# Improved Drying of *Eucalyptus nitens*: Screening standing trees and drying thin boards

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# EXECUTIVE SUMMARY


Following on from work in 2016/17, a model was created to predict the propensity for checking and collapse in *E. nitens* standing trees. This model was validated by measuring 100 trees, then selecting 10 that were expected to produce checking and collapse ('bad' logs) and 10 that were not ('good' logs). Two thicknesses of boards were cut from these logs (10mm and 30mm) and these were dried using two methods; air drying and kiln drying at 50°C. Following drying, levels of checking and collapse were assessed.

Air dried boards show much lower levels of degrade compared to kiln dried boards, however around 50% of kiln dried boards had no degrade, or acceptably low levels of degrade. For each drying method, the 10mm boards showed slightly less degrade than 30m boards, but this difference was not significant. The majority of the degrade was in the form of collapse but a small proportion (10-20%) of the 30mm boards had within ring checking.

No significant difference in levels of degrade were seen between boards cut from the 'good' and 'bad' logs. As with previous studies, some logs consistently produced boards with low levels of degrade, and some logs consistently produced boards with high levels of degrade, irrespective of drying method. This suggests that the underlying mechanisms causing checking and collapse propensity are not well correlated to the tree properties that were measured in this study. These mechanisms are currently not well understood. If these mechanisms become better understood in future, there may be scope to revisit this screening work using non-destructive measurements that better target the wood properties responsible for checking and collapse.

# INTRODUCTION

A major barrier to processing *Eucalyptus nitens* into high value products is the difficulty in drying timber without excessive checking and collapse. Work at Scion to reduce checking and collapse in nitens is currently focussing on methods to screen standing trees for the propensity to check or collapse. Work in 2016/17 developed a model to predict checking and collapse in dried boards from a variety of non-destructive measurements taken on the standing trees. A variety of drying methods were also trialled, which found that kiln drying at 50°C increased levels of checking and collapse over air drying, but some boards still remained free of checking and collapse. Different methods of air drying did not have a significant impact on the levels of checking and collapse.
In the this year’s work, the model created in 2016/17 is validated using two drying schedules; kiln drying at 50°C and air drying indoors.

Board thickness is known to have an effect on drying quality (Washusen & Innes, 2008), with thinner boards having less checking and collapse than thicker boards. Here two board thicknesses will be cut from each log (10 and 30mm) and these are dried using the two drying schedules outlined above.

# METHODS

## Non-destructive screening

The trees used in this study were from SouthWood Exports Goldingham forest and were taken from a compartment adjacent to that used in the 2016 trial. Scion field staff identified one hundred trees that were ready to be harvested and >250mm DBH. The identified trees are representative of the range of trees in the compartment that would be suitable for sawlogs.
The standing trees were measured in the same manner as the 2016 trial:
For each tree identified the following measurements were taken:

- DBH
- ST300
- 10mm increment core
- Two Pith to bark Resi traces at breast height at a feed speed of 200 cm/min, and a needle speed of 5000 r/min (core and trace were taken in similar radial positons).

Each measurement was labelled with the tree number, and the duplicate Resi traces included an “A” or “B” after the tree number.

Cores were sent to Scion, weighed, volume measured, then measured according to WQI App 22 (found in the appendix of Sargent, et al. (2017)). In addition to the method in App 22, the cores were weighed after oven drying so basic density could be calculated. Basic density and green density were calculated for each core. MOE was calculated from ST300 velocity and green density.

Resi traces were analysed in the same manner as the 2016 trial (Sargent, et al., 2017).

## Log selection and sawing

Using the data from the 2016 drying study, models were created to predict the check propensity of each log. The check propensity of a log was defined in two ways:

- The average score for the severity of checks and collapse in dried boards from each log (a larger number indicates greater degrade)
- Logs being classified as ‘good’ if they had no checking and collapse in any dried boards (or ‘bad’ if there were checks or collapse present).

The 2016 data was split into a ‘training’ data set (containing 75% of logs) and validation data set (the remaining 25% of logs). This enabled the model to be developed then used to predict log scores (or good/bad ratings) on logs with a known log score. The data was split into training and validation sets multiple times, to understand how repeatable the model results were.
Initial modelling using a Random Forest model (Breiman, et al.) did not give very repeatable results when predicting either the log score, or classifying logs into ‘good’ or ‘bad’ categories. Because of this, a second set of models was created using Principle Component Analysis (Jolliffe, 2002; R Core Team, 2017). No one model appeared to be picking the best and worst of the 2016 study logs consistently, so it was decided to select logs based on predictions from all four models.

From the 100 tress measured in 2017 twenty trees were selected, 10 with a ‘good’ rating, and 10 with a ‘bad’ rating. Within each group of 10 trees, trees with a wide range of non-destructive measures were selected.

The selected trees were felled and a breast height disc cut from each. Discs were sent to Rotorua via refrigerated freight, after a week’s delay where they were stored in bags in the back of a ute. The Scion genetics team requested that a foliage sample be taken from each tree and these were air freighted to Rotorua.

A 3m long log was cut, starting from 3m up each tree. The logs were coated with end seal and sent to Rotorua in a container.

After arriving in Rotorua, a disc was cut from the large end of each log, and a barcode attached to the freshly cut face. The logs were sawn at the Waipa Campus of Toi Ohomai into 100x30mm boards, aiming for quarter sawn boards.

The two sets of discs (log height and breast height) were sawn in half to reduce cracking during drying, then photographed. They were air dried (fillet stacked) in the VRC Lab at Scion. Following drying, the discs were cross cut into two thin discs and the sawn face of one disc sanded to show any checks. The number of checks in each growth ring were counted and recorded. The approximate heart-sap boundary was noted.

## Drying Study

Sawing yielded more boards than were required for this work. Following sawing, boards were sorted into three sets of 20 boards, each containing one board from each log. Boards with defects (splits, wane, large variation in dimension) were excluded where possible. The boards were labelled with the log number, then a letter from 'F' onwards.
All selected boards were measured with the Joescan to give dimensions, stiffness, weight and distortion, and the barcodes on the end of the board recorded to show where in the tree each board was cut. Following measurement one set of 20 boards was ripped to pairs of 100x10mm boards.

All the boards were cross-cut into two 1.2m lengths, with 30mm long moisture content blocks being cut from each end of the short boards. All boards were end sealed with Carboguard 635 paint. The moisture content blocks were labelled with the board number, then the numbers 1-3. These had their width and thickness measured with calipers, then their green weight and volume recorded, then oven dried and their weight recorded again.

