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The Influence of Timber Treatment Preservative Systems on the Performance of Commercial Resistance-Based Moisture Meters

G Kear

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Preface

This report examines the influence of preservative treated timber on the performance and calibration of electrical resistance-based moisture meters.

Acknowledgements

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External Reviewer

Dr Tony Bergervoet, Koppers Arch.

Note

This report is intended for use by researchers considering the influence of timber preservative treatments on the performance of moisture meters.

The Influence of Timber Treatment Preservative Systems on the Performance of Commercial Moisture Meters

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Reference

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Abstract

In this report three conductivity-based moisture meters have been used to measure the moisture content of 10 timber specimens – treated or untreated and all based on the wood species *Pinus radiata*. The moisture meters and the timber specimens used within this work are all commercially available in New Zealand. Moisture content data is measured and presented as a function of atmospheric equilibration at 65%, 75% and 98% relative humidity at 21±2°C. Verification was provided by the standard oven-dry method as specified by AS/NZS 1080.1

The aim of the research was to quantify the applicability of using all commercially resistance-based meters (available in New Zealand) with a single table of correction figures. With an examination of the results presented in this report, however, such an approach does not appear to be feasible without more thorough standardisation of meter use in New Zealand. Two of the three meters examined in this work were produced overseas, but are also instruments that are commonly sold in New Zealand. In some instances, the internationally produced meters did not reproduce the behaviour of one commercial meter which, it is reported, was manufactured and calibrated to the specifications and the correction figures laid out in AS/NZS 1080.1.

When the individual moisture meter correction figures (as supplied with each meter type) were introduced to the directly measured resistance data, all of the meters were able to accurately determine the moisture content of untreated *Pinus radiata* to within ±1% moisture meter units. In many cases, however, the introduction of treated timbers significantly lowered the accuracy of all of the meters to a degree which was dependent on the timber preservative type and the mode of meter operation. Of particular concern was the inability of some meters at 65% and 75% relative humidity to accurately determine the moisture content of ACQ, LOSP and boron treated timbers within at least ±2% moisture meter percentage units.

Keywords

Moisture meters, AS/NZS 1080.1, electrical resistance, oven-dry, correction figures, timber preservatives.

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1. INTRODUCTION

1.1 Moisture content determination

From the standpoints of decay and corrosion of associated metallic components, the accurate determination of moisture content within timber is essential for the assessment of durability. The use of commercial meters is often the most practical and most widely used method of acquiring levels of water content both prior to and post-construction (Anon 1966, Anon 1991, Simpson 1996, Burkinshaw 2002). Accurate assessment of moisture levels in timber, however, may be complicated by the presence of ionically conductive preservative treatments such as CCA, CuAz and ACQ formulations. It is prudent, therefore, to assess meter accuracy and reproducibly in relation to the more accurate standard weight loss method of moisture content analysis. For example, that described by AS/NZS 1080.1:1997 *Timber-methods of Test: Method 1: Moisture Content* (Standard 1997).

1.2 Moisture meters and treated timbers

There is a current requirement within the New Zealand building industry to have an improved understanding of the performance of moisture measurement in treated timbers. This report aims to confirm whether calibration curves produced for specific timber treatments can be applied to all conductivity-based commercial meters available in New Zealand. This work will contribute to fundamental knowledge regarding interactions between the standard oven-dried method, timber treatment preservative systems, modes of electrode application and a range of resistance-based instruments currently available to the New Zealand building industry.

Confirmation that calibration curves may be successfully applied to all commercial meters available in New Zealand could possibly address the issues surrounding the practical application of moisture measurements in a very simplistic manner i.e. via tabulated data. This report does not include the effects of additional problems such as localised preservative overloading and excessive surface moisture content.

Conversely, if it is proven that not all commercially available moisture meters can be used with universal calibration tables, the solution to the problem of preservative treatments will not be solved without further standardisation – quite possibly at an international level. More effective standardisation of the instrumentation, such as that attempted by AS/NZS 1080.1:1997 (Standard 1997), may have to be introduced.

Regardless of the outcome of this report, an increased level of industry awareness of the issues associated with timber treatments and moisture content measurements will result from technology transfer of the knowledge and recommendations as published. Thus, this research will lead to an improved understanding of the use of moisture meters in the building and construction industry, and hence an improvement in the monitoring, maintenance and durability of the built environment.

In this report three conductivity-based moisture meters will be used to measure the moisture content of 10 timber specimens (based on *Pinus radiata*). The moisture meters and the timber specimens used within this work are all commercially available in New Zealand. Data will be presented as a function of fully moisture equilibrated timber post-exposure under conditions of 65%, 75% and 98% relative humidity and 21±2°C. Verification will be provided by the oven-dry method as specified by AS/NZS 1080.1:1997 (Standard 1997).

Of particular interest are treated wood samples used in the field for framing timbers at the H1.2 or H3.1 levels. Unlike H3.2, H4 and H5, these timbers are only specified for dry or periodically wetted locations, and they are most likely to be the subject of moisture content estimation in practice. In some cases, the H3.2 hazard class may also be applied within similar environments to that of H3.1. Appropriately treated CCA- and ACQ-based timbers, therefore, were also included along with untreated *Pinus radiata*. Typical in-service conditions of each hazard class as summarised by NZS 3640:2003 (Standard 2003) are presented in Table 1. Each timber was examined using AS/NZS 1080.1 (Standard 1997). The BRANZ Pilot Study: *Determination of Water Content in CCA, ACQ and CuAz Treated Timbers Using Commercial Moisture Meters* (Kear 2004) is also referenced.

The results taken from each of the meters will be analysed as a function of timber preservative type. Individual correction figures will be determined relative to measurements made using the oven-dried method. A positive result for all meters can be assumed if a statistically identical correction figure for each timber treatment can be applied to the population of all the meters examined. This report does not aim to directly assess the relative performance of the individual moisture meters.

Table 1. Hazard classification as described in NZS 3640:2003 (Standard 2003).

Hazard class	Exposure	Service conditions	Biological hazard	Typical uses
H1.2	Protected from the weather, above ground, but with a possibility of exposure to moisture	Protected from the weather, but with a risk of moisture content conductive to decay	Borers and decay	Wall framing (see NZS 3602)
H3.1	Exposed to the weather above ground	Periodic wetting, not in contact with the ground	Decay, fungi and borers	Cladding, fascia, joinery (see NZS 3602)
H3.2	Exposed to the weather, above ground, or protected from the weather, but with a risk of moisture entrapment	Periodic wetting, not in contact with the ground, more critical end uses	Decay, fungi and borers	All H3.1 uses plus structural and decking (see NZS 3602)

1.3 Conductivity- and capacitance-based meters

In general, there are two types of commercially available moisture meters commonly available in New Zealand (Burkinshaw 2002):

- *Electrical resistance meter*s operate via two, or more, 'pin probes' that are pressed directly into the matrix of the substrate. A voltage (V) is applied between the electrodes and the current (I) is measured. The resistance (R) is calculated from Ohm's law (Atkins 1992):

  $$R = V/I \qquad (1)$$

  In theory, the electronic resistance of timber will decrease in a relatively constant manner over a given range of moisture content as the concentration of free water increases. The response of the meter is calibrated using a standardised electrical resistance circuit and adjusted to comply with a range of timber species and timber treated with various preservative types (Simpson 1996, Standard 1997). For all of the conditions examined in this work, the tabulated series of correction figures (given at various temperatures) as supplied by the manufacturer with instrumentation packaging will be used in preference to those published in AS/NZS 1080.1 (Standard 1997).

- *Capacitance meters* produce an electrical field beneath the body of the meter (Burkinshaw 2002). Transmitter/receiver electrodes enable a capacitance response to be measured, which is again dependent on the concentration of the moisture within the timber and any other conductive media within range of the instrument. The capacitance meter has the advantage of significantly reducing or eliminating the damage caused by the diagnostic procedure.

Work at BRANZ has shown (Kear 2004) that capacitance-based meters are considerably less reliable than resistance-based instruments. In this previous work, the most accurate percentage moisture determinations (relative to weight loss studies) were produced by the resistance meter method. The resistance meter also produced the highest precision and no gross dependency on sample thickness or grain orientation was observed.

It was also noted that localised effects resulting from uneven treatment (preservative loading) of the timber can result in erroneous measurements. Significant over-estimations of moisture levels can result within areas of excess surface and sub-surface preservative chemical loading. As noted by others (Simpson 1996), therefore, preservative timber treatments will influence measurements made with conductivity-based instruments in wood. All meters should be used with caution when applied to preservative treated timber. Indeed, the application of meter measurements to H4, H5 and H6 hazard class (Standard 2003) preservative treated timber may be extremely detrimental to the accuracy of both the capacitative- and conductivity-based meters as the concentrations of preservative will be of a relatively high order in these cases (Kear 2004). Conditions of exceptionally high uniform preservative overloading will not be a common occurrence under the majority of circumstances of meter use i.e. with dry or periodically wetted timbers. But if such conditions are encountered, independent verification should be sought via an alternative oven-drying method of moisture determination.

Further details relating to the correct use, applications and limitations of commercial moisture meters can be found within a number of recent (Burkinshaw 2002, Crissinger 2006a, Crissinger 2006b) and established (Anon 1991, Simpson 1996) review articles and publications. In this report reference will only be made to the specific instructions provided by each manufacturer and the limitations specified in AS/NZS 1080.1:1997 (Standard 1997).

AS/NZS 1080.1 (Standard 1997) states that electrical resistance-based moisture measurements are generally limited in accuracy between 8% to 25% moisture wt./wt. Although this standard states that for timbers thicker than 25 mm the use of ‘short electrodes’ will be misleading, such an approach was included in this research in order to quantify the effects of electrode depth and separation. In general, AS/NZS 1080.1 notes that the depth of electrode should be correlated with the required depth of moisture analysis and insulated electrode should be used in these cases where the core of timber thicker than 25 mm is of interest. As with most of the other publications quoted in this report, it is also made clear in this standard that:

> *In the case of preservatives, the meter will read differently for treated timber and untreated timber of the same moisture content. This effect increases with the preservative loading and the moisture content (i.e. the effect is greater at higher moisture content.*

The detrimental influence of sea salt and increasing temperature will decrease the electrical resistance, and the meter reading will produce erroneously positive values in a response for a given specified moisture content. Overall, the text of AS/NZS 1080.1 makes clear that oven-drying of the timber under controlled conditions is the preferred method of moisture concentration determination and calibration is permitted using this methodology.

The accuracy of the resistance type of meter is generally accepted to be 1% error within the range of 7% to 10% values of moisture content (Standard 1997). This error increases with higher water concentrations and is unsuitable above 40% MC.

It is noted in AS/NZS 1080.1 that needle electrodes should be inserted into the timber at their fullest length. From practical experience, however, this is often impossible to achieve without damaging the electrodes. In this regard, probes of the hammer type must be considered to be the more accurate choice of electrode assembly.

1.4 NZS/AS 1080.1 and Approved Document for the New Zealand Building Code, Clause E2/AS1

The use and application of methods of test for the determination of moisture in timber structures is covered in the New Zealand Building Code (NZBC), Clause E2/AS1 (NZBC 2005) where it is stated that moisture meter usage shall be limited to the recommendations given in the New Zealand Forest Research Institute (SCION) publication *Measurement of Moisture Content of Assembled Timber Framing* (Anon 1993). This publication, which cross-references other SCION documents (Simpson 1996), recommends and describes only the use of conductivity-based meters. The Australian and New Zealand standard NZS/AS 1080.1:1997 (Standard 1997) only covers two methods of test:

- *The oven-dry method* – 'applicable where accuracy rather than time taken to obtain a result is important', and
- *The electrical resistance method* – 'gives less accurate results but can be used for routine monitoring'.

The capacitance methodology, therefore, is not covered by any Acceptable Solution or standard and will not be included in the findings of this report.

1.5 Existing tables of correction figures

Tabulated correction figures for standard resistance-based conductivity meters (described at the time by AS/NZS 1081.1:1996) were published by Simpson through the New Zealand Forest Research Institute (Simpson 1996). These tables included corrections for temperature and timber species commonly utilised in Australasia. It is these tabulated values that are presented verbatim to the purchaser of Moisture Meter Type 'Y' used in this research (see Section 2, 'Experimental procedure' for details of each meter type). Currently, AS/NZS 1081.1:1997 presents the widest range of correction figures for both Australasian and international timber species (including preservative treated *Pinus radiata*). It should be noted in this regard that moisture meters produced in, for example, the USA and Canada, are supplied with correction figures which do not entirely correlate with those presented in AS/NZS 1081.1:1997 or with the work of Simpson.

The various values of correction figures are discussed in more detail in Section 3, 'Results and discussion'. The comprehensive review of publications which led to the AS/NZS 1081.1 correction figure tables is also available from Appendix A of this standard.

2. EXPERIMENTAL PROCEDURE

In all cases involving the application of the oven-dry moisture content methodology, the procedures set out in AS/NZS 1080.1 (Standard 1997) were rigorously adopted. The timber species used throughout was *Pinus radiata* (supplied and used in 45 x 90 mm cross-section). Timbers were purchased from retail outlets or supplied directly by the manufacturer in multiples of 3 m lengths – all of which were later cut to 1 m lengths prior to moisture equilibration (see later for details).

In addition to untreated timber, nine different formulations of preservative treated *Pinus radiata* were selected for analysis as described in Table 2. The treated timber was selected from both LOSP (TBTN, TBTO, propiconazole and tebuconazole, IPBC and CuN) and waterborne (CCA oxide, ACQ and boron) preservative systems. The specific identification of the treatment hazard class, active preservative and treatment plant was obtained via analysis of the timber branding (when available) as described in NZS 3640:2003 (Standard 2003). During testing and data analysis, uniform preservative loading was assumed throughout. Evidence of the non-compliance of the treated timbers in this respect resulted in immediate rejection of the sample prior to analysis.

Table 2. Identification, hazard class and origin of the treated specimens (*Pinus radiata*).†

BRANZ ID	Generic description	NZS 3640 hazard class	Active preservative ingredients (brand)	(WOODmark®* brand) treatment plant
A	LOSP	H3.1	(64) Propiconazole and tebuconazole	(098) WPI Sawmilling, Tangiwai, Ohakune
B	Untreated	–	–	–
C	ACQ	H3.2	(90) Alkaline copper quaternary	(285) Eastown Timber Products, Whanganui
D	Boron	H1.2	(11) Boron	(168) Red Stag Timber, Rotorua
E	CCA	H3.2	(01) CCA oxide	(756) Davis Sawmilling Ltd, Featherston
F	T1.2 boron	Non-approved hazard class (T1.2)	(No brand) Boron	(058) South Pine, Nelson
G	LOSP	H1.2	(63) IPBC	(131) Papakura Timber Processors Ltd, Papakura
H	LOSP	H3.1	(56) TBTO	(131) Papakura Timber Processors Ltd, Papakura
I	LOSP	H3.1	(62) TBTN	(144) Hunters (1998) Ltd, Richmond, Nelson
J	LOSP	H3.1	(No brand) CuN	No brand (Source: Koppers Arch)

* Woodmark (NZ Timber Preservation Council Inc) Licensees
† Date of timber treatment is variable

Post complete moisture equilibration over a period of at least one month under conditions specified by ASTM D 4933 (Standard 1999), the moisture content of the timber samples was measured using each of the meters and probes as noted (anonymously) in Table 3. A total of six moisture meter conditions were established.

- X, Y and Z relates to three different manufacturers
- (i) and (ii) relate to different models originating from a single manufacturer, and
- E, H and C relate to the electrode mode of application
  - ‘E’ externally held and pushed into timber
  - ‘H’ hammer electrode (insulated – excluding tip – and driven to 25 mm depth), and

- ‘C’ electrodes directly attached to the case of the instrumentation and pushed into timber.

The electrode tip separation and mean penetration distances are also listed in Table 3.

Table 3. Moisture meter origin, usage and arbitrary identification.

BRANZ ID	Company	Model	Origin	Detail of usage	Electrode spacing / mm	Average penetration
X(i)E	X	(i)	USA	External hand-held electrodes	13 mm	2–5 mm*
X(i)H	X	(i)	USA	Hammer electrodes	23 mm	15 mm†
X(ii)E	X	(ii)	USA	External hand-held electrodes	13 mm	2–5 mm*
X(ii)H	X	(ii)	USA	Hammer electrodes	23 mm	15 mm†
Y(i)H	Y	(i)	New Zealand	Hammer electrodes	23 mm	15 mm†
Z(i)C	Z	(i)	Canada	Case attached electrodes	15 mm	6–10 mm*

* Dependent on hardness of timber at time of measurement
† Only bottom 8 mm of both electrodes active due to shaft insulation

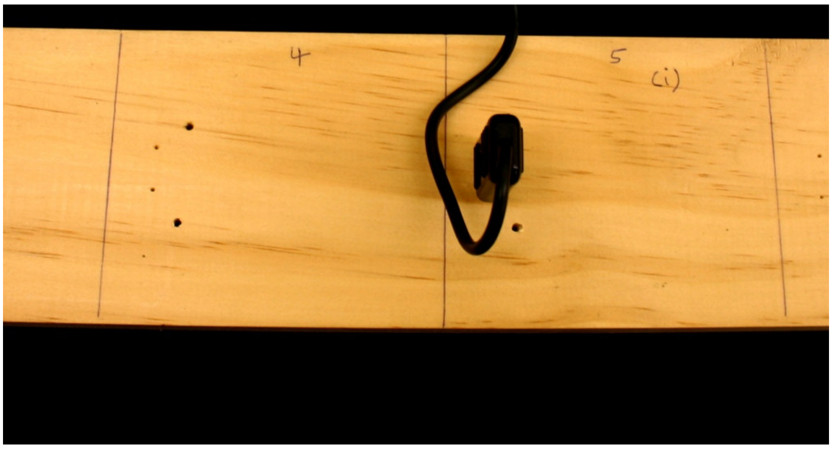

Figure 1. Test Positions 4 and 5 as shown for the untreated timber specimen (the hand-held probe is shown which relates to meter conditions X(i)E and X(ii)E). Note that to this point, as shown, only meter conditions X(i)E and X(i)H have been used in this sample – the difference in electrode tip separation and electrode width can be clearly seen via the holes left within the timber.

Each 1 m length of timber was superficially divided into 10 segments prior to cutting (each section 100 mm length) and labelled from 1–10 (see Figures 1 and 2). The 10 segments on the single piece of timber were examined with each class of meter. The surface temperature of the timber at the time of analysis was held between the limits of 21±2ºC. Note that the timber was never re-measured in an identical location i.e. the electrode pins were never re-inserted at any single point along the length of the timber. The timber itself was always supported above the floor of the air-conditioned and humidified work space using two wooden ‘saw-horses’ positioned at either end of the 1 m long specimen. Measurements were made away from imperfections such as knots and other surface defects (during purchase, the specimen timbers were specifically chosen for purity in grain and lack of structural discontinuity).

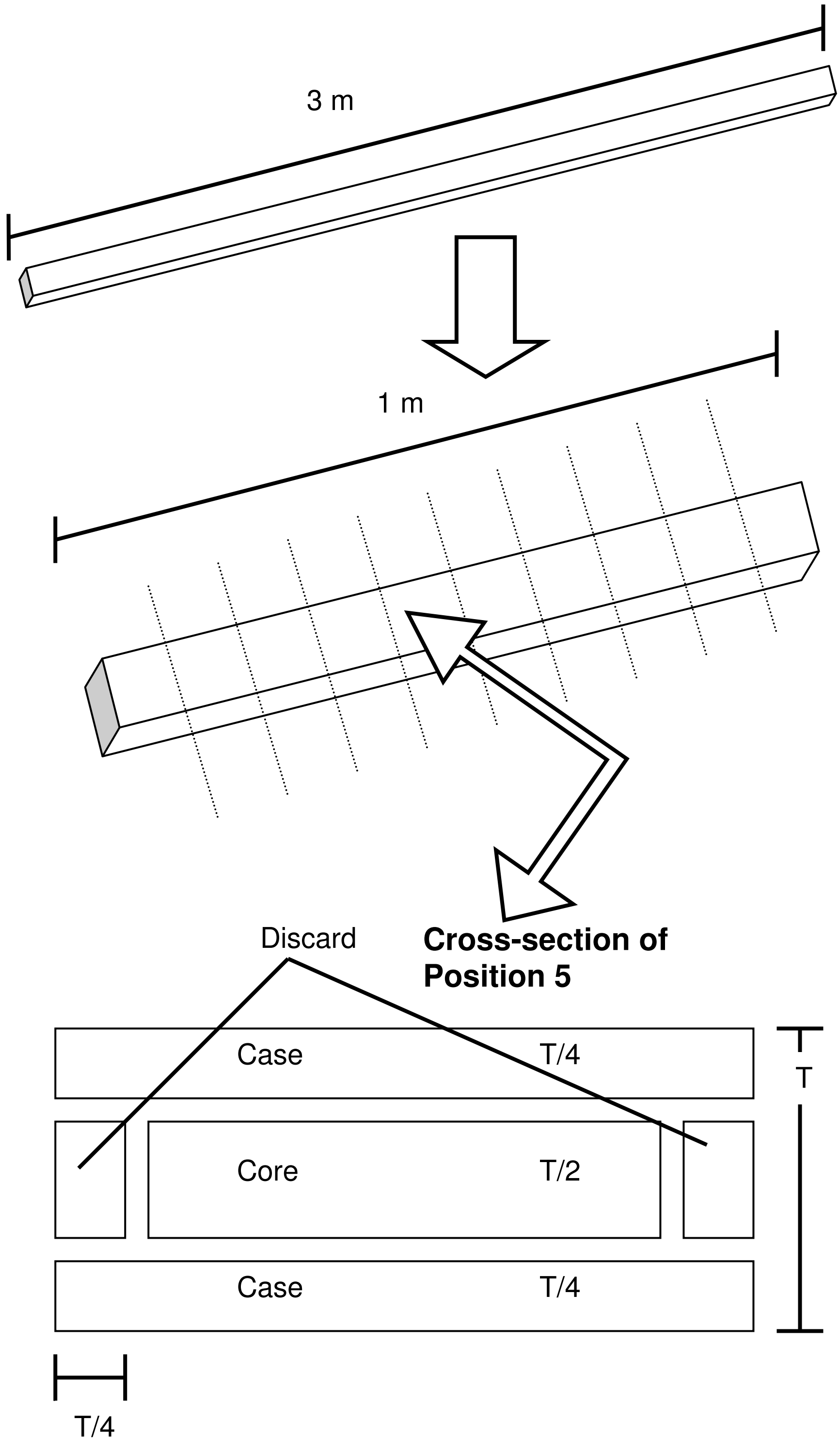

Figure 2. Cutting and sequencing of the timber specimens according to Cutting Pattern (a) as described in AS/NZS 1080.1 (Standard 1997). T = 45 mm (drawing not to scale).

The operation of each meter was performed strictly according to the manufacturer's instructions and always without the use of correction figures. The precautions in the use of the meters were followed as specified in AS/NZS 1080.1:1997, Appendix E (Standard 1997). Calibration of the meters was performed using the manufacturer's calibration circuits as supplied. This was carried out immediately prior to testing. Standard deviation as shown is calculated at 95% confidence limits.

Samples for weight loss measurements were cut immediately after each moisture meter analysis and always taken from the centre of the 1 m timber lengths at Position 5 – a section which was at a position greater than 0.4 m from the end of each length of timber. The Position 5 timber sample was then cut into test pieces for determining moisture distribution according to Cutting Pattern (a) as presented in AS/NZS 1080.1 (Standard 1997). Figure 2 describes this pattern which resulted in a single core with two case components (all of which were 100 mm in length). The timber components were then oven-dried within 103±2℃ until constant mass was achieved. The percentage moisture content (MC) was then determined through the relationship (Standard 1997):

$$MC = \frac{(M_i - M_o)}{M_o} \times 100 \qquad (2)$$

M_i Initial mass of test piece

M_o Oven-dry mass of test piece

Theoretically, it may be proposed that the use of small pins at a relatively reduced depth, i.e. X[i]E, X[ii]E and Z[i]C, will result in a higher accuracy in the determination of the moisture content of the cases as shown in Figure 2 (Simpson 1996, Anon 1997). Conversely, the hammered electrodes are used at greater depths and should produce values closer to that of the timber core.

3. RESULTS AND DISCUSSION

3.1 Distribution of moisture content

The distributions of electrical resistance-based moisture content, as measured along the whole 1 m lengths of the 10 timber specimens, are presented in Appendices 6.1, 6.2 and 6.3 (see Figures 9–36). The appendices are split into those measured at timber moisture equilibrated at 65% relative humidity (Appendix 6.1, Figures 9–18), 75% relative humidity (Appendix 6.2, Figures 19–28) and 98% relative humidity (Appendix 6.3, Figures 29–36). In all of these figures, the Position 5 core and case oven-dried moisture contents are presented as the straight lines running from left to right. These oven-dried data strictly only apply the moisture meter measurements made at timber specimen Position 5, and comparison between the oven-dried and the electrical resistance methodology types should only be made at this position on the original timber specimen.

In these appendices, all six moisture meter conditions are shown from meter conditions X(i)E to Z(i)C. Note that the output of meters Y(i)H and Z(I)C is limited to integers. The meters signified by the manufacturer 'X' are capable of presenting data to a single decimal place. As can be seen from a number of the figures, it is possible to observe a significant variation in the distribution of resistance derived moisture content from one end of the 1 m length of timber to the other. This effect was especially prevalent for the 98% relative humidity conditions. Such deviation was probably a combination of the natural variation in the structure of the wood and the extremely large error associated with meter measurement at high moisture content. In a small number of cases, it may be possible that uneven loading of water due to incomplete moisture conditioning had occurred.

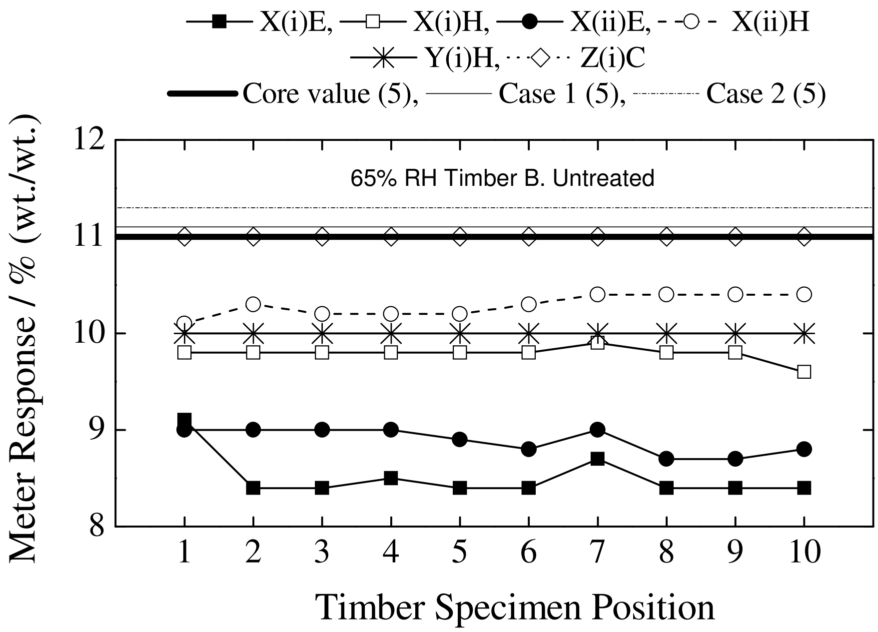

Figure 3. Distribution of moisture content across the length of Timber B (untreated) at 65% relative humidity – presented as a function of analysis methodology.

