**Enhancing the quality
and adding value to UK
timber by improved
conventional drying**

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Executive Summary

This guidance report is the final output from the project 'Enhancing the quality and adding value to UK timber by improved conventional kiln drying'. The project was funded by the Forestry Commission under contract number PPD 94, and was due for completion at the end of October 2005. This research programme complements work previously carried out under both Forestry Commission and European Commission funded projects and forms part of the extensive BRE and UK sawmilling industry research programme, targeted at optimising drying efficiency and improving the quality of kiln dried softwood timber.

This project specifically targeted the improvement and optimisation of conventional drying techniques using current drying equipment for the drying of UK spruce. Most of the equipment in use by the UK softwood sawmilling industry has the capability of drying timber using higher temperatures, which, in theory, should reduce drying times. However, a number of industrial kilns are limited in their maximum temperature capability due to the low thermal capacity of the insulation material used during construction. This effectively limits the maximum temperature achievable during drying.

The main objective of this project was to investigate how increases in drying temperature (and changes in other drying parameters) affect drying times and the final quality of kiln dried UK spruce. From the analysed information, a series of kiln drying schedules were produced to supplement those already in use and provide additional information to improve drying times and quality.

During the production of the final report, it became apparent that the results from this project would only provide a small section on improvements required to improve the drying process. The kiln drying process is multi-faceted, consisting of a wide range of processes, which, if not undertaken correctly, either individually or collectively, will have a detrimental effect on the quality of the dried timber. For this reason, the report has been written as a form of guidance manual on the improved drying of UK spruce using conventional kiln drying technology.

A proportion of the information contained in this guidance manual, has in some instances been previously reported, although not as a complete manual. The specific results from the main project 'Enhancing the quality and adding value to UK timber by improved conventional kiln drying' have been inserted in the technical annex at the rear of this document, whilst a summary of the results has been used to complete several of the main sections of the document.

Contents

Introduction

The UK softwood sawmilling industry has invested heavily in conventional drying technology over the last fifteen years. During this time, significant improvements in drying efficiency have been achieved. Improvements in work practices and the optimisation of drying schedules have ensured that softwood drying in the UK is some of the most advanced in Europe. Although significant improvements have already been achieved, further improvements are always possible.

This project specifically targeted the improvement and optimisation of conventional drying techniques using current drying equipment. The equipment in use by the UK softwood sawmilling industry has the capability of drying timber using higher temperatures, which, in theory, should reduce drying times. However, the maximum temperature capability is limited in number of industrial kilns due to the low thermal capacity of the insulation material used during construction. This effectively restricts the maximum temperature achievable during drying.

The main objective of this project was to investigate how increases in drying temperature (and changes to other drying parameters) affect drying times and the final quality of kiln dried UK spruce. From the analysed information, a series of kiln drying schedules have been produced. These were specifically targeted at drying UK spruce.

During the writing of this report, it became apparent that the presentation of results from this project may not provide a complete picture of how improvements to the drying process could be achieved. For this reason, this report was written in the form of a guidance manual on drying UK spruce using conventional drying technology. The drying process consists of a range of procedures, which, if not undertaken correctly, will have a detrimental effect on the quality of the dried timber. Therefore, information included in this report, has in some instances been previously reported, although not as a complete drying manual. As a note of interest, specific results from the project have been included in the technical annex at the end of the document, whilst a summary of the results has been included in the main text.

Description of the project

The main objective of the improved conventional drying project was achieved by undertaking a series of accelerated drying trials in BRE's experimental wood drying kiln. The trials incorporated a number of different drying parameters to speed up the drying process, whilst attempting to retain or reduce distortion on dried material. Each trial in the series consisted of cross-cutting one single pack of 'green' spruce into two, then evenly mixing the two packs to provide two almost identical packs. One pack was then dried under a set of controlled conditions and one dried under experimental conditions. This approach ensured that each experimental trial could always be compared to a direct control, dispensing with problems associated with variations in raw material.

The first trial in the work programme was planned as a baseline control trial. A single pack of 'green' spruce was cross-cut into two, and then mixed to provide two almost identical packs. One pack was dried by one of the industrial partners and the other dried using the experimental kiln at BRE. Both packs were dried utilising the same schedule. The results from this trial were then compared to ensure similarity between the drying parameters of the industrial and experimental drying. This provided confidence that any results generated by the experimental drying programme could be transferred directly to units used by industry. This trial was then used as the main control run throughout the remaining programme.

The next phase of the programme consisted of six accelerated drying trials. Each of these trials had a stepwise increase in maximum temperature of 5ºC increments up to a maximum temperature of 87ºC. The remaining drying parameters remained constant, whilst maintaining a similar schedule shape in accordance with the rise in dry temperature. The target moisture content for all trials was set at 18%. The timber from each of the trials was measured for distortion and uniformity of moisture content after drying. Each drying schedule was also monitored by external electronic equipment to verify the computerised kiln control unit.

After the completion of the main programme of trials, further optimised trials were undertaken. Information from previous projects was also re-assessed in order to provide a number of common spruce schedules.

All the trials were undertaken on timber with a dimension of 50 mm x 100 mm. Previous trials have indicated that this dimension tends to be the most affected by distortion.

From the completed programme of experimental trials, three kiln schedules were produced for use by industry.

The conventional wood drying kiln

A wood drying kiln is basically an insulated box with the facility to produce heat and to humidify and circulate air. Heat, humidity and airflow are essential elements of the drying process and are controlled via sensors within the kiln to optimise the removal of moisture from wet timber at a controlled rate.

Most kilns used by the UK softwood sawmilling industry dry their material using conventional over-head fan kilns (figure 1). This denotes that the fans and heat exchangers are positioned in the roof space, above a false ceiling, situated above the kiln load. Top and side flaps or rubber partitions reduce or block the gaps which occur around the timber parcels, ensuring that the heated air is directed through the load as efficiently as possible. Many kilns have forced air extraction units to remove moisture-laden air during drying, whilst vents introduce fresh air. Most if not all modern kilns have their operation and schedules controlled via computer.
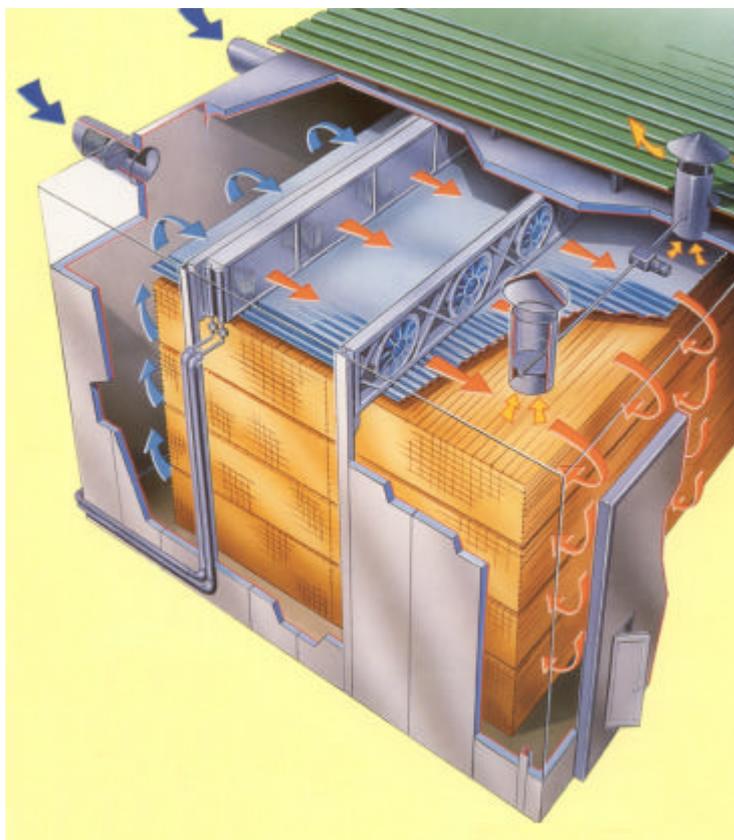

Figure 1. Industrial conventional over-head fan kiln (courtesy of HB Koeltechniek, Netherlands)