Prior to drying all boards were weighed and their width and thickness measured at each end of the board. Two drying methods were used to get the boards to 30% MC: Kiln drying at 50/40°C and air drying in the VRC lab. One charge of each thickness were dried at each temperature. The two charges of 50/40°C boards were dried as separate kiln charges. The air dried stacks had low-velocity forced circulation from fans to keep stack conditions uniform (measured velocities were 1-1.9 m/s). A temperature and humidity logger was placed inside the air-dried stack to record actual conditions during drying. Once boards had reached 30%MC, the same low temperature kiln drying method was used on all boards: dry at 40/30°C (48% Relative humidity) until ~12% MC, then condition at 40/34°C for 48 hours.

Once boards were dry, they were conditioned at 25°C, 65%RH until their weight stabilised, and weighed. 100mm was cut from one end and the freshly cut surface of each board was assessed using the same 4-point scale as the 2016/17 study. Checking and collapse were assessed separately, and given one of the following ratings:

0. Not present
1. Present, but at an acceptable level
2. Present, at an unacceptable leve
3. Present at a very severe level

Examples of each rating are given in Appendix 2.

# RESULTS

## Non-destructive screening

A summary of the non-destructive measurements from the cores and ST300 are given in Table 1. There are a wide range of values for each metric, showing that a broad range of trees have been measured, giving a high likelihood of including trees with a high or low propensity for checking and collapse. Analysis of the resi traces is outlined in detail in the 2016/17 report (Sargent, et al., 2017).

Table 1. Non-destructive measures from 10mm cores and ST300

| | Basic Density (kg/m$^3$) | S1 (mm) | S2 (mm) | S3 (mm) | S4 (mm) | S5 (mm) | S6 (mm) | Max shrinkage (mm) | Av shrinkage (mm) | Acoustic Velocity | DBH (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Av | 394 | -0.04 | 0.07 | 0.36 | 0.49 | 0.39 | 0.28 | 1.31 | 0.32 | 3.89 | 317 |
| Stdev | 20 | 0.64 | 0.55 | 0.49 | 0.54 | 0.52 | 0.55 | 1.60 | 0.28 | 0.22 | 44 |
| Min | 336 | -2.00 | -1.29 | -0.81 | -1.87 | -1.43 | -1.45 | 0.11 | -0.35 | 3.26 | 218 |
| Max | 437 | 2.72 | 1.66 | 2.23 | 2.10 | 1.93 | 2.36 | 11.93 | 1.06 | 4.53 | 444 |
| Number of cores | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

## Log selection and Sawing

For each model, the 100 trees were ranked according to how likely they were to produce boards free of checking and collapse. The median ranking for each tree was used to select 10 trees with the highest ranking (least likely to check or collapse) and 10 with the lowest ranking (most likely to check or collapse). Trees with a DBH below 250mm were excluded as being too small to saw effectively. Rankings from each model for the trees selected is given in Appendix 1.
Table 2 shows the average model outputs for the logs selected as 'good' or 'bad'. For the classification as 'good' or 'bad', the model output is a value between 0 (bad) and 1 (good). Conversely the log scores range from 0 (no checking or collapse) to 3 (severe checking and collapse).

Table 2. Predicted log scores and goodness ratings for each model used.

| | Log score PCA | | Log score RF | | 'Goodness' PCA | | 'Goodness' RF | |
|---|---|---|---|---|---|---|---|---|
| | Av. | Stdev | Av. | Stdev | Av. | Stdev | Av. | Stdev |
| Good | -0.36 | 0.14 | 0.65 | 0.14 | 0.47 | 0.09 | 0.66 | 0.07 |
| Bad | 0.82 | 0.16 | 1.47 | 0.02 | -0.05 | 0.10 | 0.47 | 0.21 |

Once the logs arrived in Rotorua, discs were cut from one end and barcodes attached to the freshly sawn face. Several logs had minor end splitting that could be removed prior to cutting a disc from the large end of the log. One log (Tree 30) had such severe end splitting that it was not possible to cut a disc (as the resulting log would be too short to saw).

The small diameter, and short length of the logs limited the number of sawing patterns that could be applied to the log (quarter-sawing requiring a larger diameter log, for example). Rather than target a specific sawing orientation, the primary aim was to reduce the dimensional variation both within and between boards, as this had been an issue in the 2016 study. Roughly half (80 out of 167) of the boards sawn were required for the drying study, so it was possible to reject boards that had obvious defects such as end splits, wane, or excessive dimension variation.

## Drying Study

The selected boards were sorted into four charges of end-matched 1.2m long boards. The green properties of each charge is given in Table 3. As the boards are end-matched the properties are very similar between the air dried and kiln dried boards for each thickness. Table 4 shows the difference in green properties between the boards from ‘good’ trees and those from ‘bad’ trees. For all the properties listed, there were no significant differences between the good and bad trees (95% confidence level).

Table 3. Board properties by drying method

| Drying method | Nominal thickness | Green MC Av | Green MC Stdev | Basic density Av | Basic density Stdev | % Q sawn | % flat sawn |
|---|---|---|---|---|---|---|---|
| Air Dry | 30 | 118.6 | 19.6 | 433.6 | 30.2 | 15 | 18 |
| Kiln Dry | 30 | 115.8 | 17.7 | 439.9 | 29.2 | 15 | 18 |
| Air Dry | 10 | 119.8 | 14.6 | 428.8 | 23.1 | 5 | 14 |
| Kiln Dry | 10 | 119.8 | 14.5 | 428.8 | 23.1 | 5 | 14 |

Table 4. Board properties for ‘good’ and ‘bad’ trees

| | Nominal thickness | Green width (mm) | Green thickness (mm) | Green MC (%) | Basic density (kg/m$^3$) | % Q sawn | % flat sawn |
|---|---|---|---|---|---|---|---|
| Good | 10 | 105.6 | 11.5 | 118.2 | 427.4 | 20 | 10 |
| | 30 | 105.8 | 34.0 | 113.6 | 441.1 | 10 | 20 |
| Bad | 10 | 105.2 | 11.5 | 121.4 | 430.2 | 9 | 18 |
| | 30 | 105.3 | 33.0 | 120.8 | 432.4 | 20 | 15 |

