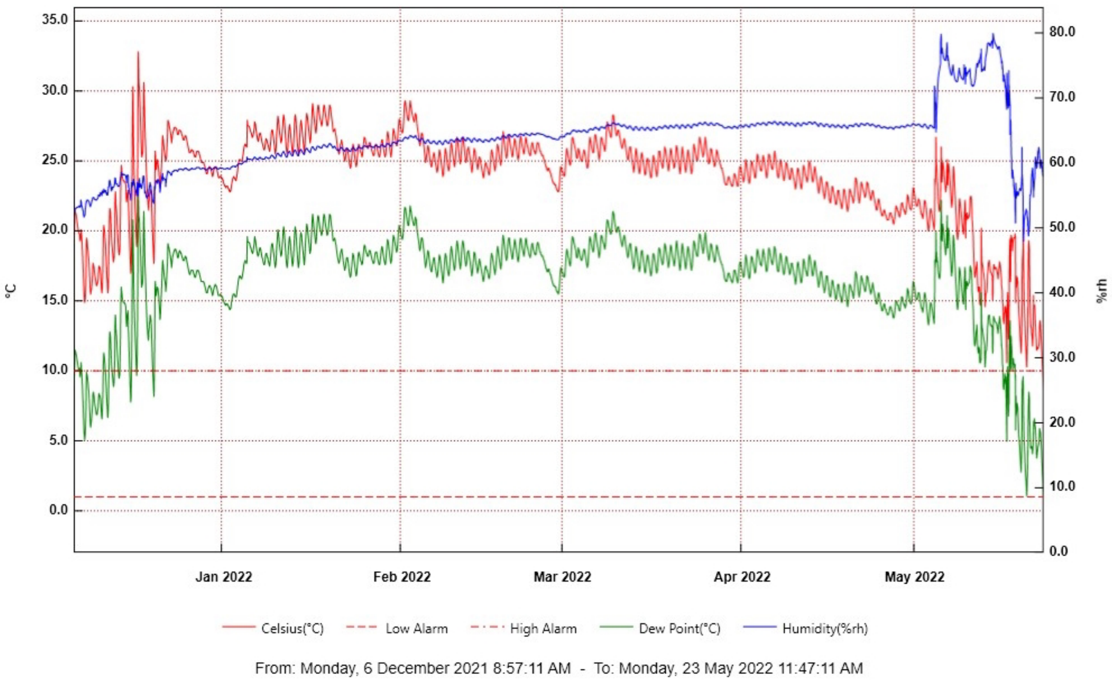


Figure 45 Measured environmental conditions in a CZ2 pack. Sensor - east facing middle

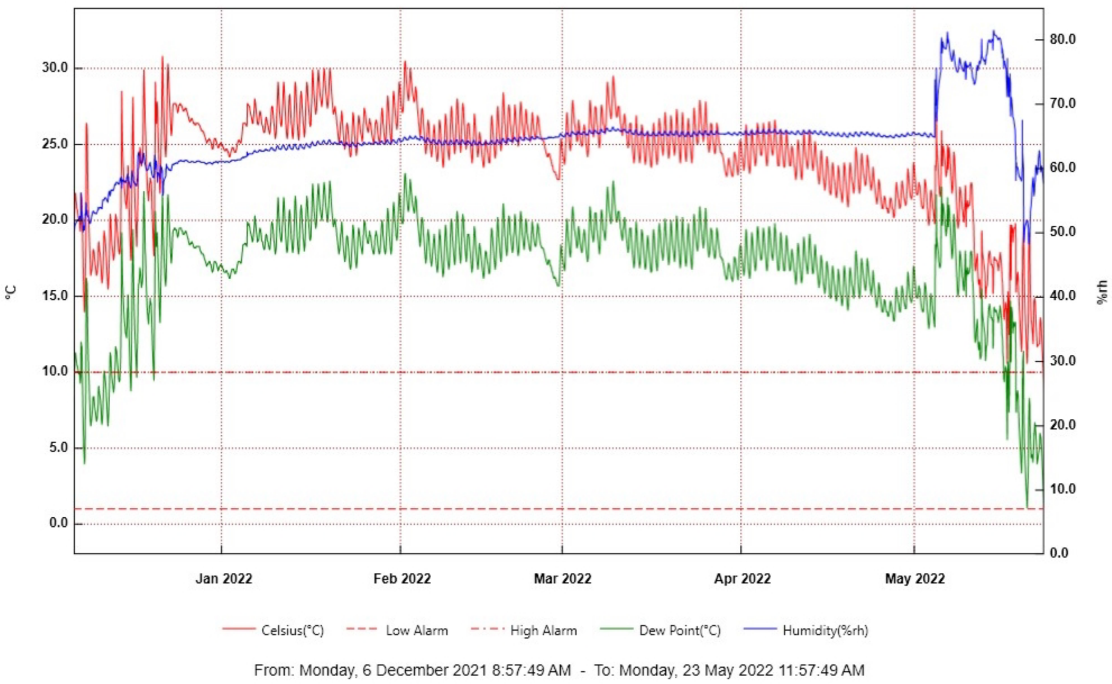


Figure 46 Measured environmental conditions in a CZ2 pack. Sensor - west facing middle