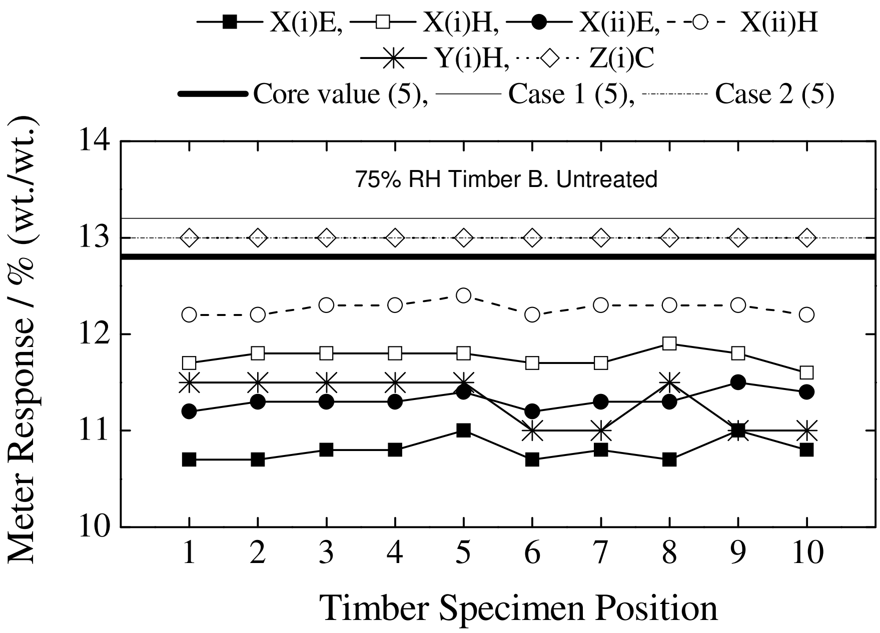

Figure 4. Distribution of moisture content across the length of Timber B (untreated) at 75% relative humidity – presented as a function of analysis methodology.

From an initial qualitative examination of the figures given in Appendices 6.1, 6.2, 6.3 (and the examples reproduced in this section for untreated timber in Figures 3 and 4), the following statements can be drawn regarding the results of the moisture meter measurements.

- Significant variation was observed to exist between the different timber specimens in terms of:
  - equilibrium moisture content, and
  - variability of moisture content distribution across the length of the samples when measured using the meters.
- The relative deviation of uncorrected moisture content measured between each of the meter types is not constant i.e. the difference in the absolute value of uncorrected measurement from one meter condition to the other was observed in many cases to vary when sampling a single timber specimen.
- For a single model of meter, the mode of operation i.e. hand-held probe vs hammer electrode will have a significant influence over the uncorrected resistance data. This effect cannot be simply assigned to depth of sampling alone. Large variations were also observed between the 'shallow sensing' hand-held probes and the oven-dried surface 'case' sections (see Figure 2) which were taken from the surfaces of the original timber specimen.

  This difference between electrode techniques observed when using an identical meter is quite possibly the result of both electrode spacing and electrode diameter considerations. No correction for such effects was supplied with any of the meters.
- Not all moisture meters can be assigned a single correction figure for a given timber treatment. This is very clear from the wide deviation of uncorrected meter determinations measured using different meter types.

3.2 Moisture content of specimen Position 5

The oven-dried moisture contents of the various timber samples (equilibrated at 65%, 75% and 98% relative humidity) are presented in Tables 4, 5 and 6. In the majority of cases, the treated timbers retained moisture at levels in excess of that of the untreated timber and, with one or two exceptions, the highest moisture content was usually measured within the core of the timber. In general, the highest moisture contents at 65% and 75% relative humidity were measured for Timber E (CCA H3.2), Timber H (LOSP H3.1 TBTO) and Timber J (LOSP H3.1 CuN).

The absolute values of oven-dried moisture content are compared to the uncorrected resistance-based meter readings in Appendix 6.4 (see Figures 39–48). To illustrate, the data for untreated and the ACQ H3.2 treated timbers has been reproduced here in Figures 5 and 6.

Considering the untreated timber specimen (which was specifically chosen for a high quality knot-free structure), exposed at 65% and 75% relative humidity (see Figures 3 and 4), only one of the meter conditions (Z[i]C) was able to accurately reproduce the oven-dried moisture content at Position 5 without the introduction of a correction figure. Due to the relative homogeneity of the timber, the moisture content was also essentially constant across the whole length of the samples. Note that the oven-dried core and case values were very similar and within an absolute value of 0.5% wt./wt. moisture content. In the uncorrected state, the 'X' and 'Y' meters were not as accurate as the Z(i)C type of condition.

Table 4. Oven-dried moisture contents at 65% moisture content.

Specimen ID	Treatment	Position	Test piece	% Moisture (wt./wt.)
A	LOSP	5	case 1	13.8
			core	15.2
			case 2	13.4
B	Untreated	5	case 1	11.1
			core	11.0
			case 2	11.3
C	Waterborne	5	case 1	13.5
			core	13.8
			case 2	13.1
D	Waterborne	5	case 1	13.9
			core	13.4
			case 2	13.1
E	Waterborne	5	case 1	15.3
			core	16.1
			case 2	15.4
F	(T1.2)	5	case 1	12.4
			core	13.3
			case 2	12.2
G	LOSP	5	case 1	11.9
			core	13.5
			case 2	12.7
H	LOSP	5	case 1	14.6
			core	15.4
			case 2	14.6
I	LOSP	5	case 1	12.3
			core	13.1
			case 2	12.1
J	LOSP	5	case 1	14.3
			core	16.4
			case 2	15.4

When using the meters manufactured by ‘X’ in the untreated timber, the uncorrected accuracy of the measurements increased somewhat with the use of the hammer probes. The difference in moisture content when using the hammer probes relative to the hand-held external probe led to measurements which were only approximately -1% to 1.5% meter percentage units lower than that of the oven-dried response of both the core and the cases at Position 5. When using the hand-held external probes, as supplied by this particular manufacturer, the equivalent concentrations were 2 to 2.5 percentage units lower than the oven-dried values.

Table 5. Oven-dried moisture contents at 75% moisture content.

Specimen ID	Treatment	Position	Test piece	% Moisture (wt./wt.)
			case 1	13.2
A	LOSP	5	core	15.5
			case 2	13.6
			case 1	13.2
B	Untreated	5	core	12.8
			case 2	13.0
			case 1	14.4
C	Waterborne	5	core	15.2
			case 2	14.8
			case 1	15.2
D	Waterborne	5	core	14.9
			case 2	15.2
			case 1	16.0
E	Waterborne	5	core	17.2
			case 2	16.5
			case 1	14.2
F	(T1.2)	5	core	15.8
			case 2	14.0
			case 1	12.1
G	LOSP	5	core	12.3
			case 2	11.9
			case 1	15.6
H	LOSP	5	core	16.4
			case 2	15.6
			case 1	13.1
I	LOSP	5	core	14.5
			case 2	13.4
			case 1	16.2
J	LOSP	5	core	17.0
			case 2	15.8

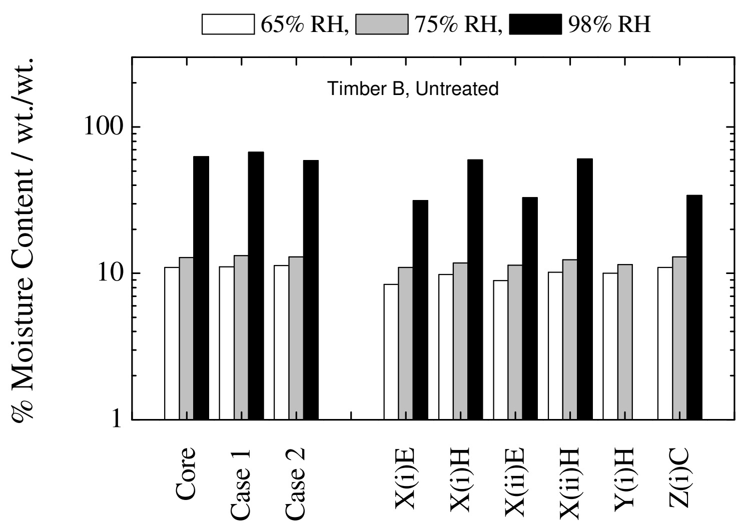

Figure 5. Comparison of oven-dry and meter moisture content methodologies at 65%, 75% and 98% relative humidity for Timber B (untreated), 'Position 5'.

Table 6. Oven-dried moisture contents at 98% moisture content.

Specimen ID	Treatment	Position	Test piece	% Moisture (wt./wt.)
			case 1	29.4
A	LOSP	5	core	27.8
			case 2	30.2
			case 1	67.2
B	Untreated	5	core	62.6
			case 2	58.8
			case 1	128.1
C	Waterborne	5	core	86.7
			case 2	131.5
			case 1	80.7
D	Waterborne	5	core	49.9
			case 2	78.8
			case 1	47.4
E	Waterborne	5	core	45.1
			case 2	45.2
			case 1	130.0
F	(T1.2)	5	core	73.4
			case 2	132.5
			case 1	35.2
G	LOSP	5	core	30.9
			case 2	36.9
			case 1	44.2
H	LOSP	5	core	31.3
			case 2	39.2
			case 1	32.2
I	LOSP	5	core	31.3
			case 2	32.9
			case 1	25.1
J	LOSP	5	core	25.4
			case 2	27.1

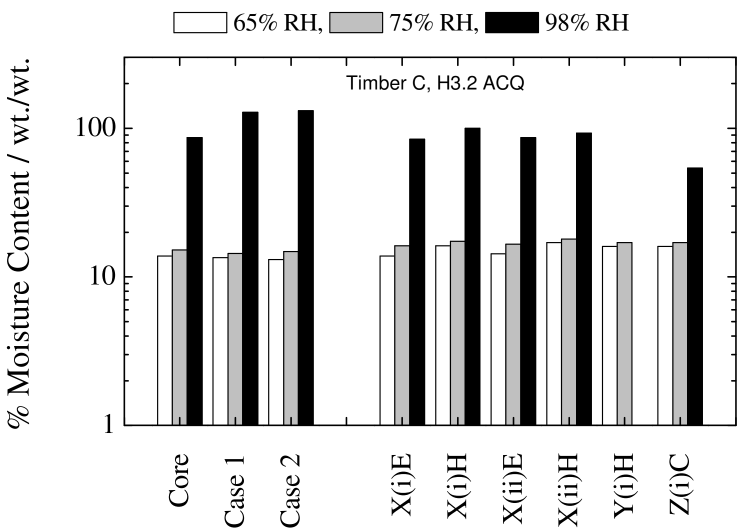

Figure 6. Comparison of oven-dry and meter moisture content methodologies at 65%, 75% and 98% relative humidity for Timber C (H3.2 ACQ), 'Position 5'.

An initial increase in ‘uncorrected accuracy’ with use of the X(i) and X(ii) meter type hammer probes was also consistently observed with treated Timbers A, E, G, H, I and J at both 65% and 75% relative humidities. With Timber C, however, the use of the probe produced a negative effect and no significant change was measured when Timbers D and F were interrogated using the two types of probe. These specific observations were very reproducible over both 65% and 75% relative humidity exposures. Clearly, timber treatments when considered as a whole do not have an identical or consistent influence over either:

- the behaviour of the electrode assemblies, or
- a single meter if used in isolation.

The data produced for meter type Y(i)H showed highly variable behaviour in some instances which was entirely inconsistent with the results produced using the other meters. Such an apparent independent mode behaviour was also replicated following immediate re-calibration and repetition of the testing. Note, for example, the behaviour of meter Y(i)H (in Appendix 6.1, Figures 12 and 14 [65% relative humidity] and Appendix 6.2, Figures 22 and 24 [75% relative humidity]) for Timber D and F – both of which are boron-based treatments). For these timbers, the meter read much lower values of moisture content than meters D(i)E, D(i)H, D(ii)E, D(ii)H and Z(i)C. When used under other conditions – where boron is not used as a preservative – the Y(i)H instrument produced very similar resistance values which were generally equivalent to the other meters when the ‘hammer’ and ‘case’ electrodes (excluding ‘external electrodes’) are incorporated. See Appendices 6.1, 6.2 and 6.4 for the moisture measurement of Timbers A, B, C, E, G, H, I and J at both 65% and 75% relative humidity.

Theoretically, the principle of operation of electrical resistance meters should be identical in every case and such relative discrepancies are surprising. This further indicates that universal calibration curves for treated timber may not provide an ideal correlation for all brands of commercially available moisture meters.

With such limitations in mind, it must be noted that these uncorrected data can only be used in an attempt to derive individual empirical correction figures. They do not provide any information on the accuracy of the meters post-calibration to factors as specified by the manufacturer. Meter accuracy post-correction of the meter using the supplied correction figures is the only true method of comparing the accuracy of each instrument as intended for use by the purchaser. It is clear that at least one of the manufacturers has calibrated the baseline response of their instrument in variance to their competitors. The use of manufacturer’s correction figures will be covered in later sections of this report, but since only a single set of correction figures was supplied with instruments X(i) and X(ii), the errors introduced by the different electrode types will certainly be present post-calibration of the readings.

The percentage error (deviation) of each moisture meter type and electrode condition is presented in Table 8. This table gives the percentage error of the uncorrected meter derived data relative to the standard (base-line) oven-dried results. Absolute values of deviation, in terms of difference in the percentage moisture content unit as presented to the operator by the meters, are presented in the following section.

The percentage error may be positive or negative depending on whether the uncorrected meter reading is in excess or lower than that of the timber core and the mean of the two timber case sections as measured using the oven-dried method. Considering the 65% and 75% relative humidity condition, the data in Table 7 can be used to show that, as seen in the preceding section, the error associated with each type of meter can be equivalent in some cases, but rather discontinuous in others.

For example, relative to the core samples at 65% relative humidity, Timber A (LOSP) produced X(i)H, X(ii)H, Y(i)H and Z(i)C errors of -9.2%, -3.3%, -14.5% and -14.5%, respectively. At 75% relative humidity the equivalent values were -10.3%, -9.0%, -12.9% and -9.7%, respectively. Only timber cores are considered here and the external hand-held pin electrodes excluded from the analyses (but the sole 'case' pin electrode of the Z(i)C instrument is included). In the example given above, all the errors are negative and of similar order. This shows that for some timbers an overall correction figure may be introduced with some success with around a maximum estimated error in the corrected moisture reading of 10% to 15%. Favourable correlations of a similar order were also found for Timbers C (ACQ), E (CCA), H (LOSP), I (LOSP) and J (LOSP).

Examples of poor correlation when measured between meters used at an identical piece of timber were Timbers D (boron) and F (boron). At 65% relative humidity the percentage errors relative to the oven-dried core samples of Timber D were +12.7% (X[i]H), +22.4% (X[ii]H), -10.4% (Y[i]H) and +26.9% (Z[i]C). These are typical of Timbers D and F where the majority of the error was introduced by the deviating performance (uncorrected) of meter type Y(i)H in the boron treated timbers.

Untreated timber also produced a generally imperfect correlation in percentage error between the meters (as did Timber G [LOSP]). The former discrepancy is certainly due to an inherent difference in the base-line value assigned to the meters during the original calibration on manufacture. It must be understood, however, that timber in general is a highly variable and anisotropic material and all treated samples will also differ in the quantity and quality of preservative loading. Moreover, it is highly unlikely that the specimens examined in this exercise will produce identical results to potential samples taken from the enormous population of timber pieces available in the New Zealand market place.

Using the data produced in this work, values of the absolute deviation of the resistance measurements relative to the oven-dried measurements have been calculated and presented both in Table 8 and in figure form in Appendix 6.5. An example is reproduced here for untreated *Pinus radiata* in Figure 7. All of the uncorrected moisture meter readings, with the exception of meter Z(i)C, under-estimate the actual concentration of moisture in the core of the timber and the mean of the cases. The uncorrected reading of Z(i)C exactly replicated the oven-dried value, but has no suggested manufacturer's correction for *Pinus radiata*. Overall, the experimental data from this work shows that in most cases there is no single correction figure which can be applied to each treated timber specimen and moisture meter in order to obtain a percentage reading which can be assumed to be accurate in every instance.

By taking the suggested correction figures as individually provided by the manufacturers (examples are given in Table 9 for 16% moisture content) the experimental data was re-calculated and presented in terms of absolute deviation from the core and mean case oven-dried data. The graphical data for all 10 timber specimens is presented in Appendix 6.6 (Timber B is reproduced in Figure 8 as an illustration). With reference to both the corrected data in Figure 8 and the uncorrected information in Figure 7 for the untreated timber, it is clear that the manufacturer correction figures as supplied with the instrumentation were able to significantly improve the correlation of the meter readings with the oven-dried method to within ±1% moisture content unit.

Table 7. Percentage error of the uncorrected meter derived moisture levels relative to the oven-dried data.

	Percentage error from oven-dry method wt./wt.					
Timber A	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	-25.7	-9.2	-23.7	-3.3	-14.5	-14.5
65% Mean of cases	-16.9	1.5	-14.7	8.1	-4.4	-4.4
75 % Core	-29.0	-10.3	-28.4	-9.0	-12.9	-9.7
75% Mean of cases	-17.9	3.7	-17.2	5.2	0.7	4.5
98% Core	-11.9	18.0	-18.7	15.1	0.7	-10.1
98% Mean of cases	-17.8	10.1	-24.2	7.4	-6.0	-16.1
Timber B	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	-23.6	-10.9	-19.1	-7.3	-9.1	0.0
65% Mean of cases	-25.0	-12.5	-20.5	-8.9	-10.7	-1.8
75 % Core	-14.1	-7.8	-10.9	-3.1	-10.2	1.6
75% Mean of cases	-16.0	-9.9	-13.0	-5.3	-12.2	-0.8
98% Core	-49.7	-5.1	-47.6	-3.5	-100.0	-45.7
98% Mean of cases	-50.0	-5.7	-47.9	-4.1	-100.0	-46.0
Timber C	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	0.0	17.4	3.6	23.2	15.9	15.9
65% Mean of cases	3.8	21.8	7.5	27.8	20.3	20.3
75 % Core	6.6	14.5	9.2	18.4	11.8	11.8
75% Mean of cases	11.0	19.2	13.7	23.3	16.4	16.4
98% Core	-2.5	15.2	-0.3	7.2	-	-37.7
98% Mean of cases	-34.9	-23.0	-33.4	-28.4	-	-58.4
Timber D	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	16.4	12.7	20.1	22.4	-10.4	26.9
65% Mean of cases	15.6	11.9	19.3	21.5	-11.1	25.9
75 % Core	16.8	21.5	20.8	24.2	7.4	20.8
75% Mean of cases	14.5	19.1	18.4	21.7	5.3	18.4
98% Core	25.3	100.2	30.1	86.2	-	-5.8
98% Mean of cases	-21.6	25.3	-18.6	16.5	-	-41.1
Timber E	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	-28.0	-7.5	-24.2	-6.2	-13.0	-13.0
65% Mean of cases	-24.4	-2.9	-20.5	-1.6	-8.8	-8.8
75 % Core	-20.3	-6.4	-15.7	-1.2	-9.9	-12.8
75% Mean of cases	-15.7	-0.9	-10.8	4.6	-4.6	-7.7
98% Core	-4.0	76.1	-3.3	90.0	-	-2.4
98% Mean of cases	-6.5	71.5	-5.8	85.1	-	-5.0

Table 7 (Continued). Percentage error of the uncorrected meter derived moisture levels relative to the oven-dried data.

	Percentage deviation from oven-dry method wt./wt.					
Timber F	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	6.8	9.8	15.8	20.3	-9.8	20.3
65% Mean of cases	15.4	18.7	25.2	30.1	-2.4	30.1
75 % Core	0.0	1.3	1.9	3.8	-8.2	1.3
75% Mean of cases	12.1	13.5	14.2	16.3	2.8	13.5
98% Core	36.1	36.1	26.6	26.6	-	-14.2
98% Mean of cases	-23.9	-23.9	-29.2	-29.2	-	-52.0
Timber G	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	-28.9	-13.3	-23.0	-4.4	-3.7	-3.7
65% Mean of cases	-22.0	-4.9	-15.4	4.9	5.7	5.7
75 % Core	-13.8	-5.7	-12.2	0.0	-2.4	5.7
75% Mean of cases	-11.7	-3.3	-10.0	2.5	0.0	8.3
98% Core	-12.9	23.3	-11.0	21.0	3.6	-12.6
98% Mean of cases	-25.4	5.7	-23.7	3.7	-11.2	-25.1
Timber H	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	-21.4	-5.2	-18.2	0.6	-9.1	-2.6
65% Mean of cases	-17.1	0.0	-13.7	6.2	-4.1	2.7
75 % Core	-9.1	0.0	-7.3	-0.6	-2.4	-2.4
75% Mean of cases	-4.5	5.1	-2.6	4.5	2.6	2.6
98% Core	19.5	68.1	13.4	70.9	-	8.6
98% Mean of cases	14.9	61.6	9.1	64.4	-	4.5
Timber I	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	-29.0	-13.0	-23.7	-6.1	-16.0	-8.4
65% Mean of cases	-23.8	-6.6	-18.0	0.8	-9.8	-1.6
75 % Core	-26.2	-15.9	-22.8	-11.7	-17.2	-10.3
75% Mean of cases	-19.2	-7.9	-15.5	-3.4	-9.4	-1.9
98% Core	-16.9	-2.9	-16.9	0.3	-10.5	-20.1
98% Mean of cases	-20.1	-6.6	-20.1	-3.5	-14.0	-23.2
Timber J	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	-27.4	-10.4	-22.6	-6.1	-14.6	-14.6
65% Mean of cases	-19.9	-1.0	-14.5	3.7	-5.7	-5.7
75 % Core	-17.6	-7.1	-15.9	-4.1	-11.8	-11.8
75% Mean of cases	-12.5	-1.3	-10.6	1.9	-6.3	-6.3
98% Core	-13.0	0.8	-13.4	-0.4	-7.5	-13.4
98% Mean of cases	-15.3	-1.9	-15.7	-3.1	-10.0	-15.7

Table 8. Individual meter correction figures for both timber core and the mean of the timber cases at the moisture contents presented in Tables 3, 4 and 5 at 21±2℃.

	Correction figures					
Timber A	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	+3.9	+1.4	+3.6	+0.5	+2.2	+2.2
65% Mean of cases	+2.3	-0.2	+2.0	-1.1	+0.6	+0.6
75 % Core	+4.5	+1.6	+4.4	+1.4	+2.0	+1.5
75% Mean of cases	+2.4	-0.5	+2.3	-0.7	-0.1	-0.6
98% Core	+3.3	-5.0	+5.2	-4.2	-0.2	+2.8
98% Mean of cases	+5.3	-3.0	+7.2	-2.2	+1.8	+4.8
Timber B	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	+2.6	+1.2	+2.1	+0.8	+1.0	0.0
65% Mean of cases	+2.8	+1.4	+2.3	+1.0	+1.2	+0.2
75 % Core	+1.8	+1.0	+1.4	+0.4	+1.3	-0.2
75% Mean of cases	+2.1	+1.3	+1.7	+0.7	+1.6	+0.1
98% Core	+31.1	+3.2	+29.8	+2.2	-	+28.6
98% Mean of cases	+31.5	+3.6	+30.2	+2.6	-	+29.0
Timber C	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	0.0	-2.4	-0.5	-3.2	-2.2	-2.2
65% Mean of cases	-0.5	-2.9	-1.0	-3.7	-2.7	-2.7
75 % Core	-1.0	-2.2	-1.4	-2.8	-1.8	-1.8
75% Mean of cases	-1.6	-2.8	-2.0	-3.4	-2.4	-2.4
98% Core	+2.2	-13.2	+0.3	-6.2	-	+32.7
98% Mean of cases	+45.3	+29.9	+43.4	+36.9	-	+75.8
Timber D	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	-2.2	-1.7	-2.7	-3.0	+1.4	-3.6
65% Mean of cases	-2.1	-1.6	-2.6	-2.9	+1.5	-3.5
75 % Core	-2.5	-3.2	-3.1	-3.6	-1.1	-3.1
75% Mean of cases	-2.2	-2.9	-2.8	-3.3	-0.8	-2.8
98% Core	-12.6	-50.0	-15.0	-43.0	-	+2.9
98% Mean of cases	+17.3	-20.2	+14.9	-13.2	-	+32.8
Timber E	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	+4.5	+1.2	+3.9	+1.0	+2.1	+2.1
65% Mean of cases	+3.8	+0.5	+3.2	+0.3	+1.4	+1.4
75 % Core	+3.5	+1.1	+2.7	+0.2	+1.7	+2.2
75% Mean of cases	+2.6	+0.1	+1.8	-0.8	+0.8	+1.3
98% Core	+1.8	-34.3	+1.5	-40.6	-	+1.1
98% Mean of cases	+3.0	-33.1	+2.7	-39.4	-	+2.3

Table 8 (Continued). Individual meter correction figures for both timber core and the mean of the timber cases at the moisture contents presented in Tables 3, 4 and 5 at 21±2°C.