Kiln design

Airflow

During wood drying, the air movement within the kiln is vitally important. A well-designed kiln ensures that the airflow generated by the fans is uniform in its velocity throughout the stack. Air transfers heat from the heating coils to the timber, initiating the movement of moisture from the core to the surface, where it is removed as water vapour by the same circulating air. This mechanism is called convection. The air velocity determines the magnitude of the convective heat transfer coefficient, and consequently there is a strong relationship between the drying rate and the air velocity. Differences in the air velocity distribution through the stack can cause large variations in the final moisture content of the battens being dried. This problem often requires an extension of the drying schedule, to reduce the percentage of boards falling outside the target moisture content requirement. In many cases, the need to extend the drying schedule is not attributed to the poor airflow distribution.
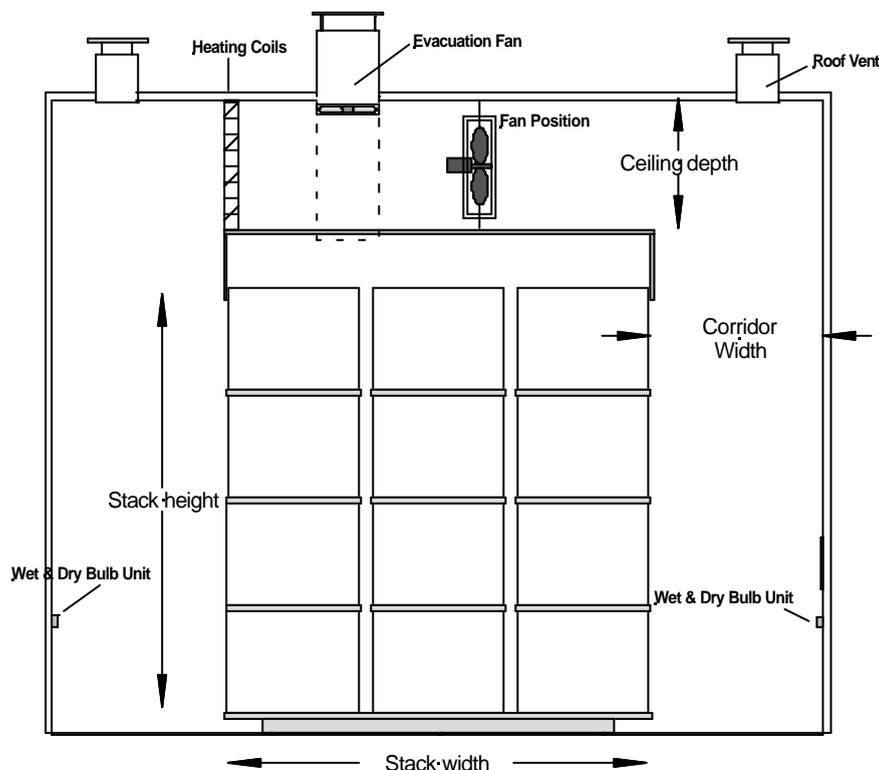

Figure 2. End view of a conventional kiln showing the position of the corridor and ceiling space

In practice, most kiln operators realise the importance of uniform airflow through the kiln stack and initiate measures to optimise that flow. Kiln design has a major impact on airflow distribution. If the design is incorrect, it is very difficult to improve the uniformity, even with efficient stacking strategies.

To help people understand what is happening in their kilns after starting the fans, airflow computer simulations packages can be a valuable tool in identifying potential problems. Figure 3 shows the calculated airflow distribution of an actual industrial over-head fan kiln where the air velocities vary from 2 m/s to 5 m/s. The low air velocity seen in the upper part of the first parcel of the stack is caused by severe turbulence at the front of the stack on the inflow (left) side. This problem is caused primarily by incorrect ratios between ceiling and corridor widths being applied at the design stage. To ensure uniform airflow, the corridors should be approximately two thirds the width of the ceiling height (distance between the false ceiling and kiln ceiling, see figure 2). The low air velocities in the upper parts of the second and third parcel columns are caused by the omission of flaps at the top of the kiln charge preventing the air bypassing the parcels. By blocking these gaps, this problem can be easily rectified. One of the main things to remember about airflow is that air will always take the line of least resistance, so, any gaps larger than the spaces between the stickers will always result in a diversion of the air.
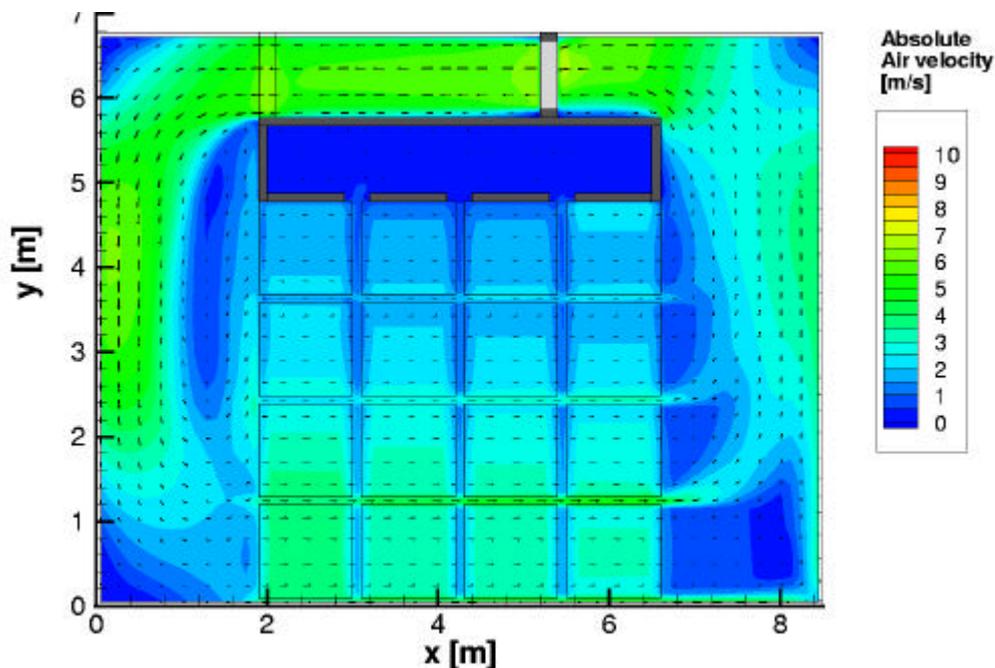

Figure 3. Airflow simulation model of an industrial conventional over-head fan wood drying kiln (courtesy of the TNO Institute of Applied Physics)

Sensor type and position

In modern wood drying kilns, the internal environment is regulated by a computer drying programme and monitored by a series of sensors. The sensors are located at specific positions, normally located at each side of the kiln. These sensors relay information on the state of the environment back to the computer. This information is then used to alter or change the conditions, increase or reduce the temperature, raise humidity or open/close the vents. Different manufacturers use a range of sensor types. These include wet and dry bulb stations, temperature and humidity sensors and temperature probe and EMC (equilibrium moisture content) systems. Each of the systems used has a set of pros and cons, and manufacturers tend to use a specific system throughout their kiln drying range. Many kilns also have a number of probes which monitor moisture content, these may be used either entirely or only partly, to drive the drying system, or provide information to the kiln manager.

For the smooth and continual running of the sensors, the manufacturer's recommendations regarding their maintenance should be closely followed. The environment within a working kiln is very harsh, and important equipment such as the sensors should have a regular checking and cleaning programme.

- EMC systems use the electrical resistance of a thin strip (wafer) of a particular tree species (*Terminalia superba*) to monitor the atmospheric conditions within the kiln. On the whole, systems which have wafers monitoring the humidity should be renewed before each kiln charge, and attached in the correct orientation. The dimension and species of these wafers are important to the running of the system. Wafers should either be purchased from the kiln manufacturer or produced as per the manufacturer's instructions.

- Systems running on a wet and dry bulb system should have the wet blanket changed regularly. The wet blanket should form a tight sleeve around the temperature probe acting as the wet bulb monitor and be set just above the water level. The wet blanket should not be allowed to 'just hang over the probe' (showing an airspace under the probe), as this will not provide accurate readings of the environment. The wet bulb station should also have an accurate water top-up feed and should not be allowed to continually overflow with fresh water.

- Systems using temperature and humidity probes can be very susceptible to being overlooked in the checking and cleaning regime. Humidity probes in particular, will require regular cleaning as the resins and other chemicals given off from the timber during drying will gradually cause a build-up of chemical scale on the sensor. Even with close visual inspection this build-up may not be noticeable. For this reason, the probe will require cleaning on a regular basis as per the manufacturer's recommendations, whether the probe looks clean or not.

On large conventional kilns (150 m^3 and over) there are usually two sets of sensors on each side of the stack, situated on the kiln walls, about 2000 mm above the walkway. In reality, this is the most convenient position to place them, as they are unlikely to get damaged. Ideally, they should be as close to the side of the stack as possible, monitoring what is happening around the drying timber. In certain sawmills, operatives have altered the probe brackets so that the probes can be attached to the sides of the stacks when loading has been completed. This provides very accurate information to the kiln control programme and allows a greater control over what is happening to the timber.

Moisture content probes

Unless a moisture content probe is attached to every batten within a kiln load, the information gleaned from a set of probes is at best, only an indication of a kiln charge's overall moisture content. If the moisture content data from the kiln charge and readings from the final dry moisture content are constantly compared and checked. An experienced kiln operator will build up a wealth of knowledge.

To ensure that the information being produced by the probes is accurate and uniform, the probes should be attached as per the manufacturer's instructions. The holes being drilled to accept the probes should be of the correct diameter and depth for the probes being used. Each set of probes should also be set at the correct distance apart. If eight sets of probes are used to monitor a kiln charge and each set is attached with different distances between probes, the information being generated will not be uniform. Although this will probably not cause a catastrophic failure in the drying, it will introduce another variable to make the drying of the timber more difficult to understand. It must also be noted, that probes should be positioned in clear sections of timber, without the presence of knots or other growth defects (i.e. compression wood).

