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Equilibrium moisture content variations of timbers commonly used in Western Australia

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SUMMARY

An equilibrium moisture content (EMC) survey was undertaken throughout Western Australia over two years. A range of species commonly used in WA was assessed indoors and outdoors (under cover) in locations ranging from the Kimberleys to the south coast. Species assessed at all sites were: jarrah (*Eucalyptus marginata* Donn ex Sm.), karri (*E. diversicolor* F. Muell.), Tasmanian blue gum (*E. globulus* Labill. ssp. *globulus*), radiata pine (*Pinus radiata* D. Don) and Douglas fir (*Pseudotsuga menziesii* Mirb.). Additional species were assessed at Como and Harvey. EMC curves for the different species closely follow the EMC curves based on ambient conditions, indicating the sensitivity of timber to changes in ambient conditions. Mean EMCs of the five species exposed to indoor conditions were lower than the EMCs for outside conditions at a given location, except at Karratha where the indoor EMC was 0.3 per cent higher. An EMC map dividing WA into three zones is provided for the timber exposed to outdoor conditions. Models developed to predict EMC from meteorological data indicated that evaporation, rainfall, relative humidity (RH) and temperature are strongly related to EMC, with RH highly significant at predicting EMC. Data on the rates of moisture absorption of specimens exposed to outdoor and indoor conditions for eight weeks are given. Seasonal variations occur in the moisture content of timber in normal use as furniture and panelling and this is accompanied by an approximately proportional change in dimension. Furniture should be designed to allow some movement owing to shrinkage and expansion of timber components.

INTRODUCTION

The performance of wood as a raw material is largely influenced by its moisture content. Wood is hygroscopic, therefore its moisture content is subject to continuous changes with varying atmospheric conditions. Such moisture content changes are associated with dimensional changes when moisture content is below the fibre saturation point (f.s.p.), i.e. when moisture is added to or lost from the cell walls (Tsoumis 1964). The bound water in wood is in equilibrium with the relative humidity (RH) of the surrounding air, at equilibrium moisture content (EMC). Moisture in wood can exist in two forms; bound or hygroscopic water, and free or capillary water (Haygreen and Bowyer 1982).

The properties of wood are influenced by the presence of water. The moisture content is very high in living trees or freshly felled wood, varying typically from 60 to 200 per cent (Richardson 1993). The green moisture content tends to vary inversely with the normal air-dry density of a timber species, i.e. high density species have low green moisture contents and low density species have high green moisture contents. During drying, free moisture is first lost from the cell spaces and this involves little change in properties except loss of weight. The loss of bound water from the cell walls reduces the separation between adjacent cellulose chains and causes shrinkage as well as progressive changes in physical properties. The amount of bound water is approximately proportional to the relative humidity of the atmosphere, although changes in moisture content lag behind changes in relative humidity, a phenomenon known as 'hysteresis' (Richardson 1993). Changes in relative humidity result in moisture fluctuations, which cause swelling or shrinkage.

The amount of water held by wood cells is dependent not only on the equilibrium relative vapour pressure, but also on the direction from which equilibrium is approached. This phenomenon is known as 'sorptive hysteresis' (Stamm 1967) and the amount of water absorbed from the dry condition is always less than the amount retained on desorption at a fixed relative vapour pressure. When timber takes up moisture it generally assumes lower EMC than when it loses moisture to the air. Koponen (1985) claimed that EMC in absorption may be approximately 80 per cent of the value in desorption.

As the atmospheric conditions in any one place vary from day to day and season to season, the moisture content of timber will be constantly changing, even in a sheltered position, but at a much slower rate than the atmospheric conditions. Wood used where humidity fluctuates will continually change in moisture content, and therefore dimensions (Haygreen and Bowyer 1982).

Ambient temperature change has very little effect on the moisture content of wood, the main factor causing such changes is variation in relative humidity (Van Wyk 1963). For example, at a constant RH of 80 per cent and temperature changes of 10°C, 20°C and 25°C, the EMCs are 16.4, 16.2 and 16.0 per cent respectively. On the other hand, at 20°C and RH of 50, 70 and 90 per cent, the EMCs are 9.2, 13.3 and 20.3 per cent respectively. Chafe (1991) stated that EMC is determined primarily by the RH of the ambient environment, but it also depends on species of wood, specific density and other wood properties, extractive content of the wood, previous drying history of wood and hysteresis.

Problems can arise when timber is used in widely varying humidity and temperature conditions, if the design and application of that product have not anticipated changes in dimension. For satisfactory performance of timber in-service, it is essential to use timber with moisture contents close to the EMC in use. Shrinkage can result in checking and warping of timber, and swelling in humid conditions can result in jammed doors and windows, and buckled table tops.

Many EMC trials have been conducted in different countries around the world, e.g. Europe (Tsoumis 1964), South Africa (Hartwig 1959; Van Wyk 1957, 1963), Malawi (Howland and Matabwa 1971), Fiji (Gough 1977), United Kingdom (Anon. 1929), New Zealand (Orman 1955), Canada (Canada Department of Resources and Development 1952), United States (Higgins 1957; Bois 1959; United States Department of Agriculture 1973), and Australia and New Guinea (Finighan 1966). Other Australian studies were in NSW (Welsh 1936; Ellwood and Leslie 1949) and Queensland (Bragg 1986).

This paper presents results of an EMC survey undertaken throughout Western Australia (WA) over two years. A range of species commonly used in WA was assessed indoors and outdoors (under cover) in locations ranging from the Kimberleys, in the north, to the south coast. The aim of this trial was to collect information on moisture contents of timbers used in different areas of WA, which could assist timber suppliers to provide products suitable for specific areas.

MATERIALS AND METHODS

Exposure sites and timber species

The following geographic areas of WA were selected.

North to South: Kununurra, Broome, Karratha, Geraldton, Perth (Como), Harvey, Busselton, Manjimup and Walpole.

West to East: Narrogin, Kalgoorlie and Esperance.

These locations were selected because district or regional offices of the Department of Conservation and Land Management (CALM) were situated there and had staff and facilities to conduct this trial.

Species assessed at all sites were:

Jarrah (*Eucalyptus marginata* Donn ex Sm.)
Karri (*E. diversicolor* F. Muell.)
Tasmanian blue gum (*E. globulus* Labill. ssp. *globulus*) - WA grown
Radiata pine (*Pinus radiata* D. Don)
Douglas fir (*Pseudotsuga menziesii* Mirb.)

At Como and Harvey additional species were assessed.

Como:

Redwood (*E. transcontinentalis* Maiden)
Dark red meranti (*Shorea pauciflora* King)
Maritime pine (*Pinus pinaster* Ait.)

Harvey:

Marri (*E. calophylla* R.Br. ex Lindl.)
Tuart (*E. gomphocephala* DC.)
Tasmanian oak (*E. delegatensis* R.T. Bak.)
Gimlet (*E. salubris* F. Muell.)
Redwood
Wandoo (*E. wandoo* Blakely)
Mulga (*Acacia aneura* F. Muell. ex Benth.)
WA sheoak (*Allocasuarina fraseriana* (Miq.) L. Johnson)
Dark red meranti
Maritime pine
Western red cedar (*Thuja plicata* D. Don)
Nyatoh (*Payena* spp.)

At each site, moisture content was monitored in three replicates of each timber species by weighing specimens at the beginning of each month. A particular set of replicates at each site was cut from the one sample board. Specimens were randomly allocated to exposure sites.

Sample Board Preparation

Specimens from backsawn boards 750 x 100 x 30 mm cut from the outer heartwood of the log and free of sapwood were assessed for basic density, dried to 12 per cent moisture content then assessed for air-dry density. Tasmanian blue gum, Douglas fir, tuart, Tasmanian oak, wandoo, dark red meranti, western red cedar and nyatoh were assessed only for air-dry density because only dry sample boards were available. Boards were dressed to 20 mm, then three replicates 200 x 80 x 20 mm were cut from each board. A hole was drilled in one end of each specimen and a cup hook inserted. Both ends were end-sealed with two coats of enamel paint to prevent excessive rates of moisture exchange through the end grain.

The trial excluded comparisons between different timber thicknesses, quartersawn and backsawn material, planed and unplaned, and different surface coatings. Previous studies have shown that for material up to 30 mm thick, the moisture changes are independent of thickness, but above 30 mm the rate of moisture content change decreases very rapidly with increase in thickness, although they reach practically the same maximum and minimum values as that of the thinner material (Anon. 1929; Orman 1955). The moisture changes of quartersawn material occur more slowly than those of backsawn material (Anon. 1929), but the difference in final EMC, for practical purposes, is insignificant. The moisture differences that occurred in samples with rough-sawn and planed surfaces appear to be of little practical significance (Anon. 1929; Hartwig 1959). In any case, comparison is difficult because the dressed size is thinner than the rough-sawn size. Paints, varnishes and other types of coatings assist in retarding moisture changes, and in lessening the range of variation. These substances are not impervious to water, and if the relative humidity changes, the wood in time will adsorb sufficient water vapour to establish a new EMC. Although several coatings are known to be highly effective, no entirely moisture-proof coating will prevent moisture fluctuations but the changes will not be excessive in either direction (Cassens and Feist 1991), therefore the effect of coatings was not examined in this trial.

Field Placement

Specimens used outdoors were suspended by cup hooks in situations that were protected from the weather but offered unrestricted air-flow, e.g. under verandas or in open sheds. Indoor specimens were also suspended by cup hooks in air conditioned or heated offices. Specimens were weighed to an accuracy of 0.1 g on the first working day of each month for a period of two years, although some locations did not provide full data.

Meteorological Data

Meteorological data for the duration of the study, including monthly rainfall, 12.00 noon (Western Standard Time) temperature and RH and evaporation figures (if possible) were obtained for each site from CALM district offices or Bureau of Meteorology records. Indoor conditions of temperature and RH, and the duration of air-conditioning or heating were obtained from district offices. No indoor temperature and RH data are available for Busselton and Walpole. EMCs based on meteorological data were calculated using an equation given in Simpson (1971).

Regression analysis was used to relate 12.00 noon temperatures and relative humidities to meteorological readings, for the two-year study period taken at 9.00 a.m. and 3.00 p.m., for Manjimup, Narrogin, Esperance, Perth and Kalgoorlie. The other centres were excluded because of limited 12.00 noon data, e.g. Broome and Kununurra, or no meteorological data, e.g. Harvey (Wokalup) had only 9.00 a.m. readings and the nearest meteorological station to Karratha is 20 km away at Dampier and considered unrepresentative.

Determination of Moisture Content

A 30 x 30 x 100 mm piece was cut from the end of each sample and oven-dried to determine moisture content. The mass of the residual piece was then recorded and the subsequent changes in mass over the trial period were compared with the initial weight (measured at the time of assessing initial moisture content) at a known moisture content, and used to predict moisture content variation. At the completion of two years assessment, specimens were returned to the Wood Utilisation Research Centre (WURC) in Harvey, where the whole specimen was oven-dried. For the denser species up to two weeks drying was required to achieve a stable mass. The oven-dry mass and monthly weighing for each specimen allowed the exact determination of moisture content at each assessment. These moisture contents were compared with those determined during the trial, based on the moisture content of the 30 x 30 x 100 mm section. Moisture contents determined by oven-drying the whole sample (actual EMC) were compared with those determined by weight change (estimated EMC) and meteorological readings (EMC formula calculated from Simpson's (1971) equation) over the two-year study period. EMC based on oven-drying the whole specimen is the most accurate and is used throughout this report, except for the EMC map referred to below.

EMC Map

An EMC map was developed by CALM's Land Information Branch. The equation developed by Simpson (1971) and the 9.00 a.m. long term mean annual temperature and RH for approximately 160 stations in WA were used to calculate mean annual EMCs for each location. Long term meteorological data were taken from 'Climatic averages - Australia' (Bureau of Meteorology 1988). Relative humidity records at 9.00 a.m. were used as they are often taken as an estimate of the mean for the 24-hour period, and 9.00 a.m. temperatures were used because they had a strong correlation with the 12.00 noon temperatures recorded throughout the survey. Owing to the difference between the EMCs of the wood samples and the EMCs based on meteorological records, e.g. Kalgoorlie had a mean wood EMC for the combined species of 5.9 per cent compared with an EMC of 10.3 per cent based on long term 9.00 a.m. readings of RH and temperature. The respective values for Geraldton were 11.7 per cent and 9.2 per cent. The equation :

$$EMC = 1.137EMC_{9am} - 3.41 \quad r^2 = 0.7$$

was used to predict the mean EMCs of the combined species for each meteorological station, using EMC data calculated from mean long term 9.00 a.m. RHs and temperatures. EMCs determined by this equation were then plotted onto a map of WA and lines of best fit were drawn to separate the State into three EMC zones:

Zone 1 - greater than 12 per cent
Zone 2 - 10 per cent to 12 per cent
Zone 3 - less than 10 per cent

The long term climatic averages were used because the survey was over only a two-year period, and long term averages give a better indication of the atmospheric conditions experienced at the different sites. For example, over the study period some locations had weather conditions that were different from the long term averages: Kalgoorlie had an exceptionally wet period in autumn 1992, with a rainfall of 64 mm above the long term average.