	Correction figures					
Timber F	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	-0.9	-1.3	-2.1	-2.7	+1.3	-2.7
65% Mean of cases	+1.9	-2.3	-3.1	-3.7	+0.3	-3.7
75 % Core	0.0	-0.2	-0.3	-0.6	+1.3	-0.2
75% Mean of cases	-1.7	-1.9	-2.0	-2.3	-0.4	-1.9
98% Core	-26.5	-26.5	-19.5	-19.5	-	+10.4
98% Mean of cases	+31.4	+31.4	+38.4	+38.4	-	+68.3
Timber G	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	+3.9	+1.8	+3.1	+0.6	+0.5	+0.5
65% Mean of cases	+2.7	+0.6	+1.9	-0.6	-0.7	-0.7
75 % Core	+1.7	+0.7	+1.5	0.0	+0.3	-0.7
75% Mean of cases	+1.4	+0.4	+1.2	-0.3	0.0	-1.0
98% Core	+4.0	-7.2	+3.4	-6.5	-1.1	+3.9
98% Mean of cases	+9.2	-2.1	+8.6	-1.4	+4.1	+9.1
Timber H	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	+3.3	+0.8	+2.8	-0.1	+1.4	+0.4
65% Mean of cases	+2.5	0.0	+2.0	-0.9	+0.6	-0.4
75 % Core	+1.5	0.0	+1.2	+0.1	+0.4	+0.4
75% Mean of cases	+0.7	-0.8	+0.4	-0.7	-0.4	-0.4
98% Core	-6.1	-21.3	-4.2	-22.2	-	-2.7
98% Mean of cases	-4.9	-20.1	-3.0	-21.0	-	-1.5
Timber I	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	+3.8	+1.7	+3.1	+0.8	+2.1	+1.1
65% Mean of cases	+2.9	+0.8	+2.2	-0.1	+1.2	+0.2
75 % Core	+3.8	+2.3	+3.3	+1.7	+2.5	+1.5
75% Mean of cases	+2.6	+1.1	+2.1	+0.4	+1.3	+0.3
98% Core	+5.3	+0.9	+5.3	-0.1	+3.3	+6.3
98% Mean of cases	+6.6	+2.2	+6.6	+1.2	+4.6	+7.6
Timber J	**X(i)E**	**X(i)H**	**X(ii)E**	**X(ii)H**	**Y(i)H**	**Z(i)C**
65% Core	+4.5	+1.7	+3.7	+1.0	+2.4	+2.4
65% Mean of cases	+3.0	+0.2	+2.2	-0.5	+0.9	+0.9
75 % Core	+3.0	+1.2	+2.7	+0.7	+2.0	+2.0
75% Mean of cases	+2.0	+0.2	+1.7	-0.3	+1.0	+1.0
98% Core	+3.3	-0.2	+3.4	+0.1	+1.9	+3.4
98% Mean of cases	+4.0	+0.5	+4.1	+0.8	+2.6	+4.1

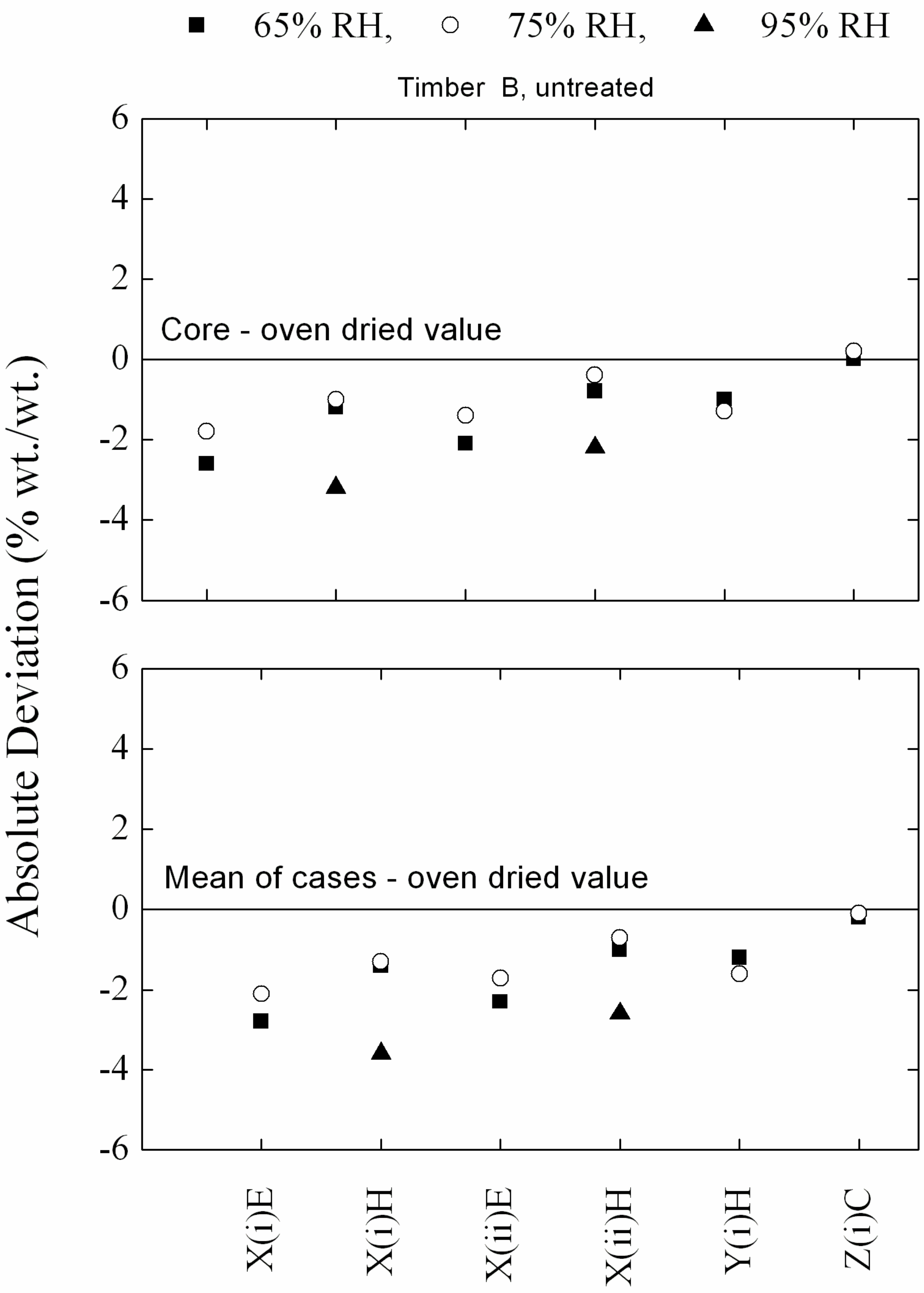

Figure 7. Timber B (untreated). Values of absolute deviation of each moisture meter reading at Position 5 (uncorrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

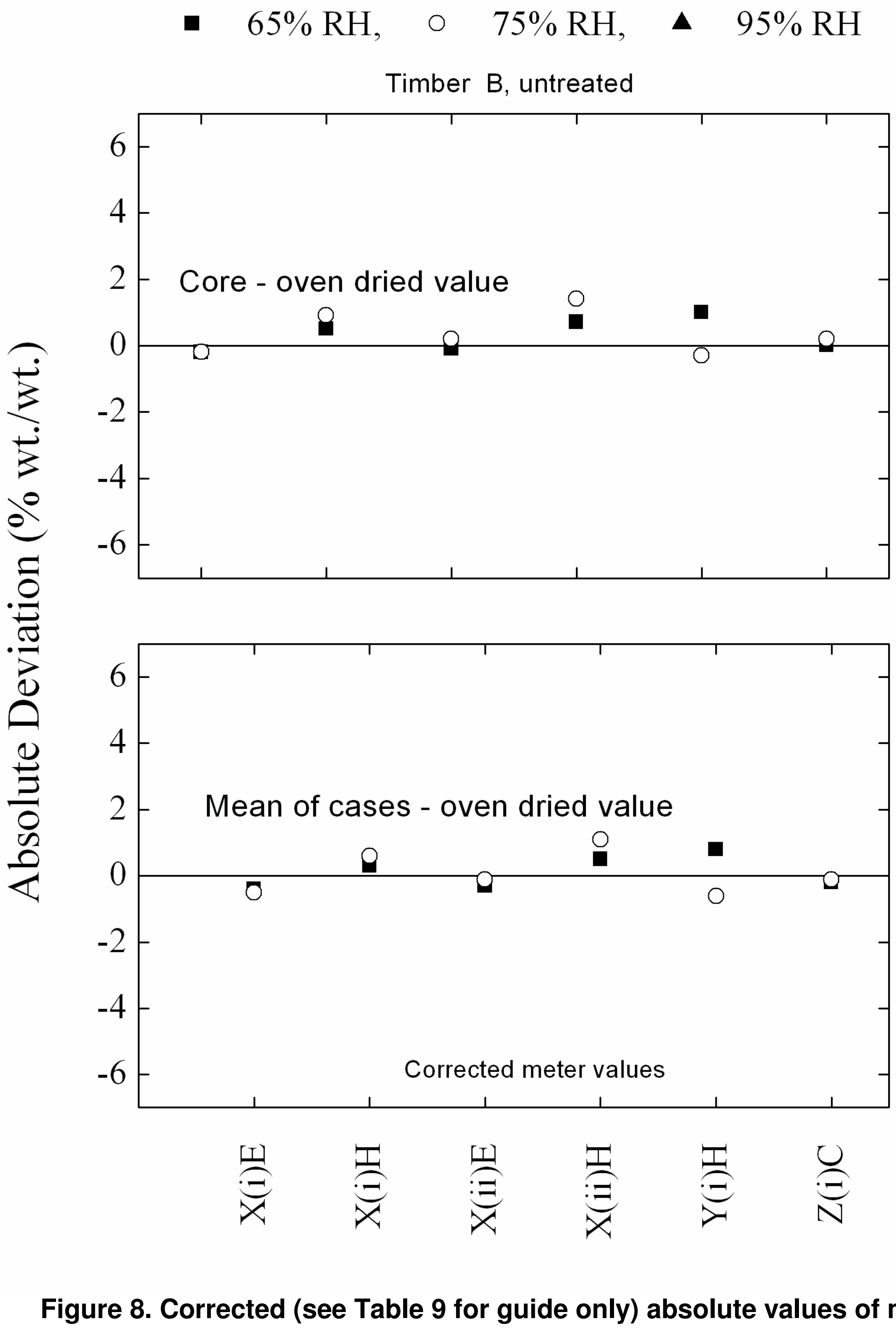

Figure 8. Corrected (see Table 9 for guide only) absolute values of meter deviation for Timber Sample B (untreated). Values of absolute deviation of each moisture meter reading at Position 5 (corrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

Table 9. Table of correction figures for each type of commercial moisture meter used in this work. Correction figures are taken from tabulated data supplied with the instrumentation. Data is given for temperature 21±2°C (corrected if necessary) and an arbitrarily chosen example uncorrected meter reading of 16% moisture (wt./wt.)*. All timber is assumed to be sapwood.

ID	Generic description	NZS 3640 hazard class	X(i)E	X(i)H	X(ii)E	X(ii)H	Y(i)H	Z(i)C	#AS/ NZS 1080.1
A	LOSP	H3.1	-	-	-	-	+3%‡	-	-
B	Untreated *Pinus radiata*	-	+1.5%	+1.5%	+1.5%	+1.5%	+1%	0%	+1%
C	ACQ†	H3.2	+2.5 to +3.5%‡	+2.5 to +3.5%‡	+2.5 to +3.5%‡	+2.5 to +3.5%‡	-	-	-
D	Boron†	H1.2	+2.5 to +3.5%‡	+2.5 to +3.5%‡	+2.5 to +3.5%‡	+2.5 to +3.5%‡	-2%	-	-2%
E	CCA†, 1	H3.2	+2.5 to +3.5%‡	+2.5 to +3.5%‡	+2.5 to +3.5%‡	+2.5 to +3.5%‡	-	-	+1%
F	T1.2 Boron	Non-approved hazard class (T1.2)	-	-	-	-	-	-	-
G	LOSP	H1.2	-	-	-	-	+3%‡	-	-
H	LOSP	H3.1	-	-	-	-	+3%‡	-	-
I	LOSP	H3.1	-	-	-	-	+3%‡	-	-
J	LOSP	H3.1	-	-	-	-	+3%‡	-	-

* Note that in all cases the correction figure, as supplied by the manufacturer in tabulated form and presented in AZ/NZS 1080.1, is dependent on the value of the initial and uncorrected meter reading.

† Waterborne preservative class as defined by Manufacturer 'X'. +3% is applied for all the waterborne preservative corrections used in this work using 'X' meters.

‡ Manufacturer's instruction for LOSP treated *Pinus radiata* as follows: 'Indicative values only – must be used with caution'.

Pinus radiata (NZ).

1 'Tanalith', as quoted in some texts, is taken in this report to mean CCA-salt treated timber only (see AS/NZS 1080.1). Since the CCA treated timber used in this work is of the oxide type, no correction can be made for 'Tanalith' as presented in many of the moisture meter manuals. This may cause confusion as, for example, the trade name 'Tanalith C' (as used in this work) is composed of CCA oxide and Tanalith E is a CuAz-based treatment (neither of which conform to the AS/NZS 1080.1 definition of 'Tanalith'). AS/NZS 1080.1 states that 'Boliden' is more representative of CCA oxide treated timber and only correction figures associated with this nomenclature will be applied to the correction of values measured in CCA oxide treated timber.

‡ +1.5 of *Pinus radiata* with an additional (+1 to +2%) for water-based preservative = range of +2.5 to +3.5%.

Success with the untreated timber samples, however, did not lead to a universal improvement in the correlation when the treated timbers were examined. With the exception of the CCA treated timbers, the correction figures for the 'waterborne' timber treatments (assumed to include both boron and ACQ) tended to grossly over-estimate the actual moisture content of the wood through higher readings associated with lower resistance of the timber structure. The moisture content of the CCA H3.2 treated timber could be determined within ±2% meter percentage units.

No specific reference to ACQ, or CuAz, treated timbers could be found in the literature, although it is clear from this and other research (Kear and Wu 2006) that the electrical resistance of timbers treated with these products is considerably lower than CCA treated timber. This point also explains the very large over-estimation of moisture content which can be seen in the results of this report (see Appendix 6.6, Figure 61).

Meter Y(i)H was the most accurate meter for boron treated timber when used with the suggested correction figure. But, from Appendix 6.6, Figures 61 and 62, it may be observed that a very large discrepancy is possible if the 'X' type meter is used in conjunction with the '+3' correction figure (presented in the instrument manual) recommended for *Pinus radiata* treated with waterborne preservatives. This is extremely non-specific and obviously leads to considerable error if the preservative in question is not CCA-based.

Moreover, the corrected measurements produced with the LOSP treated timbers were rather irreproducible, and in many cases a minimum accuracy of at least ±2% moisture meter units could not be achieved.

4. CONCLUSIONS

The aim of the research was to quantify the applicability of using all commercially resistance-based meters (available in New Zealand) with a single table of correction figures. When the individual moisture meter correction figures (as supplied with each meter type) were introduced to the directly measured resistance data, all of the meters were able to accurately determine the moisture content of untreated *Pinus radiata* to within ±1% moisture meter units.

In many cases, however, the introduction of treated timbers significantly lowered the accuracy of all of the meters which varied to different degrees depending on the preservative type and the mode of meter operation. Of particular concern was the inability of some meters to accurately determine the moisture content of ACQ, LOSP and boron treated timbers within at least ±2% moisture meter percentage units. The specific case associated with the boron treatment (Timber F) may be due to significant variations in formulations and processes used for treatment. This H1.2 boron material from Red Stag would have been treated by a traditional 'diffusion' process. Alternatives may be treated with glycol borate formulations. A conductivity-based moisture meter could respond very differently between these two types of preservatives and entirely independent correction figures may be required.

With an examination of the results presented in this report, an approach of universal correction figures does not appear to be feasible without national standardisation as recommended in AS/NZS 1080.1. Two of the three meters examined in this work were produced overseas, but are also instruments that are commonly sold in New Zealand. In some instances, the internationally produced meters did not reproduce the behaviour of commercial meter 'Y' which, it is reported, was manufactured and calibrated to the specifications and the correction figures laid out in AS/NZS 1080.1. Clearly, the base calibration value varies from meter to meter and the application of correction factors (which have been reproduced in AS/NZS 1080.1 assuming a constant base value) will lead to erroneous readings. Standardisation of a universal resistance base value for each actual value of moisture content should be the initial step towards continuity in meter use. Standardisation of electrode geometry (width, depth and spacing etc) and applied voltage is also essential if universal calibration curves are to be adopted in practice by all users. An approach leading to meter standardisation in New Zealand may be possible through amendment of E2/AS1 with reference to a modified AS/NZS 1080.1, whereby it is clearly stated that only standard technology conforming to specific base level calibration requirements shall be applied in order to satisfy the requirements of the NZBC.

5. REFERENCES

Anon. 1991. *Moisture Meters for Wood*. TRADA (Timber Research and Development Association), High Wycombe, UK.

Anon. 1993. *Bulletin: Measurement of Moisture Content of Assembled Timber Framing*. SCION (formerly New Zealand Forest Research Institute Ltd), Rotorua, New Zealand.

Anon. 1966. FPL–0142: *A Probe for Accurate Determination of Moisture Content of Wood Products in Use.* US Department of Agriculture, Forest Products Laboratory, Madison, USA.

ASTM International. *Standard Guide for Moisture Conditioning of Wood and Wood-Based Materials (*ASTM D 4933–99). 1999. West Conshohocken, USA.

Atkins PW. 1992. *The Elements of Physical Chemistry*. Oxford University Press, New York, USA.

Australian Standards/Standards New Zealand. *Timber-methods of Test. Method 1: Moisture Content* (AS/NZS 1080.1:1997). 1997. Wellington, New Zealand.

Burkinshaw R. 2002. 'What is the Moisture Meter Trying to Tell Us?' *Structural Survey* 20: 162–172.

Chemical Preservation of Round and Sawn Timber. (NZS 3640:2003). 2003. Standards New Zealand, Wellington, New Zealand.

Compliance Document for New Zealand Building Code, Clause E2, External Moisture. (Acceptable Solution E2/AS1). 2005. Department of Building and Housing, Wellington, New Zealand.

Crissinger J. 2006a. 'Mysteries of Moisture Meters'. *The Construction Specifier* (May) 56–69.

Crissinger J. 2006b. 'Using Moisture Meters'. *The Construction Specifier* (June) 38–45.

Kear G. 2004. *DR0106 Pilot Study: Determination of Water Content in CCA, ACQ and CuAz Treated Timbers Using Commercial Moisture Meters*. BRANZ Ltd, Judgeford, New Zealand.

Kear G, Wu H-Z and Jones MS. 2006. 'The Corrosion of Metallic Fastener Materials in Untreated, CCA-, CuAz- and ACQ-based Timbers'. BRANZ *Study Report 153*. BRANZ Ltd, Judgeford, New Zealand.

Simpson I. 1996. *FRI Bulletin No. 200: Measuring the Moisture Content of Wood*. SCION (formerly New Zealand Forest Research Institute Ltd), Rotorua, New Zealand.

6. APPENDICES

6.1 Moisture meter measurements across the length of the timbers at 65% relative humidity

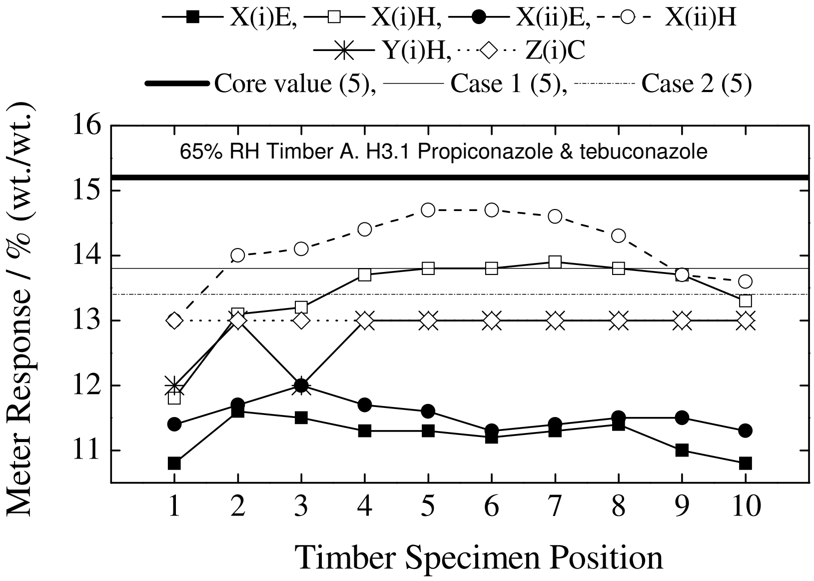

Figure 9. Distribution of moisture content across the length of Timber A (H3.1 propiconazole and tebuconazole) at 65% relative humidity – presented as a function of analysis methodology.

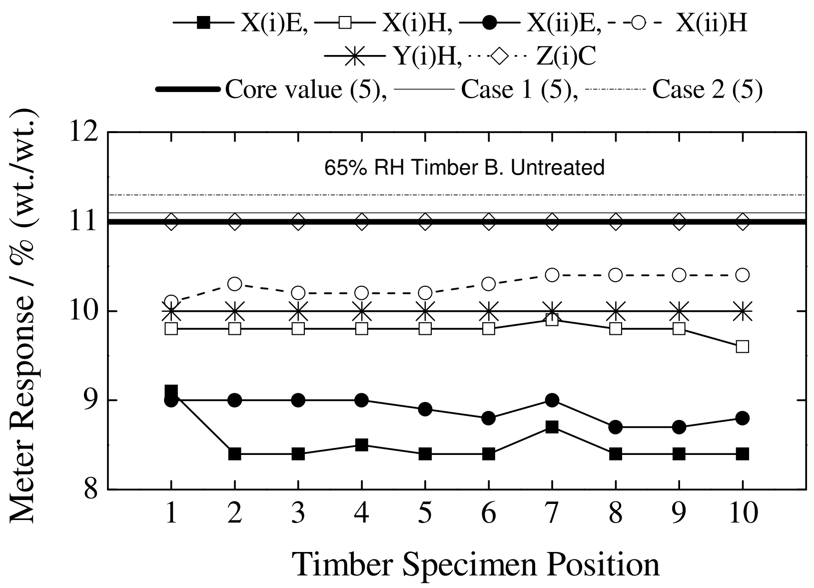

Figure 10. Distribution of moisture content across the length of Timber B (untreated) at 65% relative humidity – presented as a function of analysis methodology.

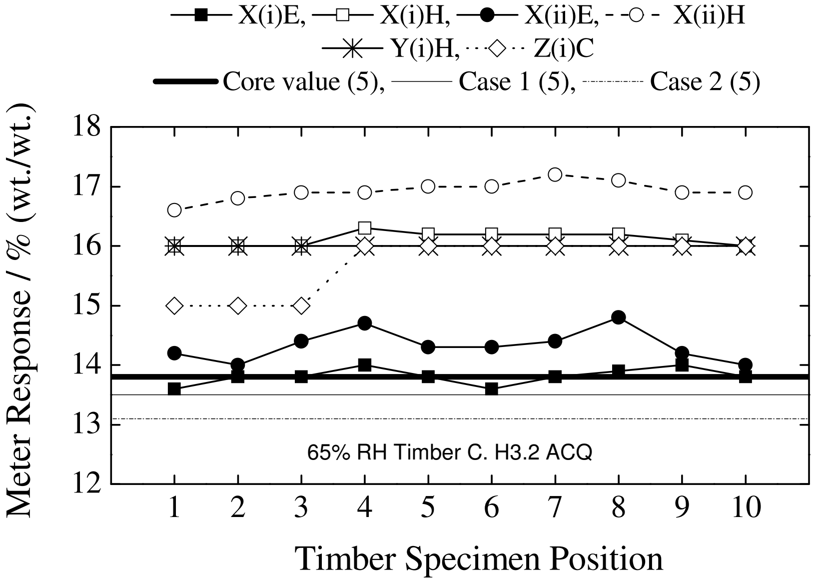

Figure 11. Distribution of moisture content across the length of Timber C (H3.2 ACQ) at 65% relative humidity – presented as a function of analysis methodology.

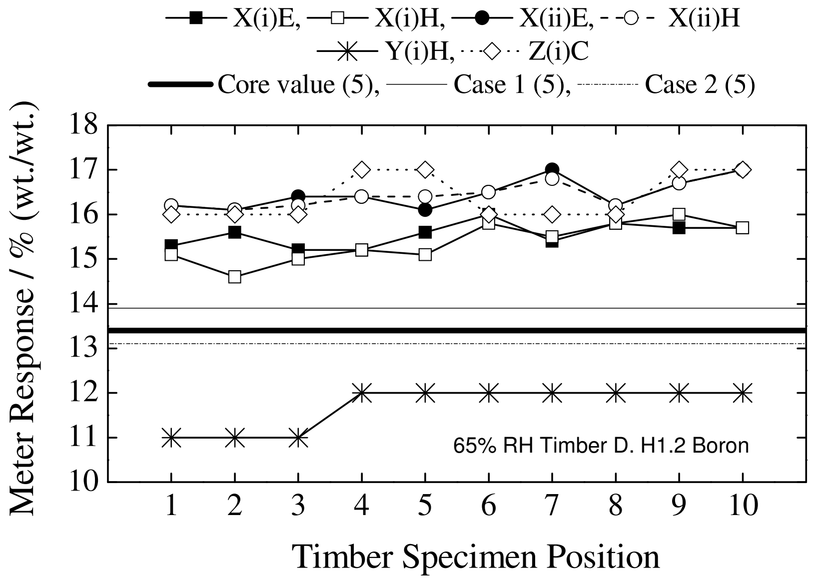

Figure 12. Distribution of moisture content across the length of Timber D (H1.2 boron) at 65% relative humidity – presented as a function of analysis methodology.

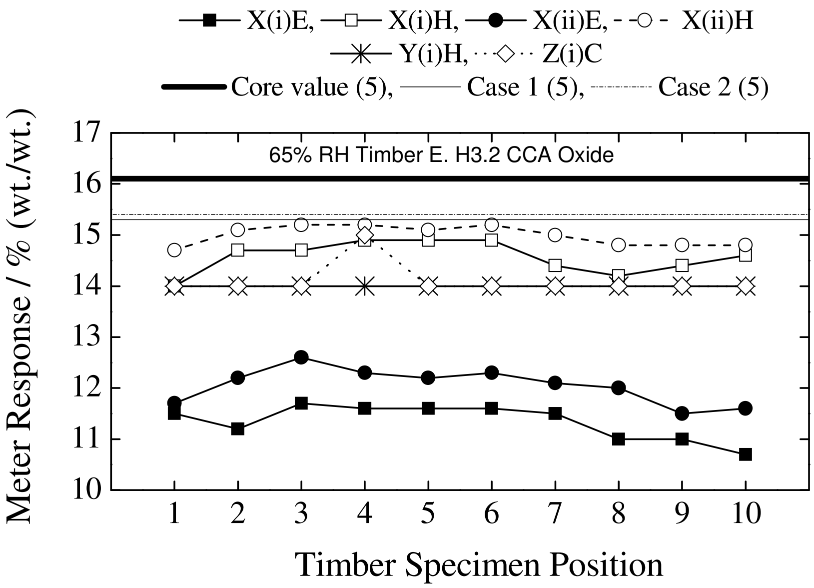

Figure 13. Distribution of moisture content across the length of Timber E (H3.2 CCA) at 65% relative humidity – presented as a function of analysis methodology.

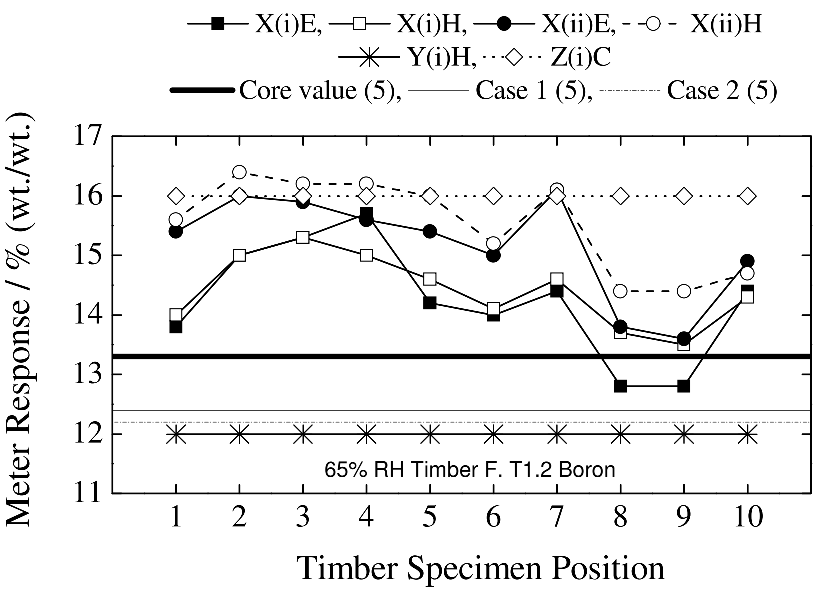

Figure 14. Distribution of moisture content across the length of Timber F (T1.2 boron) at 65% relative humidity – presented as a function of analysis methodology.