Humidification systems

There are a number of different humidification systems available for use in wood drying kilns. These include steam, low pressure cold and hot water spray and high pressure cold or hot water atomised spray. In the UK, very few, if any conventional kilns use steam for the production of heat or humidity. The main reason for this is the legislation (and cost) surrounding the use of steam generating boilers in the UK. Steam is a good medium for the production of humidity, and also has excellent re-conditioning capabilities.

On slightly older conventional kiln systems, both low-pressure cold and hot water spray is common. The main drawback of these systems is that the spray droplets produced are often too large to be retained in the atmosphere, and large pools of water can collect on the kiln floor below the spray nozzles, especially during the heating-up phase when high humidity is most required.

On the whole, most new conventional kilns are fitted (or can be fitted) with high-pressure atomised spray systems. These systems produce very small water droplets, which are easily retained in the atmosphere, even during heating-up. This type of system is as close to a steam generating system as it is possible to get. The main draw back of such systems is that the spray nozzles can become blocked very easily. A good quality atomised spray system requires an effective multi-water filtration system at or near the main pump. Filter changing should be accessible and simple to undertake. Many systems also have small gauze filters situated just behind the main spray nozzles. In effect, this is the last line of defence to stop contaminants getting through the system and blocking the nozzle. These types of filter should not be the only line of defence. Spray nozzles are normally situated in fairly inaccessible positions, and take time and specialist equipment to clean.

Out of all the systems presently on the market, a good high-pressure atomised spray system will fulfil most, if not all the requirements of a conventional softwood kiln.

Although mentioned earlier in the text, the integration of hot water into any type of system will raise the quality of the humidification. Making any system with hot water will also add cost. If a good quality high-pressure atomised spray system was selected for use in a conventional softwood kiln, it would be difficult to recommend the need for the system to use hot water, unless the system was supplied using this medium.

Venting systems

Venting systems allow moisture-laden air, produced during the drying process, to be vented to the atmosphere and draw in fresh air. There are two main types of venting system; forced air and passive. A forced air extraction system has fans situated within the vent tubes that are activated when an air exchange is required. One set of vents will draw air in and one will suck moisture-laden air out. The passive system utilises the main fan system within the kiln to drive out moisture-laden air and suck in fresh air when an exchange is required and the vents are opened.

There is no little evidence to support the recommendation of either system, although it is important to have an optimum number of vents to facilitate a rapid change of air. The number and dimension of vents will depend on the size of the kiln and timber charge.

Heating capacity

Heating capacity is calculated based on the maximum required drying temperature, kiln dimension; stack size, timber species and expected moisture content. Although it may add cost to the purchase of a new kiln, stipulating that a maximum drying temperature of 85°C to 90°C is required will provide a degree of versatility to your drying process at a later stage.

Heating coils are made using a variety of different processes, each being preferred by different manufacturers. Heating coils are generally positioned in the ceiling space above the kiln load adjacent to the fans. In some instances, booster coils (and in some instances main coils), are positioned vertically between the central stacks of timber to aid drying. It is difficult to recommend any one system without some form of in-depth research. Unless the load is comprised of one narrow stack, increased localised drying will occur on one side of the wide stack during the drying process. Regular fan reversal is required to ensure uniform drying of the load is achieved.

The heat required by the kilns can be supplied by a variety of different boiler types, each capable of being fired by a different medium, be it electricity, gas, oil or sawmill residue. The choice of boiler is not covered within the scope of this report.

Insulation

The main fabric (walls, roof and doors) of most modern conventional kilns are composed of a three layer construction, with either aluminium or stainless steel inner and outer surfaces, sandwiching a central core of insulation material. The insulation type and its specification is an important aspect, with regards energy consumption and future increases in drying temperature.

The insulation type, thickness and specification will regulate the effectiveness of the overall thermal capacity. Most insulation cores are usually expanded polystyrene or mineral wool (rock or glass). As well as regulating the thermal capacity of the kiln, the type of material utilised can have a direct bearing on possible future changes in work practices. Expanded polystyrene normally has a very specific maximum working temperature restriction. If the stated temperature is exceeded, the insulation material will rapidly breakdown and lose its insulation properties.

It is very important when choosing a new kiln that thought is given to the type of insulation being specified, and whether it is able to withstand the working temperatures now, and possibly in the future.

Stacking, stickering and loading

Stacking, stickering and loading are an important part of the kiln drying procedure and play an important role in optimising the drying process and minimising distortion. Timber stacked neatly, loaded uniformly and supported adequately along its length, will dry with a consistently higher quality than that with widely spaced supports and randomly stacked lengths. The roughness of the cut surface and dimensional uniformity will also affect the drying process by disrupting the flow of air over the timber and causing un-even drying. Chippers, bandsaws and circular saws should therefore be adequately maintained to ensure a good surface finish, with good dimensional accuracy.

Parcel and pack design

Pack design is a fundamental part of the kiln drying process. Correct stacking of parcels will enhance the overall drying process and assist in producing a high quality product. This will dry to a uniform moisture content, with very little distortion, thus making the product highly acceptable to the buyer.

Where possible, it is advisable that all parcels contain battens of the same length and dimension. Initial analysis of moisture content variation undertaken on material from previous kiln trials indicates that significant variation of moisture content and distortion occurs when mixed batches of wide (50 mm x 200 mm) and narrow (50 mm x 100 mm) battens are dried together. Depending on which set of battens is being monitored during drying will result in either narrow battens being over-dried or wide battens not being dried enough. Therefore it is recommended that a kiln load be made up of parcels containing battens with all the same dimension. If this is not possible, wider battens should be monitored for the desired moisture content, although this will result in over-drying of the narrower pieces (which in turn will increase the severity of distortion).

Parcels of timber containing battens of different lengths will cause problems in relation to moisture content and stacking. Although differences in moisture content between battens of differing lengths cannot be identified, the parcels are difficult to stack correctly and are often un-supported at various points along their length. This creates distortional problems during drying. If it is not possible to make up parcels containing the same length battens, extra stickers should be incorporated to ensure each layer of battens are adequately supported, and the ends of the parcel are square.

To minimise distortion developing during the drying process, stickers must be positioned at regular intervals across each layer of battens, thus providing support to each successive layer. Battens within a parcel are therefore supported by those stickers above and below each layer as shown in figure 4. In turn, each parcel is supported, by dunnage positioned below each column of stickers, which is then supported by the kiln floor or kiln trolley.

Where stickers and dunnage are correctly positioned, the battens within a load are supported and to some extent and restrained by the overall weight of the load. If stickers or dunnage are positioned in a non-uniform pattern, the weight of those parcels above can cause distortion to occur in battens within parcels which are out of alignment or poorly stickered.
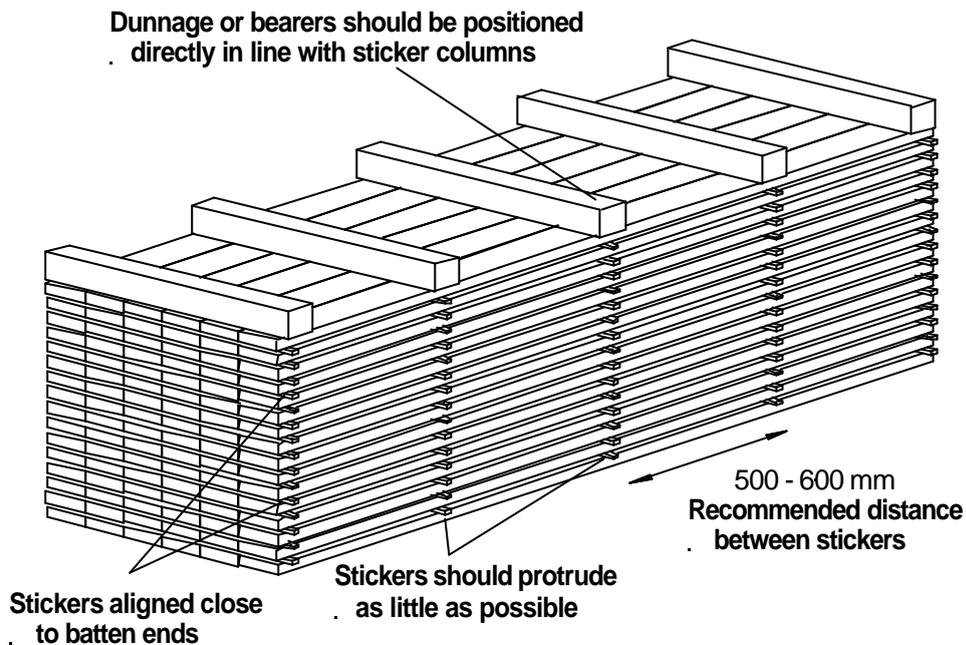
Dunnage or bearers should be positioned directly in line with sticker columns

500 - 600 mm Recommended distance between stickers

Stickers aligned close to batten ends

Stickers should protrude as little as possible

Figure 4.   Good parcel design

The automatic stacking and stickering machine is an important part of the wood processing chain. It automates what was once a particularly labour intensive operation and speeds up the transfer of timber from the end of the saw line to the kiln area. It also ensures a consistency in the sticker spacing, thereby reducing the chance of miss-placed stickers.   Even so, the sticker placement chutes occasionally jam or partially jam, dropping rectangular dimension stickers edge down. This effectively inserts a wider section sticker between two battens. If this is not rectified before drying commences, the timber may set with induced distortion causing battens above and below to become excessively bowed. Close supervision of the stacking and stickering machine and correctly dimensioned or even square dimension stickers may reduce or even eliminate this problem.