Absorption Rates

The current moisture contents of exposed timber depends on actual and past moisture and temperature and humidity conditions. Moisture-sensitive species would depend on conditions of the very recent past, probably restricted to the few preceding weeks, while less reactive species would be better related to conditions for some preceding months. To determine the absorption rates of different species, samples assessed at Harvey were oven-dried after the EMC survey and exposed indoors and outdoors at Harvey in October and November 1993. Samples were weighed weekly to determine moisture uptakes and ambient temperatures, and RHs were recorded daily at 12.00 noon.

RESULTS AND DISCUSSION

Effect of Density

Mean basic and air-dry densities of specimens assessed at all sites are listed in Table 1 and densities of the additional specimens assessed at Como and Harvey are listed in Table 2. Standard deviations and ranges indicated a large variation in basic and air-dry densities, which is consistent with the results given by Kingston and Risdon (1961) and Bootle (1983), and considered representative of these timber species.

TABLE 1

Basic and air-dry densities of samples assessed at all sites.

SPECIES	BASIC DENSITY			AIR-DRY DENSITY[b]			SAMPLE SIZE
	Mean	S.D.	Range	Mean	S.D.	Range	
Jarrah	647.2 (658)[a]	22.2	602.1-682.3	840.5 (823)[a]	34.7	774.7-901.6	24
Karri	732.5 (695)[a]	18.9	676.3-756.0	967 (905)[a]	26.1	908.6-1003.5	25
Douglas fir	- (372)[a]	-	-	531.7 (449)[a]	41.8	465.4-642.5	24
Radiata pine[c]	435.7 (485)[a]	34.9	377.8-523.8	520 (593)[a]	33.1	467.5-599.7	25
Tasmanian blue gum[c]	- (561)[a]	29.7	484-634	813.0 (790)[a]	24.4	768.6-867.1	24

[a] Figures are the species average given by Kingston and Risdon (1961).
[b] Air-dry densities are before reconditioning.
[c] Specimens for Douglas fir and Tasmanian blue gum were obtained from dry timber, therefore basic densities were not measured.

TABLE 2

Basic and air-dry densities of additional samples assessed at Harvey and Como.

SPECIES	BASIC DENSITY			AIR-DRY DENSITY[b]			SAMPLE SIZE
	Mean	S.D.	Range	Mean	S.D.	Range	
Marri	582.0 (663)[a]	2.7	579.8 - 585.1	748.0 (855)[a]	3.3	745.7 - 751.8	3
Tuart	895.2 (836)[a]	-	-	1081.6 (1030)[d]	10.6	1092.3-1071.0	2
Tasmanian oak[e]	(511)[a]			770.1 (663)[a]	9.5	759.1 - 775.1	3
Gimlet	948.9 (897)[a]	17.9	936.3 - 961.6	1190.1 (1099)[a]	8.3	1184.2-1196.0	2
Redwood[c]	958.2	27.1	934.5 - 997.0	1146.9	20.6	1127.9-1166.6	4
Wandoo	856.1 (921)[a]	-	-	1094.4 (1099)[a]	0.4	1094.8-1093.9	2
Mulga	990.6	13.6	981.0-1000.2	1166.3 (1100)[d]	5.0	1162.8-1170	2
WA Sheoak	610.9 (622)[a]	17.6	598.5 - 623.3	718.0 (734)[a]	20.6	703.5 - 732.6	2
Dark red meranti[ce]				798.0 (680)[d]	0.7	797.3 - 798.7	2
Maritime pine[c]	454.2 (490)[a]	25.4	426.3 - 487.4	573.0 (596)[a]	24.0	550.6 - 606.4	4
Western red cedar[e]				351.1 (350)[d]	2.2	349.2 - 353.5	3
Nyatoh[e]				777.3 (650)[d]	181	574.9 - 923.7	3

[a] Figures are the species averages given by Kingston and Risdon (1961).
[b] Air-dry densities are before reconditioning.
[c] Assessed at both Harvey and Como.
[d] Figures given by Bootle (1983).
[e] Specimens for Tasmanian oak, dark red meranti, western red cedar and nyatoh were obtained from dry timber, therefore basic densities were not measured.

Bootle (1983) referred to an inverse relationship between the EMC and the density of a timber. That is, the lower the density, the higher the EMC and the faster the rate of moisture exchange. However, low density timbers have an appreciably lower movement (shrinkage or swelling) per 1 per cent change in moisture content. This advantage over the dense timbers tends to be counterbalanced by their greater short-term susceptibility to large moisture content movement through greater sensitivity to humidity variations.

Features of Certain Locations

Certain features of some locations have affected the results and need clarification. Kalgoorlie had an exceptionally wet period in Autumn 1992, with rainfall 64 mm above the long term average, giving above average EMCs for that period. The Walpole indoor specimens were located above a slow-combustion fire within the district office, approximately 4 m from a major doorway, which was regularly opened and closed on working days. This presumably would have caused moist air from the outside to enter into the office and affect the EMCs of the indoor specimens. No air-conditioning was used in the Walpole district office during the summer. The indoor specimens at Narrogin were located in a small office attached to a large nursery shed, with no air-conditioning or heating. The door was constantly opened and closed on working days, resulting in conditions similar to outdoor ambient conditions. Indoor specimens assessed at Harvey were stored in a large enclosed wood-processing shed, and although the shed is partly insulated, no air-conditioning or heating was used, thus causing conditions to fluctuate with outside ambient conditions.

EMC Survey

Tables 3 and 4 list the mean monthly EMCs of specimens assessed outdoors and indoors at all sites throughout WA over a two-year period, and indicate the likely maximum and minimum EMCs that can occur. Monthly fluctuations in the EMCs of specimens and EMCs based on ambient conditions can be seen in Figures 1 and 2. Results for Broome and Kununurra are based on only eight months of data, making graphical representation difficult, but mean EMCs are presented in Table 3. EMC curves based on ambient conditions for Busselton are from Bureau of Meteorology records of yearly conditions (RH at 9.00 a.m. and the average of daily maximum and minimum temperature). No EMC curves based on ambient conditions are available for the indoor sites of Busselton and Walpole. The Esperance indoor EMC based on ambient conditions indicated a much higher than expected EMC, with conditions similar to outdoor EMCs in sub-tropical areas. For example, Brisbane has an outdoor EMC of 14 per cent (Bragg 1986).

Results for Broome and Kununurra are based on an eight-month assessment, with Broome having measurements in March, April, July, August, September, October (1991), December (1992) and January (1993). Kununurra had measurements in February, September, October, November, December (1991) and January, October and November (1992), which are spring/summer months, giving a biased overall mean EMC. Measurements for Broome are taken over all seasons and give a better indication of the mean EMC. Staff restrictions at these two locations affected the data collection over the two-year period. Broome had a combined species EMC of 10.4 per cent and an EMC of 10 per cent based on the 9.00 a.m. long term RH and temperature. Broome and Kununurra have similar climates, but the combined species EMC for Kununurra was 5.2 per cent and is lower than the EMC of 8.3 per cent based on the 9.00 a.m. long term RH and temperatures. It is difficult to recommend an EMC for Kununurra, based on results from this trial, because of no field data in autumn/winter, but an EMC based on long term meteorological records of 8.5 per cent can be predicted. An EMC based on the wood samples of 10.4 per cent can be predicted for Broome because data were available for all seasons. Adjustments were made using a regression equation to these two EMCs for developing the EMC map. Owing to the limited field data, these two locations were excluded from the statistical analysis.

Moisture Content Fluctuations

Figure 1 shows the mean outdoor and indoor EMCs of five species assessed at ten sites and EMCs based on ambient conditions averaged over a two-year period. Figure 2 shows the outdoor and indoor EMCs of the additional species assessed at Harvey and Como. No graphs are given for Broome and Kununurra owing to limited monthly data, and no EMC curves based on 12.00 noon RH and temperature data are given for Busselton and Walpole indoor sites as data are unavailable. Table 3 lists the mean EMCs, range and standard deviation of specimens assessed at all sites and Table 4 lists the EMCs of the additional specimens assessed at Harvey and Como. Fluctuations in EMC with changes in ambient conditions can be clearly seen, and these are discussed below.

Outdoor EMC

The EMC curves of the different species in most cases closely follow the EMC curves based on ambient conditions, indicating clearly how sensitive timber is to changes in the ambient conditions of the surroundings. In general, the EMCs of the wood specimens were similar to the EMCs calculated from 12.00 noon RH and temperature readings, but Busselton data indicated wood EMCs 2 to 3 per cent below the EMCs based on ambient conditions. EMCs in the south-west locations showed the greatest seasonal fluctuation, for example, Manjimup had summer EMCs from 10 to 13 per cent and winter EMCs from 16 to 19 per cent, and Perth (Como) 8 to 10 per cent (summer) and 11 to 14 per cent (winter).

Karratha and Kalgoorlie had mean EMCs for all species of 5.8 and 5.9 per cent respectively, which is approximately 4.3 per cent lower than the next highest

TABLE 3

EMCs of samples assessed at all sites throughout WA (outdoors and indoors) over a two-year period.

SITE	JARRAH			KARRI			RADIATA PINE			DOUGLAS FIR			TASMANIAN BLUE GUM			COMBINED SPECIES		
OUTDOOORS	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
Kununurra (8)	4.8	2.2-8.6	1.6	4.8	2.4-11.4	2.7	6.0	2.2-15.1	3.2	5.6	1.8-14.8	3.5	4.5	2.2-11.8	2.1	5.2	1.8-15.1	2.7
Broome (8)	11.4	9.2-12.8	1.0	10.9	9.4-12.0	0.8	9.2	5.6-11.5	1.7	10.6	8.1-12.3	1.2	9.8	8.0-11.3	1.0	10.4	5.6-12.8	1.4
Karratha (22)	6.4	4.1-9.3	1.2	5.6	3.9-8.1	1.1	6.3	2.9-11.5	2.0	5.6	2.8-9.6	1.5	5.3	3.2-7.7	1.1	5.8	2.8-11.5	1.5
Geraldton (17)	11.8	9.6-13.2	0.8	12.4	11.3-13.4	0.6	12.3	8.6-14.2	1.3	11.4	8.9-12.9	1.0	10.6	8.8-12.5	0.7	11.7	8.6-14.2	1.1
Perth (24)	11.8	8.6-15.0	1.9	10.5	7.6-13.1	1.5	10.7	6.6-14.6	2.4	9.5	5.9-13.2	1.9	9.4	7.1-12.5	1.6	10.6	5.7-15	2.1
Harvey (27)	13.4	10.1-17.7	2.5	13.2	10.6-16.8	2.1	12.3	5.1-20.6	3.6	10.7	5.0-16.1	3.3	10.3	5.2-16.7	3.9	12.0	5.0-20.6	3.4
Busselton (26)	10.9	6.4-14.7	2.2	10.3	7.0-13.4	1.7	10.9	5.6-17.8	2.9	9.0	3.8-13.6	2.3	9.5	5.6-13.8	2.3	10.1	3.8-17.8	2.4
Manjimup (20)	14.9	10.2-18.3	2.1	15.2	12.5-17.9	1.7	14.7	7.7-19.8	2.8	12.9	8.8-16.9	2.2	14.0	9.2-17.8	2.4	14.4	7.7-19.8	2.4
Walpole (24)	15.4	13.1-17.8	1.2	15.2	11.9-17.6	1.2	15.0	12.0-18.2	1.7	12.4	10.3-14.6	1.2	13.1	10.8-15.2	1.1	14.2	10.3-18.2	1.8
Narrogin (23)	13.0	9.6-17.6	2.4	11.8	8.9-15.4	2.0	12.2	7.3-18.3	3.2	10.8	7.1-15.3	2.4	10.6	7.2-15.0	2.4	11.7	7.1-18.3	2.7
Esperance (24)	11.0	8.6-12.6	0.9	10.3	8.8-11.5	0.6	11.0	8.2-13.4	1.3	8.9	6.3-10.7	1.0	9.1	6.6-10.6	0.9	10.1	6.3-13.4	1.3
Kalgoorlie (26)	6.2	3.4-9.6	2.0	5.9	4.2-8.4	1.4	6.6	1.4-11.8	2.9	5.4	1.9-9.7	2.3	5.4	2.9-8.6	1.8	5.9	1.4-11.8	2.2
INDOORS																		
Kununurra (7)	6.3	4.1-9.6	1.4	4.9	2.6-9.5	1.7	7.4	3.7-10.8	1.9	6.7	2.9-11.5	2.1	4.7	2.5-6.2	1.0	6.0	2.5-11.5	1.9
Broome (8)	11.4	9.3-12.7	1.1	11.3	10.2-12.1	0.6	9.3	6.0-11.2	1.7	10.6	8.2-12.0	1.2	9.5	7.8-10.6	0.9	10.4	6.0-12.7	1.4
Karratha (22)	6.9	5.5-7.9	0.7	5.9	4.7-8.1	0.8	7.1	4.5-8.8	0.9	5.6	3.9-7.2	0.8	5.0	3.9-6.0	0.6	6.1	4.0-8.6	1.1
Geraldton (17)	10.5	9.4-11.2	0.4	10.2	9.3-11.5	0.5	10.1	8.1-11.2	0.7	8.4	6.7-9.4	0.6	8.2	7.3-8.7	0.3	9.5	6.7-11.5	1.1
Perth (25)	10.3	8.7-11.7	0.7	10.6	8.7-12.0	0.8	9.7	7.5-11.6	1.0	10.3	7.7-12.1	1.1	8.8	7.4-10.0	0.7	10.3	7.4-13.3	1.2
Harvey (27)	11.8	10.0-13.7	0.9	11.5	10.1-13.0	0.7	10.8	5.5-13.0	1.5	8.7	5.1-11.2	3.3	8.4	5.1-10.9	2.1	10.2	5.1-13.7	2.1
Busselton (26)	9.6	7.3-12.0	1.0	9.2	7.5-10.4	0.7	9.5	5.6-12.6	1.3	7.8	4.8-10.2	1	8.2	6-10.8	1.1	8.8	4.8-12.6	1.3
Manjimup (20)	11.2	10.1-11.9	0.4	11.9	11.2-12.4	0.3	10.9	9.9-12.0	0.5	9.7	8.6-10.6	0.5	8.4	6.6-9.0	0.4	10.4	6.6-12.4	1.3
Walpole (24)	13.9	11.4-18.0	1.5	12.3	10.0-14.9	1.1	11.4	8.3-16.1	1.8	10.2	7.7-14.1	1.5	11.1	9.1-14.1	1.2	11.8	7.7-17.6	1.9
Narrogin (23)	12.6	9.3-16.5	2.3	11.4	9.0-14.1	1.6	10.9	6.4-15.6	2.7	9.9	6.5-13.7	2.2	9.7	6.5-13.6	2.2	10.9	6.4-16.5	2.5
Esperance (24)	9.4	7.8-11.1	0.7	8.8	7.3-10.1	0.6	9.0	7.1-10.9	0.9	8.3	6.9-10.0	0.7	7.2	5.7-8.5	0.6	8.6	5.7-11.1	1.0
Kalgoorlie (26)	6.0	5.1-7.4	0.5	5.5	4.8-6.7	0.5	6.2	5.0-7.9	0.7	5.7	4.8-7.0	0.6	4.6	3.8-5.8	0.5	5.6	3.8-7.9	0.8