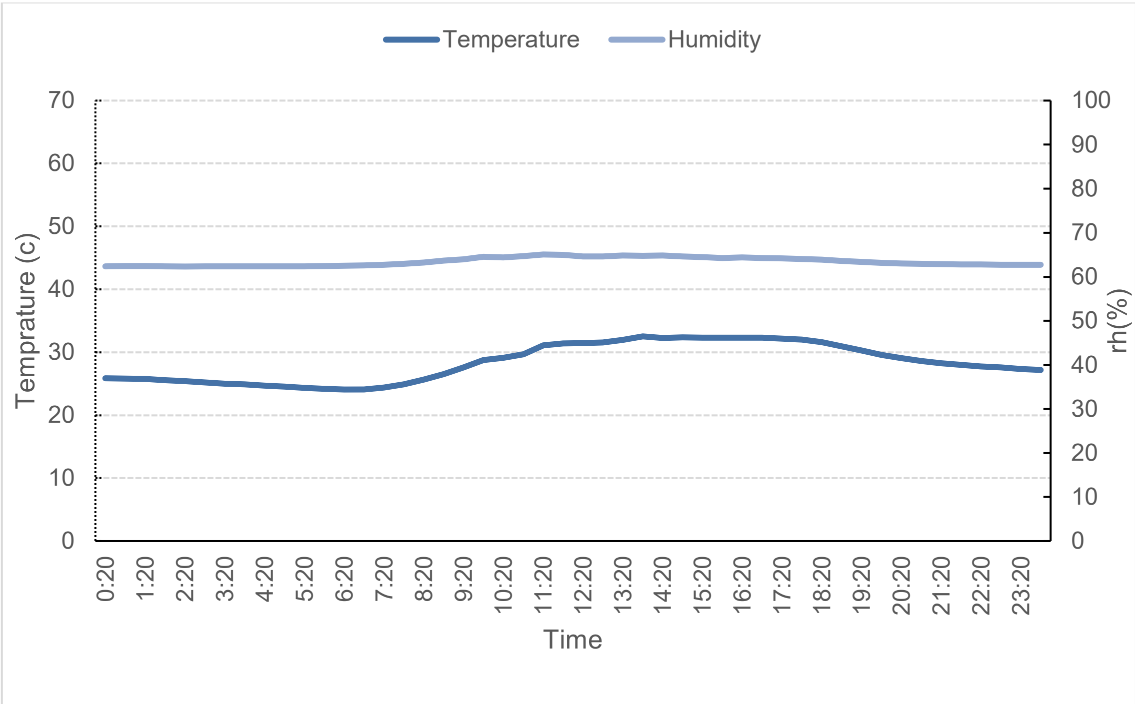


Figure 47 Measured environmental conditions in a CZ2 pack on January 15, 2022. Sensor - north facing top middle

Discussion

Ambient conditions outside and inside the wrap

This section of the report demonstrates the wide environmental range of temperature and humidity that a pack of timber can be exposed to over a short duration and over several months. There are obvious differences between each type of wrapping, exterior vs interior environments and Queensland vs Tasmania.

While not judging which type of wrapping is best for industry to use, the results indicate that wherever possible storing wrapped timber in an interior environment is preferable to storing it in exposed locations. For a hygroscopic material such as timber, a more stable environment will reduce but not eliminate the amount of change in timber MC. Evident in Table 8, Table 9, Table 10, and Table 11, the average change in MC was minimal due to the stable environment conditions shown in associated figures and in particular Figure 49 and Figure 52. Interior locations are therefore ideal for storing high value timber products where MC and dimensional stability are imperative.