Plots of the conditions during air drying and kiln drying are given in Appendix 3. Air drying conditions averaged around 15°C and 77% RH. This is a lower temperature and higher RH than the indoor air drying used in the 2016/17 study, but warmer and drier than air drying in an open shed (which averaged around 10°C and 90-100%RH).
There were a number of process upsets during the kiln drying of the 30mm boards. There was a communication failure with the PLC, leading to the kiln switching to a 70°C default schedule for a number of hours, later there were two power cuts where the kiln shut down for a several hours (shown as gaps in the data in Figure A3).
The remaining kiln schedules ran smoothly. Times for drying from green to 30% MC and final kiln drying from 30 to 12% MC are given in table 5. Not surprisingly the air dried boards took much longer to dry to 30% MC, but drying times from 30 to 12% MC were similar to those of the boards kiln dried from green. For the air dried boards, the 10mm boards dried in around 60% of the time required for the 30mm boards. For the kiln dried boards, the 10mm boards dried substantially faster, requiring only around 20% of the time taken for the 30mm boards.

Table 5. Drying times for each charge.

| Charge number | Nom. width (mm) | Time to 30%MC (days) | Kiln Drying time (days) |
|---|---|---|---|
| Air Dry | 30 | 49 | 12 |
| Kiln Dry | 30 | 6 | 19 |
| Air Dry | 10 | 30 | 7 |
| Kiln Dry | 10 | 1 | 5 |

Following drying and equilibration, boards had 100mm docked from one end and the cut face was visually assessed for collapse and within-ring checking.

For each charge, the proportion of boards with different levels of degrade are shown in Figure 1. The 10mm air dried boards had the lowest level of degrade, with over 70% of boards showing no degrade. There are significant differences in the proportion of boards with degrade between the treatments ($\chi^2$ = 46.395, df = 9, p < 0.001), with large differences in the proportion of degrade in the kiln dried and air dried boards. For both the kiln dried and air dried boards, the proportion of 10mm thick boards with degrade can be compared to the proportion of 30mm boards with degrade. For each drying method there was no significant difference in the proportions of degraded boards. Within each board thickness, there were significant differences in the level of degrade from each drying method (form 10mm boards ($\chi^2$ = 25.516, df = 3, p < 0.001, for 30mm boards ($\chi^2$ = 13.172, df = 9, p = 0.0043). The 2016/17 pre-screening work also found that kiln dried boards had higher levels of degrade than air dried boards, so this result is not surprising. It is interesting that there is no significant difference in degrade between the 30mm and 10mm boards, as drying thinner boards is often suggested as a way of reducing degrade (Washusen & Innes, 2008).

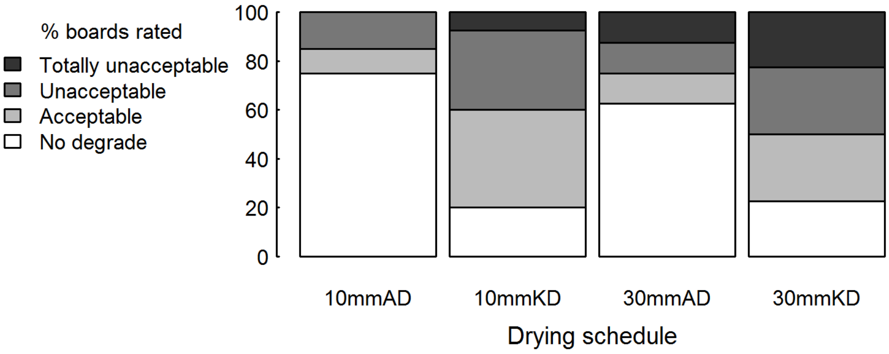


Figure 1. Proportions of each level of degrade in the different charges.

If we only look at within-ring checking (Figure 2), the 10mm boards have significantly lower levels of checking than the 30mm boards, but for each thickness there is no significant difference between air dried and kiln dried boards. In situations where collapse can be planed off, but within-ring checking must be avoided, using thinner boards may be an option for reducing degrade. Boards that had within-ring checks also tended to have collapse, so the levels of collapse for each drying schedule is almost identical to Figure 1.

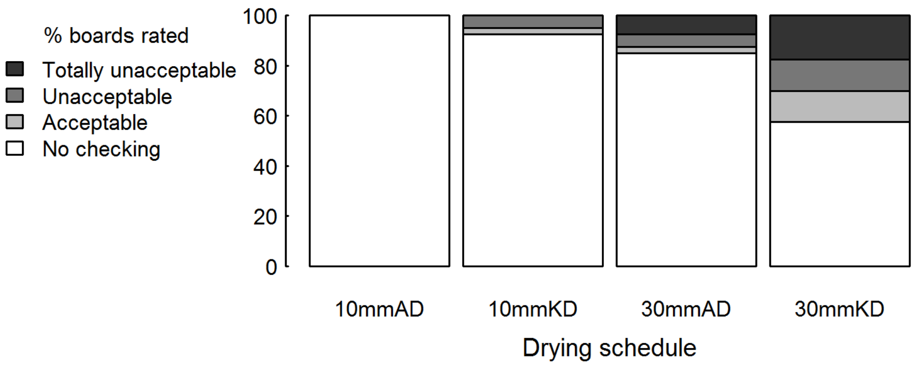


Figure 2. Proportions of each level of within-ring checking in the different charges

Within each drying charge, boards can be separated into those from 'good' logs and those from 'bad' logs. This is shown in Figure 3. Within each drying charge the 'good' logs gave slightly lower levels of degrade, but these differences are not statistically significant.