Notes: Number of months assessed are given in parentheses.
The mean EMCs (outdoor and indoor) for Kununurra are lower than expected as only spring/summer months were assessed.

TABLE 4
EMCs of additional wood samples assessed at Harvey and Como (outdoors and indoors) over a two-year period.

SPECIES	OUTDOORS Mean	OUTDOORS S.D.	OUTDOORS Range	INDOORS Mean	INDOORS S.D.	INDOORS Range
HARVEY (27)[a]						
Marri	14.1	2.4	10.5-19.6	11.4	0.9	9.7-13.1
Tuart	13.3	1.5	11.1-15.7	12.8	0.7	11.4-14.1
Tasmanian oak	12.8	1.6	10.3-15.6	12.0	0.7	10.4-13.4
Gimlet	14.5	2.0	11.0-18.0	14.6	0.8	12.9-16.9
Redwood	14.3	1.9	11.8-18.0	12.9	1.0	11.1-15.6
Wandoo	12.4	1.5	10.5-15.1	11.9	0.6	10.6-13.7
Mulga	12.4	1.6	10.2-15.4	11.1	0.7	9.6-12.4
WA sheoak	12.5	2.0	9.5-15.8	11.4	0.8	9.8-12.6
Dark red meranti	12.7	2.1	9.6-16.2	11.4	0.8	9.8-13.2
Maritime pine	12.2	3.7	5.1-19.6	10.3	1.8	5.3-13.3
Western red cedar	9.1	3.0	5.0-14.1	6.8	1.0	5.0-8.0
Nyatoh	11.6	2.8	5.3-16.0	10.1	1.3	5.6-11.5
Combined	13.0	2.6	5.0-19.6	11.6	2.1	5.0-16.9
COMO (24)[a]						
Redwood	11.8	1.6	9.0-14.4	12.0	0.8	10.3-13.3
Dark red meranti	11.2	1.6	8.3-13.8	10.8	0.7	9.3-12.0
Maritime pine	9.5	2.3	5.7-13.8	9.8	0.9	7.7-11.6
Combined	10.8	2.1	5.7-14.4	10.9	1.2	7.7-13.3

[a] Number of months assessed are given in parentheses

EMC (Busselton and Esperance) and 8.6 per cent lower than the EMC for Manjimup. Kalgoorlie had exceptionally high rainfall in March, April, May and June 1992, with 3.5 times the average for those months, giving a higher EMC than the expected long term figure. In comparison, Lamond and Hartley (1991) reported that in the very dry western areas of New South Wales, such as Broken Hill, timber will dry down to approximately 7 per cent moisture content during summer. Bragg (1986) found a mean EMC of 14 per cent for coastal areas of Queensland and Lamond and Hartley (1991) reported EMCs for coastal areas of New South Wales between 12 and 15 per cent. The coastal town of Karratha has ambient conditions of mean yearly 9.00 a.m. RH and temperature of 45 per cent and 26.3°C (EMC 8.2 per cent) indicating dry conditions and low EMCs. CALM staff describe climatic conditions for Karratha as similar to those in drier inland areas of WA. For example, the inland town of Kalgoorlie has a mean yearly 9.00 a.m. RH and temperature of 56 per cent and 18.3 °C respectively, giving an EMC of 10.3 per cent.

Busselton, Esperance and Geraldton, and Perth (Como) and Harvey had similar EMCs for the combined species, ranging from 10.1 per cent to 11.7 per cent (Table 3). Busselton, Esperance and Geraldton are located on the coast, whereas Como is 15 km and Harvey 20 km inland. The combined species mean EMC for Como is 10.6 per cent and Harvey 12.0 per cent. Como has a mean annual rainfall of 756 mm, whereas Harvey is on the edge of the Darling Scarp, surrounded by forest, with a higher rainfall (mean annual rainfall of 996 mm) and twelve more raindays per year, giving a slightly higher EMC for Harvey. Busselton and Esperance have slightly lower EMCs than Como, Harvey and Geraldton. The annual EMC for Busselton, based on ambient conditions from Bureau of Meteorology records, is approximately 2 per cent higher than the specimen EMCs, indicating that the conditions in which the specimens were stored had a lower humidity.

The EMC based on long term meteorological data for Esperance is 13.4 per cent, 3.3 per cent greater than the combined specimen EMC and the EMC based on the 12.00 noon RH and temperature figures supplied by CALM staff, indicating that the location of the specimens under a sheltered verandah is at a lower EMC. Manjimup and Walpole's EMCs are similar and the highest recorded in this trial. High mean annual rainfalls (between 1000 and 1040 mm), a large number of raindays (156 and 186 respectively) and high humidities (mean 9.00 a.m. RH of 75 per cent) would result in high EMCs.

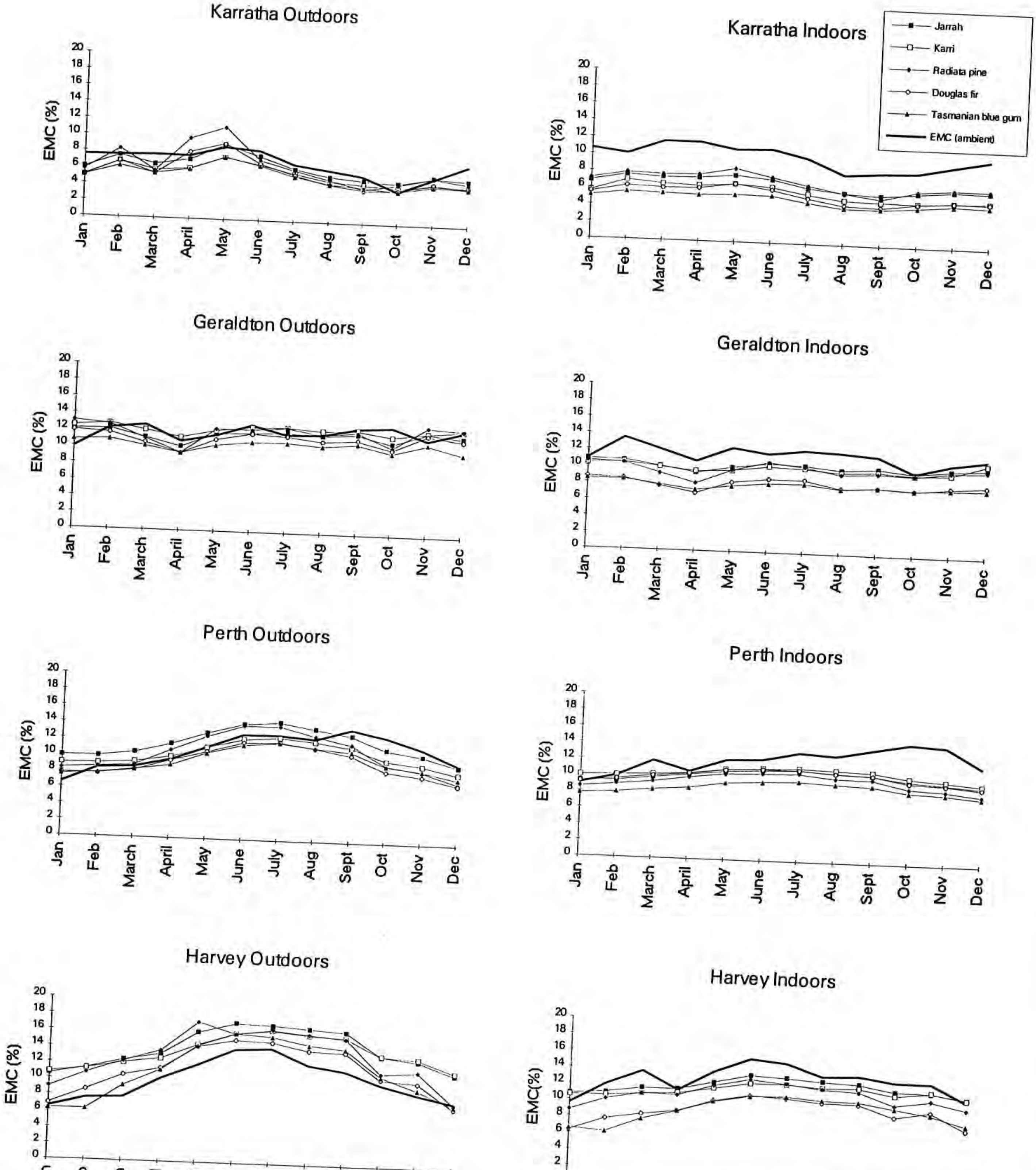

Figure 1. Mean outdoor and indoor EMCs of five species assessed at ten sites and EMCs based on ambient conditions averaged over a two-year period.

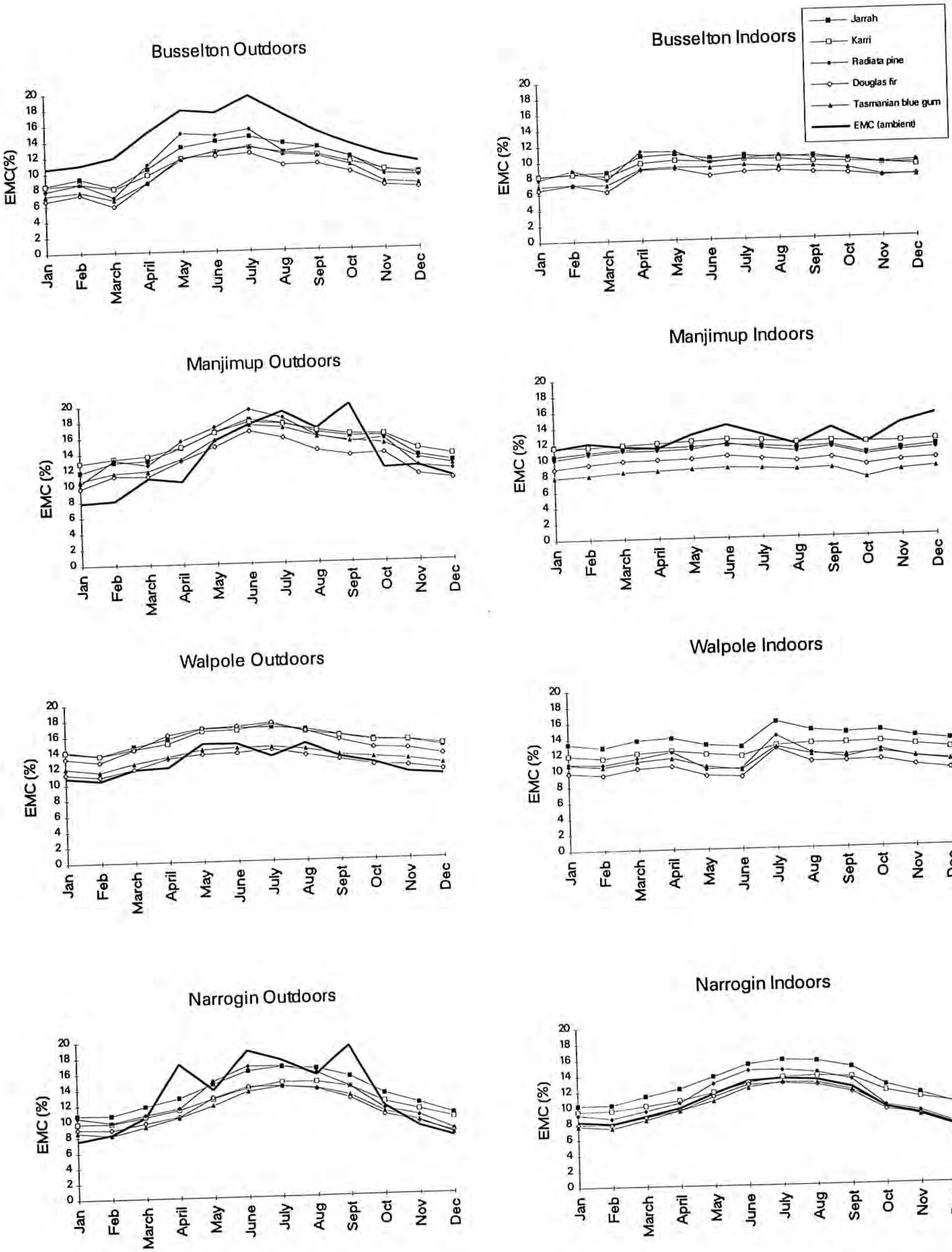

Figure 1 (continued)