In some sawmills large variations can occur between sticker spacings, some being as wide as 1200 mm or as low as 550 mm. It is recommended that the distance between stickers should be in the region of 500 to 600 mm in order to reduce the likelihood of distortion and provide adequate support over the batten length. Stickers positioned at the end of the parcel should be within 50 mm of the parcel end, but preferably less. The minimum sticker frequency will be determined by the longest sawn length produced and the number of chutes on the stickering machine.

Recommendations

- Where possible, parcels of battens should be made up of timber containing all the same lengths and dimensions.

- Where this is not possible, extra stickers should be inserted to provide adequate support to the battens below and above the different length battens. This will provide continuity of support to adjacent parcels.

- Care should be taken when rectangular stickers are used (22 x 38 mm). This will eliminate 'rogue' stickers being inserted 'thin edge down'.

- Sticker spacing is important; it provides support to battens throughout the drying process and reduces the development of distortion. It is recommended that sticker spacing should be in the region of 500 to 600 mm.

- Stickers should be positioned as close to the end of the parcel as possible (within 50 mm, preferably less) to ensure little or no overhang of battens.

Bearer and sticker dimensions

During recently completed kiln trials, air velocity was measured entering, and exiting the kiln load, both through the stickers and the bearers supporting individual parcels. Figure 5 shows the variation in airflow velocity measured whilst exiting part of an industrial kiln load. This figure clearly shows the difference in air velocity measured between the sticker spaces and the bearer spaces. There can be a considerable variation between air velocity readings from different areas of the kiln load. The larger spaces created by the bearer sections allows the passage of a greater volume of air, thus reducing the velocity and volume of air passing through the stickered parcels. Bearer dimensions should therefore be as small as possible, whilst still allowing easy forklift access.
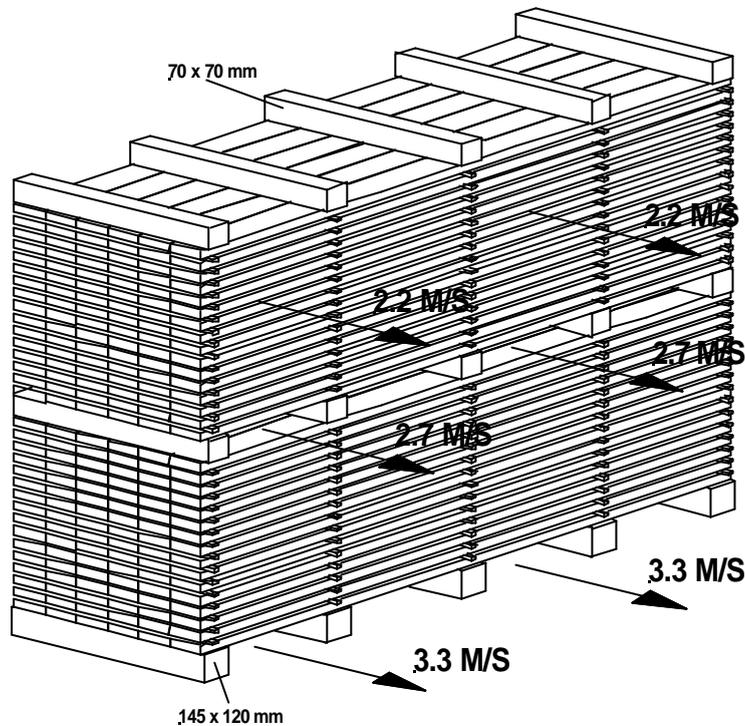
Figure 5. Variations in airflow through a kiln load

Bearers or dunnage situated at the base of kiln loads is often of a larger dimension than that used to separate the remainder of the stack. This practice, although common, has no direct benefit to the drying or loading process and only allows a larger volume of air to divert beneath the load rather than through the stack. As previously stated, bearers or dunnage should be as small a dimension as possible whilst still allowing easy fork lift access. If larger section bearers must be used, a baffle should be constructed to restrict the movement of air under the parcels.

Stickers and sticker material

Stickers and bearers are subjected to an extremely hard working life. Both are subjected to constant wear and damage, eventually becoming unsuitable for their chosen purpose.   Stickers and bearers, which are worn or damaged, should be replaced. If possible, old and new stickers should not be mixed, as dimensional changes caused by compression damage and shrinkage can result in a mixture of different dimension stickers being used throughout a parcel. To prevent new and old stickers being mixed and as an aid to identification, new batches of stickers can be colour coded (each end). This ensures sticker batches are not mixed and when a batch comes to the end of its life the whole batch can be disposed of as one job lot.

Sticker length is another important consideration. Over length stickers form a physical barrier between parcels when they are being loaded into the kiln. This prevents close stacking of parcels and often results in stickers being broken or moved as loading progresses. Sticker length should be optimised to provi de adequate support to each layer of battens without excessive protrusion from the edges.

As a general rule, all UK softwood sawmills use stickers produced on site. These stickers are usually machined from spruce and are most often rectangular in shape (38 mm). The most common sticker dimensions are 22 mm x 38 mm, although some mills also use 19 mm x 38 mm. As previously discussed, a sticker's life is extremely hard. The sticker undertakes an important job during the drying process, providing support between each layer of drying battens. Although the recommendation given is not to mix old and new stickers, in practice this is very difficult to achieve. By using a mix of new and old, each layer of battens has a variation in the thickness of support. Although this is difficult to actually see, the variations that occur throughout a full industrial kiln load is substantial. In practice, this causes varying levels of bow to occur during the drying process.

In contrast, the hardwood industry has been using purpose made stickers for a number of years. The most common material for these is either plastic or laminated wood (figure 6), although steel and aluminium have also been used in the past. Purpose made stickers have a number of advantages over homemade:

- Purpose made stickers retain their original dimensional thickness, even after extended periods of time.

- They have an extremely long working life.

- Due to their accurate dimensions, less problems would occur in automatic sticker laying.

Their main disadvantage is initial cost.

Figure 6. Laminated and fluted Laonda sticker (courtesy of Sperrholzwerk Schweitzer)

The use of purpose made stickers in a large industrial softwood sawmill would require careful economic consideration. Improvements in streamlining throughput and reductions in distortion are difficult to quantify, although their use should be considered carefully.

Recommendations

- Dunnage or bearers should be as narrow as possible, whilst still allowing easy entry of forks for loading and un-loading

- Bearers and stickers should be machined square to the correct dimensions.

- Stickers should be of adequate length to support the timber, but not excessively long to hinder loading.

- Damaged bearers and stickers should be replaced.

- Where possible new and old stickers should not be mixed.

Wood surface finish

A small-scale kiln trial undertaken at BRE monitored the air velocity through a parcel of timber to assess how different surface finishes affect air velocity. Results from this trial indicate that air velocity was markedly reduced over battens with band-sawn surfaces in comparison to battens with planed surfaces. This indicates that worn chipper teeth or bandsaw blades can have a significant effect on the drying process by reducing or disrupting the air velocity. It is recommended that saw blades and chipper teeth are kept as sharp as possible to ensure the surface finish of processed battens is consistently smooth. A large number of battens are seen that have obviously been through worn chipper canters, which prompted this small experiment. In many cases, the surface finish was extremely rough or pitted, indicating worn or badly maintained chipper blades or teeth.

Recommendations

- Saw blades and chipper canter blades should be changed regularly to produce a smooth surface finish on battens, thus ensuring a uniform and constant air flow through the load.

Sawing accuracy

Over the past decade, improvements in sawing technology have resulted in great improvements in the dimensional consistency of sawn battens. Attempting to dry a batch of material with widely differing thicknesses is very difficult. Thinner battens are bridged by the supporting stickers, which are then allowed to distort due to the lack of restraint from the other battens in the packs. On the other hand, thicker battens are subjected to excessive loads applied by the material stacked above, again resulting in excessive distortion. Airflow across such loads is also badly affected, resulting in poor drying and inconsistent final moisture contents throughout the kiln charge.

Although sawing equipment and sawing accuracy has improved, regular checks on the consistency of dimensions produced should be implemented as a matter of course. The speed of cutting of new equipment is such that if a problem does occur, quite large volumes of material are produced before remedial action can be put on place.