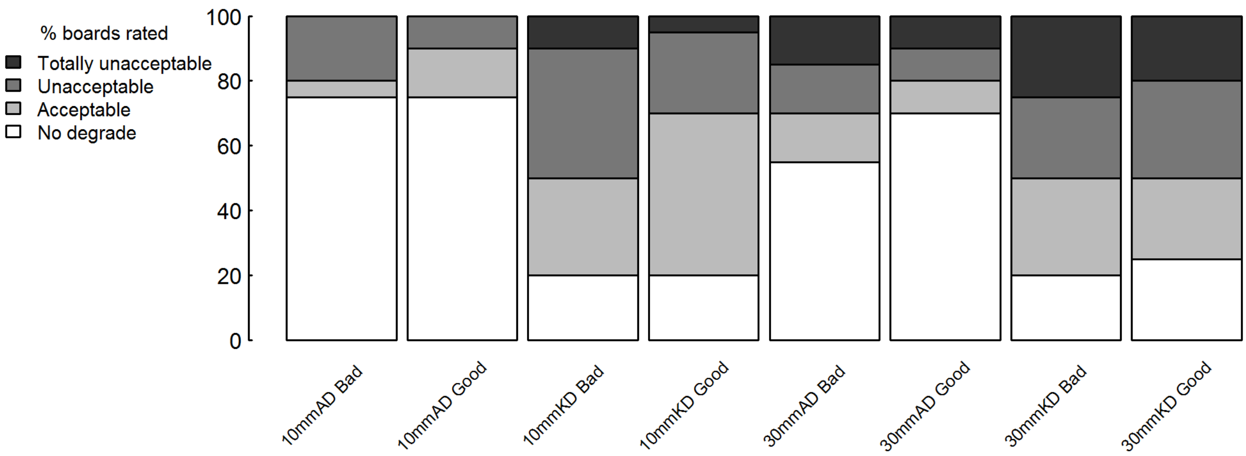


Figure 3. Proportions of each level of degrade for the 'good' and 'bad' logs.

The levels of degrade in each board is shown as a function of drying charge and log number in Figures 4. As with the 2016 work, there are logs that consistently produce high levels of degrade, and logs that consistently produce low levels of degrade, but both of these types are present within the ‘good’ and ‘bad’ log groupings.

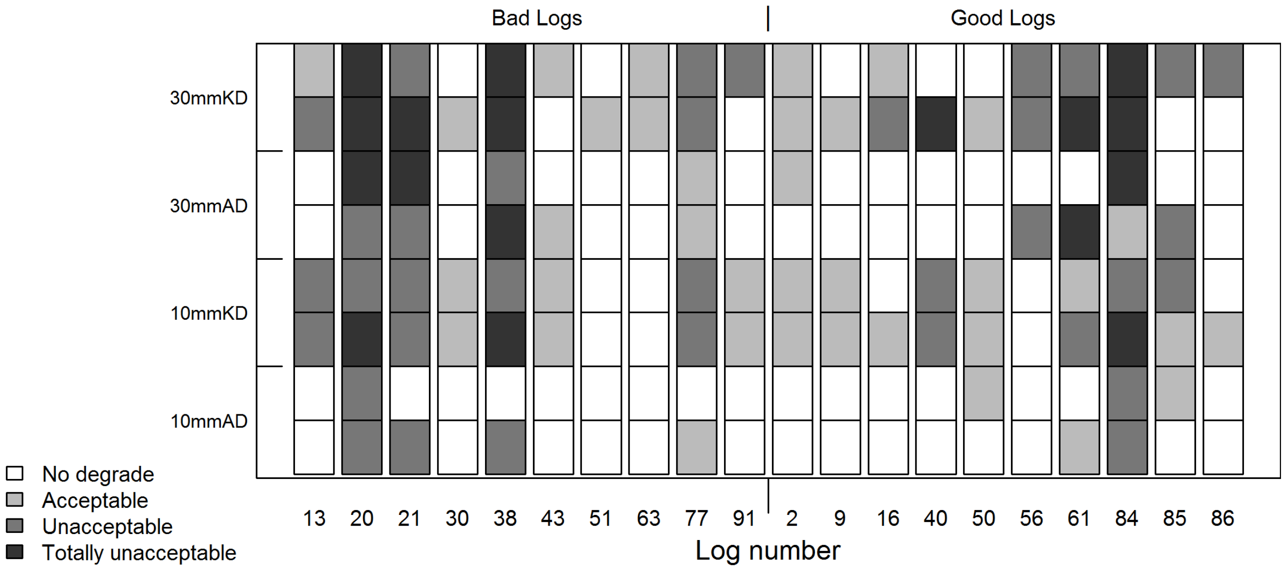


Figure 4. Levels of degrade in each board, arranged by log and by charge.

Levels of within-ring checking and collapse in each board can be shown in the same way (Figures 5 & 6). As with the overall levels of degrade, there are logs that have high levels of checking or collapse, and logs with no checking and collapse, but both these types are found in both the ‘good’ and ‘bad’ groupings. This shows that the non-destructive measurements used here are not good predictors of the propensity for checking and collapse. The causes of between-tree variations in the propensity to check and collapse are not well understood, and until these causes are identified, it is extremely difficult to select measurement techniques that have a high likelihood of correlating with levels of checking and collapse.