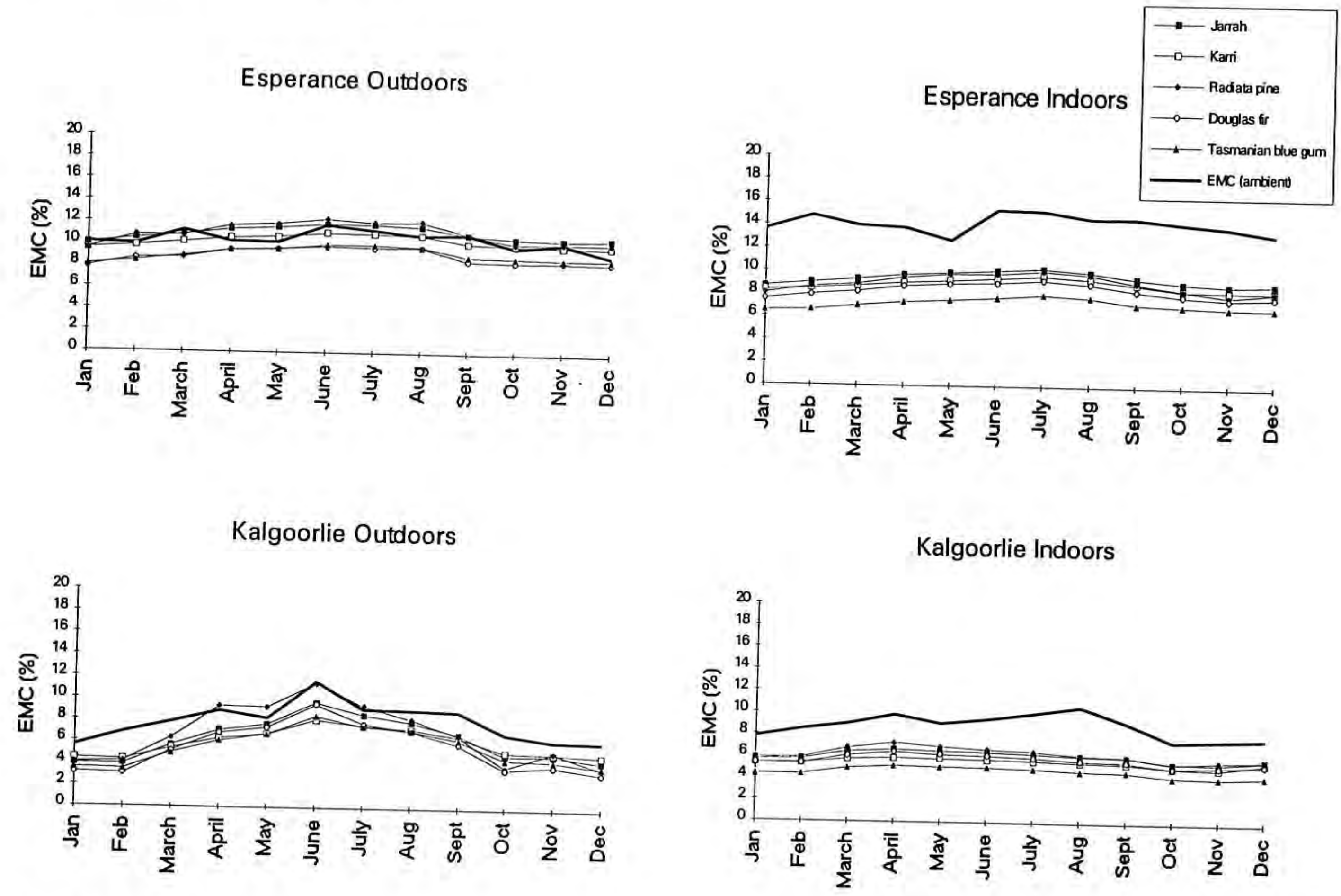

Figure 1 (continued)

Finighan (1966) found the mean annual EMC and ranges for 20 mm jarrah and radiata pine based on monthly readings at the following WA towns were :

Town	Jarrah		Radiata pine	
	Mean (%)	Range (%)	Mean (%)	Range (%)
Albany	18	18 - 19	16	15 -17
Bridgetown	16	15 - 19	15	12 - 17
Perth	16	13 - 18	13	10 - 16

In this survey EMCs at Albany and Bridgetown were not assessed. Walpole has a similar climate to that of Albany, and Manjimup is similar to Bridgetown, and the following mean annual EMCs were recorded in this survey:

Town	Jarrah		Radiata pine	
	Mean (%)	Range (%)	Mean (%)	Range (%)
Walpole	15.4	13.1-17.8	15.0	12.0-18.2
Manjimup	14.9	10.2-18.3	14.7	7.7-19.8
Perth (Como)	11.6	8.6 -15.0	10.7	6.6-14.6

These figures indicate lower means, particularly those for Perth, than the EMCs given by Finighan 30 years previously, but the ranges indicate high EMCs do occur. The lower density pine specimens indicate large fluctuations in EMC, with Manjimup having an EMC fluctuation of 12.1 per cent between summer and winter.

The greatest amount of change in EMC likely to be experienced in the more populated areas of Australia may be estimated from the fact that most of the regions experience monthly average relative humidities within the range 50 to 70 per cent, and they only occasionally fall to as low as 40 per cent, or rise to as high as 80 per cent (Anon. 1967). For the temperatures normally associated with these relative humidities, the equivalent seasonal EMCs for timber under sheltered outdoor sites usually range from about 9 per cent to 14 or 15 per cent, with only periodic departures to as low as 7 per cent or as high as 16 per cent. At the same time, it should be recognized that in some of the less populated inland parts of Australia the mean seasonal EMC may drop to as low as 5 per cent (e.g. central Australia), and may rise to as high as 20 per cent in others (e.g. North Queensland).

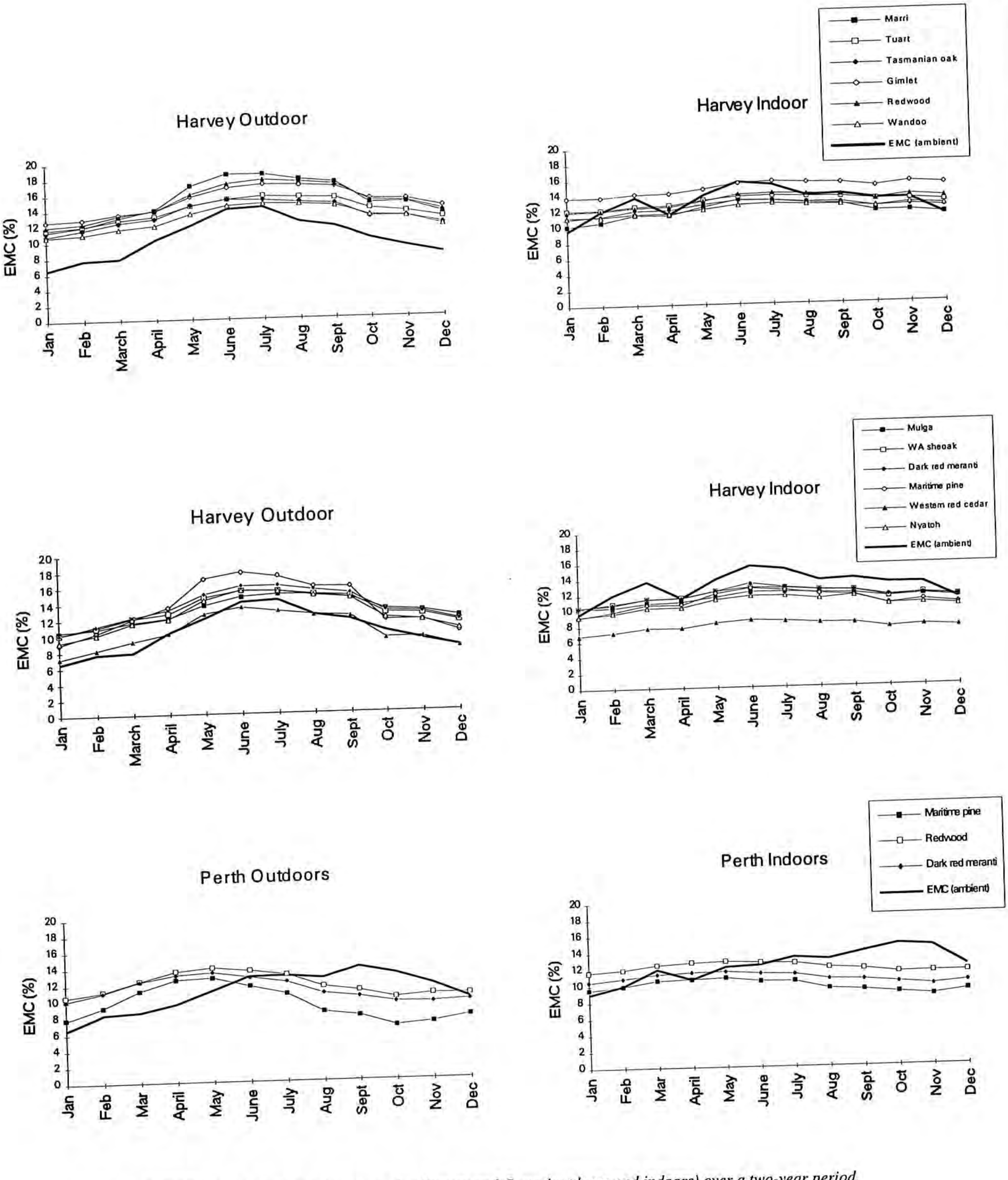

Figure 2. EMCs of additional species assessed at Harvey and Como (outdoors and indoors) over a two-year period.

Indoor EMC

Indoor conditions are not as predictable as outside conditions because of varying forms of heating and circulation that are encountered in houses and offices (Orman 1955). However, in many situations ambient conditions can be constant owing to modern air-conditioning and central heating as found in large office buildings. Generally the EMCs of indoor specimens show less seasonal fluctuations than the outdoor specimens, although Walpole, Narrogin and Harvey show marked seasonal changes. These fluctuations would be owing to samples being in sites without constant heating or air-conditioning and therefore under the influence of changing ambient conditions as occur in the outdoors. For example, the Harvey specimens were stored in a large enclosed wood-processing shed, which although partly insulated, had no air-conditioning or heating.

Mean indoor EMCs varied from Kalgoorlie (5.6 per cent) and Karratha (6.1 per cent) to Narrogin (10.9 per cent) and Walpole (11.8 per cent). Specimens at Kalgoorlie and Karratha were stored in air-conditioned environments, whereas Narrogin and Walpole indoor sites had no air-conditioning and were influenced by outside ambient conditions. The Perth indoor samples were subjected to reasonably constant indoor conditions, with a mean EMC of 10 .3 per cent, but a range of 7.4 to 13.3 per cent still occurred. The Kalgoorlie indoor samples had the lowest range in EMCs between species (1.6 per cent) and Walpole the highest (3.7 per cent).

Comparing the mean EMCs of the five species exposed to indoor and outdoor under cover situations showed indoor specimens with lower EMCs, except for Karratha where the indoor EMC was 0.3 per cent higher. The indoor specimens at Karratha were stored in an air-conditioned environment and maintained a constant EMC, but the extremely dry outdoor conditions resulted in EMCs being lower than the indoor specimens. Kalgoorlie also had very low indoor and outdoor EMCs. Finighan (1966) showed that there is a distinct tendency for indoor values (non-centrally heated houses) to be 1 to 4 per cent lower than the outdoor values, depending on the microclimatic conditions. In all locations the wood EMCs were below the EMCs based on ambient conditions, with Karratha 3 to 4 per cent, Esperance 5 to 6 per cent and Kalgoorlie 2 to 4 per cent below the ambient EMCs.