Figures 7 and 8 show the results of thickness measurements recorded from two batches of spruce (approximately 140 battens per batch). Measurements were taken at the central point of each batten before drying was undertaken. The graphs show that a problem with sawing accuracy has developed in figure 8. This may be due to inconsistencies in the wear of the saw blade teeth, the saw guides being out

Figure 7. Thickness measurements of approximately 140 pieces (one bar per batten) of green UK spruce showing good sawing accuracy (average batten thickness 48.3 mm, standard deviation of 0.33)
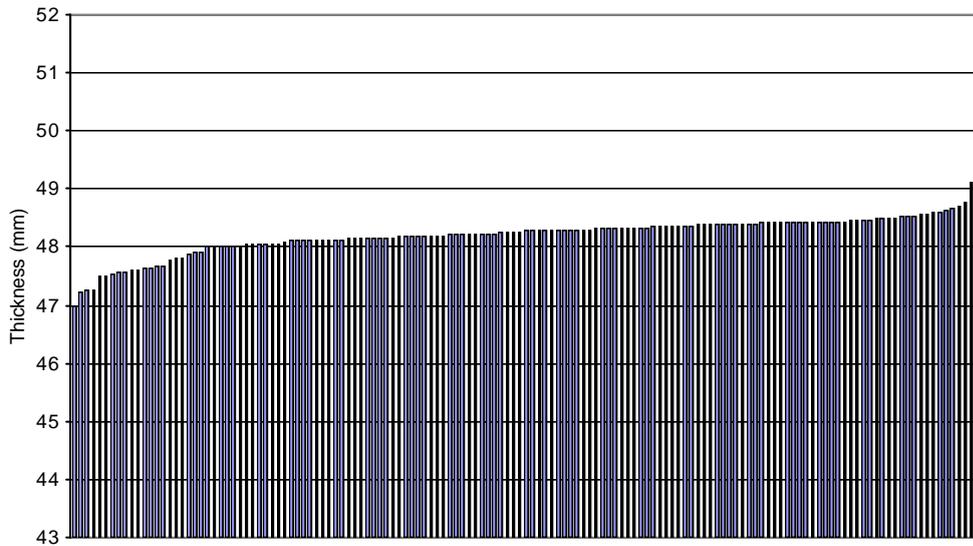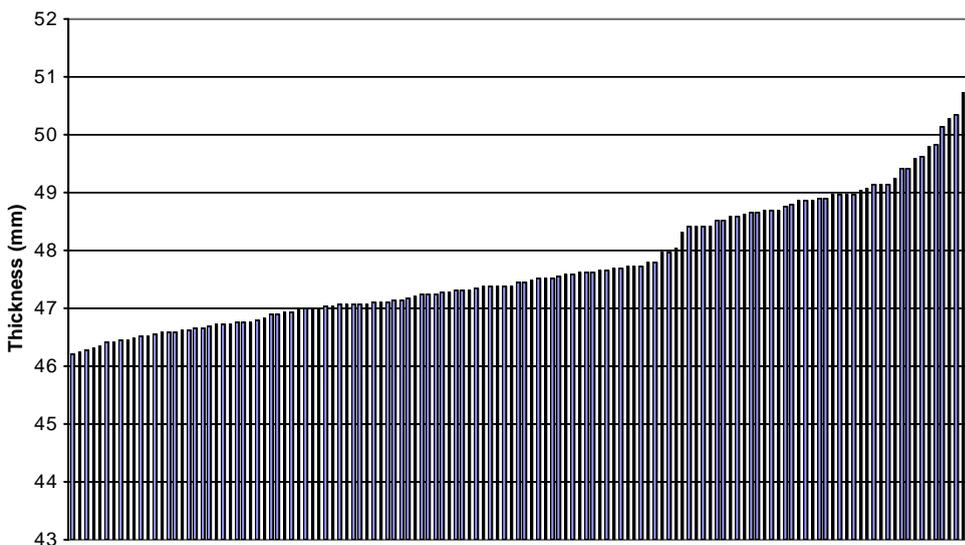

Figure 8. Thickness measurements of approximately 140 pieces (one bar per batten) of green UK spruce showing poor sawing accuracy (average batten thickness 47.7 mm, standard deviation 1.03)

of alignment or movement of the timber whilst being processed. This is not an exhaustive list of possibilities as the reasons for problems with dimensional accuracy can be quite complex where modern high-speed equipment is concerned.

Recommendations

- ▪ Regularly check the dimensional accuracy of material being processed. This will maintain material quality and indicate potential problems with the saw-line

Loading the kiln (load design)

In many cases, only one operative undertakes the kiln loading process. These individuals exhibit a high degree of skill and precision, completing the task quickly and efficiently. It is not unusual for an operative to intersperse kiln loading with loading delivery vehicles and removing timber from the end of the saw line and into storage areas. Operatives are under constant pressure to un-load and re-load the kilns as quickly as possible in order to speed up the turnaround of timber for kiln drying. Excessive pressure can compromise the neat and uniform loading of timber for kiln drying.

Loaders generally use a predetermined pattern concerning bearer position and number. Bearers are generally, but not always, placed beneath a line of stickers at regular intervals along a parcel. However, they do not correspond with the line directly beneath all columns of stickers. It is frequently noticed that the centre of a parcel is often left clear of dunnage for easy entry of the forklift blades. Protruding stickers also cause problems when attempting to load the parcels into the kiln.

Kiln loading is one area where the operative with loading responsibility can have a significant influence on the drying process. The kiln must be loaded correctly i.e. stickers should align through each successive parcel, dunnage should be positioned in line with each column of stickers and parcels should be loaded as close as possible. Adequate time should therefore be allocated to this task to ensure that it is carried out correctly and external pressure to complete the task is kept to a minimum.

It is recommended that bearers should be positioned beneath each column of stickers throughout the kiln load, not more at the base and less further up the load, as is frequently seen. This ensures adequate support is given to the whole load, thereby minimising distortion caused by irregular growth patterns and the drying process.

The kilns and surrounding area should always be kept clear of un-wanted debris such as old stickers and dunnage. A clean and tidy kiln ensures that a uniform airflow is achieved through the stack, reducing turbulence by the elimination of obstacles. It also provides a safe working environment.

Recommendations

- • Where possible the kiln load should fill all the available kiln space.

- • Bearers should be positioned directly beneath each line of stickers to provide adequate support to all parcels, thus minimising drying distortion.

- Parcels of timber should be loaded in a manner which reduces the number and size of gaps between alternate parcels.

- The kiln area should always be kept clean and tidy.

Control of air through the stack

Most kilns encountered have some form of side and top flaps to reduce the size and number of large gaps between kiln walls, ceiling and timber. Any large open spaces or gaps will always be the preferred route of the heated air, considerably reducing the efficiency of the drying process. Flaps and curtains should be well maintained and used for the process they were designed for; ensuring that the flow of high cost air is maximised through the stickered timber.

The top flaps can, in some kilns, overhang the top parcels by several batten thicknesses. This problem is often caused by over wide flaps or slightly oversize stickers, bearers or parcels. Where this problem occurs, battens covered by the flaps will dry at a much slower rate than the majority of un-covered battens in the kiln. This causes the covered battens to have higher final moisture content, which will be out of specification for its intended end use.

Recommendations

- Where possible, all large gaps or spaces i.e. those spaces at the stack ends (between door and stack) the base (floor and stack) and top (ceiling and stack) should be adequately blocked to ensure air is forced through the stickered battens (air will take the line of least resistance).

- Ensure that all baffles, curtains and flaps are well maintained and work correctly.

- Ensure that top flaps do not overhang the front or rear top parcels.

Top-loading

Top loading is the process of applying weight to the top of kiln drying stacks in an effort to reduce the development of distortion. The most commonly applied top-loading medium is concrete, although it is possible to use any material with sufficient weight. Several manufacturers also produce kilns with pneumatic top-loading systems incorporated within the kiln fabric. These systems are easy to use and do not require concrete weights to be applied before drying, and remove after drying. The one downside is that the system is an expensive addition when purchasing a new kiln. These systems can also be retro-fitted on existing kilns.

The application of top weight will reduce the severity of distortion occurring (especially twist) within a drying load. The optimum top-loading weight is 500 kgm^2 over the timber area. It has been found that the application of greater loads has very little effect in reducing distortion below that attained by the recommended load.

Although a certain load is applied to a drying stack under its own weight, the parcels positioned in the top layers are effectively under very little load. It is in these regions that many of the battens being rejected due to excessive distortion will have been located.

It is wise to ensure that when a new kiln is purchased, the small amount of headroom required to apply top-loads is included in the height calculation, otherwise the top stacks will require downsizing to accommodate the added height of the weights.

Care of timber after drying

A lot of money and effort goes into drying timber. Much of this effort can be wasted if correct aftercare procedures are not followed.

After the completion of drying, the parcels can be un-loaded from the kiln and the timber de-sticked before being passed through the grading line. It goes without saying, that dry timber should not be left out in the open in adverse weather conditions or if these are expected prior to being de-sticked and graded.

After the grading and stamping process, the dry timber is stickered into parcels of a given size and number of battens. To ensure a stable parcel, thin fillets of dry spruce can be inserted every four to eight rows. Parcels can then be banded. Banding fulfils a number of criteria. It prevents the parcel falling apart during transportation and also provides a certain level of restraint to the pack, concerning the development of distortion during storage and transportation. If a parcel of timber is left loose and allowed to dry further than the moisture content achieved during kiln drying, distortion will develop, and where already developed, it will become worse. Banding will reduce the development of distortion after drying. The banding material should ideally be plastic or nylon, and applied approximately every metre length. If thin fillets are used to provide added stability to the pack, the banding should correspond to the position of the fillets. It is also good practice to use banding corner supports to prevent crushing of the timber edges by the banding.