By comparison, all timber packs stored in an exposed exterior environment experience an increased change in MC. For Tasmania, the results summarised in Table 2, Table 4 and Table 6 indicate a slight increase in average MC. The location of the timber in a pack however did impact the change in MC particularly for the top middle specimen that was naturally exposed to all environment conditions such as rain and sunshine. The same can be said for Queensland, where Table 3, Table 5 and Table 7 all returned a significant increase in average MC. The most obvious change in MC was the clear exterior wrap in Queensland with a change in MC of 27.7 % for the top middle north facing specimen. Demonstrated in Figure 48, Figure 50 and Figure 51 the maximum and minimum temperature and humidity recorded for both Queensland and Tasmania can be considered very harsh conditions that are not ideal for timber products. The following tables and graphs were produced from the top middle north facing sensor of each timber pack. The maximum, minimum and average temperature and humidity for each timber pack is presented along with key dates when they occurred.

Poorly wrapped packs

Table 12 Measured data from a poorly wrapped pack in an exterior environment

Poor Exterior	QLD	TAS
Max Temp (^{O}C) / Date	50.3 / 15/01/22	46.6 / 30/01/22
Min Temp (^{O}C) / Date	18.1 / 13/01/22	2.7 / 22/04/22
Average Temp (^{O}C) / no. included days	29.4 / 15	19.7 / 146
Max RH (%) / Date	98.1 / 9/01/22	99.3 / 23/04/22
Min RH (%) / Date	42.9 / 18/01/22	38.7 / 27/12/21
Average RH (%) / no. included days	76.1 / 15	64.8 / 146

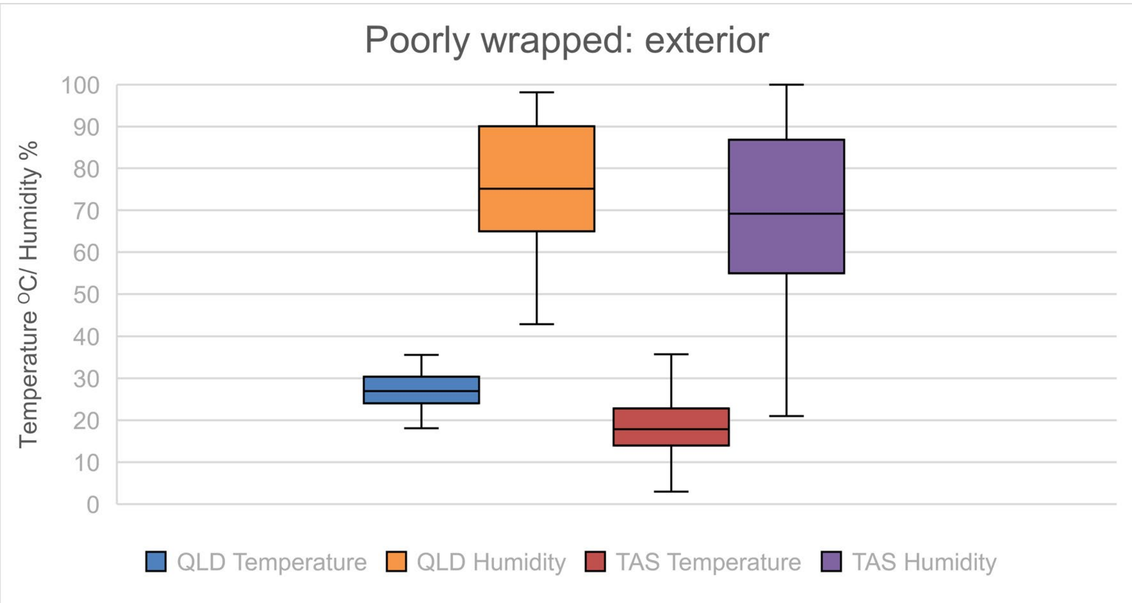


Figure 48 Measured temperature and humidity range: poorly wrapped pack in an exterior environment In Queensland and Tasmania

Table 13 Measured data from a poorly wrapped pack in an interior environment

Poor Interior	QLD	TAS
Max Temp (°C) / Date	33.3 / 17/01/22	24.3 / 14/12/21
Min Temp (°C) / Date	25.2 / 13/02/22	11.7 / 24/04/22
Average Temp (°C) / no. included days	27 / 15	18.4 / 146
Max RH (%) / Date	67.1 / 18/01/22	74.9 / 29/04/22
Min RH (%) / Date	62 / 5/01/22	52.8 / 15/12/21
Average RH (%) / no. included days	63.9 / 15	63 / 146