Lamond and Hartley (1991) reported that in air-conditioned buildings timber should be seasoned to about 10 per cent. Timber dried for the higher outdoor EMCs is not appropriate for use in indoor air-conditioned environments, and should be strip stacked within the air-conditioned environment prior to fixing. In general, moisture contents for indoor unheated conditions range from 1 to 4 per cent lower than outdoor values depending on locality and site factors and a correction factor of 2 per cent lower, would seem acceptable, for practical purposes in most temperate areas of Australia (Finighan 1965). In areas close to the sea, the correction could be smaller while in houses that tend to have high indoor temperatures (e.g. large glassed-in areas) the correction may tend to be larger. Smith *et al.* (1991) recommended the applicable target moisture content for timber products used in air-conditioned buildings in Queensland as 9 per cent, unless otherwise required and specified. If the timber is not at the recommended EMC it should be allowed to dry to the required EMC by strip stacking or loose laying the timber under shelter for two to four weeks prior to fixing. This is particularly important with flooring and joinery timbers. AFRDI (1993) also recommended a mean indoor EMC of 9 per cent, with a range between 6 and 12 per cent, and timber used in dry centrally heated offices or in permanently air conditioned buildings can have EMCs as low as 6 or 7 per cent.

Variation between Species

Although the EMC of certain species for any specific set of psychrometric conditions is often found to be approximately the same, the rates of moisture movement for these species often differ very markedly. This phenomenon of varying rates of absorption cannot be owing solely to climatic differences, but other factors include the degree of heating, ventilation and sheltering, and the density of the timber. Because of the greater response of some timbers than others, the maximum and minimum figures vary considerably for fluctuating conditions. The mean EMCs for jarrah, karri and radiata pine were higher than those for Douglas fir and Tasmanian blue gum, and radiata pine EMC was slightly less than those for jarrah and karri, in both outdoor and indoor situations. This survey indicates that species EMCs may vary by more than 2 per cent, both indoors and outdoors, for a given location and time.

The high standard deviations of the lower density softwood timbers (radiata pine and Douglas fir) and Tasmanian blue gum, indicate large variations in moisture content at all sites compared with jarrah and karri, particularly in outdoor locations that experience large seasonal fluctuations (Table 3). For example, the outdoor EMCs for Harvey gave a standard deviation of 3.6 per cent for radiata pine, 3.3 per cent for Douglas fir and 3.9 per cent for Tasmanian blue gum, with jarrah 2.5 per cent and karri 2.1 per cent. Similar examples for other locations can be seen in Table 3. The additional species assessed at Harvey and Como indicated similar trends with the lower density species indicating greater fluctuations than the higher density species. For example, the standard deviations of maritime pine, western red cedar and nyatoh were 3.7, 3.0 and 2.8 per cent respectively, whereas the higher density species had smaller variations, e.g. the standard deviations for mulga, tuart and wandoo were 1.6, 1.5 and 1.5 per cent respectively. Tasmanian oak and western red cedar assessed indoors indicated a small fluctuation in EMC despite having a lower density than mulga, tuart and wandoo. Other factors, e.g extractive contents, previous drying history and hysteresis, may be influencing the EMC of the Tasmanian oak specimens. Similarly, at Como maritime pine had a higher standard deviation (2.3 per cent) than dark red meranti (1.6 per cent) and redwood (1.6 per cent).

The specimens assessed indoors at all sites showed less fluctuations than the outdoor specimens, owing to the constant indoor ambient conditions (Figs 1 and 2). The standard deviations of the indoor EMCs assessed at Narrogin are similar to the outdoor EMCs and generally higher than the standard deviations assessed at other locations. Like the outdoor specimens the indoor specimens of radiata pine and Douglas fir showed greater fluctuations than the higher density hardwoods, e.g. radiata pine and Douglas fir assessed at Harvey were 1.5 and 3.3 per cent respectively and jarrah and karri were 0.9 and 0.7 per cent respectively. Maritime pine assessed at Harvey also showed a large variation with a standard deviation of 1.8 per cent.

Figure 2 gives the EMC curves for the additional species assessed at Harvey and Como. For both indoor and outdoor specimens assessed at Harvey, EMCs for western red cedar were 2 to 3 per cent lower, and gimlet was approximately 2 per cent higher than the other species. All the other species were within 1 per cent of each other and followed the trend of changes in EMC with changes in the environmental conditions. For the three additional species assessed at Como (indoors and outdoors), redwood had the highest EMC, then dark red meranti and maritime pine. Where there is a considerable variation between species and winter and summer conditions, timber should be protected as far as possible by using moisture resistant coatings.

Because of the greater response of some timbers than others, the maximum and minimum figures vary considerably for fluctuating conditions. Hardwoods usually possess a lower mean EMC than softwoods, though various exceptions do occur (Orman 1955). Hartwig (1959) found the EMCs of eucalypts were significantly higher than those of the pines when the minimum values only were compared. However, when the mean values were examined, no significant differences in EMCs were found between the eucalypt and pine specimens. Ellwood and Leslie (1949) found that the EMC of various species for any specific set of psychrometric conditions can have a difference of up to 4.5 per cent moisture content, although for practical purposes they are assumed to be the same. Howland and Matabwa (1971) found that species EMCs can vary as much as 5 per cent within sites. Measuring weather conditions in close proximity to wood specimens, Tsoumis (1964) found the difference between average actual and EMCs from meteorological data ranged from 0 to 2.8 per cent. This is a good agreement for practical purposes, and EMC values may serve as estimates of expected wood moisture content variations.

Temperatures and RH Comparisons

Regression analysis was used to compare the 12.00 noon temperature and RH readings taken over the two-year study period with the 9.00 a.m. and 3.00 p.m. meteorological readings for Manjimup, Narrogin, Esperance, Perth (Como) and Kalgoorlie. These equations were developed to allow any missing 12.00 noon data to be determined. Very good relationships were found between the temperature readings at 12.00 noon and the 9.00 a.m. and 3.00 p.m. temperatures recorded by the meteorological bureau over the two-year study period, with correlation coefficients greater than 0.90. Comparing the RH at 12.00 noon with the RH at 9.00 a.m. and 3.00 p.m. indicated good correlations for Manjimup, Narrogin and Kalgoorie with coefficients between 0.70 and 0.80. Poor correlations for Esperance and Perth could be owing to the coastal influence, where humidity can change very quickly with the onset of coastal sea breezes. Regressions based on 9.00 a.m. temperature and RH data were used to determine any missing 12.00 noon data.

Regression Analysis of Density and EMC

No correlation was found between basic and air-dry density when compared with actual EMCs (based on oven-drying the whole specimen) for the five species assessed at all locations, owing to the small sample size of three basic and five air-dry densities for each location. When the EMC and density data of all the species assessed at Harvey (indoors and outdoors) were included in the analysis the sample size was increased and the following were found:

- outdoor EMC was not related to air-dry density ($r^2 = 0.43$);

- indoor EMC was directly related to air-dry density, i.e.

$$EMC_{indoors} = 0.005ADD + 6.5 \qquad (r^2 = 0.57)$$

- the best relationship between EMC and basic density was found for the indoor samples (r^2 0.47).

When EMCs of all the species assessed at Harvey by season, i.e. summer (December, January and February) and winter (June, July and August) or by eucalypt and softwood were compared with density the following were found:

- the EMCs of the summer outdoor and indoor specimens were directly related to air-dry and basic density, i.e.

Air -dry density

$$EMC_{indoors} = 0.005\,ADD + 6.33 \quad (r^2 = 0.60)$$

$$EMC_{outdooors} = 0.0047\,ADD + 6.7 \quad (r^2 = 0.51)$$

Basic density

$$EMC_{indoors} = 0.005\,BD + 7.4 \quad (r^2 = 0.59)$$

$$EMC_{outdoors} = 0.004\,BD + 8.542 \quad (r^2 = 0.50)$$

Although the correlation coefficients are between 0.50 and 0.60 the large sample size would indicate significant relationships.

Owing to the small number of basic densities, these data were excluded and only air-dried density was used to relate the EMCs assessed in summer or winter and EMCs of the eucalypt or softwood. For example, the relationships for the summer outdoor and indoor specimens are:

$$EMC_{outdoors} = 0.005\,ADD + 6.938 \quad (r^2 = 0.58)$$

$$EMC_{indoors} = 0.008\,ADD + 3.595 \quad (r^2 = 0.72)$$

Softwood Regressions

EMC was directly related to air-dry density for the softwoods, but no relationships were found for the eucalypts assessed in summer or winter.
The regressions for the softwood specimens over the two-year period were:

$$EMC_{indoors} = 0.017\,ADD + 1.024 \quad (r^2 = 0.74)$$

$$EMC_{outdoors} = 0.16\,ADD + 3.504 \quad (r^2 = 0.92)$$

The softwood EMC was also directly related to air-dry density for summer outdoors and winter indoors and outdoors. The relationships are:

Softwoods - summer

$$EMC_{outdoors} = 0.014\,ADD + 1.977 \quad (r^2 = 0.85)$$

Softwoods - winter

$$EMC_{outdoor} = 0.18\,ADD + 6.534 \quad (r^2 = 0.94)$$

$$EMC_{indoors} = 0.03\,ADD - 4.218 \quad (r^2 = 0.90)$$

Hardwood Regressions

Owing to the large variation in densities for the eucalypts, the lower density species of Tasmanian blue gum, Tasmanian oak and marri were excluded from the regression analysis. The following relationship was found between EMC and air-dry density for the higher density eucalypts assessed indoors over the two-year study period and outdoors during summer:

Indoors - over the two-year study period

$$EMC_{indoors} = 0.007\,ADD + 4.88 \quad (r^2 = 0.62)$$

Outdoors - during summer

$$EMC_{outdoors} = 0.005ADD + 6.94 \quad (r^2 = 0.58)$$

Chafe (1991) found that wood blocks (25 mm square and 20 mm long) and thin sections (1 mm thick) of mountain ash (*Eucalyptus regnans* F. Muell.) equilibrated to 17 per cent, 12 per cent or 5 per cent were positively related to density. Christensen and Kelsey (1959) had estimated for mountain ash that the relative contributions to the total sorption of the wood by cellulose, hemicellulose and lignin were 47 per cent, 37 per cent and 16 per cent respectively. This suggested that wood of higher density may have proportionally more cellulose and/or hemicellulose and less lignin than wood of lower density, hence higher moisture absorption properties. However, in this trial the lower density softwoods, particularly radiata pine, had higher maximum EMCs compared with the hardwoods. Bragg (1986) found that EMC was directly related to air-dry density, when he assessed a number of timber species throughout Queensland. Hartwig (1959) found that the lower density pine samples absorb moisture at a faster rate than eucalypts and the ultimate EMCs of the pine samples are higher than those of the eucalypt samples. This is discussed in more detail under 'Absorption rates' below.

Outdoor EMC Compared with Indoor EMC

Regression analysis was used to relate outdoor and indoor EMCs, based on oven-drying the whole specimen at the end of the trial. The overall equation for all species at 10 sites (excluding Broome and Kununurra) based on mean monthly readings is:

$$EMC_{indoors} = 0.83\,EMC_{outdoors} + 0.49 \quad (r^2 = 0.70)$$

Relationships for individual locations are given in Table 5. Significant relationships were found for Harvey, Esperance, Karratha, Narrogin and Perth as indicated by the high coefficient of determination. Outdoor and indoor EMCs for jarrah, karri, radiata pine, Douglas fir and Tasmanian blue gum assessed at Harvey were compared by regression analysis and indicated significant relationships for all species (Table 6).

TABLE 5

Regression analysis of outdoor EMCs and indoor EMCs for ten locations (all regressions are significant at $P < 0.001$).

LOCATION	REGRESSION EQUATION	R^2	N
Karratha	$EMC_{indoor} = 0.97\,EMC_{outdoor} + 0.45$	0.57	107
Geraldton	$EMC_{indoor} = 1.95\,EMC_{outdoor} - 12.8$	0.24	85
Perth	$EMC_{indoor} = 0.65\,EMC_{outdoor} + 3.15$	0.55	120
Harvey	$EMC_{indoor} = 0.56\,EMC_{outdoor} + 3.48$	0.70	135
Busselton	$EMC_{indoor} = 2.00\,EMC_{outdoor} - 9.97$	0.21	129
Manjimup	$EMC_{indoor} = 1.30\,EMC_{outdoor} - 8.44$	0.18	100
Walpole	$EMC_{indoor} = 2.35\,EMC_{outdoor} - 21.61$	0.20	119
Narrogin	$EMC_{indoor} = 0.96\,EMC_{outdoor} - 0.28$	0.96	107
Esperance	$EMC_{indoor} = 0.90\,EMC_{outdoor} - 0.47$	0.76	120
Kalgoorlie	$EMC_{indoor} = 0.59\,EMC_{outdoor} + 2.15$	0.38	130

TABLE 6

Regression analysis of outdoor EMCs and indoor EMCs of five wood species assessed at Harvey (all regressions are significant at $P < 0.001$).

SPECIES	REGRESSION EQUATION	R^2	N
Jarrah	$EMC_{indoors} = 0.40\,EMC_{outdoors} + 6.56$	0.86	27
Karri	$EMC_{indoors} = 0.44\,EMC_{outdoors} + 5.70$	0.74	27
Radiata pine	$EMC_{indoors} = 0.37\,EMC_{outdoors} + 6.22$	0.83	27
Douglas fir	$EMC_{indoors} = 0.38\,EMC_{outdoors} + 5.30$	0.85	27
Tasmanian blue gum	$EMC_{indoors} = 0.35\,EMC_{outdoors} + 5.78$	0.80	27

In the absence of indoor EMC data, EMC values appropriate to the inside of non-heated or non air-conditioned buildings can be computed from outdoor EMCs using the above overall equation or for a specific location where there is a significant relationship (Table 5). If indoor RH and temperature data are available, the equation given by Simpson (1971) can be used to determine EMC of the room, which is the EMC a timber specimen should eventually attain.