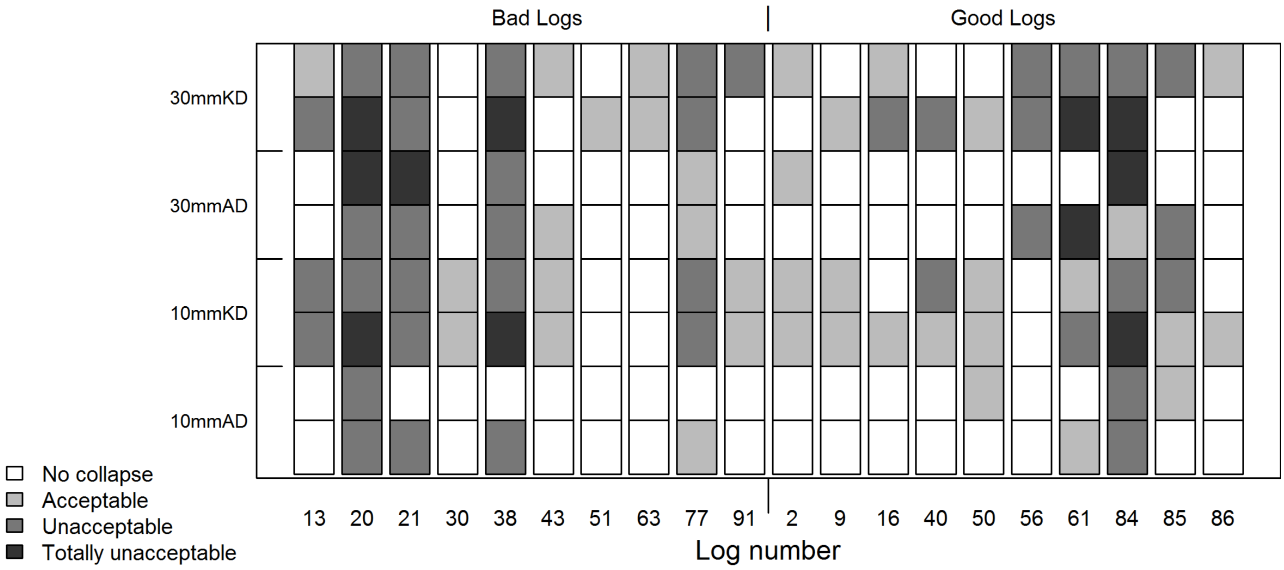


Figure 5. Levels of collapse in each board, arranged by log and by charge

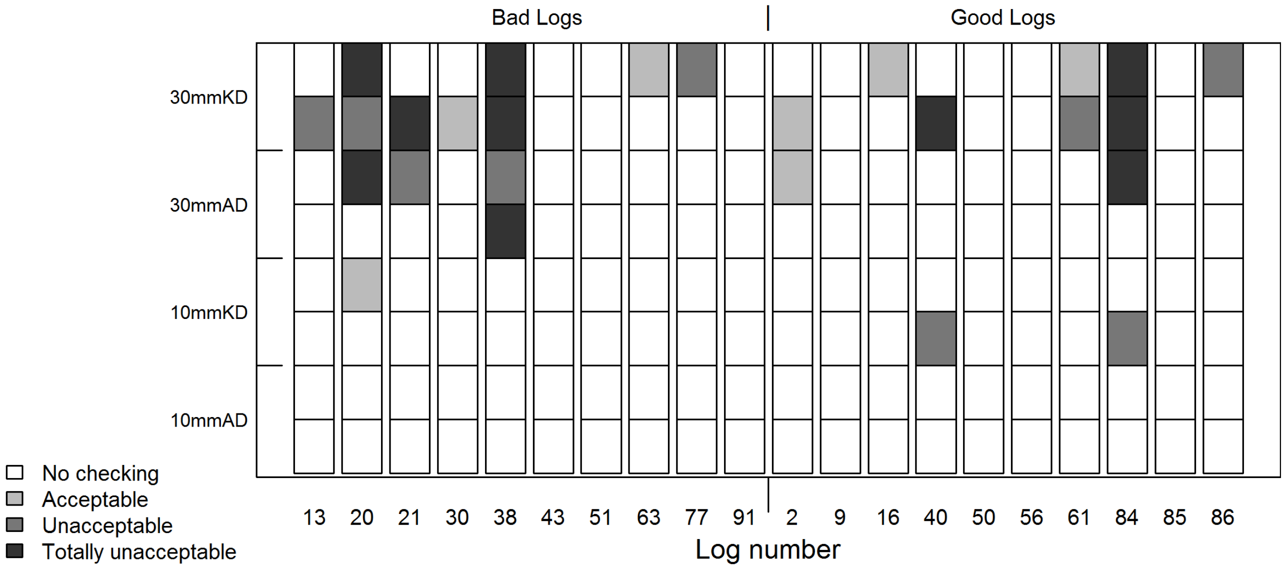

Figure 6. Levels of within-ring checking in each board, arranged by log and by charge.

For each log, the levels of degrade were averaged for all the kiln dried boards, and for all the air dried boards. These 'log condition' ratings can be compared to the log condition ratings that were predicted from the non-destructive screening, using either the Random Forest (RF) model, or the Principal Component Analysis (PCA) model. This is shown in Figure 4. There is no obvious correlation between the actual and predicted log condition for either model, or either drying method.

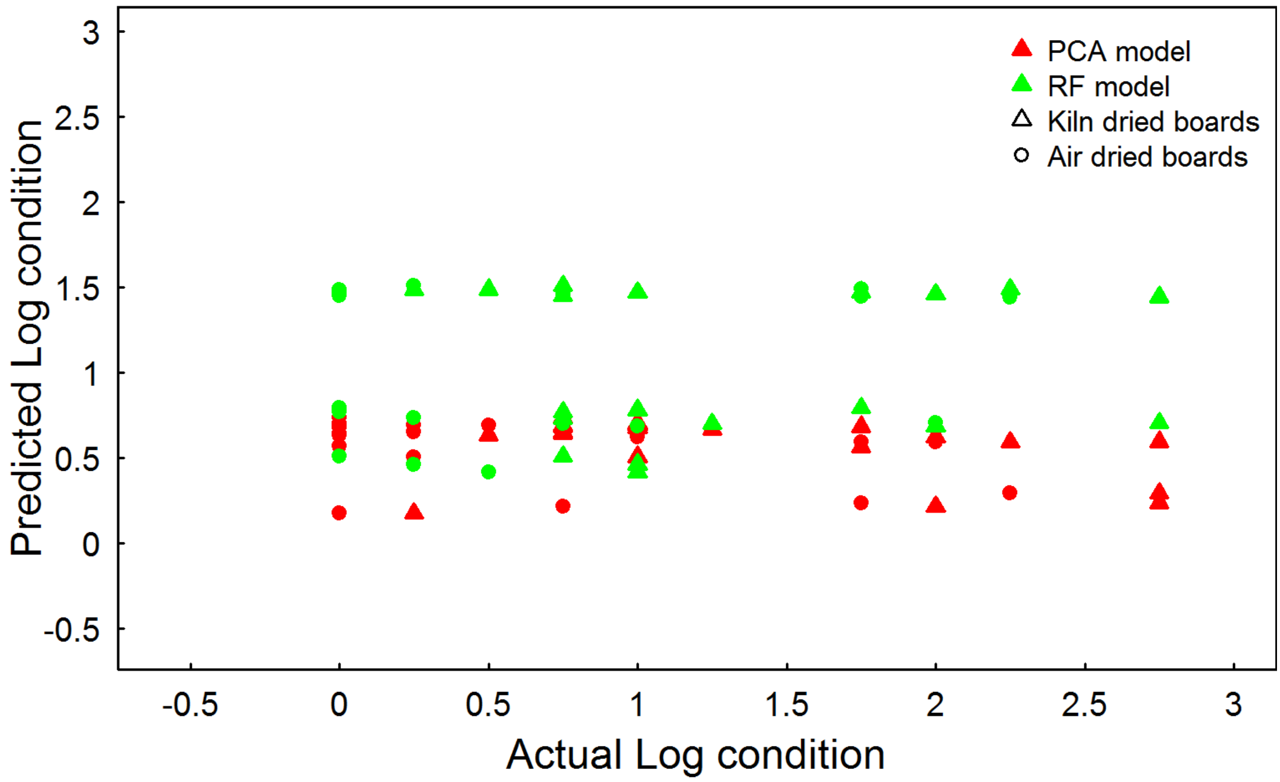

Figure 4. Measured values of Log condition compared to predictions from the Random Forest and Principal Component Analysis models.