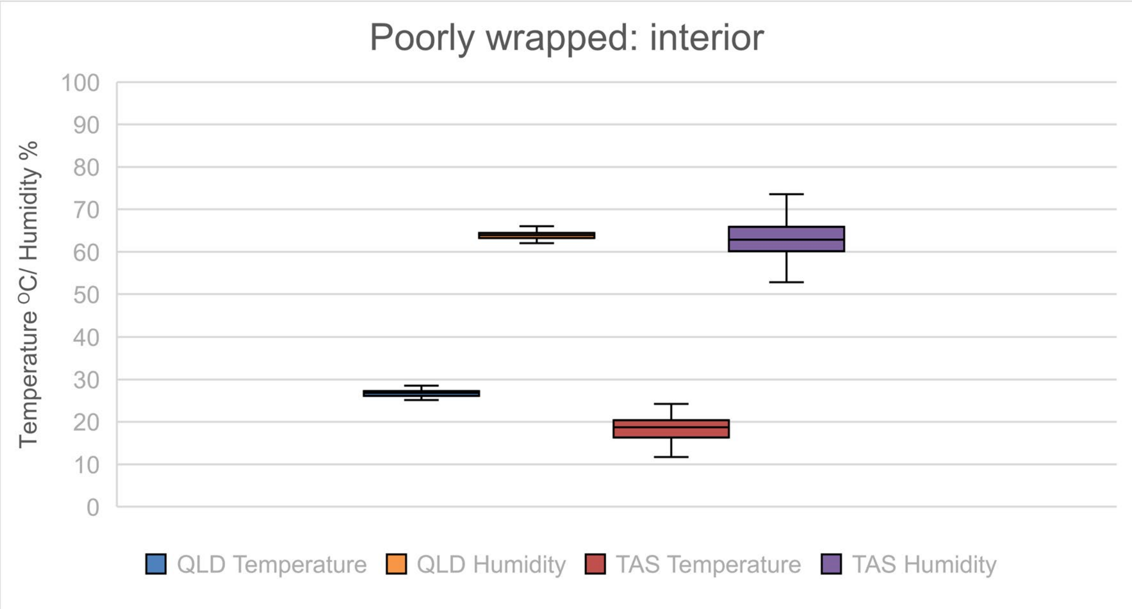


Figure 49 Measured temperature and humidity range: in a poor timber wrap in an interior environment In Queensland and Tasmania

Fully wrapped – opaque packs

Table 14 Measured data from fully wrapped – opaque packs in an exterior environment

Opaque, Exterior	QLD	TAS
Max Temp (°C) / Date	53.7 / 17/01/22	42.8 / 11/01/22
Min Temp (°C) / Date	18 / 11/01/22	2.7 / 22/04/22
Average Temp (°C) / no. included days	24.8 / 15	19.7 / 127
Max RH (%) / Date	93.6 / 7/01/22	99.3 / 23/01/22
Min RH (%) / Date	61.4 / 6/01/22	38.7 / 27/12/21
Average RH (%) / no. included days	78.8 / 15	64.8 / 127

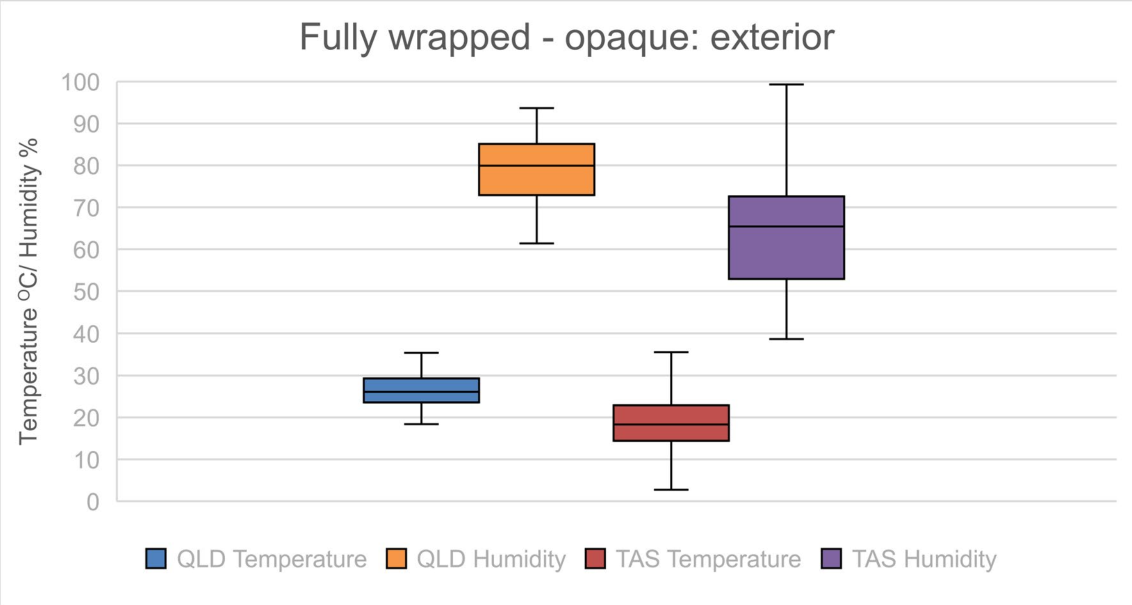


Figure 50 Measured temperature and humidity range: fully wrapped – opaque packs in an exterior environment In Queensland and Tasmania