Bragg (1986) found:

$$EMC_{indoors} = 0.83\ EMC_{outdoors}$$

which gives a 0.5 per cent difference to the indoor EMC calculated from the above equation, developed from data collected in this trial. In comparison, Finighan (1966) found that indoor EMCs of non centrally heated houses were between 1 and 4 per cent less than in outdoor sheltered positions, but that the effect was variable and dependent on the microclimate specific to each building.

Comparison of Actual EMC and Theoretical EMC

Figure 3 shows the relationship between actual EMC (based on oven-drying the whole sample) and theoretical EMC (based on 12.00 noon RH and temperature data) for five species assessed and overall for outdoors sites at Harvey, Kalgoorlie and Manjimup. These locations were selected because they occur in different EMC zones and complete sets of data were available. Regression analysis showed the outdoor specimens had strong correlations for the individual species and the overall EMC. The overall relationships for Harvey, Kalgoorlie and Manjimup were :

Harvey: $EMC = 0.902EMC_{form} + 3.71 \quad (r^2 = 0.68)$

Kalgoorlie: $EMC = 0.88EMC_{form} - 0.95 \quad (r^2 = 0.61)$

Manjimup: $EMC = 0.38EMC_{form} + 9.26 \quad (r^2 = 0.56)$

EMC_{form} is the theoretical EMC.

The indoor specimens showed poor correlations owing to the small variation in data, as shown with the small standard deviations given in Table 3. Using the 12.00 noon RHs and temperatures, the actual EMCs for Harvey, Kalgoorlie and Manjimup can be determined from the regression equation or the graphs in Figure 3. Similar relationships can be developed for other locations.

Howland and Matabwa (1971) found strong correlations between actual EMC and the theoretical EMC based on mean weekly RHs and temperatures. Ellwood and Leslie (1949) found that when EMCs calculated from directly weighing specimens (estimated EMC) and theoretical EMC calculated from monthly RH and temperature were compared, the EMCs were very irregular and did not correspond at all well with the moisture contents estimated from weighing specimens.

Finighan (1966) related the EMC of wood specimens exposed to outdoor conditions by an empirical equation using mean monthly temperatures and RHs. The predicted moisture contents determined by the equation for the sites assessed differ from the observed moisture contents by more than 2 per cent, but when Alice Springs and Broken Hill data were excluded, approximately 95 per cent of predictions differed from observed values by only 1 per cent or less.

Models for Predicting EMC from Meteorological Data

The meteorological data used in regression analysis presented in Table 7 were compared with the combined species EMCs (based on oven-drying the whole sample) for each location given in Table 3. Evaporation data were unavailable for Busselton, Narrogin and Walpole, therefore when evaporation was included in the regression analysis these locations were excluded.

In Table 7 temperature and RH data recorded at 12.00 noon were used, whereas long term data are recorded at 9.00 a.m. and 3.00 p.m., therefore 12.00 noon readings should be used to predict EMC. A stepwise regression determined which meteorological readings were best at predicting EMC. The correlation coefficients and probabilities derived using all the available data from ten locations (excluding Broome and Kununurra) are listed in Table 8.

All four variables were strongly correlated with EMC, as indicated by the correlation coefficients and the probabilities. RH is highly significant at predicting EMC ($P < 0.001$) and, as expected, evaporation and temperature were strongly inversely related to EMC. The regression analysis (with evaporation included) showed that RH was the strongest predicter of EMC with the following relationship:

$$EMC = 0.26\ RH_{12pm} - 4.393 \quad (r^2 = 0.80)$$

When the evaporation figures were excluded from the analysis, the sample size was increased to ten locations and the relationship derived was:

$$EMC = 0.19\ RH_{12pm} + 0.003\ RAIN - 2.559 \quad (r^2 = 0.87)$$

Rainfall has been included in the equation, although it does not have the same effect as RH. Temperature and evaporation have minor effects in determining EMC. When the other variables are used either singly or in combination, they are not as strong at predicting EMC as RH with correlation coefficients between 0.60 and 0.75. When RH and temperature were used to determine EMC the following equation was derived:

$$EMC = 0.248\ R.H._{12pm} - 0.038\ TEMP_{12pm} - 2.863 \ (r^2 = 0.80)$$

This equation shows the small effect temperature has in determining EMC.

These three regression equations, combined with long term meteorological data (12.00 noon readings) allow the prediction of EMC for 20 mm thick timber in sheltered outdoor situations throughout WA. RH is the most significant variable in predicting EMC, however, where rainfall and temperature data are available they can be used to improve the prediction.

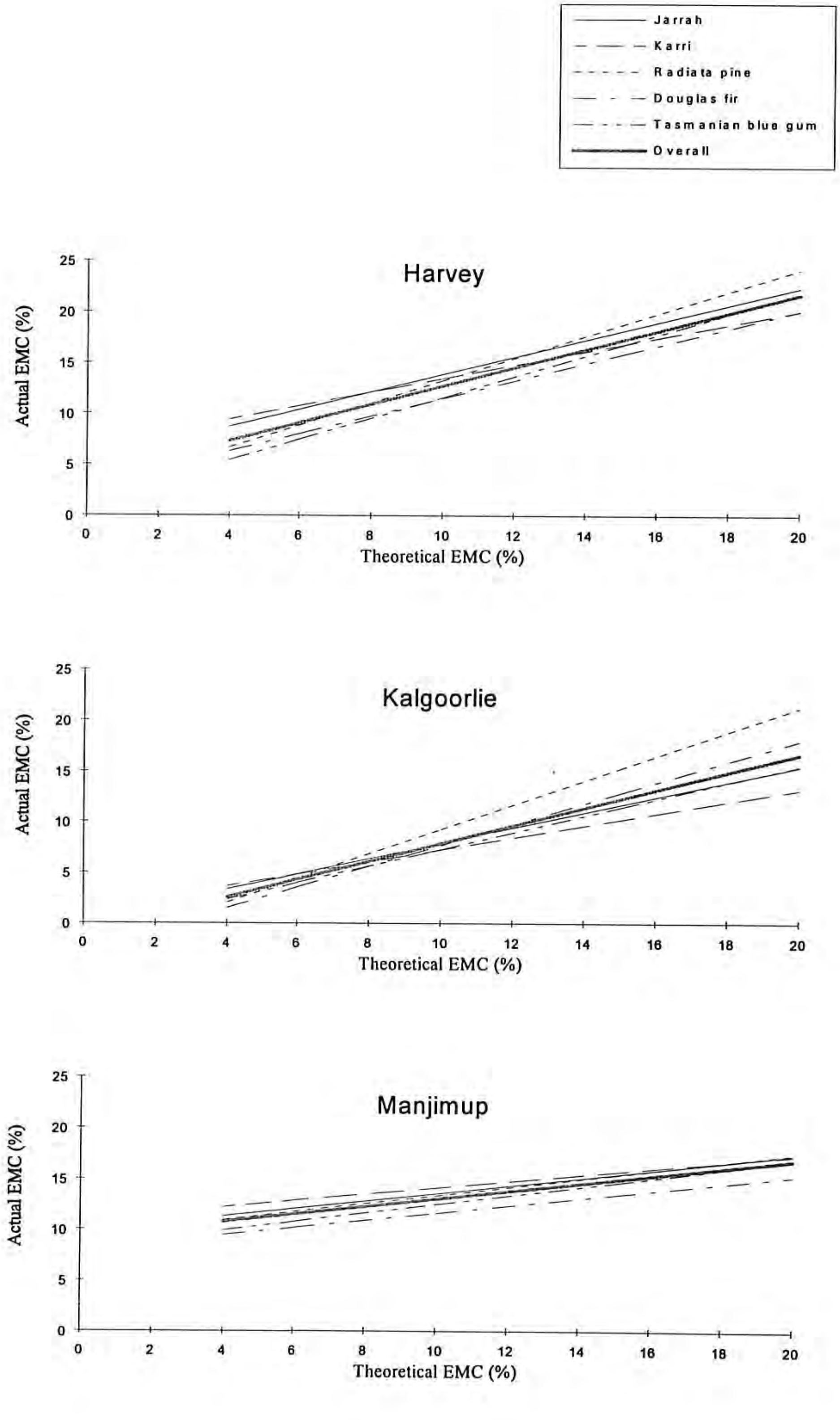

Figure 3. The relationship between theoretical EMC (based on 12.00 pm RH and temperature data) and actual EMC (based on oven-drying the whole sample) values for five species assessed outdoors at Harvey, Kalgoorlie and Manjimup.

TABLE 7

Meteorological data[a] used in the regression analysis.

LOCATION	RAINFALL (mm)	EVAP (mm)	TEMP 12.00 noon(°C)	RH (%)
Karratha	209.7	3146.8	31.2	37.8
Geraldton	469.3	2301.7	21.8	63.6
Perth (Como)	931.9	2007.4	24.0	60.2
Harvey	1025.3	1652.1	21.1	55.7
Busselton	860.3	N.A.	18.6	65.0
Manjimup	1005.0	1043.6	18.2	67.3
Walpole	1252.3	N.A.	18.9	65.5
Narrogin	545.3	N.A.	21.0	63.8
Esperance	645.1	1610.0	19.8	57.1
Kalgoorlie	347.3	2442.9	24.1	42.4

[a] Meteorological data are based on annual means for the study period of two calendar years, which may vary from the long term values.

Data from Broome and Kununurra are excluded.

N.A. - Not available.

TABLE 8

Correlation coefficient (r) and probability matrix for meteorological variables using the mean of the annual readings from ten locations.

	EMC	EVAP	RAIN	RH 12.00 noon	TEMP 12.00 noon
EMC	1.00 (0.000)				
Evap	-0.85 (0.016)	1.00 (0.000)			
Rain	0.83 (0.022)	-0.86 (0.014)	1.00 (0.000)		
RH_{12pm}	0.95 (0.001)	-0.80 (0.032)	0.73 (0.061)	1.00 (0.000)	
$Temp_{12pm}$	-0.81 (0.028)	0.93 (0.003)	-0.69 (0.086)	-0.82 (0.024)	1.00 (0.000)

Notes:

Probabilities are given in parentheses.

EMC = EMC (%) based on oven-drying the whole wood sample.

Evap = evaporation mm/annum.

Rain = rainfall in mm/annum for 1991 and 1992.

RH_{12pm} = relative humidity 12.00 noon (%), yearly mean for 1991 and 1992.

$Temp_{12pm}$ = Temperature 12.00 noon (°C), yearly mean 1991 and 1992.

Bragg (1986) developed models for predicting EMC in Queensland and found that RH (9.00 a.m. and 3.00 p.m.) and the natural logarithm of rainfall were highly significant, and when 3.00 p.m. RH was used the prediction was better than using 9.00 a.m RH. Ellwood and Leslie (1949) examined the effect of EMC using monthly mean 9.00 a.m. humidities and temperatures, for the current month, the previous month and the previous two months, because current EMC of exposed timber depends on both the actual and past RH and temperature conditions. They found the current mean monthly humidity and mean humidity for the past two months were highly significant, but mean humidity for the previous month generally had no significant effect. The effect of temperature for the previous two months was non-significant, but the current monthly temperature in general had a significant effect (Ellwood and Leslie 1949).

Comparison of Estimated and Actual EMC

Initially EMCs were estimated from monthly specimen weighings and the moisture content calculated from these readings. At the completion of the trial the whole specimen was oven-dried and moisture content determined from the initial and oven-dry weights. Table 9 lists the regressions comparing the EMCs based on weight change (estimated EMC) and EMCs based on oven-drying the whole (actual EMC) specimen, for all locations (outdoors and indoors). The regressions for the outdoor equations indicated good correlations for the five species assessed at all locations and the overall equation for the combined species. For the indoor specimens, all species except karri had direct correlations between EMCs based on weight change and EMC determined by oven drying the whole specimen (Table 9). When the EMCs for the additional species assessed at Harvey and Como were included in the regression analysis they also produced good correlations for outdoor and indoor sites.

EMC Map

A map dividing WA into three EMC zones for outdoor conditions is given in Figure 4. The map was developed by using the long term climatic averages for 160 different meteorological stations in WA and the combined timber species mean EMC for each site assessed. A regression based on the mean wood EMCs measured at 12.00 noon and long term mean 9.00 a.m. RH and temperatures were used to arrive at the EMC for each meteorological station.

The three EMC zones for WA give seasoning targets for timber used in outdoor sheltered conditions.

Zone 1 is for EMCs greater than 12 per cent and covers the high rainfall areas of the south-west and from the edge of the Darling Scarp, east of a line extending from Northam to the South Coast, midway between Bremer Bay and Albany.