After banding, the parcels are usually wrapped in plastic to provide some form of protection from the elements. There are a number of arguments of how this wrapping should be undertaken. Very often the parcels are half or three quarter wrapped (the top, sides and ends are covered and the plastic reaches either half or three quarters of the way down the sides of the parcel, leaving the bottom layer un-covered). The idea behind this is that if the plastic leaks, and water penetrates through the top into the parcel, air passing through the sides will allow the parcel to dry out. If the plastic were to cover the ends and sides completely, and a leak developed in the plastic, there would be no way the parcel could dry out. Either way, parcels are at risk of getting wet and staying wet. There are a number of ways of providing attached support to the parcels to reduce the likelihood of damage to the plastic, especially during loading and movement of the parcels. Considering all the arguments, it is better if wrapped, kiln dried parcels are stored under cover before being transported off site.

When the parcels are loaded for transportation to the customer, the lorry should be sheeted, even though the parcels are plastic wrapped. This small precaution will ensure no damage occurs to the plastic sheeting during transit and that parcels arrive in good order.

After all the hard work to ensure the timber is dry and of good quality, it is always helpful to provide some form of written recommendation to the client/buyer about how and where to store the timber once it arrives. Any bad practice on the storage of timber on site or at the builder's merchants will always find its way back to the supplier. If good practice recommendations are provided with every delivery, the message may slowly get through.

Poor wrapping and storage before distribution can adversely affect the quality of kiln dried timber. Problems created in these areas may be inadvertently attributed to the sawing or drying process. It is therefore

important that improvements in the quality of processing and kiln drying are not compromised by practices further down the production/delivery chain.

By incorporating a combination of basic improvements and the reinforcement of good practice in stickering, stacking and loading, a significant increase in the quality of dried timber can be obtained. An assessment of the stacking, stickering and loading regimes by sawmill staff utilising this document may identify areas, which require attention. This would allow standardisation of common procedures, thus ensuring uniformity of working practices between staff and different shifts. Guidelines can also be implemented to identify good practice, and ensure the various tasks outlined in this document are carried out to written specifications. This would ensure that the quality and uniformity of each given task was attained and adhered too.

Problems associated with kiln drying

During drying, timber will shrink. Although shrinkage, which occurs when timber is dried, is not normally regarded as a form of degrade, there are several defects which are associated with the drying process. Wood is anisotropic with regard to shrinkage and swelling (the reduction or increase of dimension for a change in moisture content is different in different directions of tree growth). The change in dimension is least in the longitudinal direction, greater in the radial direction and even greater in the tangential direction. Figure 9 shows the initial shape and final shape after drying of different cross sections of timber, depending where the section was cut from the tree.
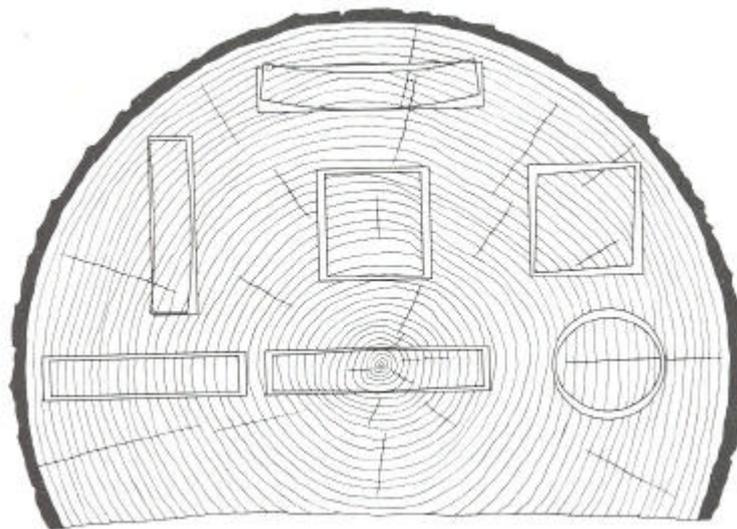

Figure 9. Change in shape of various cross-sections due to differential radial and tangential shrinkage[3]

Distortion

Further inherent physical characteristics (microfibril angle, slope of grain, density variations) and the presence of abnormal cells due to specific growing conditions (compression wood), coupled with differential shrinkage, can also cause the timber to distort. Figure 10 shows the four most common types of distortion encountered after drying. Of those pictured, twist causes the most problems and is also the most difficult to contend with when the material is used in construction. Almost all spruce destined for the construction market will pass through a strength grading procedure. This may be undertaken visually or by machine. Battens exhibiting excessive levels of twist (and other forms of distortion) will be rejected during grading and before delivery to a customer.
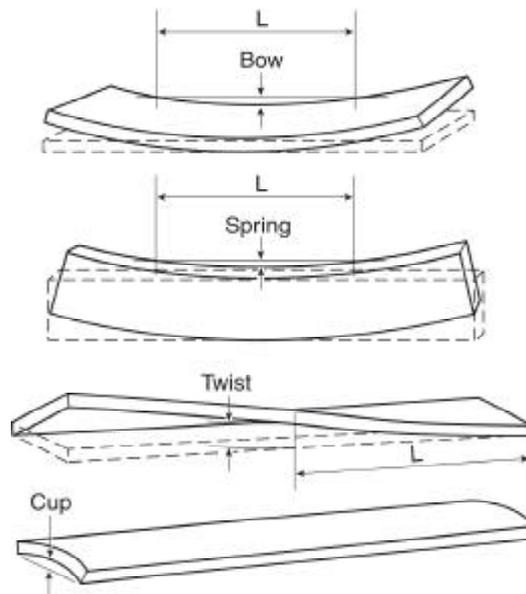
Figure 10. Distortion types

The visual override requirements for the distortion of softwood timber grades above and below C16 are specified in BSEN 519: 1995 Structural Timber, 'Grading Requirement for Machine Strength Graded Timber and Grading Machines'. This standard replaced BS 4978: 1988 which was previously used to assess distortion parameters.

In BSEN 519: 1995, the maximum allowable distortion is expressed over a 2000 mm length (and 100 mm height in the case of twist). The limiting values for this important criterion are set out in table 1 for two common batten dimensions.

Table 1. BSEN 519: 1995 Visual override requirements for C16

Distortion	50 x 100 mm	50 x 200 mm
Twist	8 mm	16 mm
Bow	20 mm	20 mm
Spring	12 mm	12 mm
Cup	No Value	No Value

During quality assessment trials undertaken on UK produced spruce, it is apparent that the industry attempts to dry their timber with much lower levels of distortion than those stipulated in BS EN519: 1995. In fact, most, if not all sawmills grade their material with regards distortion, to much lower levels than those stipulated in the standard. This is because any batten exhibiting the maximum allowable levels shown in the standard would be totally unacceptable to most purchasing customers. The standard can also be quite confusing; the maximum allowable values for twist, bow and spring are measured over a length of 2000 mm. Therefore, in simple terms an 8 mm reading of twist on a 2000 mm length of timber doubles to 16 mm on a 4000 mm length piece and so on. Considering that a large majority of battens produced are well over 2000 mm in length, certain defects become highly visible, even when distortion values measured over 2000 mm seem reasonably small.

Other drying defects

Surface checking and splitting

Surface checking and splitting develop when steep moisture gradients form within the timber during drying. If significant differences occur in the moisture gradient (very dry near the timber surface and very wet in the core), the amount of shrinkage occurring at the surface compared to the centre is markedly different; due to these differences, stresses will develop within the piece. If these stresses become pronounced, the fibres in the outer layers will tear and surface checking and splitting will occur.

Collapse

Collapse is a common form of drying degrade. It is thought to occur in the early stages of drying when free moisture leaving the cells creates a surface tension due to the reduction of moisture in the cell. This causes the cells to be pulled inwards and eventually collapse, causing a rippled effect to occur on the timber surface. This form of degrade commonly occurs in UK spruce, and can often be seen as narrow longitudinal, sunken bands. These bands occur mostly in fast grown material with wide thin walled growth rings. Although common, collapse is not often so severe as to cause rejection of the batten (figure 11).

Other forms of degrade do occur on kiln-dried spruce during drying. Those mentioned above are the most common forms encountered. Continual improvements in processing, drying and grading procedures by the UK softwood sawmilling industry ensure that the quality of UK timber is constantly monitored and maintained.

Figure 11. Batten showing severe collapse

Moisture content

'Green' moisture content

In order to dry spruce efficiently, it is important to have an understanding of how the initial or 'green' moisture content of spruce affects the drying process. The initial moisture content of the timber will have a direct influence on the speed of drying, which in turn will have both logistic and economic implications.

It is well known that green moisture content varies between different species of softwoods, between the sapwood and heartwood of the same tree and even between logs cut from different heights in the tree. In many species, including Sitka spruce (*Picea sitchensis*), seasonal variations in green moisture content also occur[1].

In one American study, it was found that the average green moisture content of Sitka spruce, based on oven dry weight, was 41% for heartwood and 142% for sapwood[2]. This particular relationship is very closely linked to wood density, which varies in both heartwood and sapwood.