Fully wrapped – clear pack

Table 15 Measured data from a fully wrapped – clear pack in an exterior environment

Clear Exterior	QLD	TAS
Max Temp (°C) / Date	66.4 / 18/01/22	65.3 / 3/01/22
Min Temp (°C) / Date	19.8 / 7/01/22	2.5 / 5/04/22
Average Temp (°C) / no. included days	33.9 / 15	23.9 / 146
Max RH (%) / Date	95 / 8/01/22	100 / 24/4/22 to 6/5/22
Min RH (%) / Date	51.1 / 18/01/22	17.4 / 31/12/21
Average RH (%) / no. included days	79.4 / 15	68.4 / 146

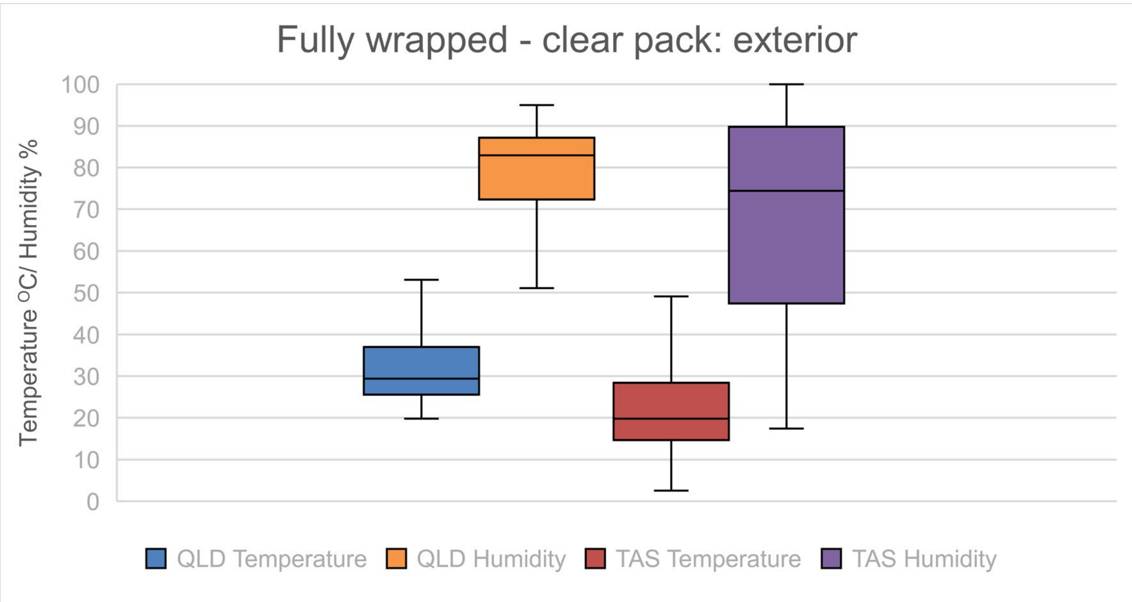


Figure 51 Measured temperature and humidity range: fully wrapped – clear pack in an exterior environment In Queensland and Tasmania

Table 16 Measured data from within a fully wrapped – clear pack in an interior environment

Clear Interior	QLD	TAS
Max Temp (°C) / Date	35.8 / 1/02/22	23.6 / 15/12/21
Min Temp (°C) / Date	18.7 / 3/05/22	12.4 / 24/4/22
Average Temp (°C) / no. included days	25.6 / 120	18 / 146
Max RH (%) / Date	78.2 / 5/05/22	69.8 / 6/5/22
Min RH (%) / Date	59.5 / 5/01/22	52.7 / 15/12/21
Average RH (%) / no. included days	68 / 120	60.6 / 146