# CONCLUSION

For both the 10mm and 30mm thick boards, levels of degrade were much higher in boards dried at 50°C compared to air dried boards. This is consistent with previous studies where kiln dried boards showed greater levels of degrade than air dried boards. For each drying method (air drying or kiln drying) there was no significant difference in degrade between the 10mm and 30mm boards.
No significant differences in drying degrade were seen between boards sawn from the ‘good’ and ‘bad’ logs, which were selected to have lower, and higher levels of drying degrade, respectively. Four different prediction models were used to select the logs, but none of these showed any correlation with the levels of degrade seen in the boards.

As with previous work, there were large differences in check propensity between different logs, with some consistently showing low levels of degrade, and some consistently showing high levels of degrade. Unfortunately these differences did not correspond to the ‘good’ and ‘bad’ log selections, which suggests that the non-destructive measurements chosen for this work are not measuring the underlying properties that affect check propensity. The properties causing within-species variation in check propensity are currently not well understood. If future studies are able to identify properties that do correlate well with check propensity, and these properties can be measured relatively easily in standing trees, it would be worthwhile to repeat this work using these new measurements.

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# ACKNOWLEDGEMENTS

The logs used in this study were supplied free of charge by SouthWood Exports. The following Scion staff assisted in this study: Toby Stovold and Kane Fleet did the non-destructive measurements on the standing trees. John Lee and Bruce Davy assisted with measuring and labelling the logs prior to sawing. John Lee also prepared the discs for drying and check assessment. Steve Riley and Steve Chapman assisted with the Joescan measurements, and drying the timber.

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# APPENDICES

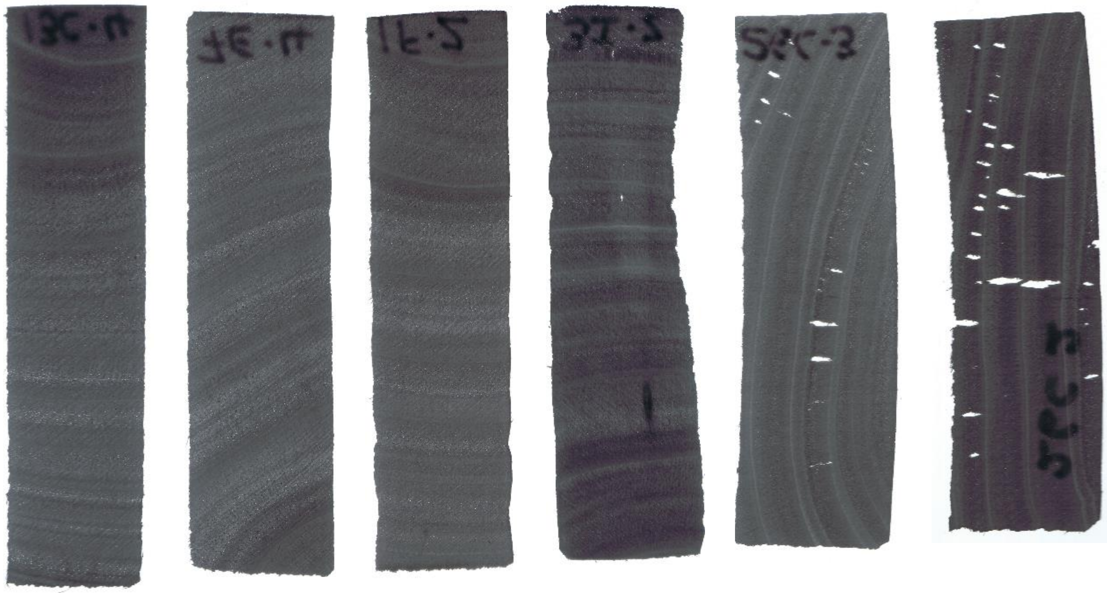
## Appendix 1: Selection of trees

Table A1. Rankings of trees chosen for study.

| Log number | Expected Board quality | PCA Log condition | PCA 'goodness' | RF Log condition | RF 'goodness' | Median rank | DBH (mm) |
|---|---|---|---|---|---|---|---|
| 9 | Good | 12 | 14 | 9 | 4 | 11 | 285 |
| 86 | Good | 6 | 10 | 31 | 20 | 15 | 261 |
| 16 | Good | 10 | 20 | 34 | 10 | 15 | 280 |
| 50 | Good | 8 | 15 | 27 | 16 | 16 | 279 |
| 61 | Good | 16 | 16 | 18 | 60 | 17 | 259 |
| 56 | Good | 23 | 28 | 3 | 15 | 19 | 289 |
| 84 | Good | 18 | 12 | 23 | 75 | 21 | 268 |
| 2 | Good | 21 | 25 | 6 | 89 | 23 | 255 |
| 40 | Good | 4 | 29 | 36 | 18 | 24 | 281 |
| 85 | Good | 19 | 33 | 21 | 27 | 24 | 298 |
| 38 | Bad | 84 | 74 | 66 | 97 | 79 | 310 |
| 91 | Bad | 96 | 79 | 81 | 22 | 80 | 335 |
| 30 | Bad | 99 | 92 | 68 | 47 | 80 | 323 |
| 63 | Bad | 87 | 85 | 86 | 48 | 86 | 373 |
| 77 | Bad | 80 | 96 | 76 | 98 | 88 | 315 |
| 13 | Bad | 93 | 94 | 82 | 84 | 89 | 326 |
| 51 | Bad | 92 | 87 | 87 | 100 | 90 | 365 |
| 21 | Bad | 97 | 91 | 89 | 78 | 90 | 346 |
| 20 | Bad | 85 | 99 | 63 | 96 | 91 | 305 |
| 43 | Bad | 98 | 84 | 98 | 45 | 91 | 390 |

## Appendix 2. Assessment of checking and collapse

Table A2: Examples of each subjective rating for checking and collapse.



| | | | | | | |
|---|---|---|---|---|---|---|
| Checking | 0 | 0 | 0 | 1 | 2 | 3 |
| Collapse | 0 | 1 | 2 | 3 | 0 | 0 |