Zone 2 is for EMC between 10 and 12 per cent and includes the Swan coastal plain, north of Bunbury to south of Jurien Bay (175 km north of Perth), then extending from Jurien Bay to between Northam and Merredin, and between Norseman and Esperance to the South Coast approximately 200 km east of Esperance. This zone encompasses the Perth metropolitan area and the major coastal towns of Mandurah and Bunbury, where the majority of WA's population live and a high proportion of the State's timber would be used.

Zone 3 is for EMC less than 10 per cent, and covers the majority of WA that is relatively low in population, but includes the major towns of Geraldton and Kalgoorlie.

Owing to the lower EMC required for Zone 3, difficulty may be experienced in supplying seasoned timber at the correct moisture content, from coastal centres, to the drier inland areas.

Bragg (1986) developed an EMC map for sheltered outdoor sites in Queensland based on predicted EMC for 148 sites and divided the State into three EMC zones. The target moisture contents for these zones are:

Zone 1 - 12 per cent (range 10 - 12 per cent)
Zone 2 - 9 per cent (range 7 - 12 per cent) and
Zone 3 - 7 per cent (range 5 - 10 per cent)

Smith *et al.* (1991) further reduced the Queensland map to two zones. Zone 1 covers the area where the 10 to 15 per cent EMC range is appropriate. This includes most of the major centres of population in Queensland, particularly around the coast. Zone 2 is for the far west where a lower EMC of 7 to 12 per cent is required.

AFRDI (1993) gave outdoor and indoor EMC for Victoria, Tasmania, New South Wales, South Australia, WA, tropical Australia and southern Queensland. For WA AFRDI recommended a mean outdoor EMC of 10 per cent (range 7 to 13 per cent). Tropical Australia presumably includes the Kimberley region of WA and AFRDI recommended a mean outdoor EMC of 14 per cent (range 12 to 17 per cent). The outdoor mean for WA of 10 per cent given by AFRDI would be appropriate for timber supplied into Zones 1 and 2, but Zone 3 would require a miosture content less than 10 per cent. Specimens assessed in the tropical areas of WA (Broome and Kununurra) had EMC for the combined species of 10. 4 per cent for Broome and 5.2 per for Kununurra, and the Kununurra specimens were assessed in hot and humid spring/summer months. EMC based on long term meteorological data for these two centres also indicate mean EMC less than 14 per cent and the EMC given by AFRDI for tropical areas of WA are not appropriate. The sources of the AFRDI (1993) data or boundaries of tropical Australia are not given.

In practice, the ideal would be to season wood to a moisture content equal to the average EMC for the particular area where it is to be used. Difficulty may be experienced in supplying seasoned timber from the coastal regions to areas of lower EMC. In such cases Smith *et al.* (1991) recommended that the seasoned timber should be allowed to come to EMC on site. This procedure is advisable throughout Zone 3, where EMC can be as low as 6 or 7 per cent, and should be done by strip stacking or loose laying the timber under shelter for two to four weeks prior to fixing. This is particularly important with flooring and joinery timbers. It is important that seasoned timber and wood-based products are protected from the weather and other dampness until fixed under the specified conditions of use. Similarly, for air-conditioned buildings in Zones 1 and 2, the 10 to 15 per cent EMC range is not appropriate, and the timber should be strip stacked within the air-conditioned environment or seasoned to the required moisture content prior to fixing. Smith *et al.* (1991) recommended the applicable target moisture content for timber products in air-conditioned buildings as 9 per cent unless otherwise required and specified. Similar practices need to be applied in WA when timber is taken from zones of high EMC to lower EMC.

In the United States, the Department of Agriculture recommended, that if it is unknown in what locality a product will be used, before drying, the wood should be dried to a moisture content of about 8 per cent, which is close to the average of the values preferred for arid and damp regions (United States Department of Agriculture 1973).

TABLE 9
Regression analysis of EMCs based on weight change (EMC_{est}) and EMCs based on oven-drying the whole specimen ($EMC_{oven\ dry}$).

SPECIES	Outdoors	(r^2)	N	Indoors	(r^2)	N
	REGRESSION EQUATIONS					
Jarrah	$EMC_{est} = 0.722\ EMC_{oven\ dry} + 5.23$	0.85	249	$EMC_{est} = 0.585\ EMC_{oven\ dry} + 6.29$	0.76	248
Karri	$EMC_{est} = 0.591\ EMC_{oven\ dry} + 6.31$	0.75	246	$EMC_{est} = 0.388\ EMC_{oven\ dry} + 8.13$	0.40	245
Radiata pine	$EMC_{est} = 0.774\ EMC_{oven\ dry} + 5.15$	0.85	248	$EMC_{est} = 0.773\ EMC_{oven\ dry} + 4.865$	0.78	247
Douglas fir	$EMC_{est} = 0.8\ EMC_{oven\ dry} + 4.058$	0.98	248	$EMC_{est} = 0.667\ EMC_{oven\ dry} + 4.82$	0.77	247
Tasmanian blue gum	$EMC_{est} = 0.762\ EMC_{oven\ dry} + 3.75$	0.89	249	$EMC_{est} = 0.588\ EMC_{oven\ dry} + 4.946$	0.72	247
Overall	$EMC_{est} = 0.749\ EMC_{oven\ dry} + 4.67$	0.83	1233	$EMC_{est} = 0.641\ EMC_{oven\ dry} + 5.344$	0.68	1235

Notes: All regressions are significant at $P < 0.001$.
Data for all locations have been included in the analysis

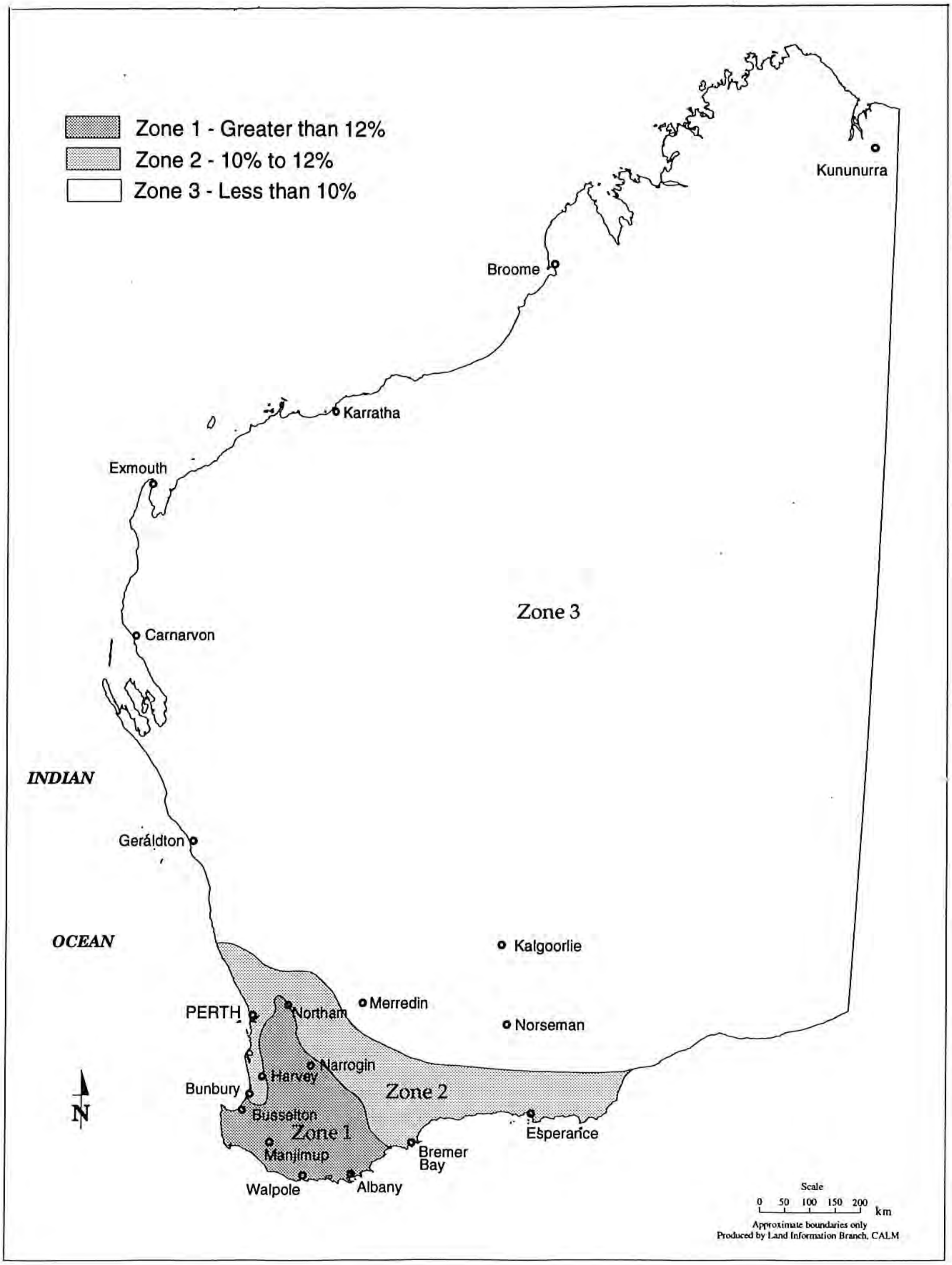

Figure 4. Equilibrium Moisture Content Zones of Western Australia.

McNaught (1988) stated that it is important to appreciate that EMC zones do not bear the same significance to framing timber as they do to appearance quality products. The effect on appearance timber, flooring and panelling can result in checking and large shrinkage or swelling when timber is supplied at the incorrect moisture content. Hardwood framing must be seasoned to moisture contents less than 15 per cent and pine framing less than 10 per cent to achieve the required stability and strength rating.

Problem with Predicting EMC

The choice of RH and temperature data to give meaningful results can have quite a bearing on the EMC values given in charts, equations or maps. It is recognized that the average meteorological conditions do not coincide with the average EMC values but there appears to be no general agreement as to which data should be used (Gough 1977). Finighan (1966) recommended the use of the mean of the daily maximum and minimum temperatures for each month and average of the 6.00 a.m. and 3.00 p.m. RH readings to be closer to the actual conditions. Ellwood and Leslie (1949) found that the current mean monthly humidity and mean RH of the past two months are highly significant in predicting EMC and generally the current mean monthly temperature has a significant effect. The mean RH and temperature for the past month generally has no significant effect on EMC.

Orman (1955) found that the monthly averages (taken from weekly readings of moisture content) showed little effect from the previous month's humidity and temperature conditions. In other words, the mean moisture content of a species could be directly related to the mean humidity and temperature conditions for a particular month, the sensitivity of the species being sufficient to overcome any residual effect of the previous month's climatic conditions.

Owing to the great number of factors influencing EMC, including such secondary factors as effects of previous drying history, air velocity, time or ageing effects, whether quartersawn or backsawn, and thickness of timber, it is not always possible to obtain perfect agreement between the empirical and theoretical determinations. Another factor of some importance is the case where meteorological data are obtained from sites not typical of the environment to which the samples are exposed. Orman (1955) found that the effect of this microclimate variation owing to local phenomena is often marked over comparatively short distances. For example, two stations less than 5 km apart show up to 0.5 per cent moisture content differences under identical exposure conditions.

In actual practice, when wood is in use, constant RH and temperature conditions are rarely attained, consequently, the moisture content of wood is seldom in equilibrium with the psychrometic conditions of the environment owing to the varying nature of the environmental conditions (Ellwood and Leslie 1949). Except in the case of extremely thin sections, wood exhibits a considerable lag in reaching the moisture content determined by the psychrometic conditions of the environment. The rate of moisture diffusion through the wood is the limiting factor. Generally, diurnal variations would only influence the percentage moisture content of thin veneer, e.g. 3 to 4 mm thick. Joinery or building timber, which is considerably thicker, is chiefly affected by seasonal and yearly changes. The effect of short term environmental fluctuations will be superimposed, to a certain extent, upon the major or long term variations of wood moisture content. Therefore, at any one time, the moisture content of wood depends not only on the EMC corresponding to the environment at that time, but also upon the rate and method of moisture exchange when subjected to the varying atmospheric conditions (Ellwood and Leslie 1949).

Tsoumis (1964) stated that when EMC values given in a chart or determined by Simpson's equation are computed on the basis of curves constructed from data obtained from Sitka pine (*Picea sitchensis* Carr.), the generalization of such data is limited to this effect. Although most temperate species show good agreement, large deviations may be expected at high relative humidities, especially in woods containing high amounts of extractives.

Absorption Rates

Figure 5 shows the comparative rates of moisture absorption and Tables 10 and 11 list the actual moisture contents and the rate of absorption for 1, 2, 4, 6 or 8 weeks after oven-drying, for the specimens assessed outdoors and indoors at Harvey. The two pine species (maritime and radiata) clearly have greater moisture absorption rates than the other species, and the lower density Tasmanian blue gum had a faster rate than the other eucalypts. The higher density species, e.g. mulga, wandoo, redwood, gimlet and tuart had the slowest moisture absorption rates. For example, radiata pine absorbtion decreased from 9.5 per cent in the first week to 0.9 per cent in the ninth week, and the higher density mulga specimens had absorbed 1.5 per cent in the first week and 0.34 per cent in the ninth week (Table 10). The absorption rates decreased after the first week and if the exposure time had been extended the specimens would have reached EMC. Owing to the 'hysteresis' effect, when timber takes up moisture it assumes an appreciably lower EMC than when it loses moisture to the air, and oven-drying specimens can cause the extractives to be redistributed within the timber, blocking cells and restricting moisture uptake. Oven-drying would restrict the uptake of moisture, but a substantial uptake would still occur (Chafe[1] personal communication). Koponen (1985) claimed that EMC in absorption may be approximately 80 per cent of the value in desorption. Further assessments are required to determine the time it takes to reach EMC and compare this with EMC of specimens that have been equilibrated to a constant EMC, e.g. 10 per cent instead of initially oven-drying. Samples were weighed weekly generally between 9.00 and 10.00 a.m., whereas temperature and RH were

[1] Dr Sam Chafe, CSIRO Division of Forest Products, Clayton, Victoria.