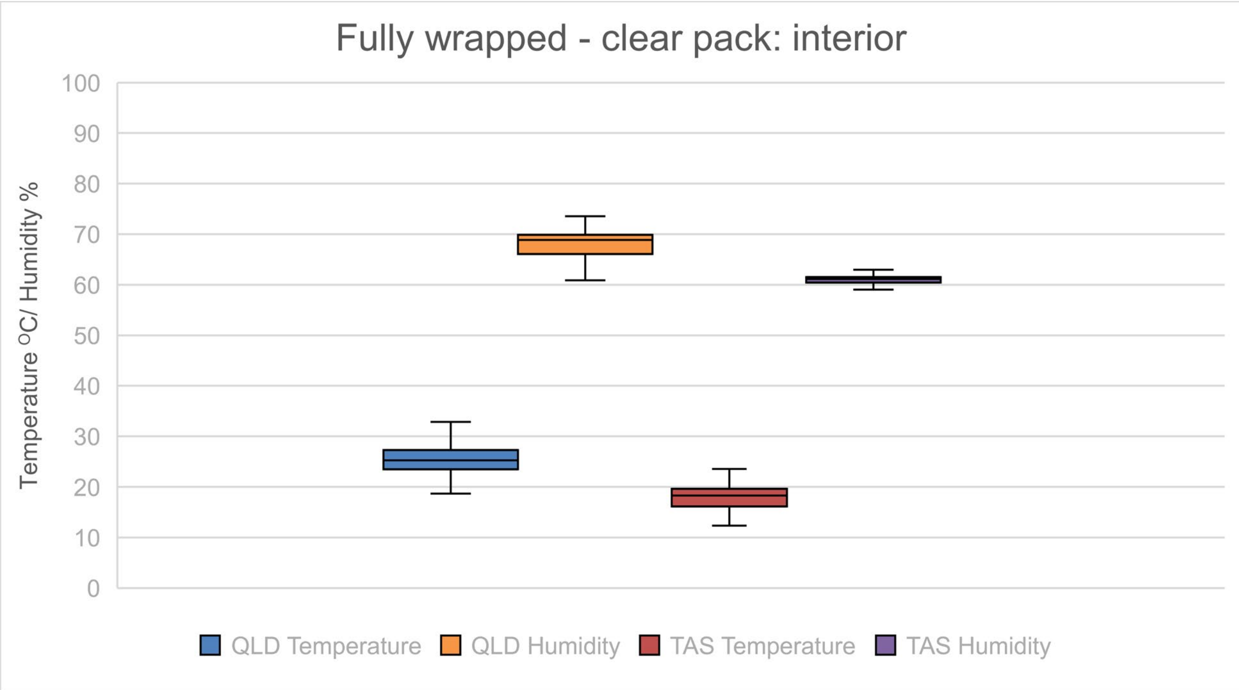


Figure 52 Measured temperature and humidity range: fully wrapped – clear pack in an interior environment In Queensland and Tasmania

The timber's MC response to conditions

Table 17 and Table 18 summarise the average change in MC in packs in CZ7 and CZ2

Table 17 MC change (%) by pack wrapping and location in Tasmania (CZ7)

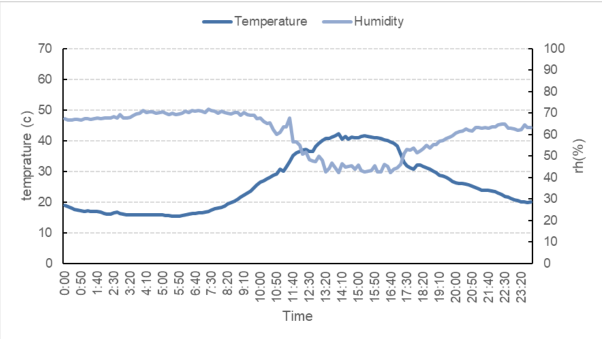
Sample board position in pack	Exterior			Interior	
	Poorly wrapped	Fully wrap - opaque	Fully wrap - clear	Poorly wrapped	Fully wrap - clear
Top middle	8.8	8.7	20.6	-0.2	-0.1
West	2.2	-0.1	-0.7	-0.5	-0.4
Middle	0.3	-0.1	0.0	-0.7	-0.2
East	0.5	1.0	-0.5	-0.3	-0.7
Bottom middle	0.6	0.9	0.1	-0.6	0.0
(average)	(2.5)	(2.1)	(3.9)	(-0.5)	(-0.3)

Table 18 MC change (%) by pack wrapping and location in Queensland (CZ2)