# Appendix 3. Drying conditions

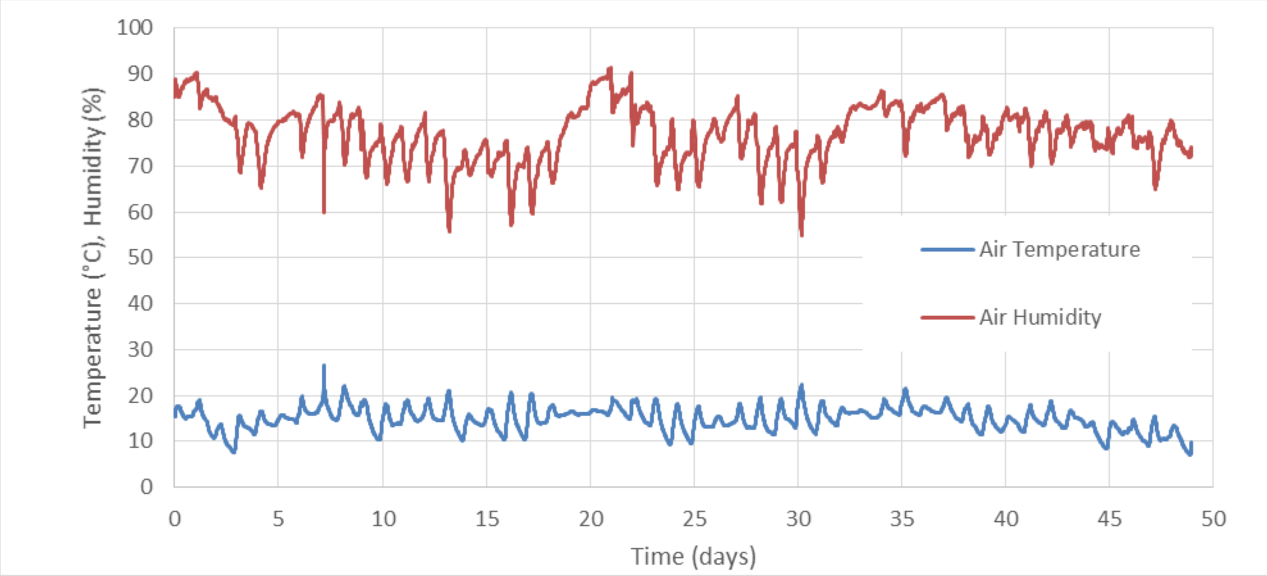



Figure A1. Temperature and humidity in the stack during air drying. After 30 days the 10mm boards had reached ~30%MC and were removed for final kiln drying.

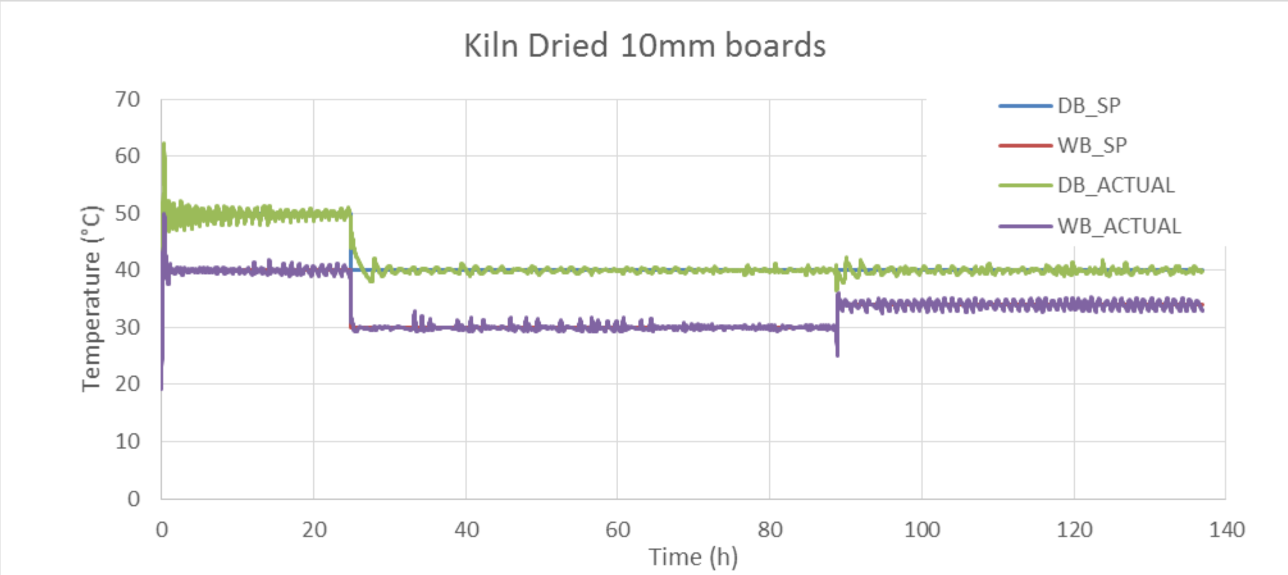



Figure A2. Kiln drying conditions for the 10mm boards kiln dried from green.