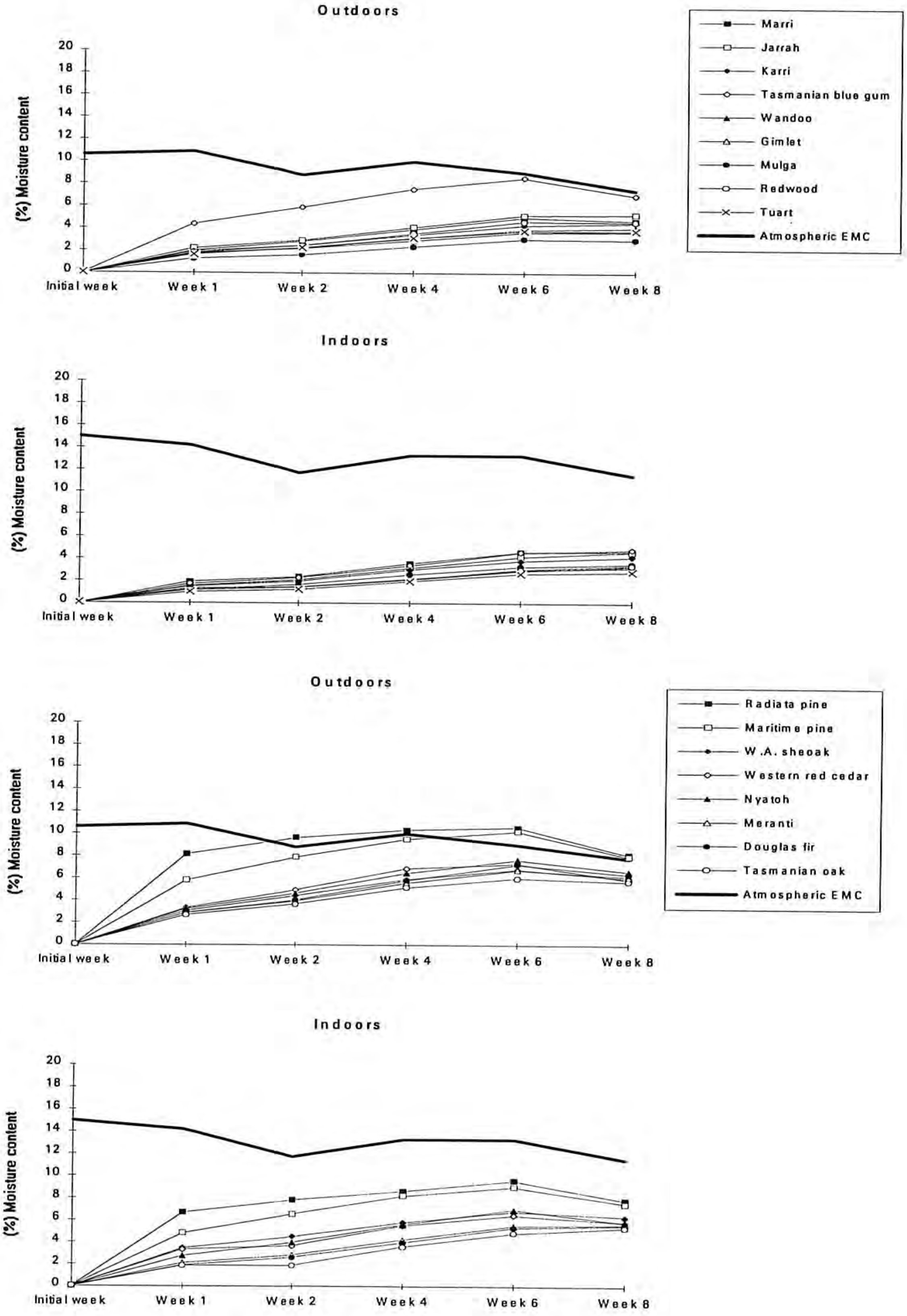

Figure 5. Rate of moisture absorption of specimens assessesd at Harvey (outdoors and indoors).

TABLE 10

Actual moisture contents and rates of absorption after oven drying and exposing to outdoor conditions at Harvey.

SPECIES	WEEK 1		WEEK 2		WEEK 4		WEEK 6		WEEK 8	
	Moisture content (%)	Absorption rate (%/week)	Moisture content (%)	Absorption rate (%/week)	Moisture content (%)	Absorption rate (%/week)	Moisture content (%)	Absorption rate (%/week)	Moisture content (%)	Absorption rate (%/week)
Jarrah	2.55	2.55	2.94	1.58	4.10	1.11	5.21	0.91	5.24	0.60
Karri	2.23	2.23	2.48	1.33	3.44	0.93	4.29	0.75	4.50	0.52
Radiata pine	9.49	9.49	9.65	5.19	10.36	2.80	10.60	1.86	8.12	0.93
Douglas fir	3.38	3.38	4.03	2.17	5.80	1.57	7.23	1.27	6.37	0.73
Tasmanian blue gum	5.10	5.10	5.90	3.17	7.53	2.04	8.51	1.49	6.92	0.80
Marri	2.31	2.31	2.86	1.54	3.91	1.06	4.99	0.88	4.70	0.54
Tuart	1.91	1.91	2.26	1.22	3.14	0.85	3.79	0.66	3.79	0.44
Tasmanian oak	3.14	3.14	3.69	1.98	5.16	1.39	6.01	1.05	5.71	0.66
Gimlet	2.04	2.04	2.19	1.18	2.91	0.79	3.66	0.64	3.71	0.43
Redwood	2.09	2.09	2.47	1.33	3.54	0.96	4.63	0.81	4.59	0.53
Wandoo	2.00	2.00	2.23	1.20	3.12	0.84	3.89	0.68	4.05	0.47
Mulga	1.46	1.46	1.62	0.87	2.39	0.65	3.05	0.53	2.99	0.34
WA sheoak	3.58	3.58	4.42	2.38	5.89	1.59	6.79	1.19	6.03	0.69
Meranti	3.38	3.38	3.93	2.11	5.58	1.51	6.75	1.18	6.15	0.71
Maritime pine	6.75	6.75	7.87	4.23	9.52	2.57	10.22	1.79	7.96	0.92
Western red cedar	3.87	3.87	4.95	2.66	6.87	1.86	7.31	1.28	5.87	0.67
Nyatoh	3.77	3.77	4.65	2.50	6.47	1.75	7.66	1.34	6.64	0.76
Atmospheric EMC	10.9		8.8		10.0		9.0		7.4	

TABLE 11

Actual moisture contents and rates of absorption after oven drying and exposing to indoor conditions at Harvey.

SPECIES	WEEK 1		WEEK 2		WEEK 4		WEEK 6		WEEK 8	
	Moisture content (%)	Absorption rate (%/week)	Moisture content (%)	Absorption rate (%/week)	Moisture content (%)	Absorption rate (%/week)	Moisture content (%)	Absorption rate (%/week)	Moisture content (%)	Absorption rate (%/week)
Jarrah	1.78	1.78	2.07	1.11	3.14	0.85	4.18	0.73	4.65	0.53
Karri	1.70	1.70	1.95	1.05	3.00	0.81	3.82	0.67	4.17	0.48
Radiata pine	7.77	7.77	7.82	4.20	8.64	2.33	9.57	1.68	7.82	0.90
Douglas fir	2.23	2.23	2.62	1.41	3.99	1.08	5.33	0.94	5.58	0.64
Tasmanian blue gum	1.97	1.97	2.28	1.22	3.38	0.91	4.58	0.80	4.83	0.56
Marri	2.21	2.21	2.35	1.26	3.56	0.96	4.62	0.81	4.68	0.54
Tuart	1.13	1.13	1.21	0.65	1.95	0.53	2.65	0.46	2.81	0.32
Tasmanian oak	2.21	2.21	1.88	1.01	3.61	0.97	4.84	0.85	5.33	0.61
Gimlet	1.39	1.39	1.43	0.77	2.09	0.56	2.91	0.51	3.33	0.38
Redwood	1.35	1.35	1.41	0.76	2.13	0.58	3.04	0.53	3.42	0.39
Wandoo	1.52	1.52	1.44	0.77	2.16	0.58	2.98	0.52	3.22	0.37
Mulga	1.36	1.36	1.65	0.88	2.58	0.70	3.30	0.58	3.54	0.41
WA sheoak	4.03	4.03	4.50	2.42	5.80	1.57	6.78	1.19	6.34	0.73
Meranti	2.46	2.46	2.85	1.53	4.24	1.15	5.50	0.96	5.62	0.65
Maritime pine	5.61	5.61	6.54	3.52	8.20	2.22	9.00	1.58	7.53	0.87
Western red cedar	3.90	3.90	3.68	1.98	5.52	1.49	6.45	1.13	5.86	0.67
Nyatoh	3.23	3.23	3.98	2.14	5.61	1.52	6.98	1.23	5.81	0.67
Atmospheric EMC	10.9		11.7		13.3		13.3		11.5	

recorded daily at 12.00 noon, and this may have affected the results. In future trials the samples should be weighed at the same time temperature and RH are recorded.

The absorption rates of the indoor specimens are similar to those of the outdoor specimens, with the two pine species showing greater absorption rates than the higher density species, particularly the eucalypts. Tasmanian blue gum indoor specimens had similar absorption rates to the other eucalypts, whereas the outdoor specimens had higher rates. Radiata pine absorbed 7.8 per cent moisture in the first week which is slightly less than the outdoor specimens, but over the eight-week assessment period the rates were similar. It was expected that the indoor specimens would absorb moisture faster than the outdoor specimens, owing to the high ambient EMC conditions.

Hartwig (1959) found, after oven-drying pine and eucalypt specimens and subsequently stacking them indoors, that after 25 days the pine specimens had reached a moisture content which varied from 6.1 to 9.0 per cent and averaged 7.75 per cent. The eucalypts after 28 days had much lower moisture contents, between 2.83 and 5.36 per cent, with an average of 3.65 per cent. After 12 months the moisture contents of the pine and eucalypt specimens were similar, but the ultimate EMC of the pine specimens was higher than that of the eucalypt specimens. The current pilot study needs to be extended to 12 to 24 months to determine the ultimate EMC of different species after oven drying.

Practical Aspects of the Results

EMC and seasonal changes in moisture that have so far been discussed and the results illustrated by curves are of no practical importance because of the shrinkage and swelling that accompanies them. Seasonal variation must be expected to occur in the moisture content of timber in normal use as furniture and panelling, and this will be accompanied by an approximately proportional change in dimension. The shrinkage or expansion of wood in common use can be minimized by choosing, as the moisture content at manufacture, the mean of the extreme values of the range of seasonal variation. Furniture should also be designed to allow some freedom for shrinkage and expansion of timber components.

In certain types of products, shrinkage may be a more serious matter than expansion, or alternatively, the most appropriate moisture content for the timber at manufacture should tend towards the lower or higher extremity rather than to the mean value. In these cases it is necessary to leave the actual choice of moisture content to the manufacturer, to be decided according to the requirements of the product.

Perth, the south-west locations, and the coastal towns of Geraldton and Esperance have higher outdoor EMCs than Karratha and Kalgoorlie. Difficulty may be experienced in supplying seasoned timber from Perth and the south-west to these areas of lower EMC. In such cases it is recommended that the seasoned timber should be allowed to come to the specified EMC for its in-service location. This could be done by strip stacking the timber under shelter for two to four weeks prior to fixing. This is particularly important with flooring and joinery timber. In the case of timber going from areas of lower EMC to those of higher EMC, e.g. from Perth to Manjimup, Walpole or Albany, allowance must be made for swelling.

Timber dried to the average moisture content that will be encountered in service, may then change during storage, delivery or installation, particularly in buildings where the wet trades such as bricklaying and plastering result in very high humidities during construction (Richardson 1993). Floors are sometimes laid in new buildings very promptly after kiln-drying and the high humidity then causes them to expand so that sometimes the entire floor lifts or the expansion causes serious damage to the surrounding walls. Stacking the wood for a period inside the building before laying will avoid this particular problem as the wood will thus reach equilibrium with the high humidity in a damp new building. When the building is ultimately occupied, the relative humidity will fall and shrinkage defects will develop (Richardson 1993). For example, quartersawn floorboards will simply shrink in width leaving gaps at the joints, but backsawn boards will cup. Backsawn boards should be laid with the heart surface upwards so that the cupping causes each board to be raised in its centre rather than at its edges where it can cause tripping. Shrinkage gaps can be reduced by using tongue and groove boards, where the tongue can span these shrinkage gaps.

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