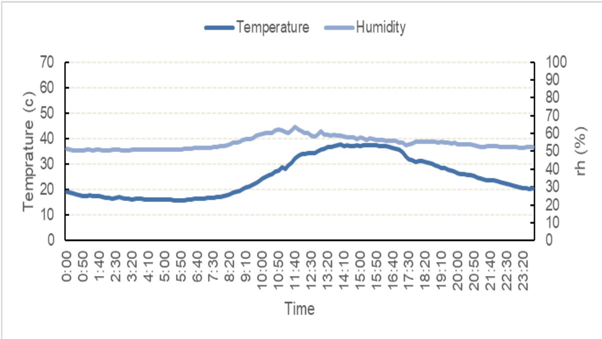
	Exterior	Interior

Sample board position in pack	Poorly wrapped	Fully wrap - opaque	Fully wrap - clear	Poorly wrapped	Fully wrap - clear
Top middle	10.9	26.2	27.7	0.2	-0.3
West	16.3	5.9	8.3	0.2	0.3
Middle	10.9	8.5	9.4	0.4	0.2
East	13.0	7.8	4.4	0.3	0.3
Bottom middle	8.4	4.2	4.5	0.4	0.6
(average)	(11.9)	(10.5)	(10.9)	(0.3)	(0.2)

Both interior sites across CZ7 and CZ2 had minimal change in timber MC after several months of exposure. By comparison there is an obvious increase in risk of unacceptable MC conditions in packs in CZ7 where the MC change was greater 5 % over the trial's duration. Figure 53 re-emphasises the environmental conditions for January 15, 2022 for the poorly and opaque wrapped exterior packs in CZ7.



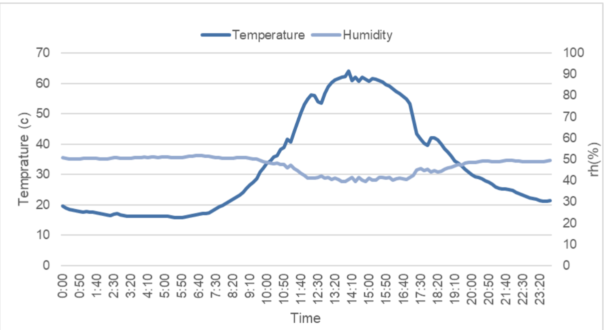
Exterior poorly wrapped CZ7 pack



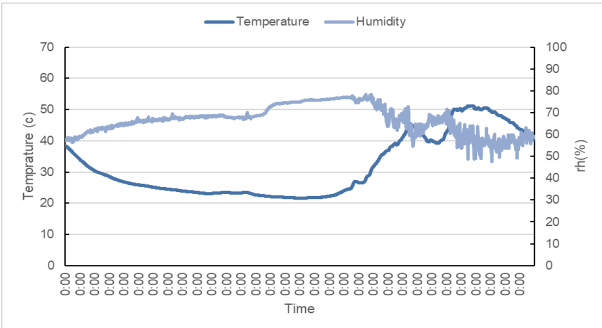
Exterior fully wrapped - opaque CZ7 pack

Figure 53 January 15 condition profiles for packs at high risk

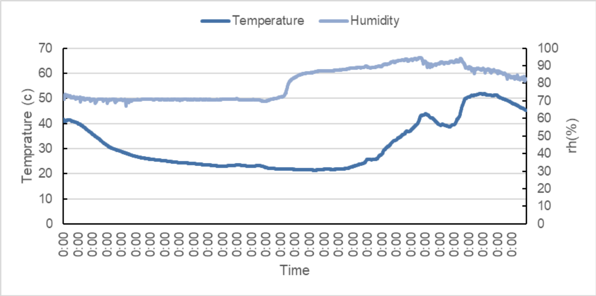
Evident in Figure 54, four packs in this trail where exposed to a very high risk with a measured increase in MC of more than 10 %. The clear wrap in CZ7 and the poorly, opaque and clear wrap in CZ2 all experienced a significant increase in MC over the trial's duration. The MC increase measured in the top middle samples for these four packs was unacceptable, particularly in the fully wrapped packs in CZ2 which increased in MC as high as 27.7 % above their initial MC. Moreover, these packs on January 15, 2022 experienced temperatures under the wrap in excess of 50^{O}C, with the highest reading pack being fully wrapped clear in CZ7.