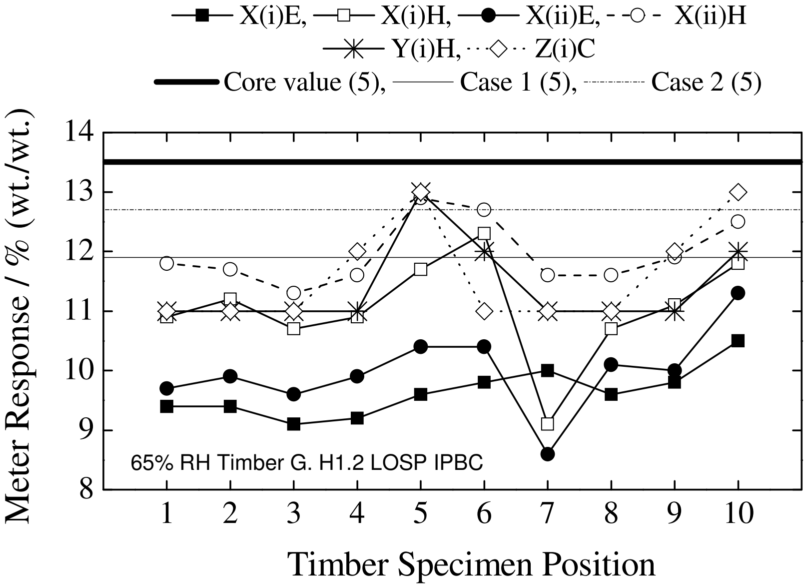

Figure 15. Distribution of moisture content across the length of Timber G (H1.2 LOSP IPBC) at 65% relative humidity – presented as a function of analysis methodology.

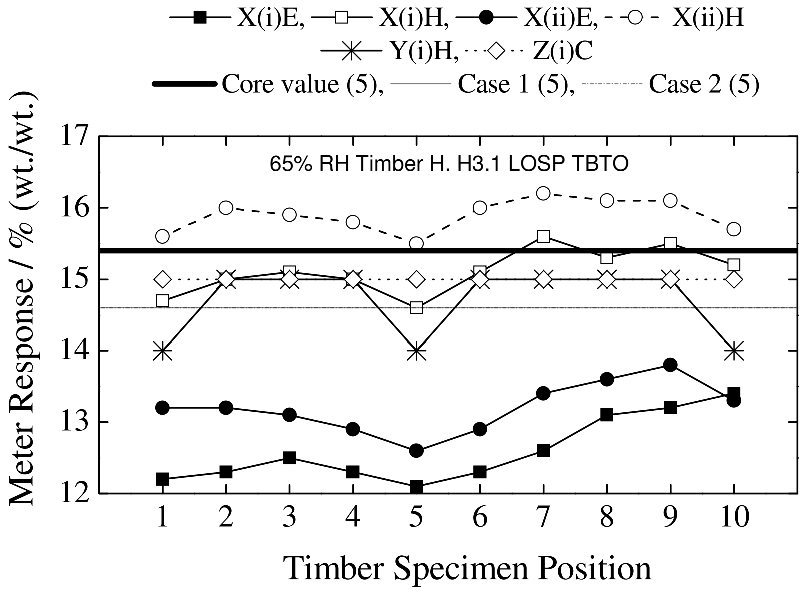

Figure 16. Distribution of moisture content across the length of Timber H (H3.1 LOSP TBTO) at 65% relative humidity – presented as a function of analysis methodology.

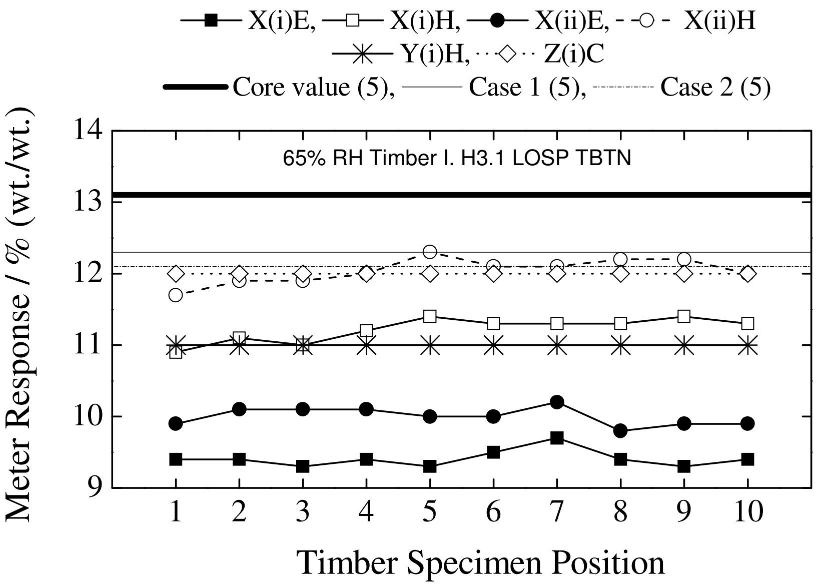

Figure 17. Distribution of moisture content across the length of Timber I (H3.1 LOSP TBTN) at 65% relative humidity – presented as a function of analysis methodology.

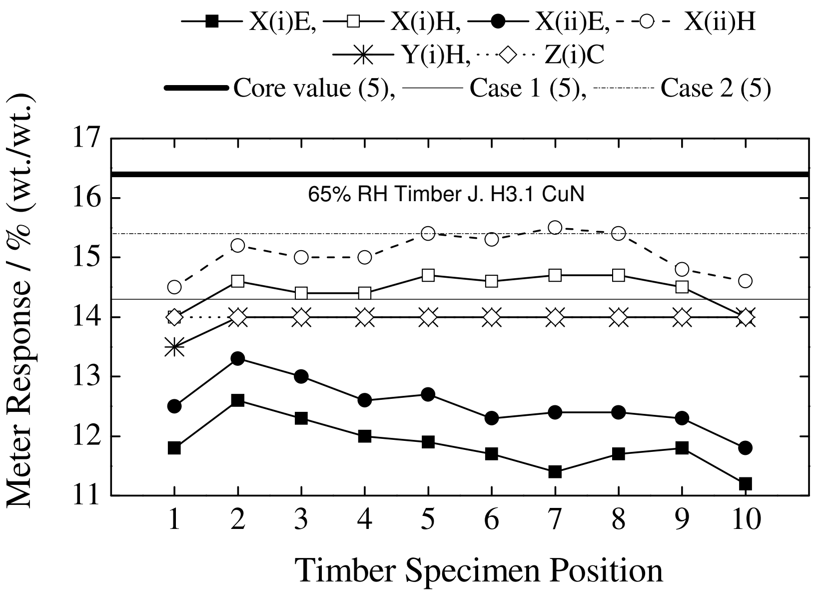

Figure 18. Distribution of moisture content across the length of Timber J (H3.1 LOSP CuN) at 65% relative humidity – presented as a function of analysis methodology.

6.2 Moisture meter measurements across the length of the timbers at 75% relative humidity

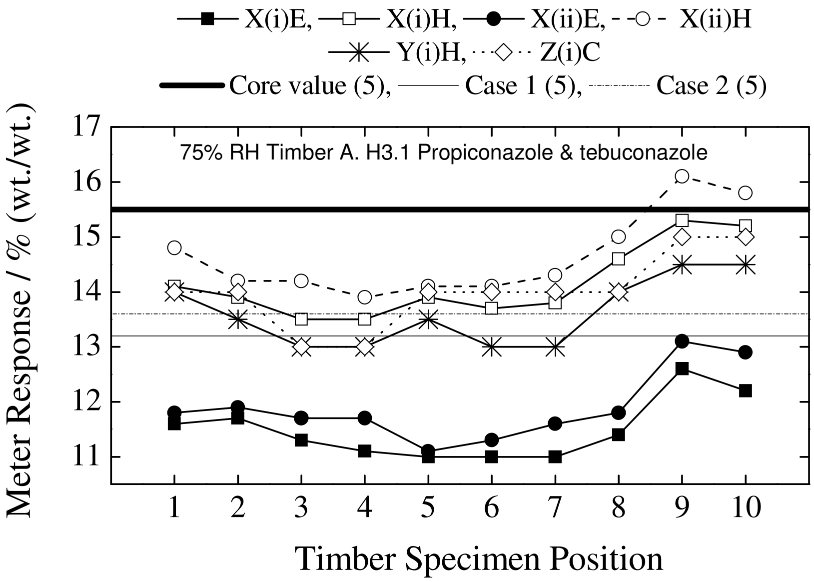

Figure 19. Distribution of moisture content across the length of Timber A (H3.1 propiconazole and tebuconazole) at 75% relative humidity – presented as a function of analysis methodology.

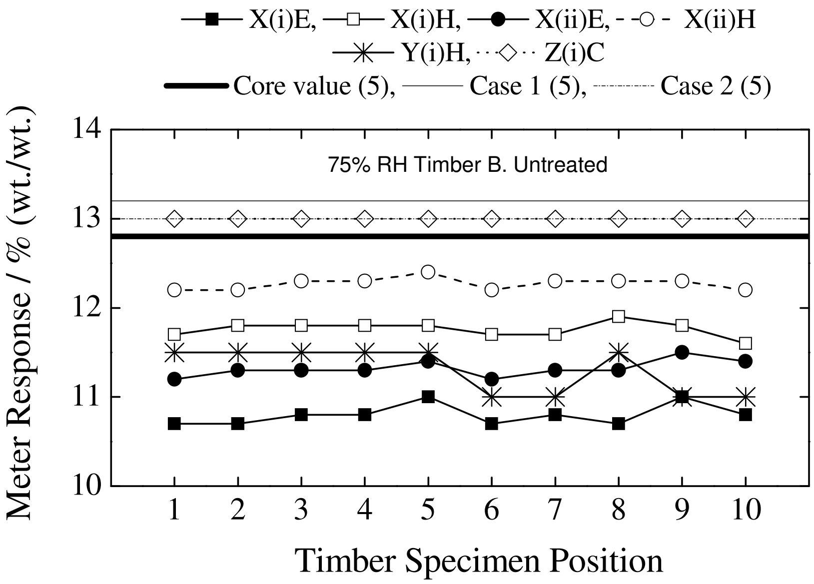

Figure 20. Distribution of moisture content across the length of Timber B (untreated) at 75% relative humidity – presented as a function of analysis methodology.

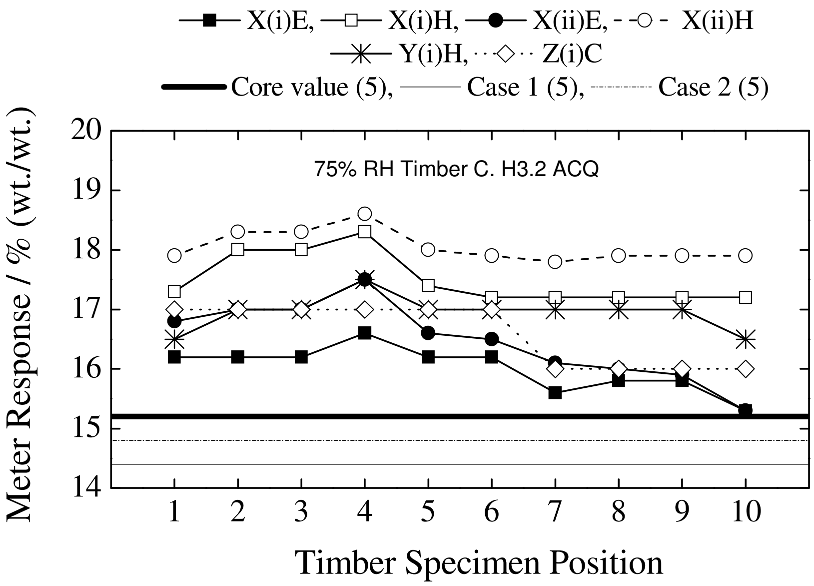

Figure 21. Distribution of moisture content across the length of Timber C (H3.2 ACQ) at 75% relative humidity – presented as a function of analysis methodology.

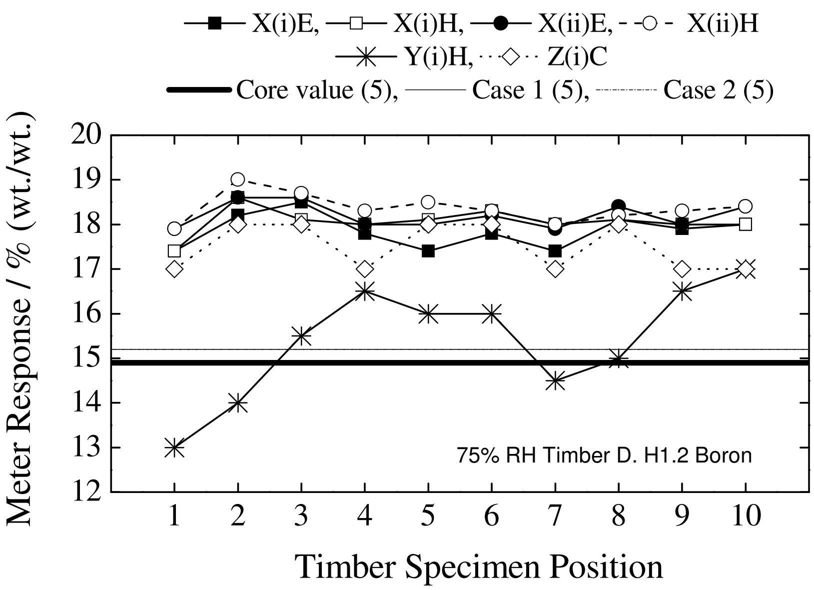

Figure 22. Distribution of moisture content across the length of Timber D (H1.2 boron) at 75% relative humidity – presented as a function of analysis methodology.

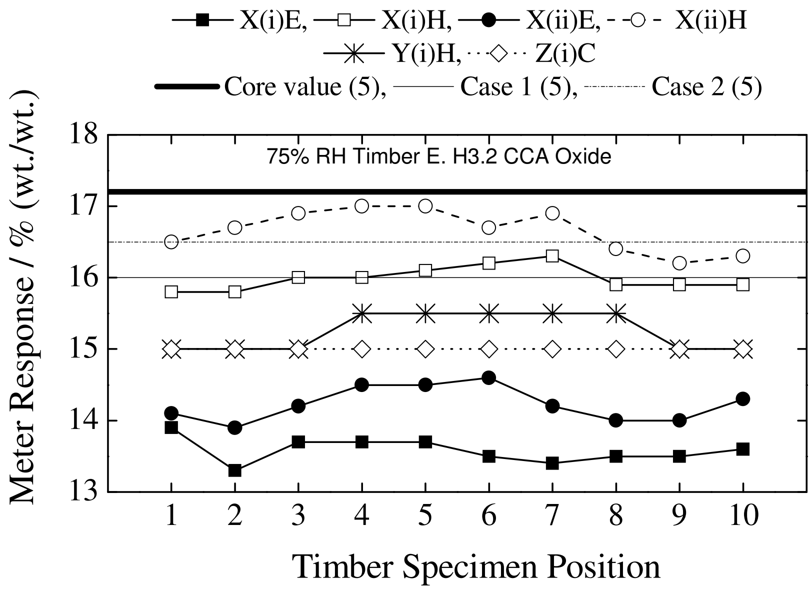

Figure 23. Distribution of moisture content across the length of Timber E (H3.2 CCA) at 75% relative humidity – presented as a function of analysis methodology.

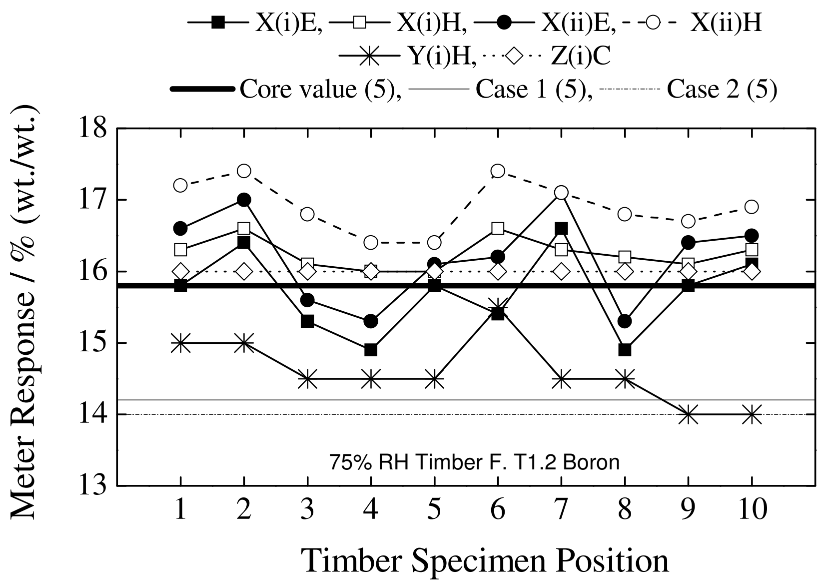

Figure 24. Distribution of moisture content across the length of Timber F (T1.2 boron) at 75% relative humidity – presented as a function of analysis methodology.

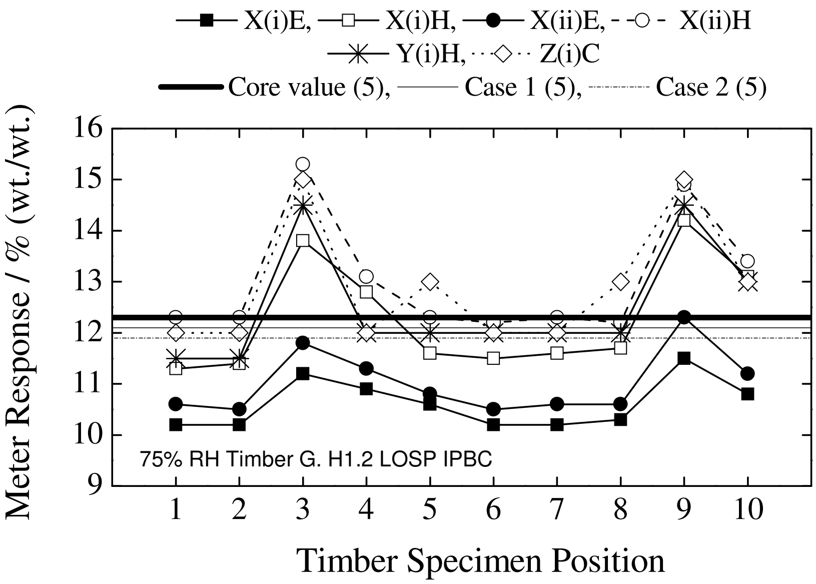

Figure 25. Distribution of moisture content across the length of Timber G (H1.2 LOSP IPBC) at 75% relative humidity – presented as a function of analysis methodology.

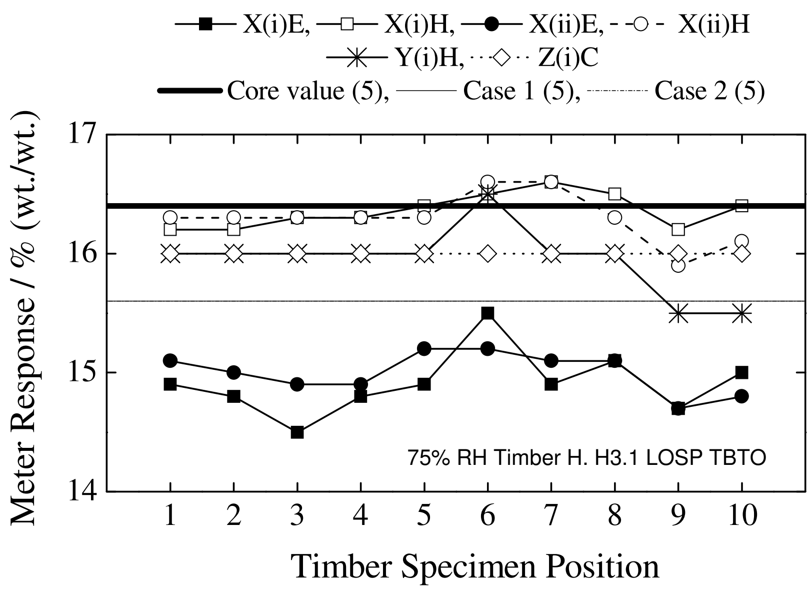

Figure 26. Distribution of moisture content across the length of Timber H (H3.1 LOSP TBTO) at 75% relative humidity – presented as a function of analysis methodology.

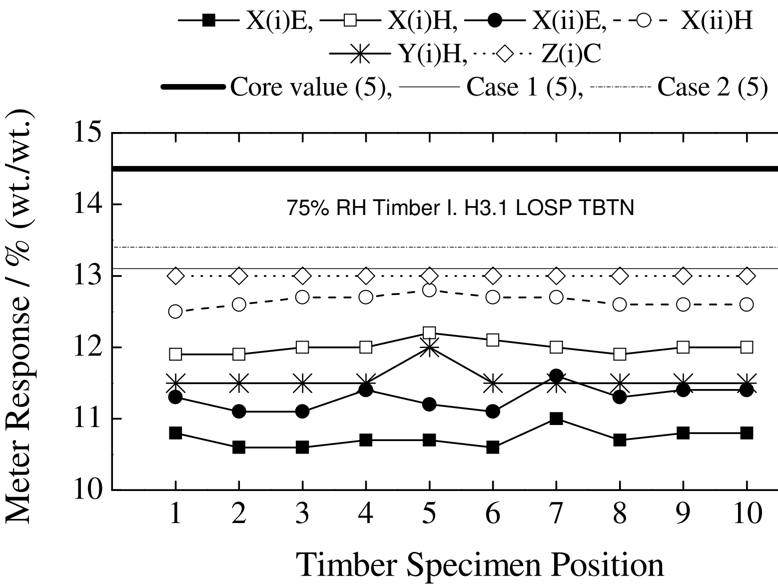

Figure 27. Distribution of moisture content across the length of Timber I (H3.1 LOSP TBTN) at 75% relative humidity – presented as a function of analysis methodology.

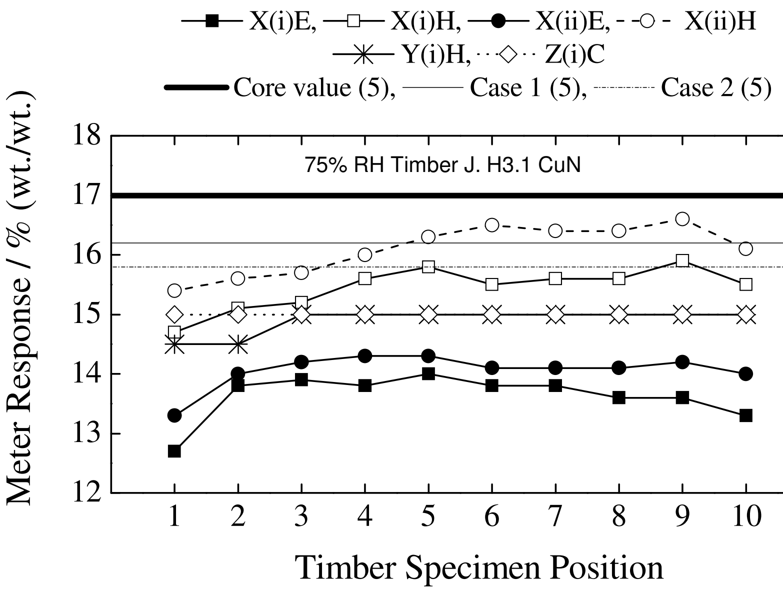

Figure 28. Distribution of moisture content across the length of Timber J (H3.1 LOSP CuN) at 75% relative humidity – presented as a function of analysis methodology.

6.3 Moisture meter measurements across the length of the timbers at 98% relative humidity

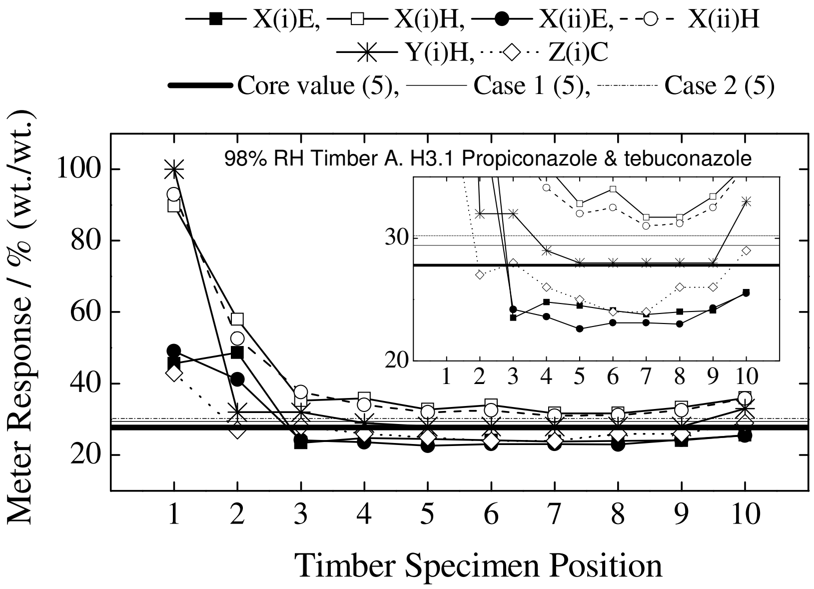

Figure 29. Distribution of moisture content across the length of Timber A (H3.1 propiconazole and tebuconazole) at 98% relative humidity – presented as a function of analysis methodology.

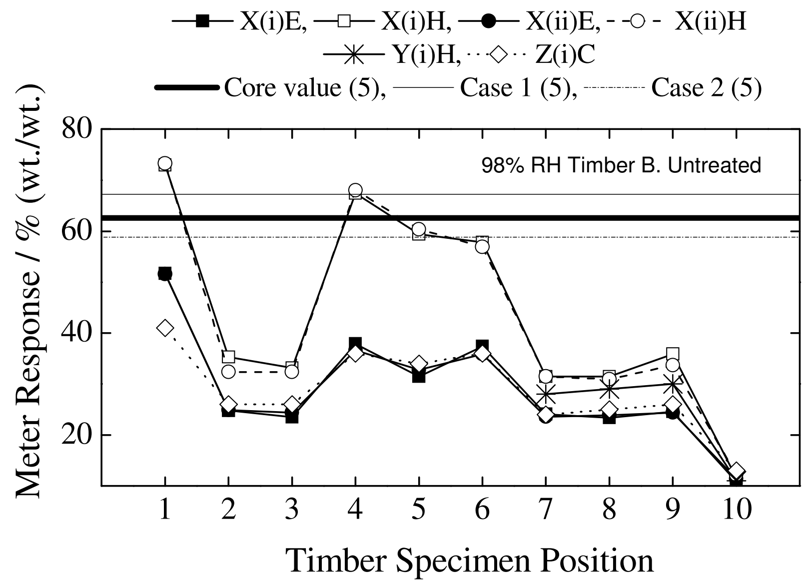

Figure 30. Distribution of moisture content across the length of Timber B (untreated) at 98% relative humidity – presented as a function of analysis methodology.