Knuchel (1930), published curves for the seasonal green moisture content of (American) spruce sapwood and heartwood. Heart wood moisture content remained fairly stable throughout the year, fluctuating between 30% and 35%, with a peak occurring in May at just over 40%. The sapwood moisture content showed much greater variation. Falling from a peak of approximately 155% during December, down to 110% in March, rising up again to 155% in June before falling to approximately 130% in September.
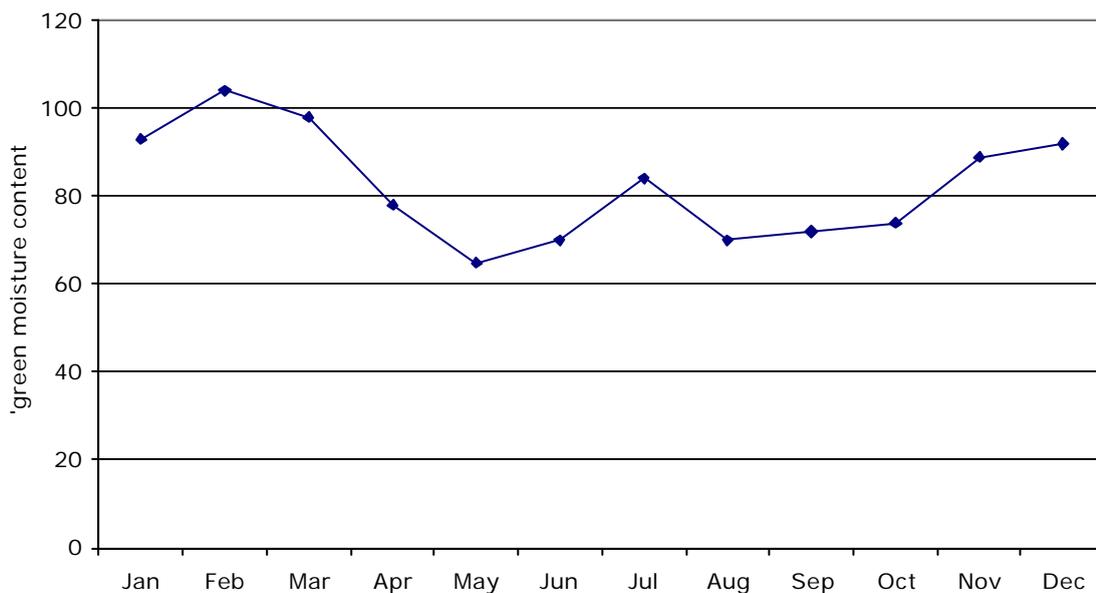

Figure 12 Seasonal variations in 'green' moisture content of UK grown spruce

Figure 12 shows the seasonal variation in the green moisture content of UK grown spruce. Each plot shows the average green moisture content of approximately 150 freshly sawn battens recorded throughout the year. During the study, no distinction was made between heartwood and sapwood, although, most of the battens from which samples were derived were sawn from small diameter logs. Due to the variations which occur in the green moisture content of battens from different sources, this graph should only be seen as indicative.

Figure 13 shows the variation in green moisture content which occurred in a batch of 158 UK grown spruce battens sampled in September. Again, during the sampling process, no distinction was made on where the batten was sawn from in the log or its original position in the tree. In realistic terms, this is the type of green moisture content variation commonly encountered in UK spruce sawn for the general construction market.
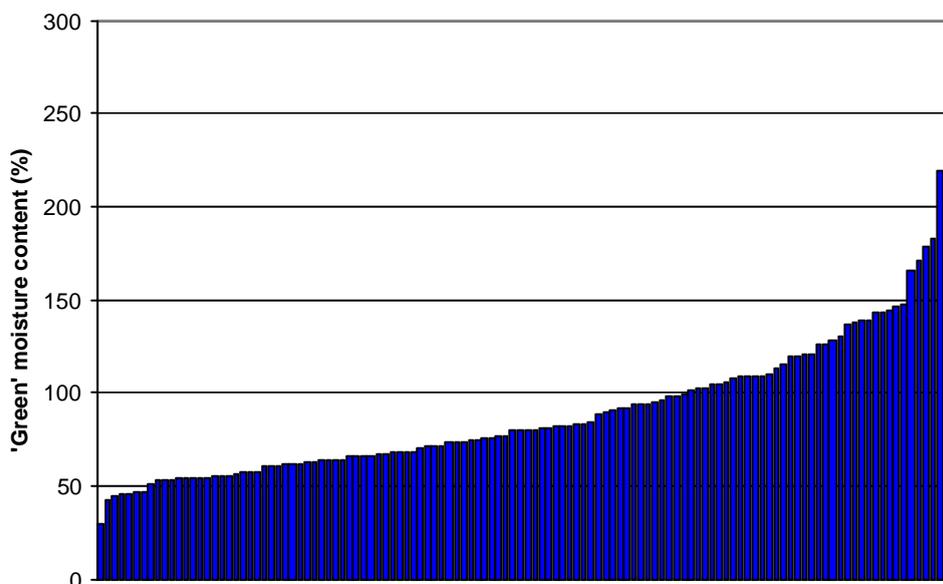

Figure 13. The variability of 'green' moisture content in UK spruce

Considering the variation in moisture content encountered in a typical spruce drying charge, it becomes apparent that careful drying is required to obtain anything near a uniform final moisture content after kiln drying is completed. Although the variations found in green moisture contents do cause problems during drying, schedules have been developed and altered to cope with these variations.

Several recently completed projects (DRYCON – Improved control of wood drying (BRST-CT98-5270) & STRAIGHT – Measures for improving quality & shape stability of sawn softwood timber during drying & under service conditions (QLK-2001-00276)) have investigated the possibility of pre-sorting green material into batches with high and low moisture contents, or batches with very similar moisture contents. This method has the potential to speed up the drying process and improve the final moisture content uniformity of a particular drying charge. Several problems exist which make the incorporation of this method into a modern sawmill setup difficult or contentious. Firstly, the electronic equipment required to assess each

batten's 'green' moisture content at speed, is still in the experimental stage (although prototype equipment has been developed which will measure green moisture content up to approximately 70%). Secondly, the utilisation of this method causes some major logistical problems. The timber would require further sorting (after dimensional sorting) into batches with similar moisture contents. This would necessitate a greater number of sorting bins, and cause a slow down the kiln loading process. Even so, the economics of incorporating such a system into the wood processing line may prove, after assessment, beneficial.

'Final' moisture content

All timber used in modern timber construction requires drying before use for a number of important reasons, these include:

- Drying prevents the growth of wood rotting fungi

- Reduces the weight of the material

- Prepares the surfaces for the application of coatings

- Allows good penetration of wood preservatives

- Increases most of the strength properties of timber

- Renders the timber as stable as possible.

Depending on the intended use of the timber, the final moisture content required will vary. For the majority of spruce produced in the UK for the construction market, the final moisture content required, according to BS 5268: Part 2: 1996 should be an average of 20% or lower, with no piece exhibiting moisture contents greater than 24%.

Due to the large variation in the 'green' moisture content of the raw material, achieving this target is not easy. Figure 14 shows the drying progress of 7 pieces of timber positioned at various points throughout an industrial kiln load, during the drying process. Although high moisture contents (especially in a high temperature environment) are difficult to accurately monitor. The chart provides an indication of the variability within a kiln charge at the beginning, and during drying. It also shows how this affects the final moisture content spread when the drying is terminated at an approximate moisture content of 20%. Experiments have shown that if the final target moisture content is more in the region of 10%, moisture content variability of the kiln load is greatly reduced.
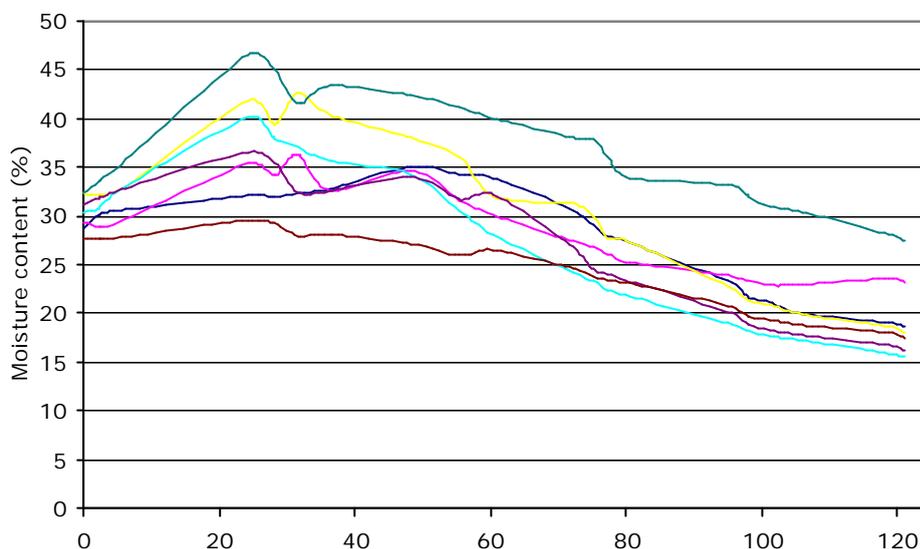
Figure 14. Moisture content reduction during kiln drying

The chart shown in figure 14 can be very misleading. Electrical resistance probes were used to monitor the moisture content reduction on the separate battens. This type of probe is not very accurate at moisture contents above 30% and the display would not show moisture contents above 40%. The values obtained were corrected for temperature and are used only as an indication of the spread of moistures contents at the termination of the drying process.