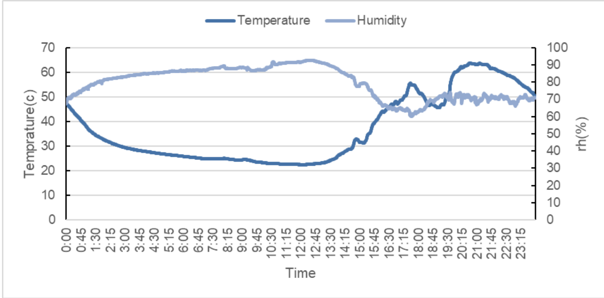
Exterior fully wrapped - clear CZ7 pack



Exterior poorly wrapped CZ2 pack



Exterior fully wrapped - opaque CZ2 pack



Exterior fully wrapped - clear CZ2 pack

Figure 54 January 15 condition profiles for packs at very high risk

Each type of wrapping has its place. For example, clear wrapping allows quick onsite confirmation that the product, colour, specie, dimensions etc is correct at the time of delivery. The downside to clear wrapping as evident in this report is the intense environmental conditions that are present inside the wrapping interior, which has the potential to significantly alter the timbers MC and dimensions. Above all, wrapping is an important part of the timber supply chain and is an essential method for protecting timber. Key to this protection however is the quality of the wrap. While the environmental conditions between an opaque wrap and a poor-quality wrap are similar the effect of exposure to elements such as sunlight or water due to loose, torn or an absence of wrap can damage the exposed timber and physically and visually alter the timber to a state where it is no longer fit-for-purpose or it is no longer compliant with standards. The season in which a timber pack is transported, stored and the duration of time that it is left onsite in wrap will also change the condition of the timber.

Conclusion

This project's objective was to generate and distribute informed industry guidance on best practice for the economic and effective moisture content (MC) control of timber and wood products in the Australian timber supply chain. It aimed to identify regular problems and key influencing factors; build an initial knowledge base of equilibrium moisture content (EMC) conditions and timber's MC performance in the timber supply chain; and generate industry best practice guidance.

This report presented the results of the project's monitoring of timber's MC content in the supply chain under varying wrapping conditions. It establishes useful correlations between observable site conditions, means for protecting wood products in the supply chain and the risk to product serviceability due to its MC behaviour and actual exposure conditions in storage, in transit, and in building under construction and in service across two locations: Tasmania (CZ7) and southern Queensland (CZ2).

Summarised by climate zone, the reports key findings are:

For CZ7 (Tasmania)

- The top layer middle board for each timber pack exposed to an exterior environment suffered the greatest increase in MC. All other samples located in the same pack remained stable.
- Every MC sample stored in an interior environment decreased in MC.
- The absolute temperature and humidity ranges were larger in CZ7 than those recorded in CZ2.
- The coldest temperature recorded in this trail was 2.5 ^{O}C (clear pack exterior).

For CZ2 (Queensland)

- The poorly wrapped exterior timber pack suffered the greatest average change in MC than any other pack in this trial (11.9 %).
- All exterior packs increased on average more than 10 % MC. Unlike the MC samples located in exterior packs in CZ7 which remained stable, all samples located throughout the packs increased in MC by more than 4 %.
- The highest temperature recorded in this trial was 66.4 ^{O}C (clear pack exterior).

Similarities between climate zones.

- All timber packs exposed to an exterior environment increased in average MC.

- All timber packs stored in an interior environment remained stable with minimal change in average MC.
- Both clear wrapped timber packs exposed to an exterior environment had the largest single MC sample change (CZ7 = 20.6 % and CZ2 = 27.7 %). This was in the top layer, middle board.
- The highest temperature recorded was in clear wrapped exterior packs (CZ7 = 65.3^{O}C and CZ2 = 66.4 ^{O}C).

Change in timber MC is inevitable. There are direct relationships between the wood's EMC, species (or product) properties, the ambient temperature and relative humidity of a location. These ambient conditions change constantly in the supply chain at rates moderated by methods of packing and wrapping the products and its protection in shelters. This report has provided evidence that timber in any wrap of varying quality is subject to change in MC. In extreme cases where timber is stored for several months exposed to exterior environmental conditions it is not surprising that such circumstances provoke a change in MC. These changes have the potential to damage timber products and render the material unsatisfactory for building applications that are governed by Australian Standards and recommended fit-for-purpose industry practice. Exterior environmental conditions undeniably provoke greater change in timber MC than stable interior conditions. Moreover, the type and quality of timber wrapping each have an affect on the interior conditions by which timber is protected.

Future research could repeat this work but vary the wrapping type, or extends the exposure periods and other locations. A 12-month trial could determine key seasonal variation and conditions that provoke the greatest change in MC. Future trials could include unwrapped timber packs to determine the importance of wrapping and measure the extreme circumstances of timber fully exposed to ambient environmental conditions both inside and out. Future trails could also include realistic timelines for storage in transit and on site to represent real change in average MC of a variety of products.