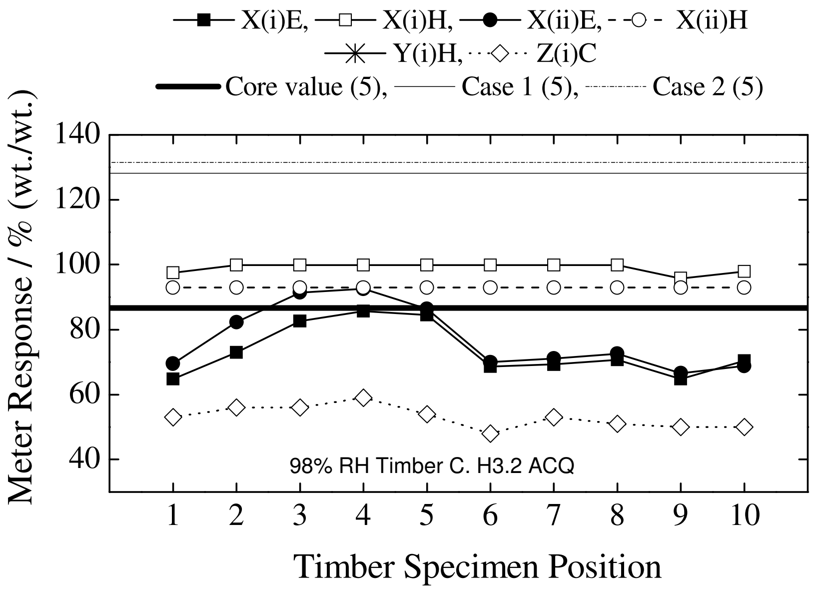

Figure 31. Distribution of moisture content across the length of Timber C (H3.2 ACQ) at 98% relative humidity – presented as a function of analysis methodology.

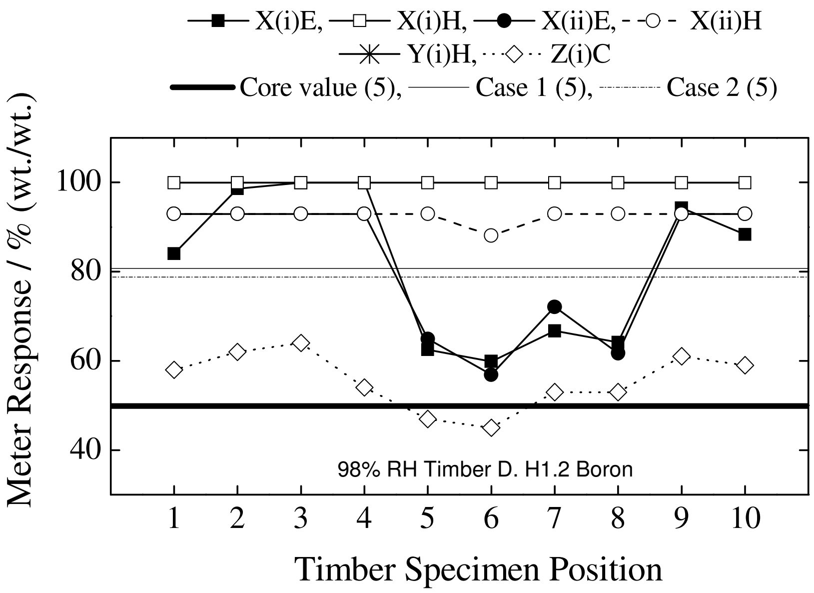

Figure 32. Distribution of moisture content across the length of Timber D (H1.2 boron) at 98% relative humidity – presented as a function of analysis methodology.

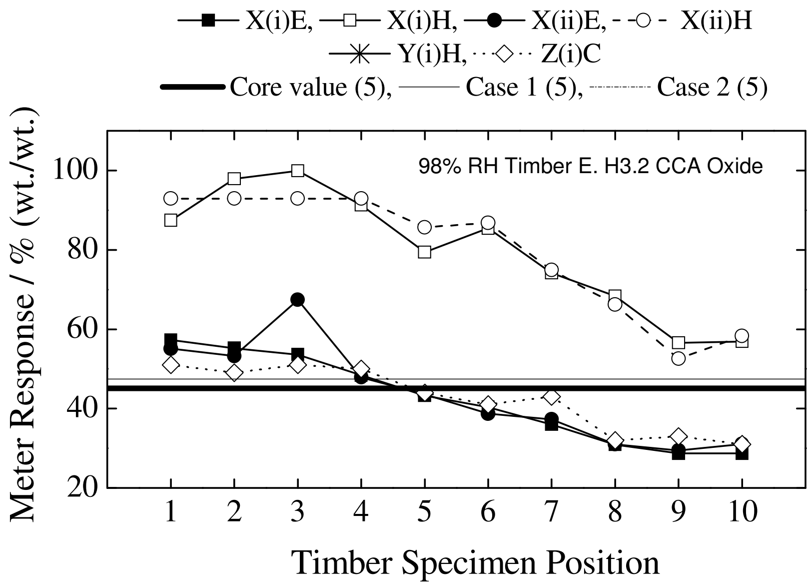

Figure 33. Distribution of moisture content across the length of Timber E (H3.2 CCA) at 98% relative humidity – presented as a function of analysis methodology.

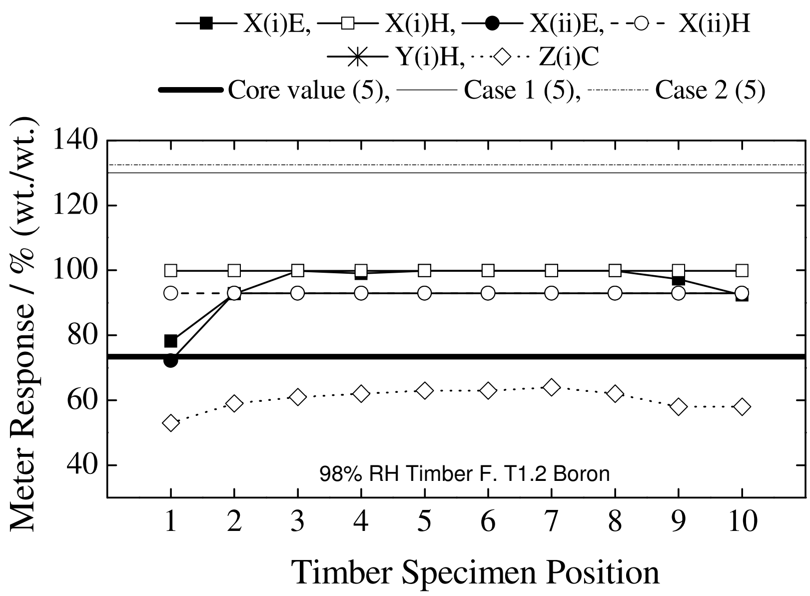

Figure 34. Distribution of moisture content across the length of Timber F (T1.2 boron) at 98% relative humidity – presented as a function of analysis methodology.

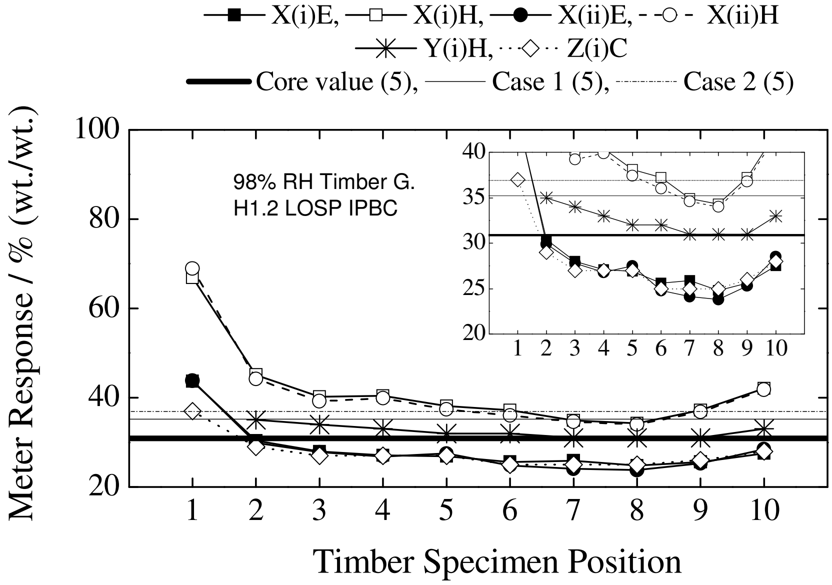

Figure 35. Distribution of moisture content across the length of Timber G (H1.2 LOSP IPBC) at 98% relative humidity – presented as a function of analysis methodology.

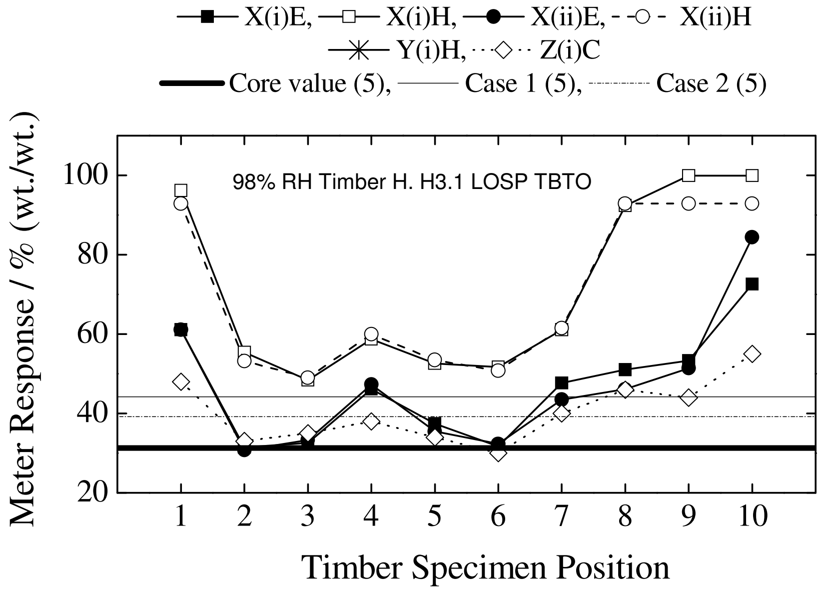

Figure 36. Distribution of moisture content across the length of Timber H (H3.1 LOSP TBTO) at 98% relative humidity – presented as a function of analysis methodology.

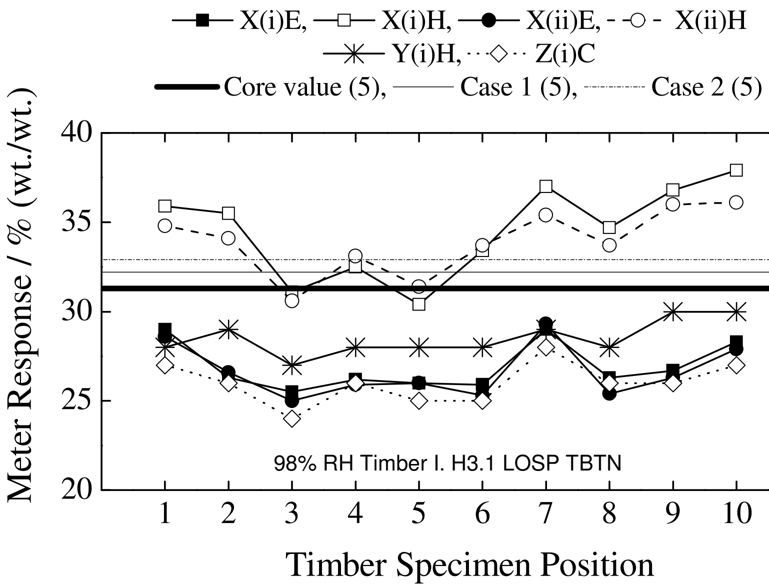

Figure 37. Distribution of moisture content across the length of Timber I (H3.1 LOSP TBTN) at 98% relative humidity – presented as a function of analysis methodology.

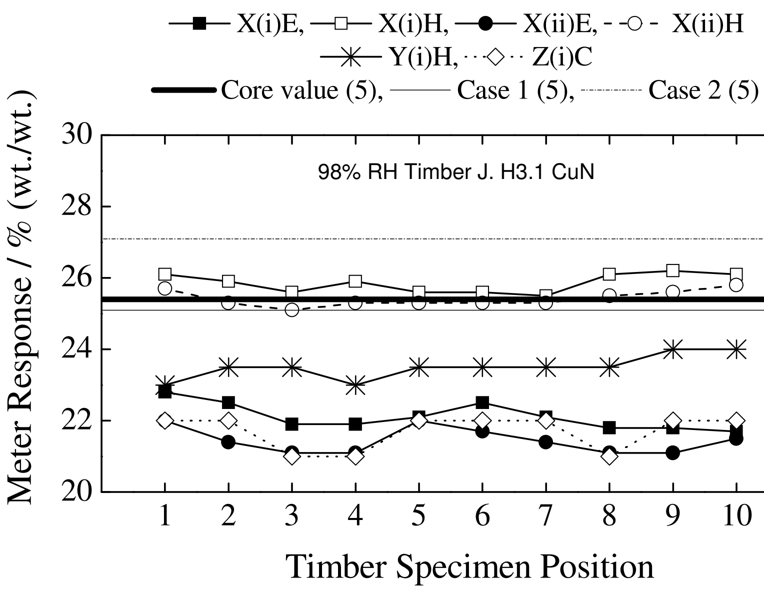

Figure 38. Distribution of moisture content across the length of Timber J (H3.1 LOSP CuN) at 98% relative humidity – presented as a function of analysis methodology.

6.4 Moisture meter performance vs oven-dried method

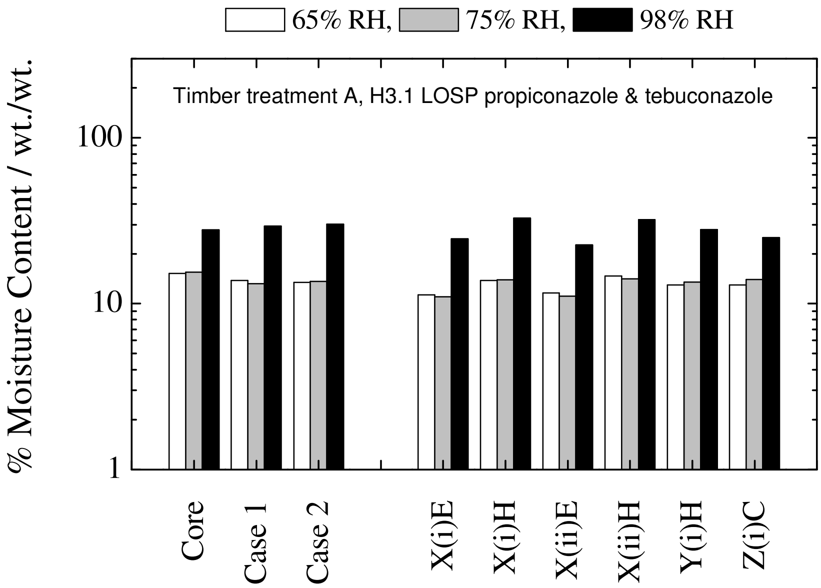

Figure 39. Comparison of oven-dry and meter moisture content methodologies at 65%, 75% and 98% relative humidity for Timber A (H3.1 LOSP propiconazole and tebuconazole), 'Position 5'.

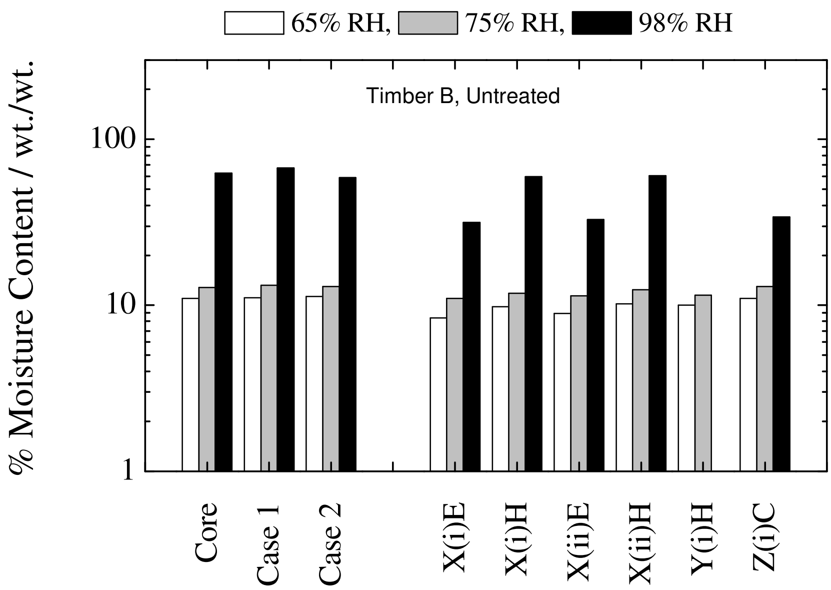

Figure 40. Comparison of oven-dry and meter moisture content methodologies at 65%, 75% and 98% relative humidity for Timber B (untreated), 'Position 5'.

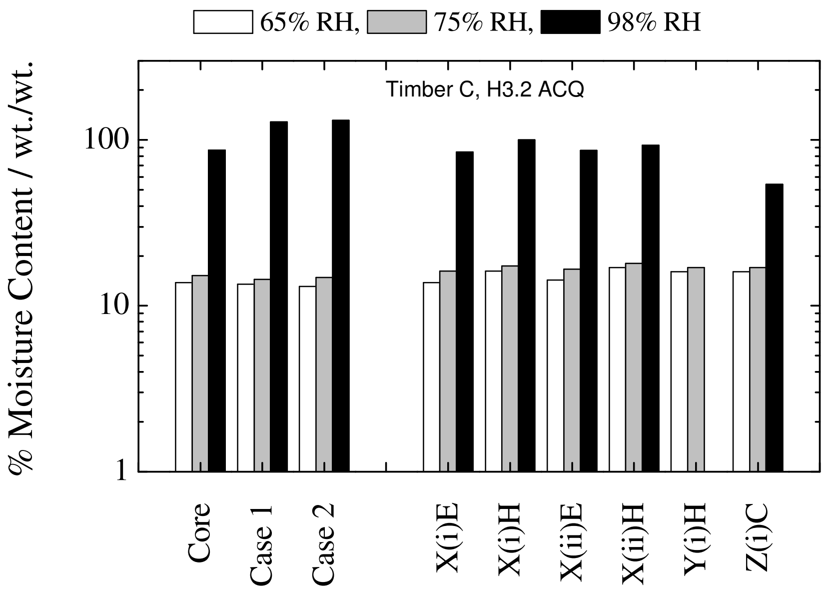

Figure 41. Comparison of oven-dry and meter moisture content methodologies at 65%, 75% and 98% relative humidity for Timber C (H3.2 ACQ), 'Position 5'.

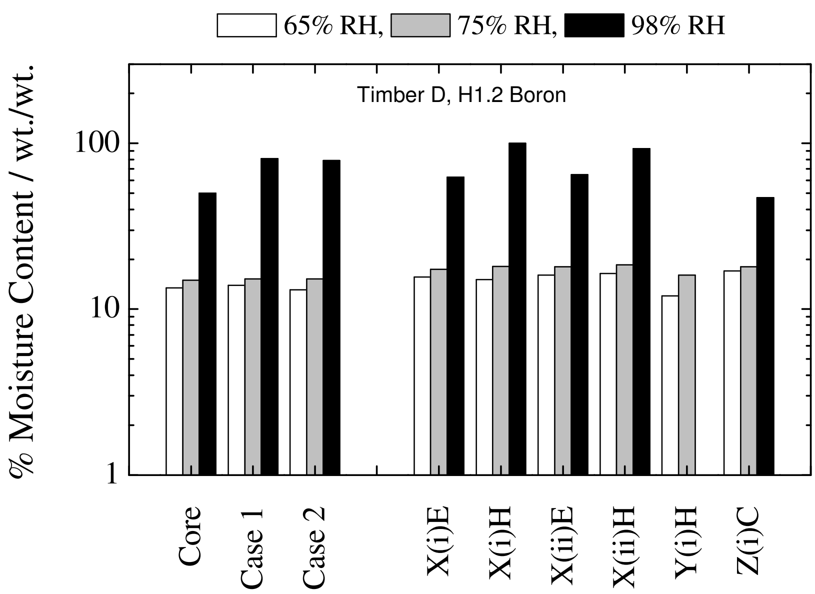

Figure 42. Comparison of oven-dry and meter moisture content methodologies at 65%, 75% and 98% relative humidity for Timber D (H1.2 boron), 'Position 5'.

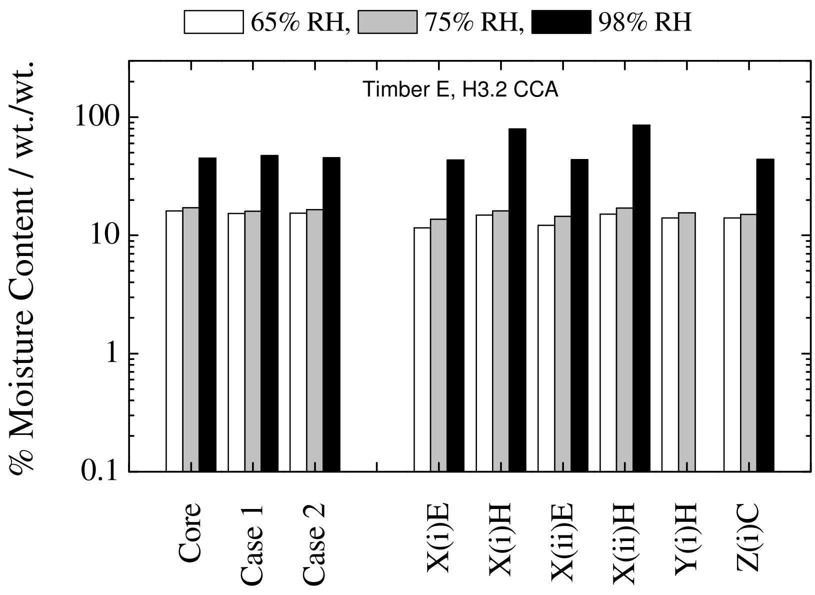

Figure 43. Comparison of oven-dry and meter moisture content methodologies at 65%, 75% and 98% relative humidity for Timber E (H3.2 CCA), 'Position 5'.

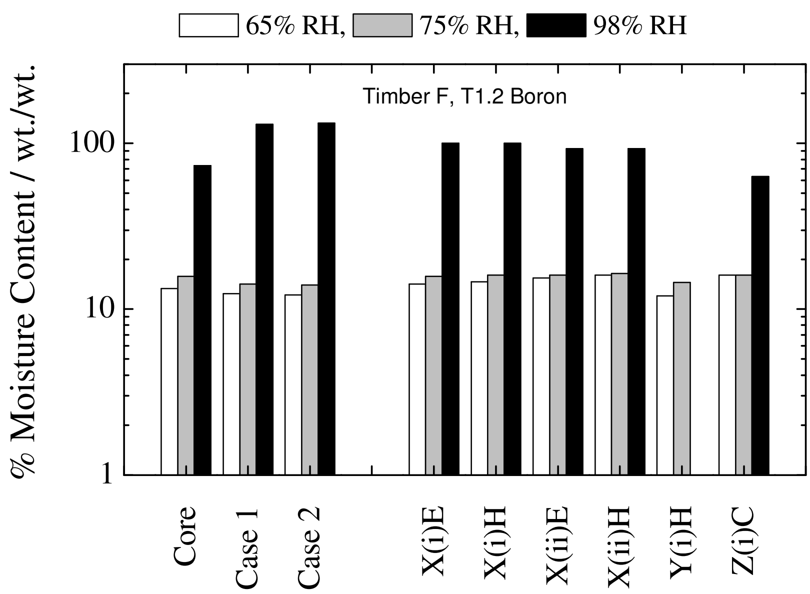

Figure 44. Comparison of oven-dry and meter moisture content methodologies at 65%, 75% and 98% relative humidity for Timber F (T1.2 boron), 'Position 5'.

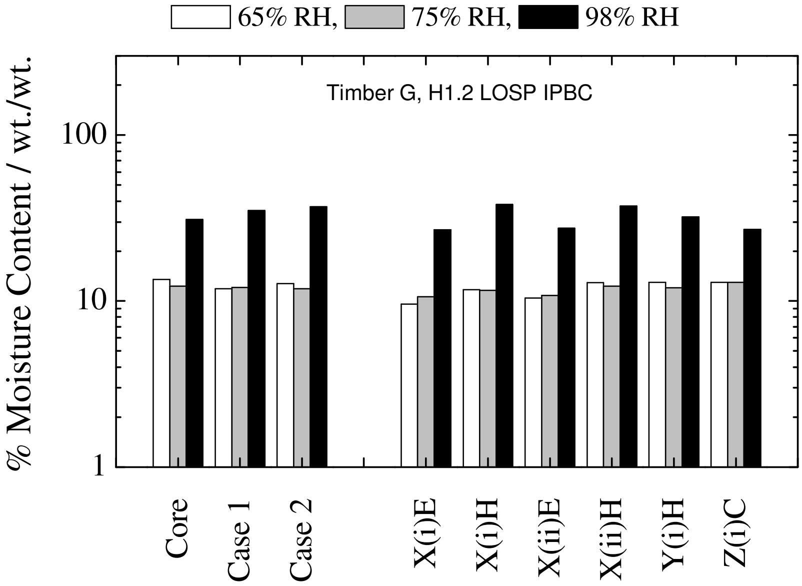

Figure 45. Comparison of oven-dry and meter moisture content methodologies at 65%, 75% and 98% relative humidity for Timber G (T1.2 LOSP IPBC), 'Position 5'.

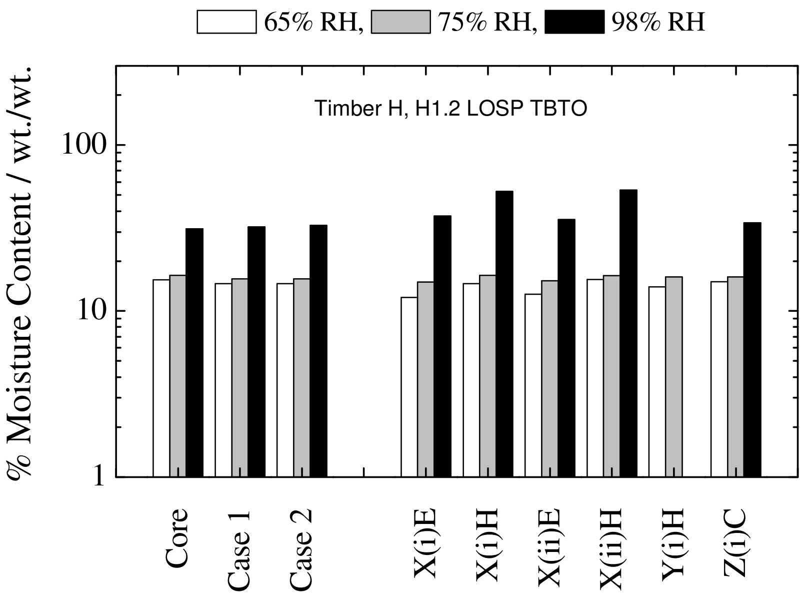

Figure 46. Comparison of oven-dry and meter moisture content methodologies at 65%, 75% and 98% relative humidity for Timber H (H1.2 LOSP TBTO), 'Position 5'.