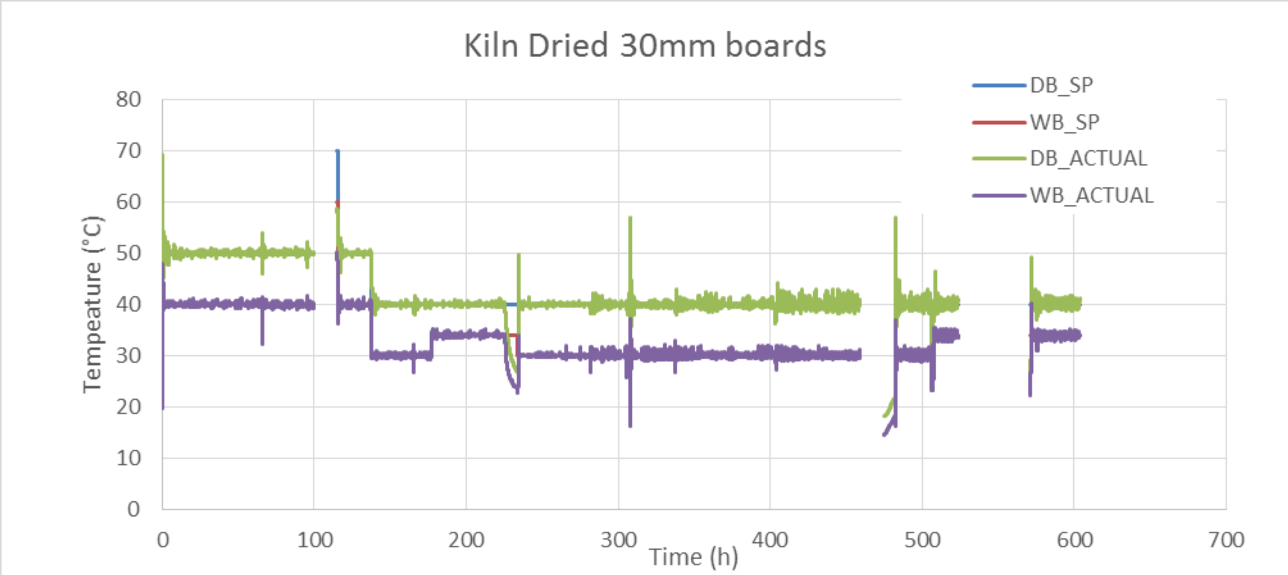


Figure A3. Kiln drying conditions for 30mm boards dried from green. There were several power cuts and a PLC communications failure leading to kiln shutdowns and gaps in the data.

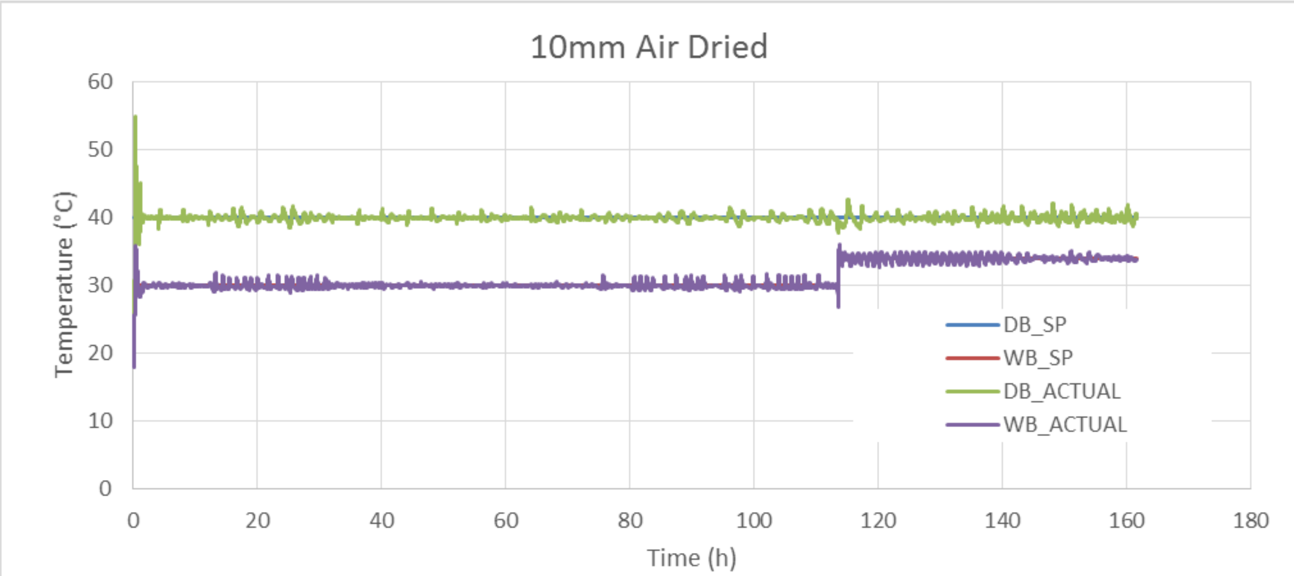


Figure A4. Kiln drying conditions for 10mm boards that had been air dried to 30% MC

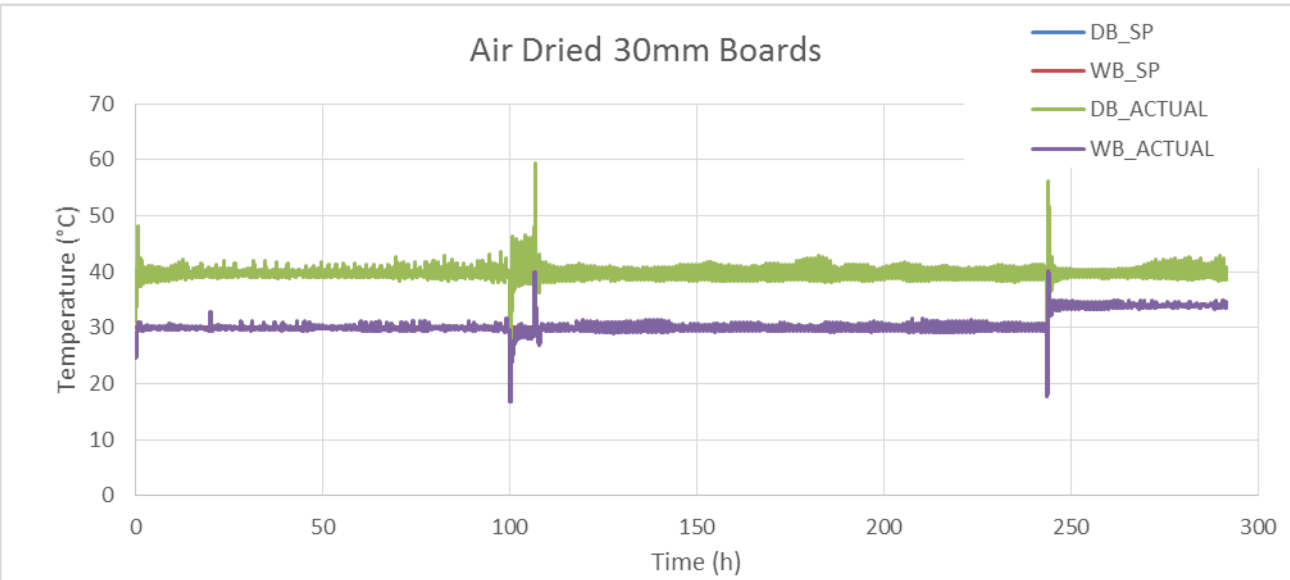


Figure A5. Kiln drying conditions for 30mm boards that had been air dried to 30% MC