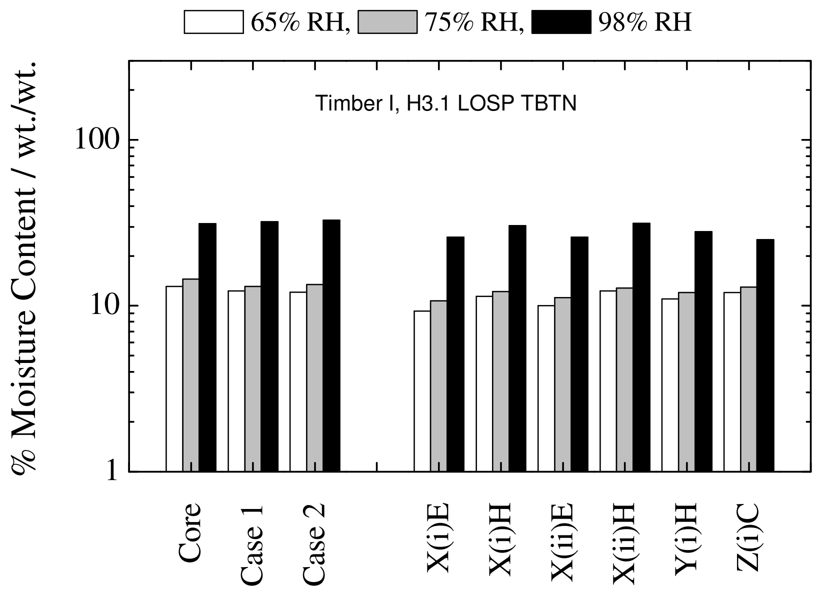

Figure 47. Comparison of oven-dry and meter moisture content methodologies at 65%, 75% and 98% relative humidity for Timber I (H3.1 LOSP TBTN), 'Position 5'.

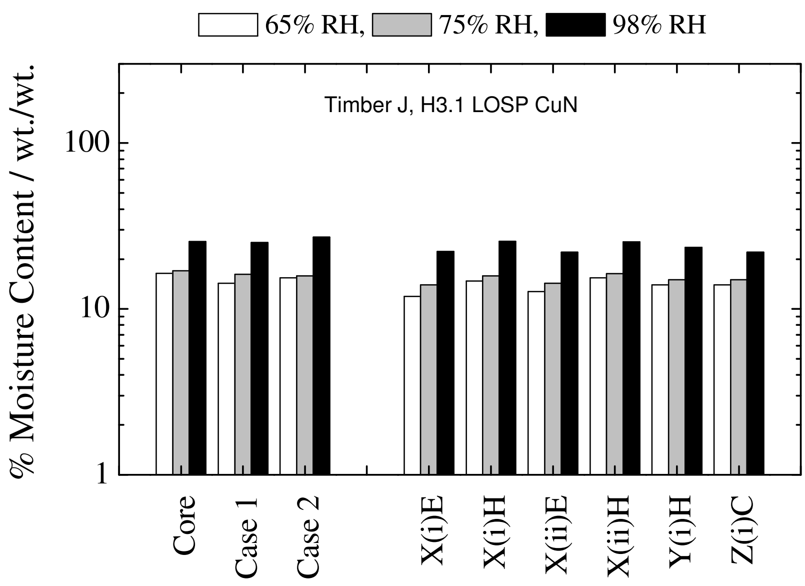

Figure 48. Comparison of oven-dry and meter moisture content methodologies at 65%, 75% and 98% relative humidity for Timber J (H3.1 LOSP CuN), 'Position 5'.

6.5 Deviation of uncorrected electrical resistance method determinations from oven-dried data

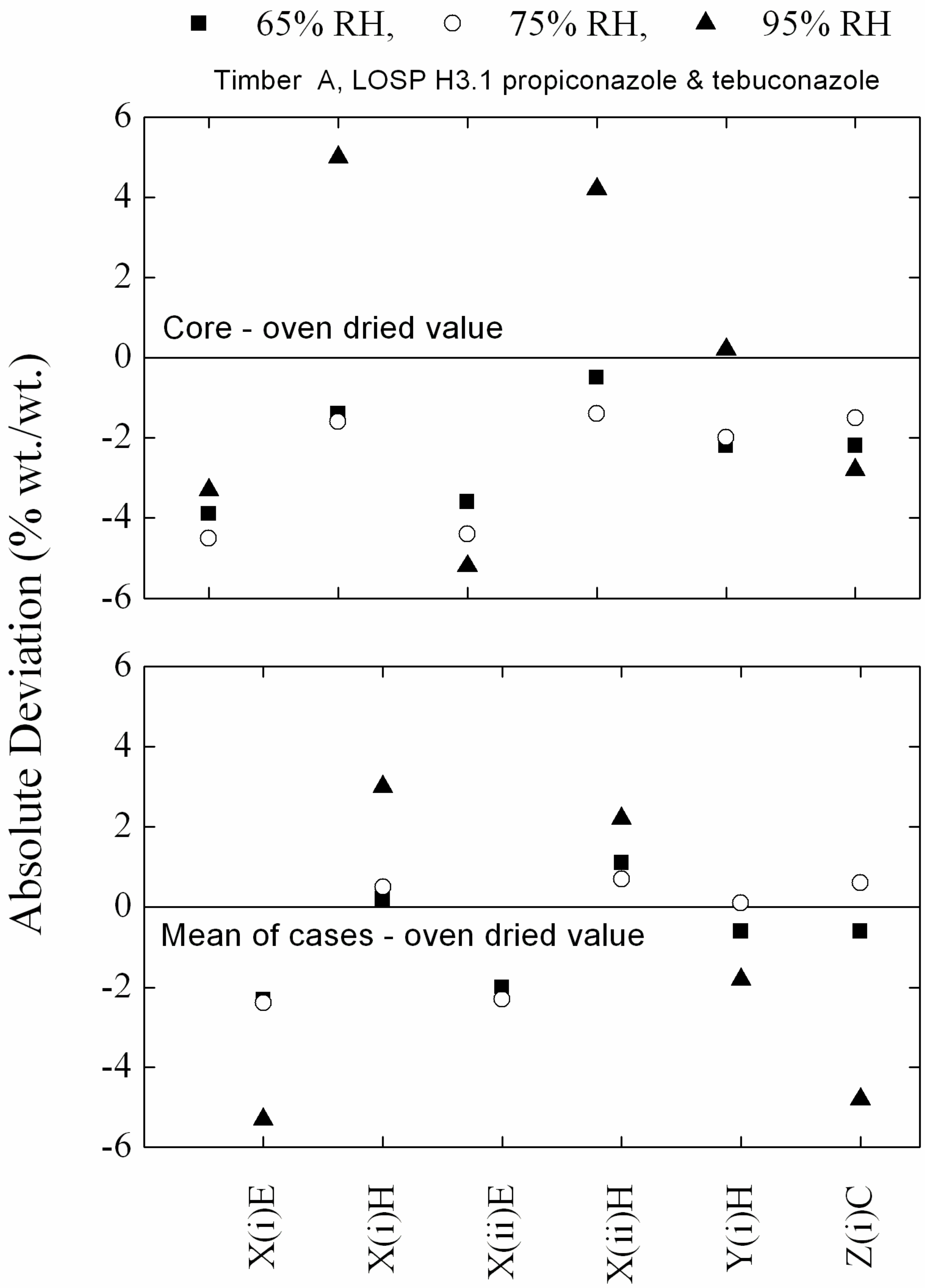

Figure 49. Timber Sample A (LOSP H3.1 propiconazole and tebuconazole). Values of absolute deviation of each moisture meter reading at Position 5 (uncorrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

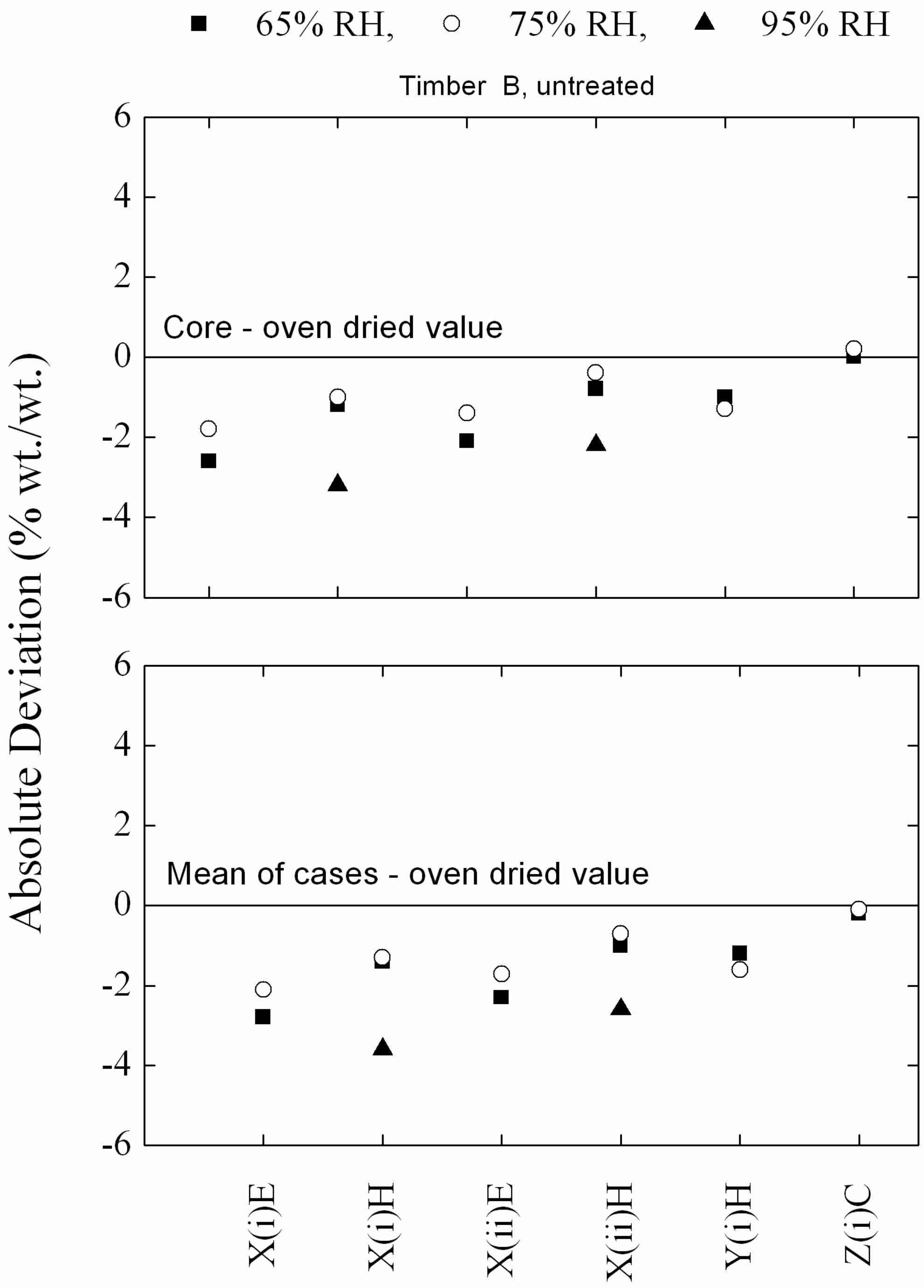

Figure 50. Timber Sample B (untreated). Values of absolute deviation of each moisture meter reading at Position 5 (uncorrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

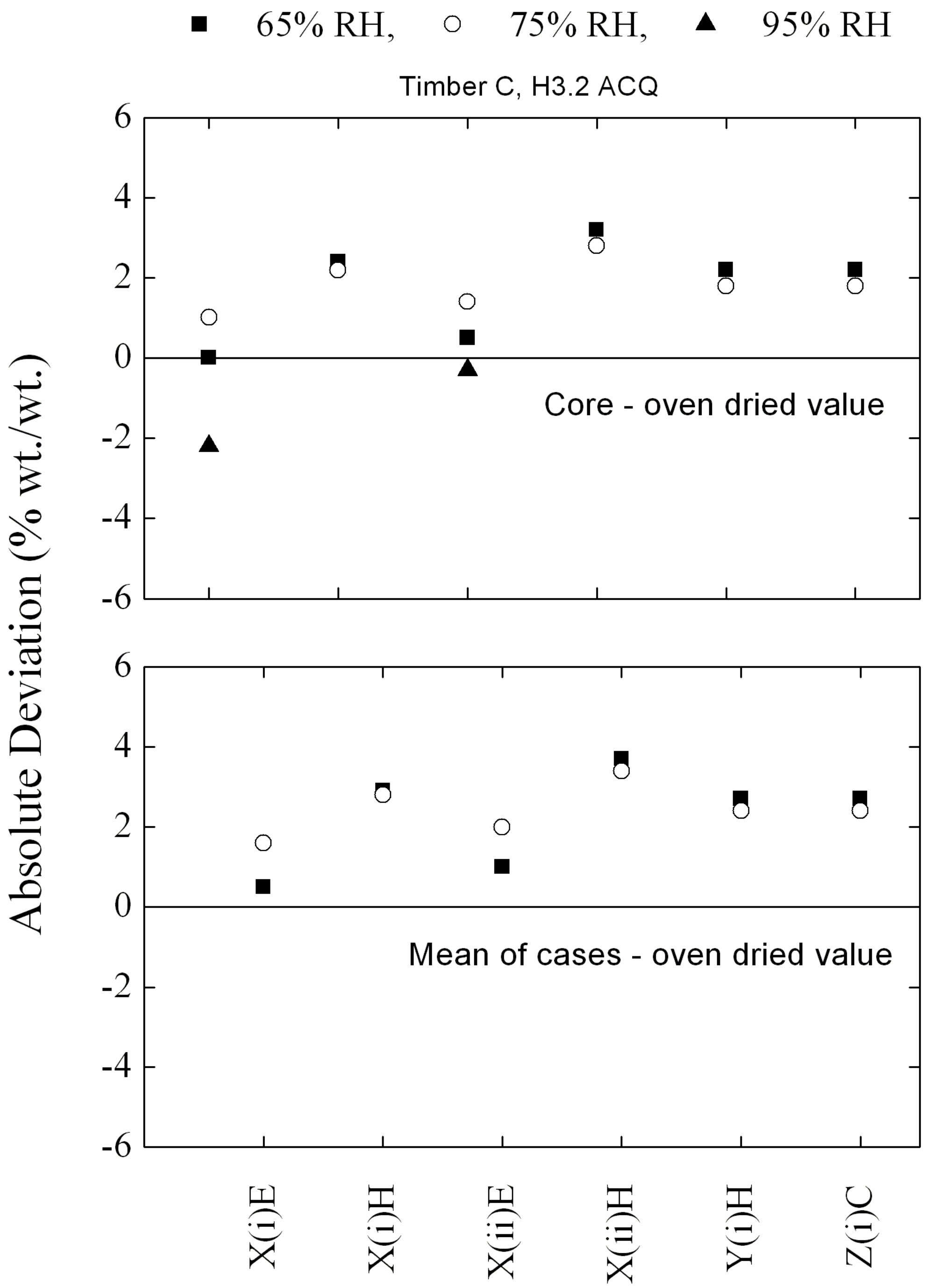

Figure 51. Timber Sample C (H3.2 ACQ). Values of absolute deviation of each moisture meter reading at Position 5 (uncorrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

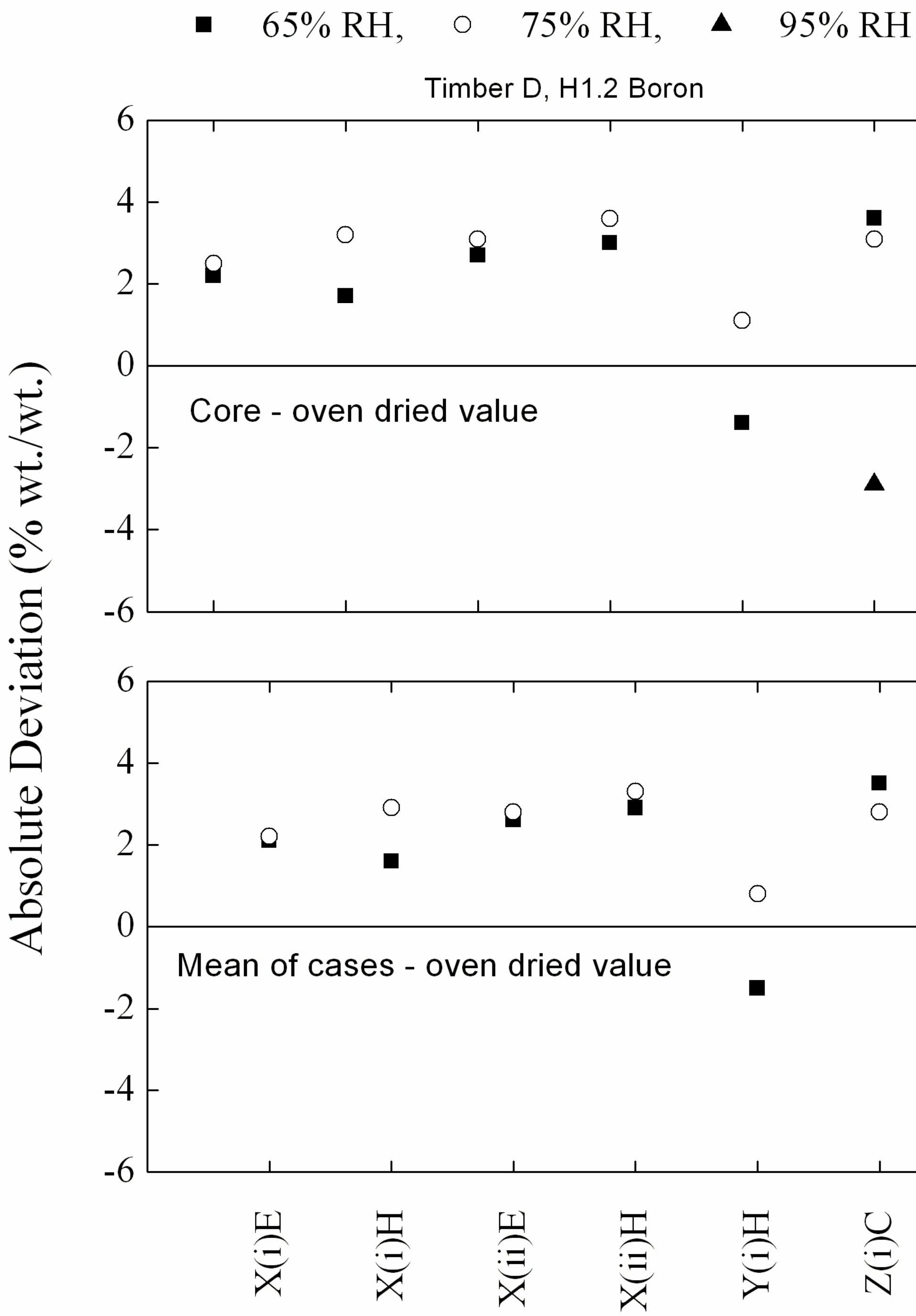

Figure 52. Timber Sample D (H1.2 boron). Values of absolute deviation of each moisture meter reading at Position 5 (uncorrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

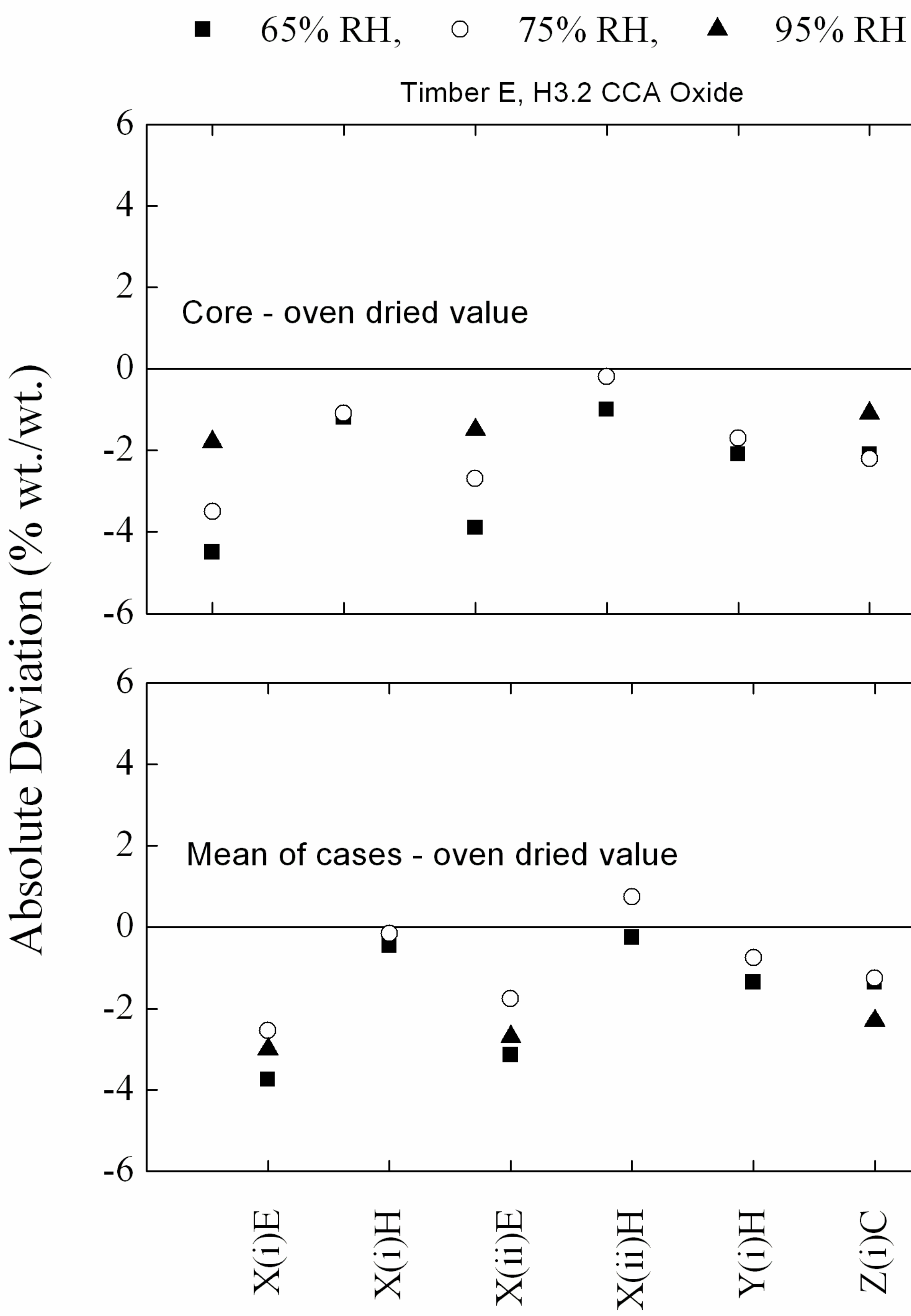

Figure 53. Timber Sample E (H3.2 CCA oxide). Values of absolute deviation of each moisture meter reading at Position 5 (uncorrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

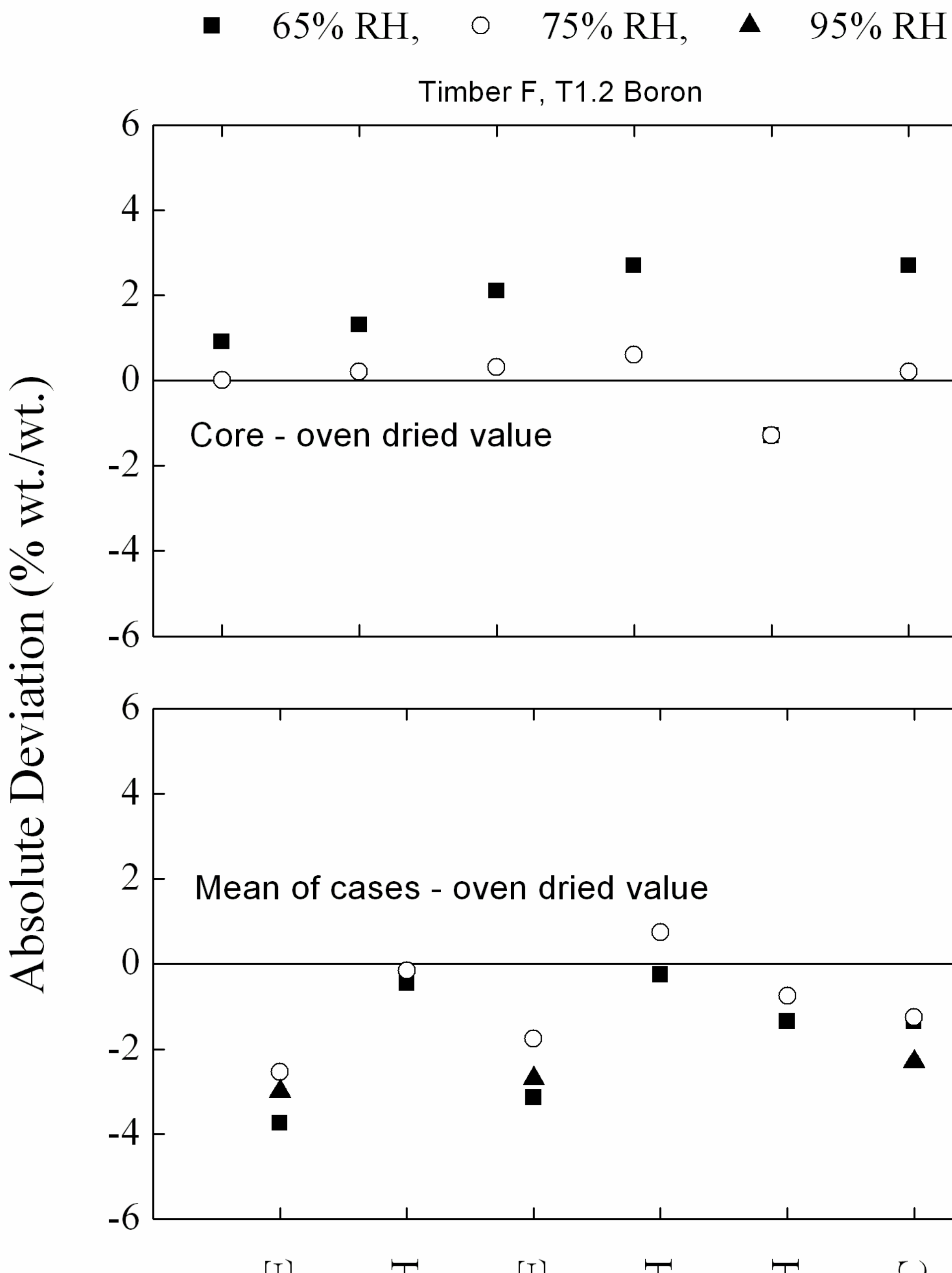

Figure 54. Timber Sample F (T1.2 boron). Values of absolute deviation of each moisture meter reading at Position 5 (uncorrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

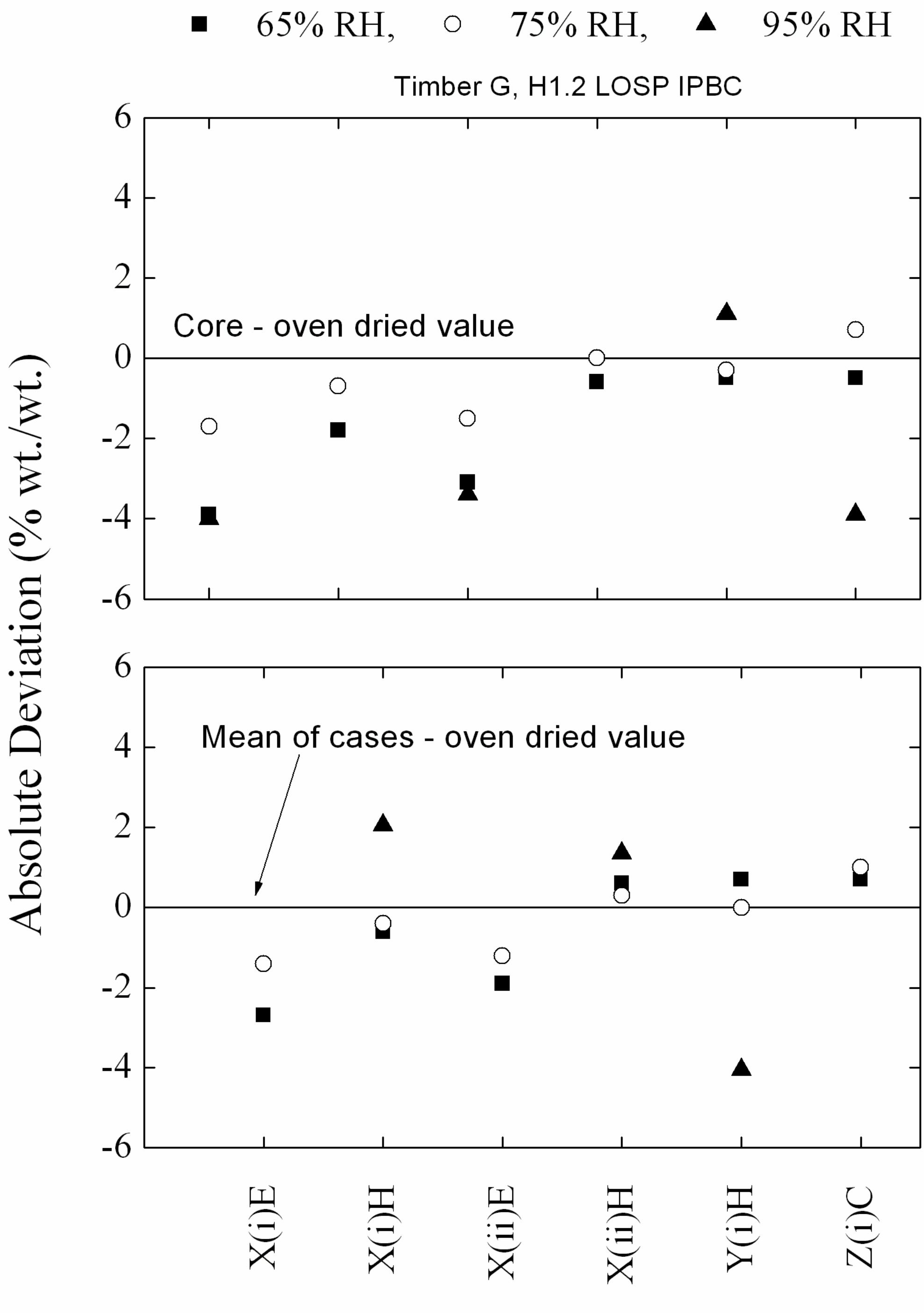

Figure 55. Timber Sample G (H1.2 LOSP IPBC). Values of absolute deviation of each moisture meter reading at Position 5 (uncorrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

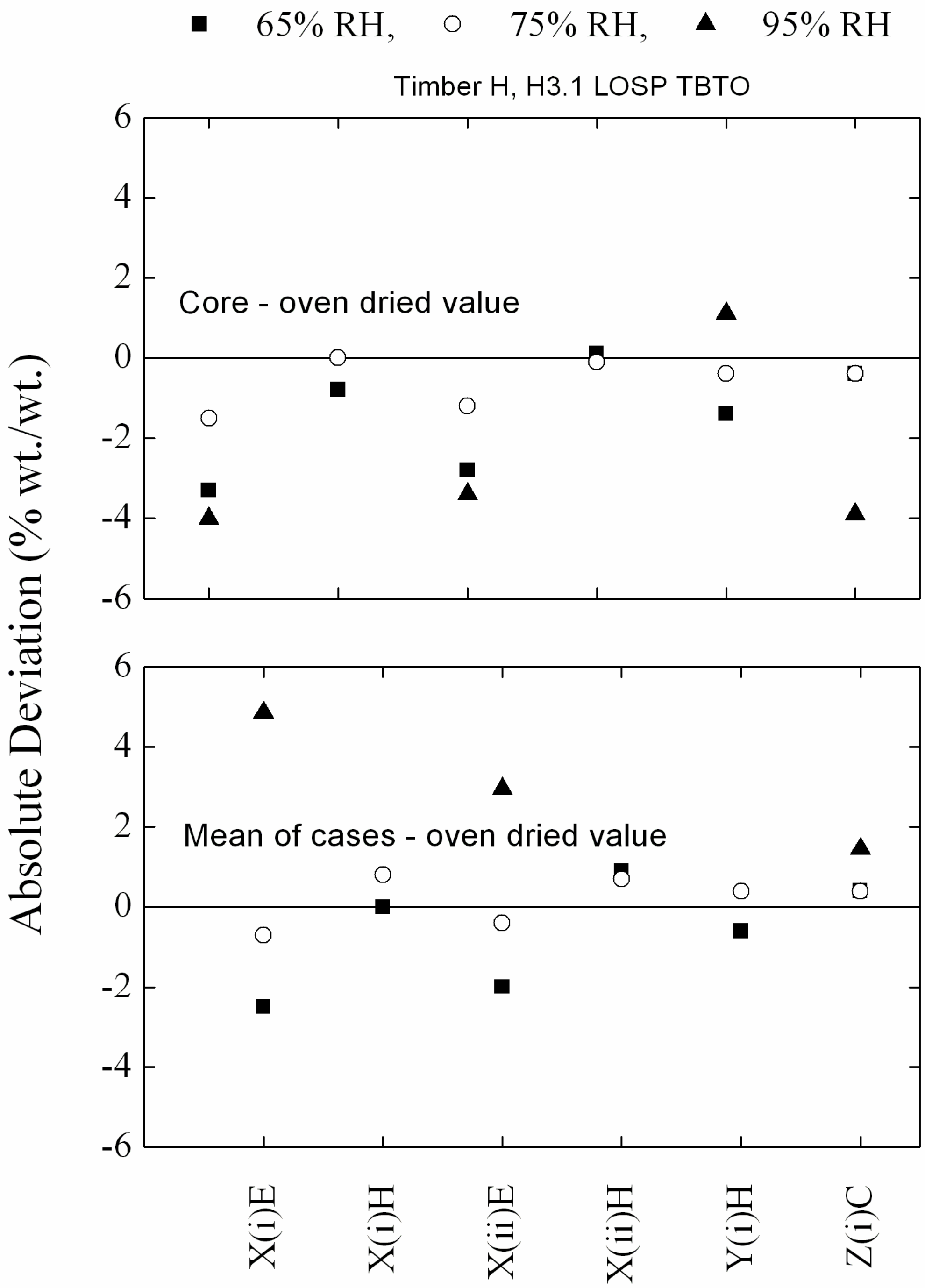

Figure 56. Timber Sample H (H3.1 LOSP TBTO). Values of absolute deviation of each moisture meter reading at Position 5 (uncorrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

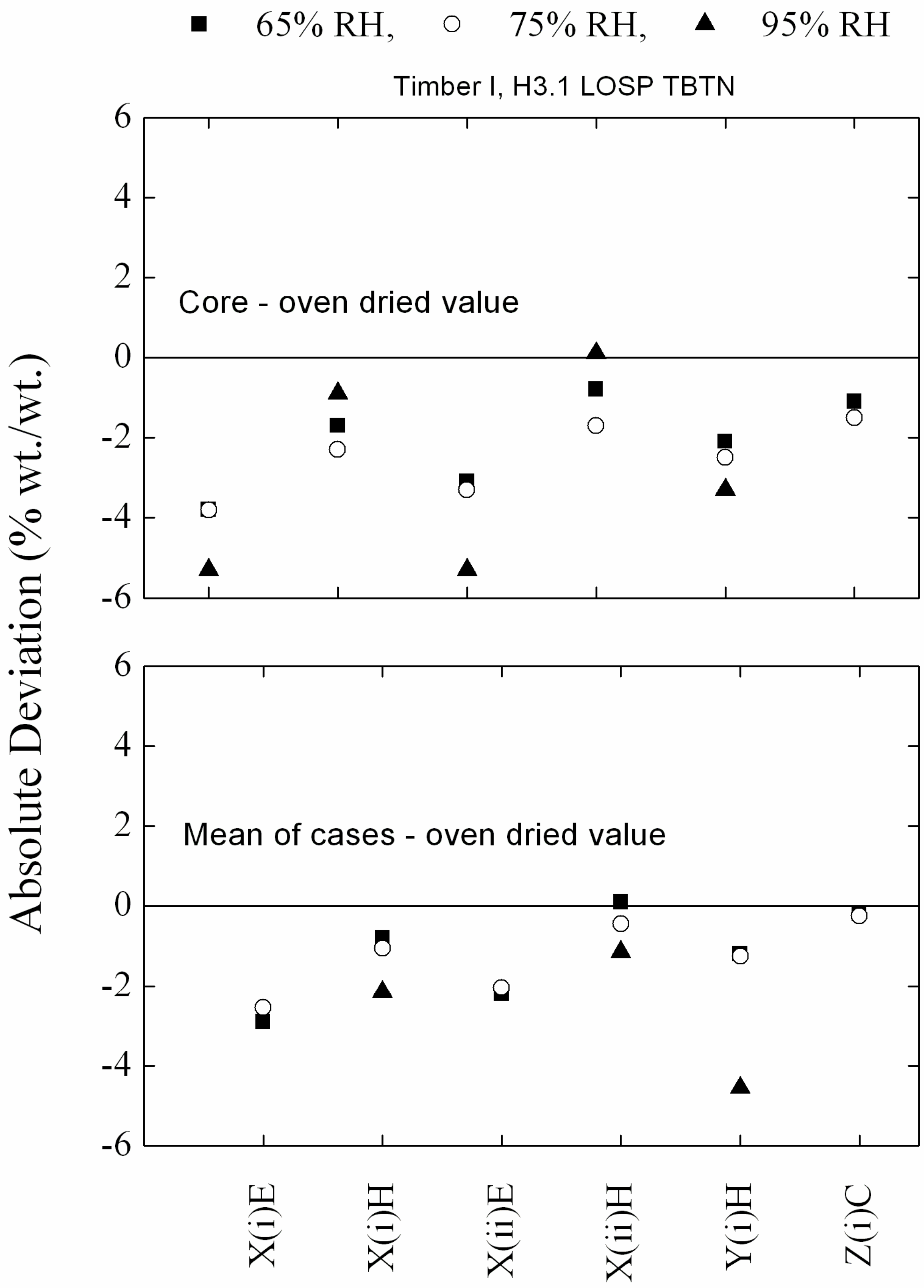

Figure 57. Timber Sample I (H3.1 LOSP TBTN). Values of absolute deviation of each moisture meter reading at Position 5 (uncorrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

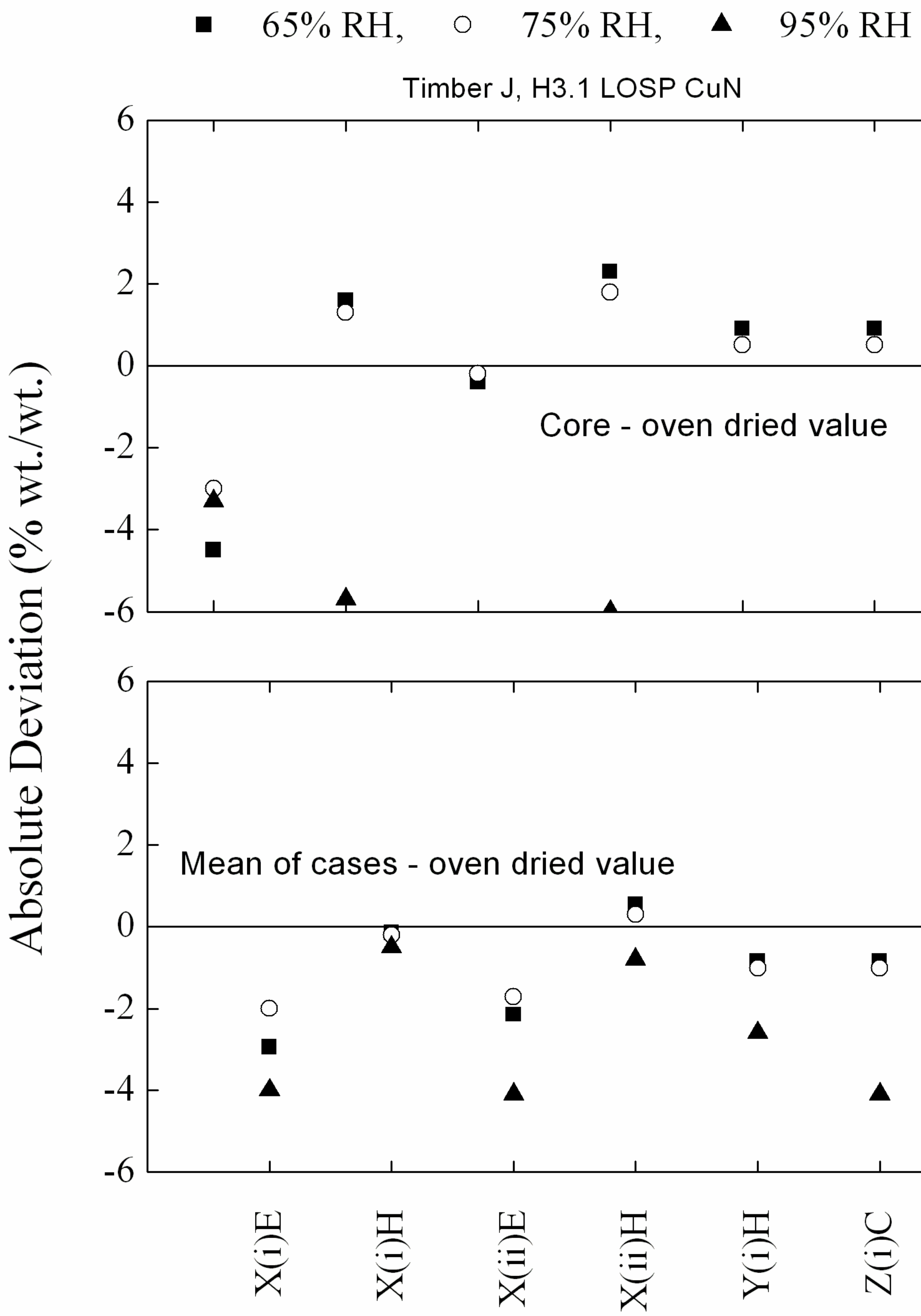

Figure 58. Timber Sample J (H3.1 LOSP CuN). Values of absolute deviation of each moisture meter reading at Position 5 (uncorrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

6.6 Application of the moisture meter correction figures as supplied with the individual instruments

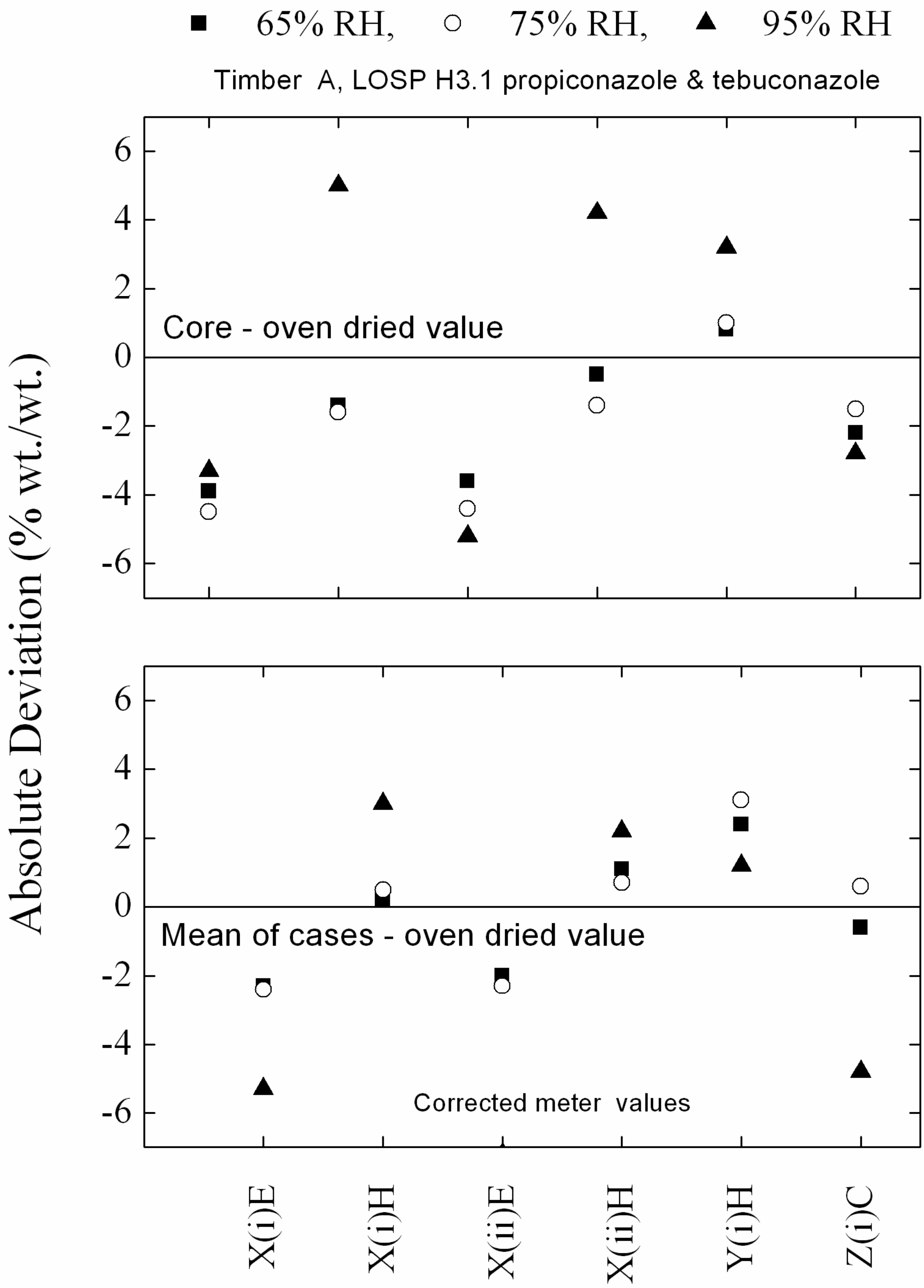

Figure 59. Corrected (see Table 9 for guide only) absolute values of meter deviation for Timber Sample A (LOSP H3.1 propiconazole and tebuconazole). Values of absolute deviation of each moisture meter reading at Position 5 (corrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

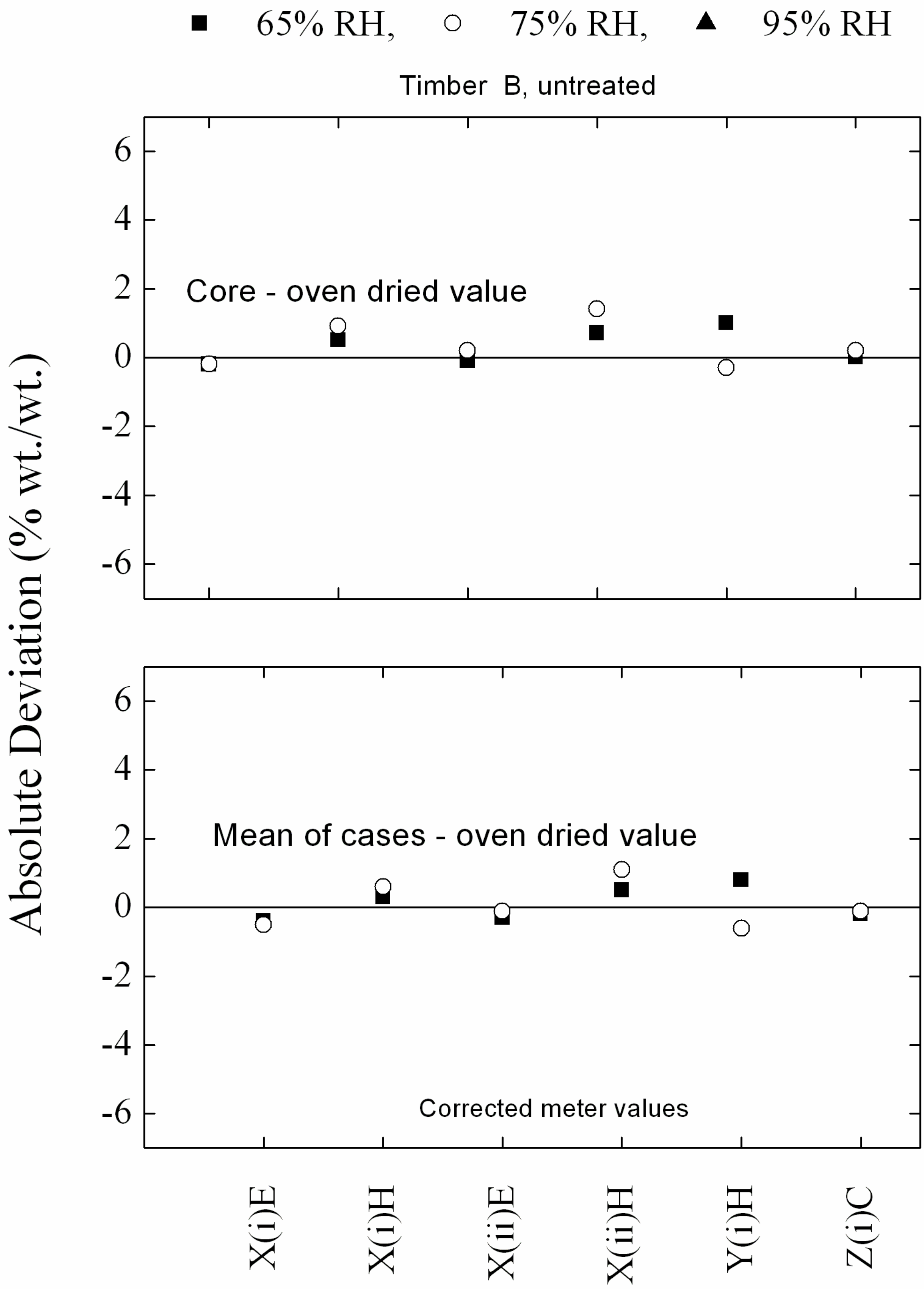

Figure 60. Corrected (see Table 9 for guide only) absolute values of meter deviation for Timber Sample B (untreated). Values of absolute deviation of each moisture meter reading at Position 5 (corrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

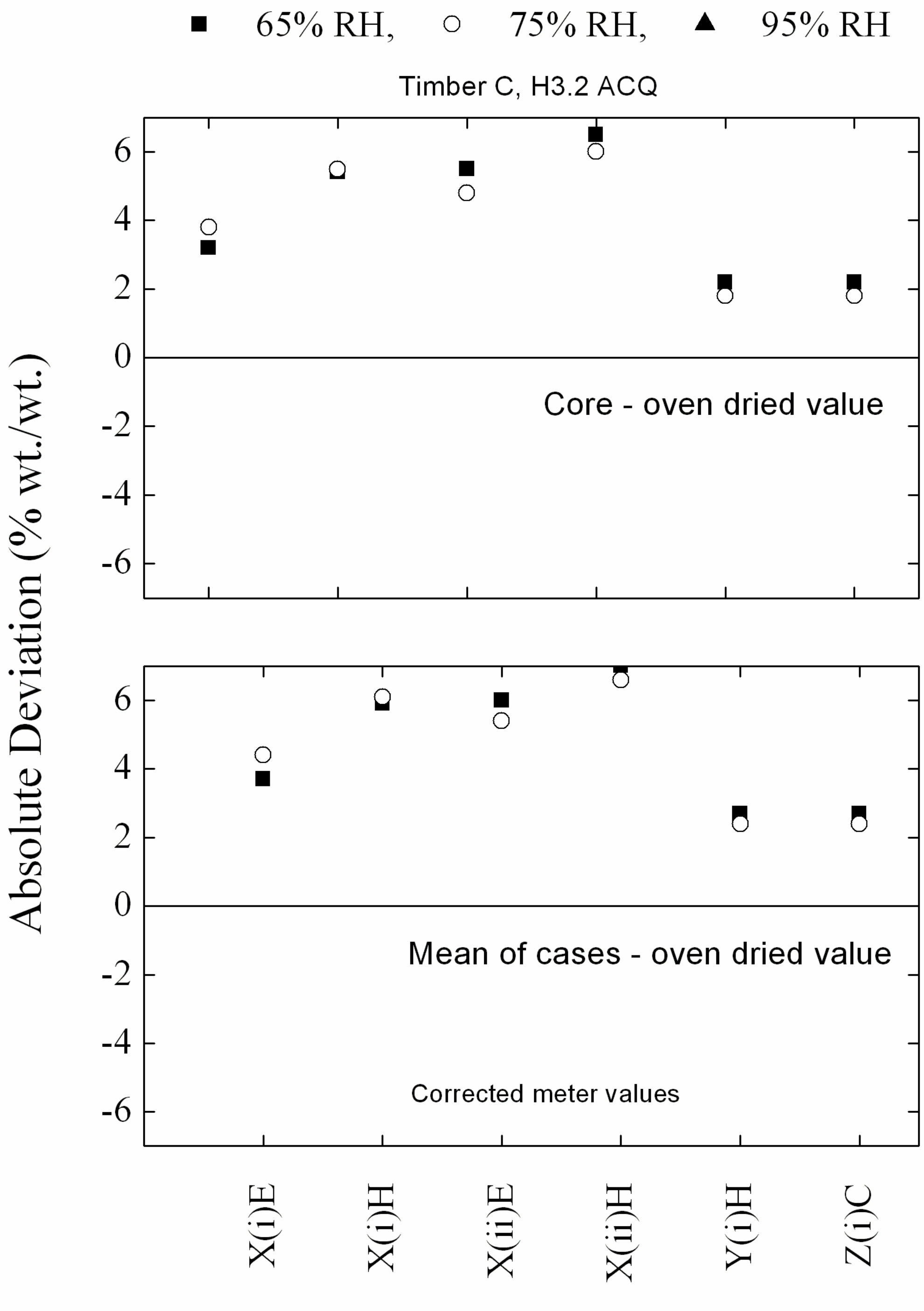

Figure 61. Corrected (see Table 9 for guide only) absolute values of meter deviation for Timber Sample C (H3.2 ACQ). Values of absolute deviation of each moisture meter reading at Position 5 (corrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

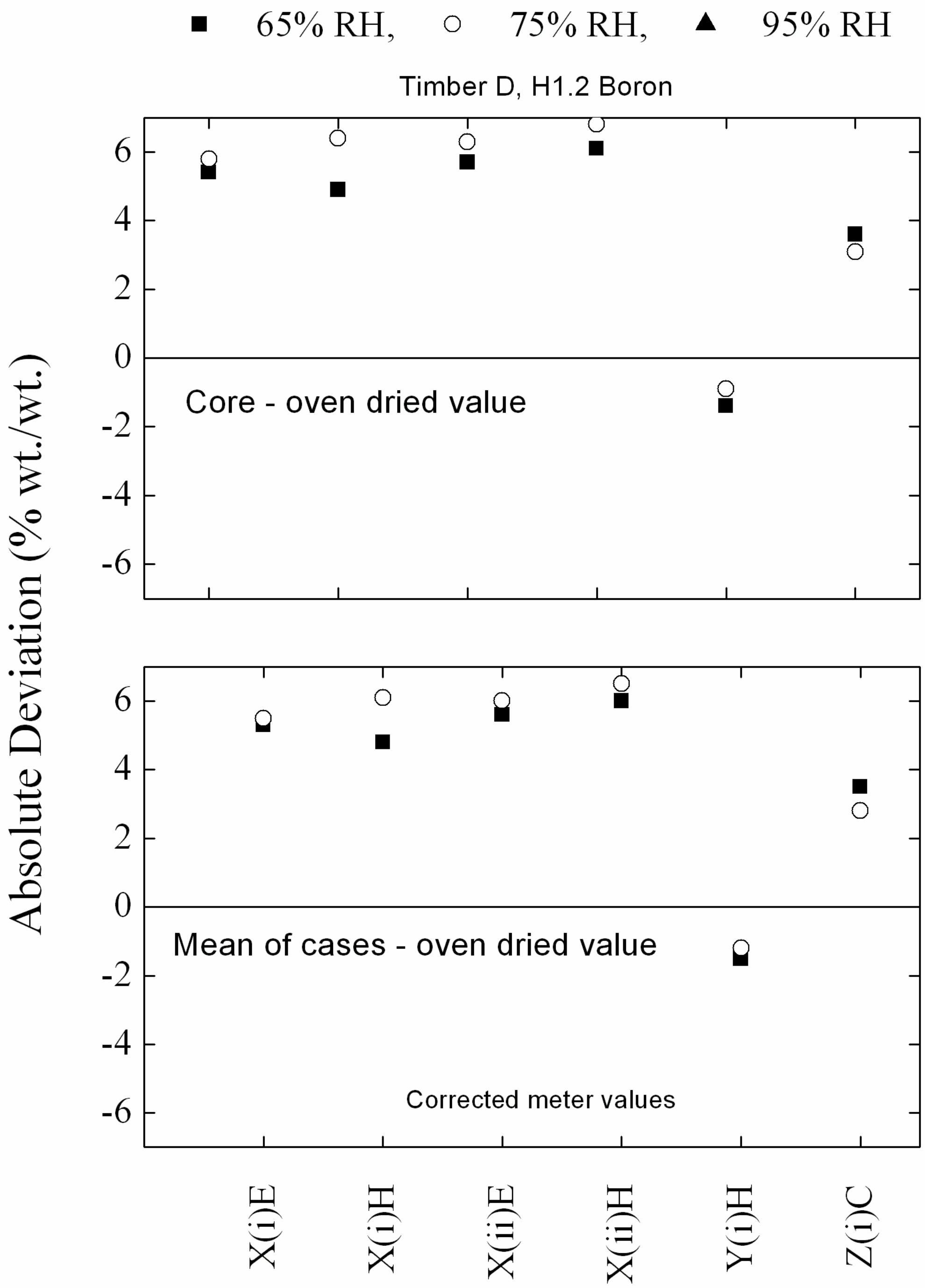

Figure 62. Corrected (see Table 9 for guide only) absolute values of meter deviation for Timber Sample D (H1.2 boron). Values of absolute deviation of each moisture meter reading at Position 5 (corrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

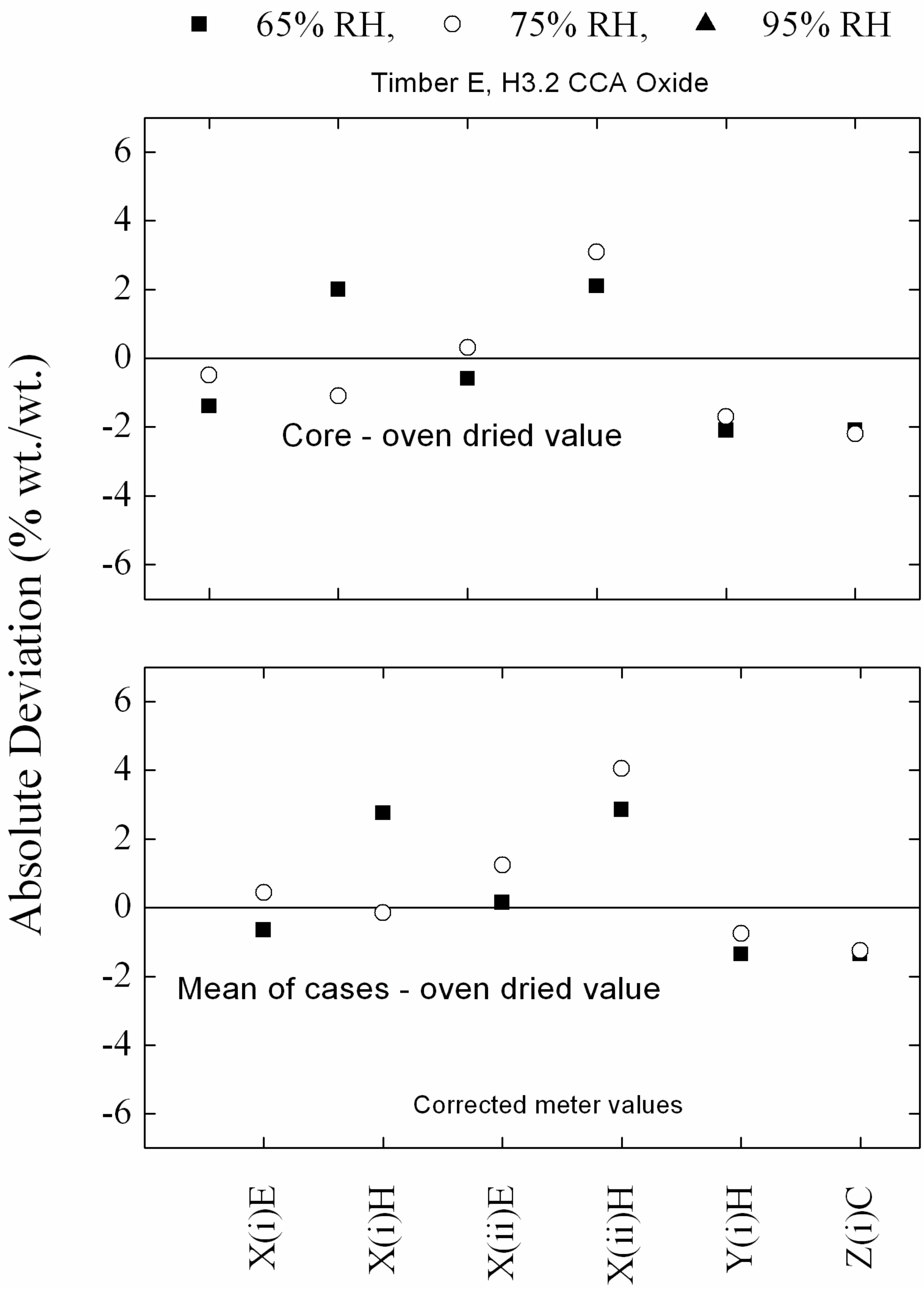

Figure 63. Corrected (see Table 9 for guide only) absolute values of meter deviation for Timber Sample E (H3.2 CCA oxide). Values of absolute deviation of each moisture meter reading at Position 5 (corrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

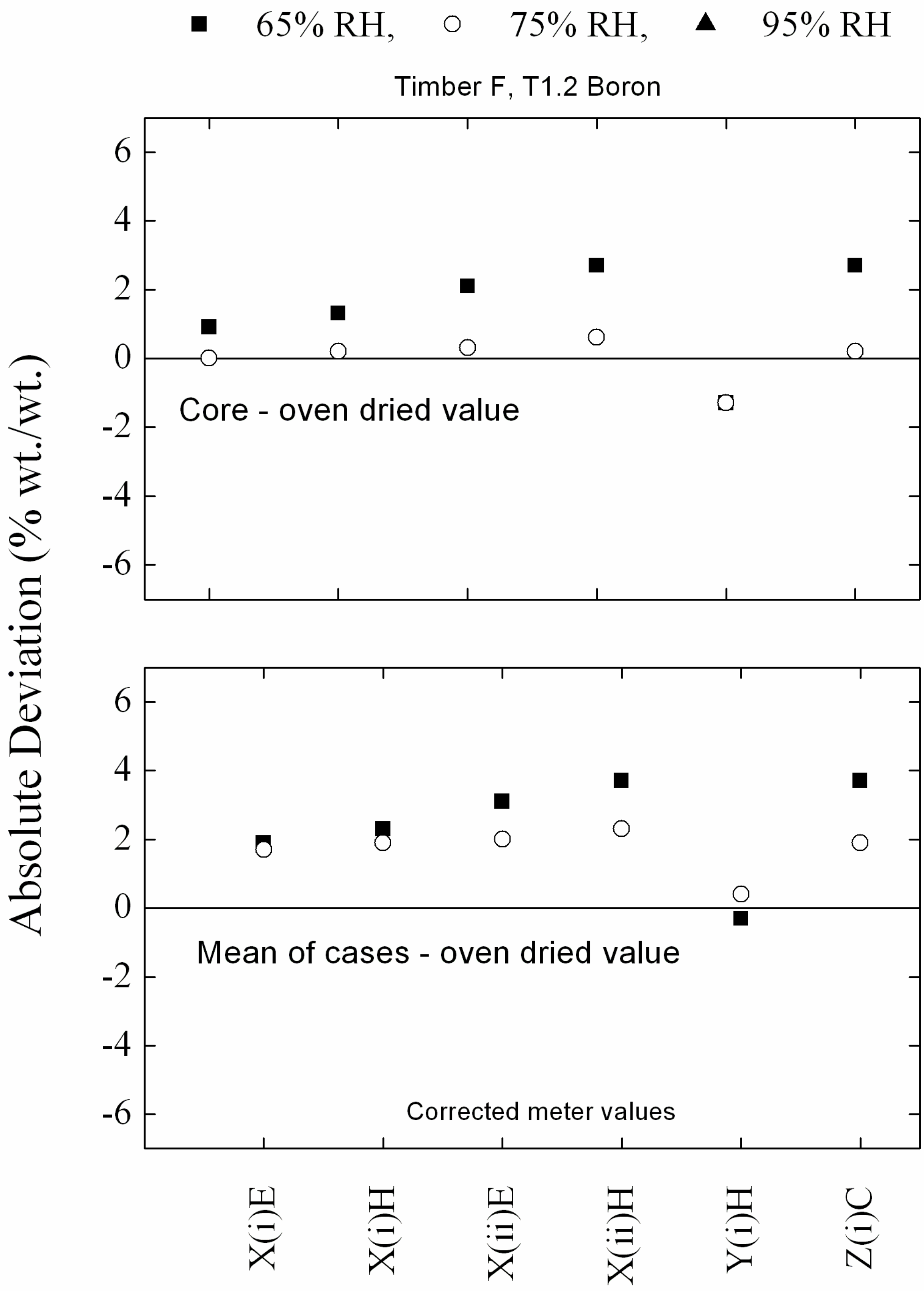

Figure 64. Corrected (see Table 9 for guide only) absolute values of meter deviation for Timber Sample F (T1.2 boron). Values of absolute deviation of each moisture meter reading at Position 5 (corrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

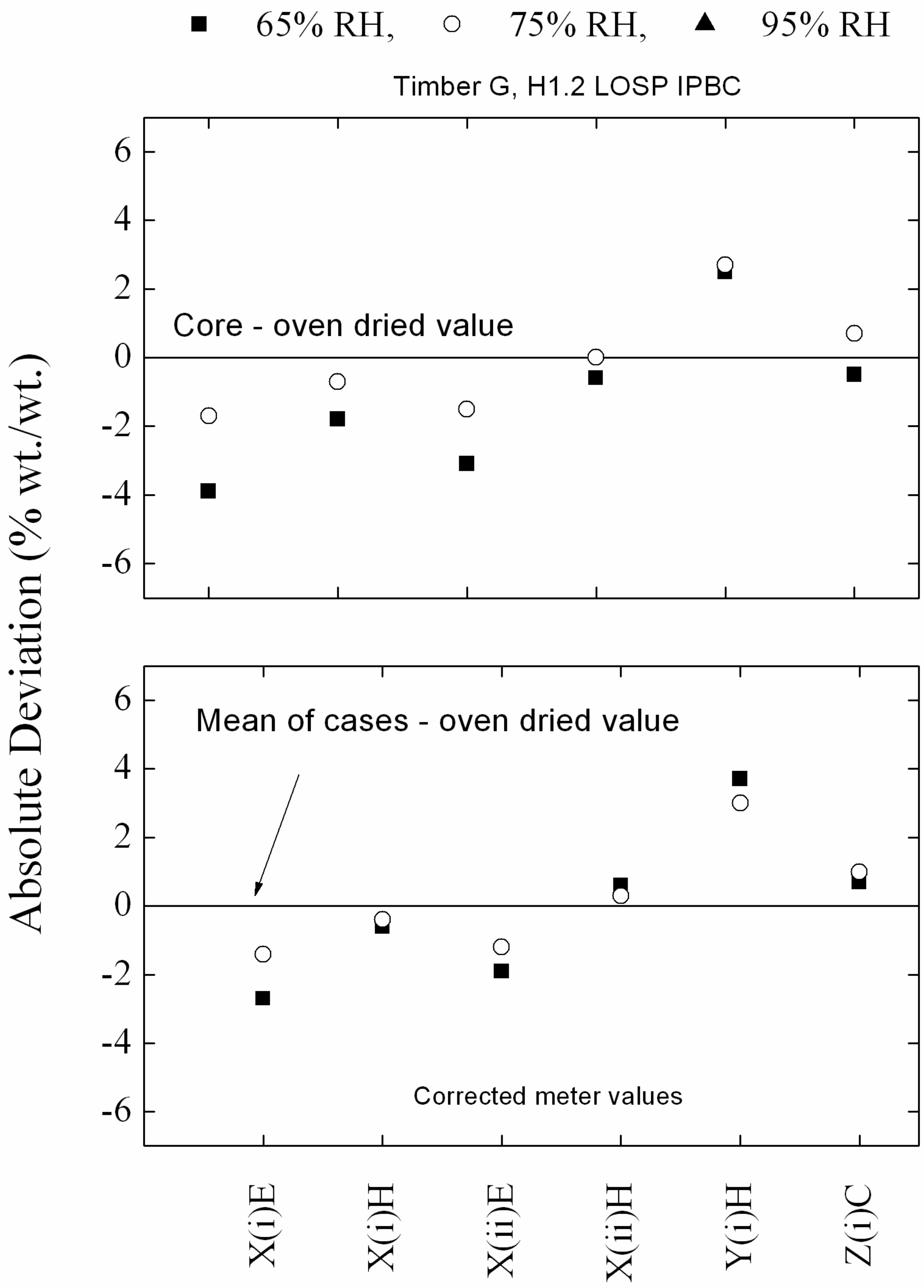

Figure 65. Corrected (see Table 9 for guide only) absolute values of meter deviation for Timber Sample G (H1.2 LOSP IPBC). Values of absolute deviation of each moisture meter reading at Position 5 (corrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

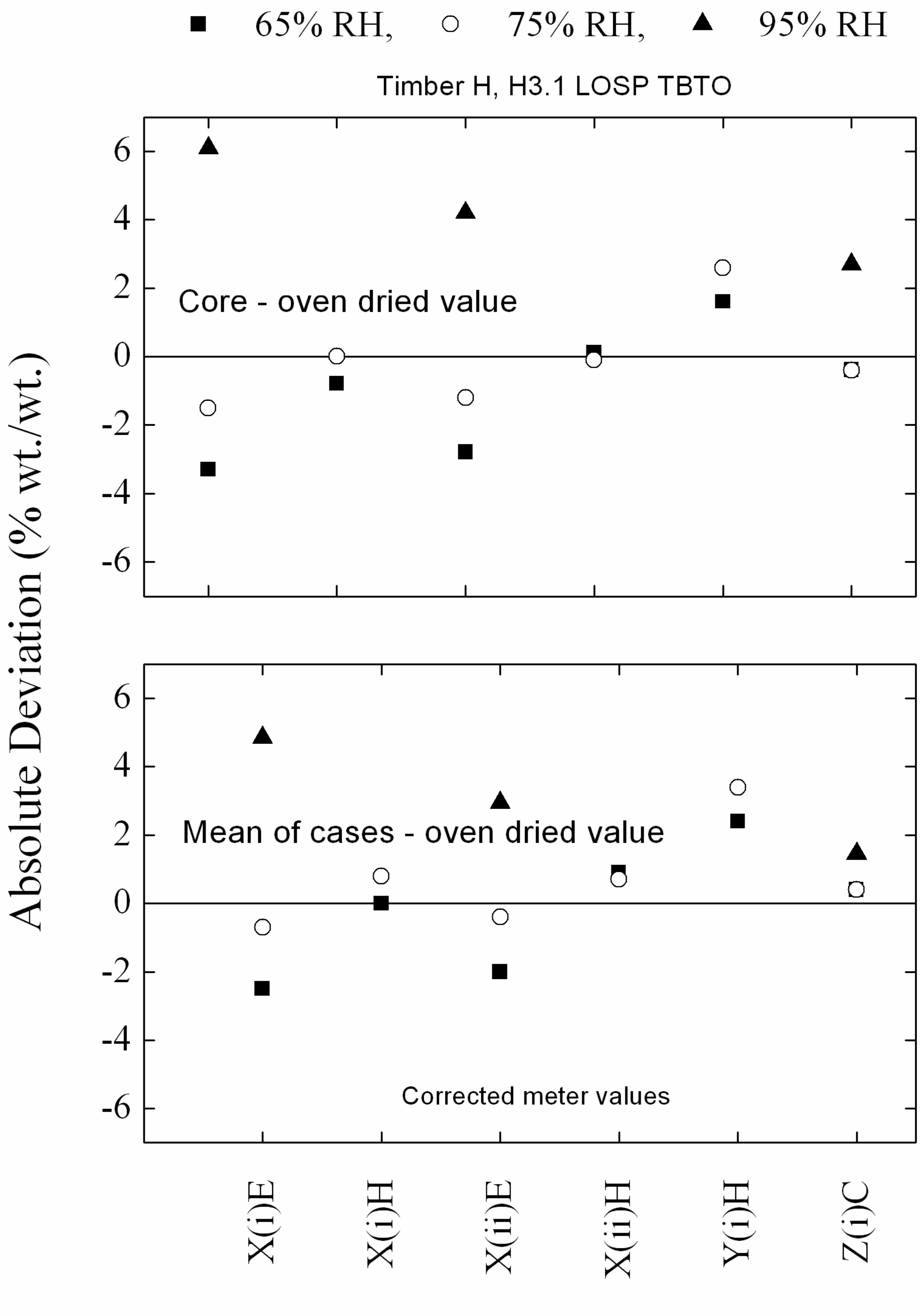

Figure 66. Corrected (see Table 9 for guide only) absolute values of meter deviation for Timber Sample H (H3.1 LOSP TBTO). Values of absolute deviation of each moisture meter reading at Position 5 (corrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

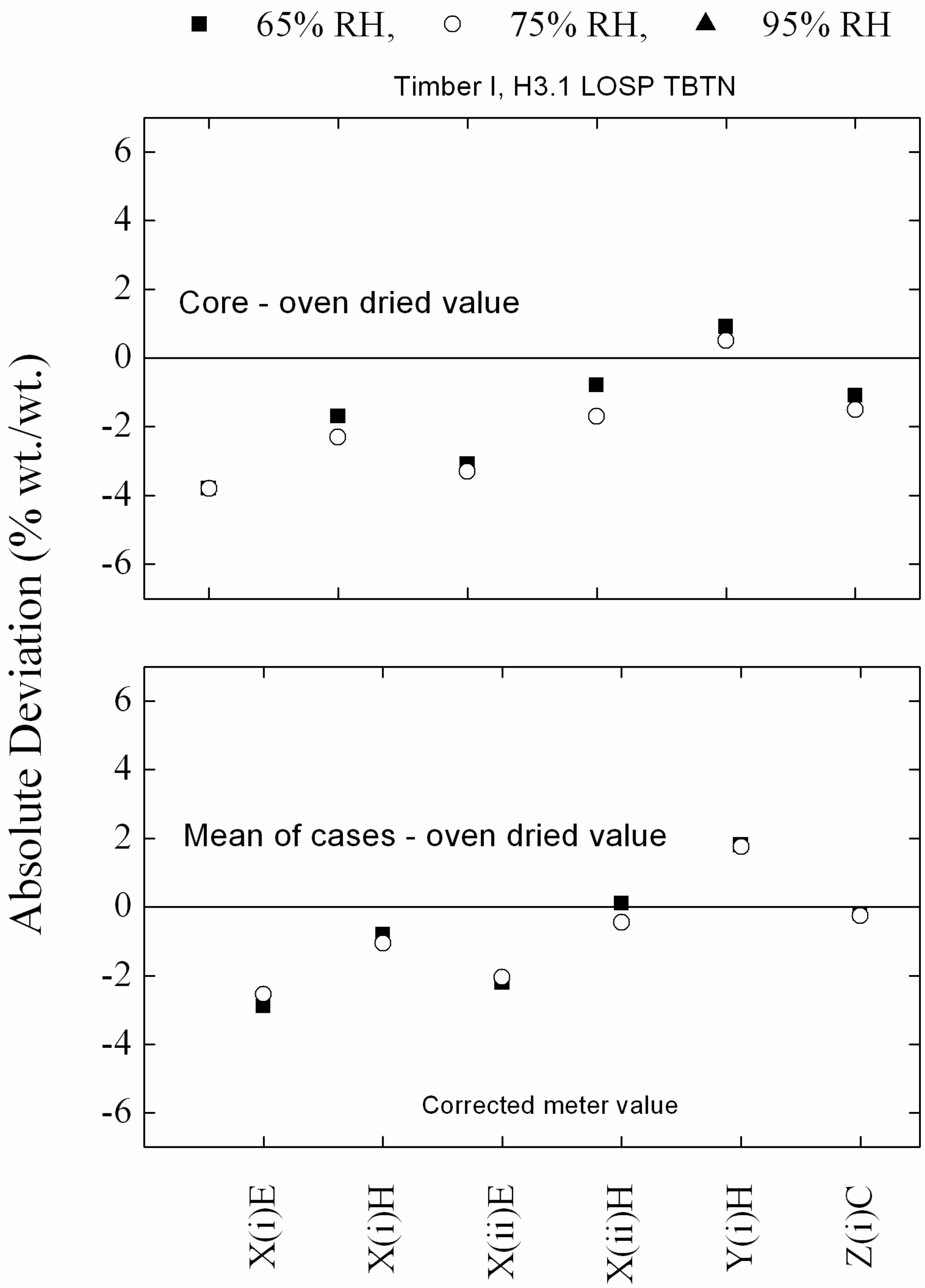

Figure 67. Corrected (see Table 9 for guide only) absolute values of meter deviation for Timber Sample I (H3.1 LOSP TBTN). Values of absolute deviation of each moisture meter reading at Position 5 (corrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).

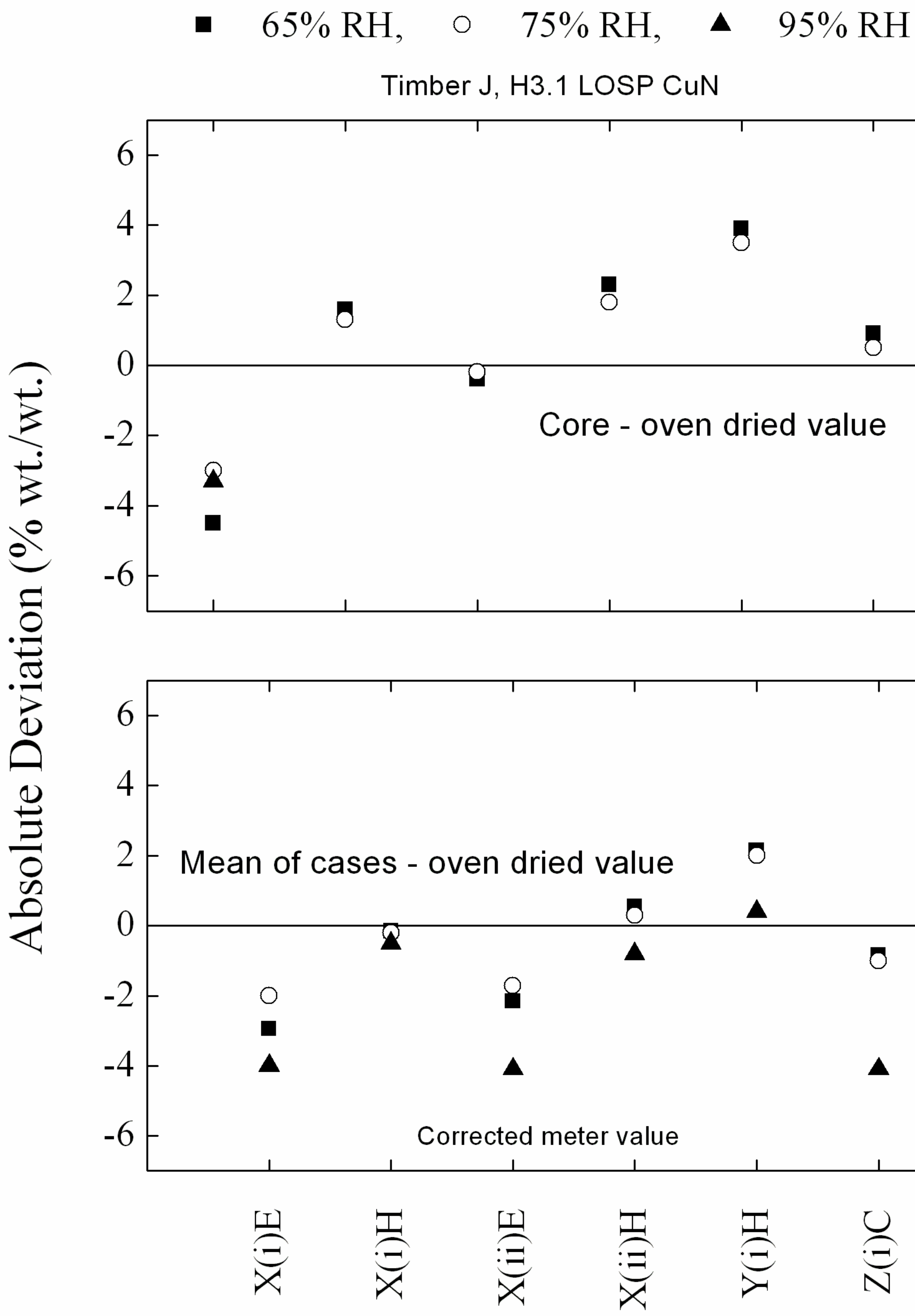

Figure 68. Corrected (see Table 9 for guide only) absolute values of meter deviation for Timber Sample J (H3.1 LOSP CuN). Values of absolute deviation of each moisture meter reading at Position 5 (corrected) from values measured using the AS/NZS 1080.1 oven-dried method (core and mean of cases).