Because the target M/C of spruce used in construction is 20%, there will always be some variability between pieces at the termination of drying. One of the primary tasks of the kiln operator is when to cease kiln drying to ensure that a majority of the load has an average moisture content of 20% or below. Using an effective drying schedule, monitoring system and conditioning phase will make this task more achievable. Figure 15 shows the final moisture content of 150 spruce battens after drying using a conventional schedule. The battens have been sorted in an ascending order (one bar per batten) from above 40% moisture to below 15%. Of this charge, six battens fail to meet the 'no batten above 24% criteria'.
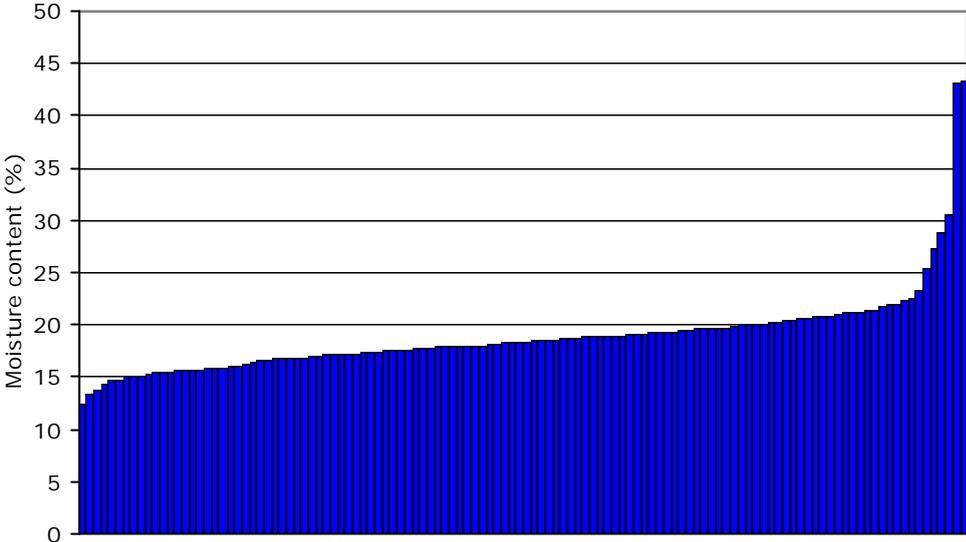
Figure 15. Final moisture content variation in a typical spruce kiln drying charge

Conventional drying schedules for spruce

A wood drying schedule can be described as a series of set stages, usually incorporating a gradual rise in temperature and a lowering of the relative humidity, whilst monitoring a fall in moisture content of the timber. Depending on the timber species, dimension, final moisture content target and timber quality, the schedule will require some adaptation to fulfil the specific criteria. Figure 16 shows a typical medium temperature schedule used to dry UK spruce using a wet and dry bulb monitoring system.
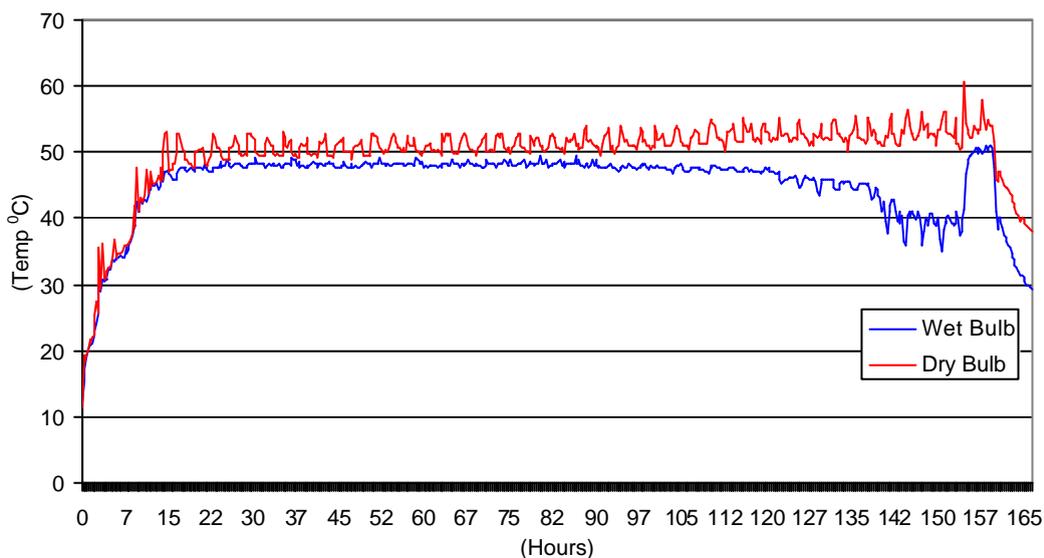

Figure 16. Typical medium temperature drying schedule for spruce

Although figure 16 shows how a schedule looks visually, more often, a schedule is written down in table form as a series of steps. The schedule shown in figure 16 is shown written in a simple table format in table 2. A kiln schedule written in table format can be produced with as many or as few phases as required. The information contained in a schedule may also be very simple or very detailed, containing wet and dry bulb temperatures, relative humidity, moisture content, equilibrium moisture content, fan speed and drying gradient.

Table 2. Typical low/medium temperature drying schedule for spruce

Schedule	Medium temperature conventional					
Phases	Heat up	Initial dry	Main dry	Main dry	Conditioning	Cooling
Variables	1	2	3	4	5	6
T Dry bulb (^{0}C)	10 - 52	52 - 54	54 - 56	56 - 56	56	56 - 20
T Wet bulb (^{0}C)	10 - 48	48 - 48	48 - 45	48 - 39	52	52 - 20
RH (%)	79	79 - 70	70 - 50	50 - 36	90	90
M/C (%)	95					18	Total
Time (Hrs)	14	70	50	20	6	5	165

When a modern industrial conventional wood drying kiln is delivered to an industrial client, the control system normally contains a series of drying schedules for a variety of different wood species and timber thicknesses. The schedules provided with the system are developed specifically for the manufacturers kiln and take into account the width of the stack, kiln geometry, air velocities and humidifying system. Very often, the schedules provided are a compromise between the production of quality timber and speed of drying. The control systems are developed in order that they can be adapted or changed for a particular country's species and the level of timber quality required by the sawmiller or dryer.

 A large amount of work has been undertaken on developing kiln schedules for UK spruce. Drying any timber species requires time and experience and, depending on the quality of timber required, will require adaptation for the kiln being used.

Most UK sawmills dry spruce using conventional drying technology. In many instances the insulation properties of the kiln body regulate the maximum temperature with which the timber can be dried. An increase in maximum drying temperature generally correlates to a decrease in drying times when all other variables remain constant.

The drying phases described

Heat-up

The heating-up phase is exactly what it says, a phase to bring the kiln charge up to the required temperature for drying to commence. This phase is an extremely important part of the drying schedule, although the only part where drying should not be allowed to occur. During heating-up, the humidity must be kept as near to 100% as possible. At the start of the schedule, the recently processed 'green' timber is very susceptible to extreme drying conditions, especially if the relative humidity is allowed to drop (any

distance) behind the rising temperature and irreparable damage to the timber can occur (surface checks, splits, case-hardening and excessive development of distortion).

In many kilns, the temperature can rise very quickly, and often, the humidifying system struggles to keep pace. In these circumstances, it is best if the heating up phase is broken down into much shorter sections to allow temperature and humidity to coincide before being increasing to the next point. The heating-up phase shown in figure 16 shows this to good effect. At several points during heating-up, the increasing dry bulb temperature is between 6°C and 7°C higher than the wet bulb temperature. This is not an ideal scenario

Although this problem may show up on the kiln schedule print out after completion of the drying. It can be quite difficult to observe, without the use of more precise external monitoring equipment being fitted. Suffice to say, many drying problems encountered after drying has been completed, are generated at the heating-up stage.

Initial drying

Initial drying tends to be the gentlest part of the drying schedule. The timber has been brought up to the required temperature, and humidity is kept fairly high. The timber contains a large amount of free water, which is removed at a steady rate to prevent collapse, whilst ensuring the pathways for the movement of moisture from the core to the surface remain open and the surface layers are not over-dried.

Main drying

At this point in the schedule, much of the free water (although not all) has been removed and the temperature increased and humidity lowered to generate the conditions for the continued movement of moisture from the timber. As always with drying, the schedule is supposed to provide the optimum conditions for the steady and continued removal of moisture from the timber. Too fast, and the timber may be damaged, to slow and the economics of the process may be compromised.

Conditioning

At some point in the drying schedule, the timber will attain the required target moisture content. At this point, the majority of the load, if removed from the kiln straight away, will show a range of moisture contents about the required average. Much of the timber will also be still under a certain degree of drying stress, as the drying would have been terminated at the harshest part of the schedule. The conditioning phase is required to do two jobs. Reduce the drying stress created by the last section of the schedule, and as much as possible reduce the wide variation in moisture contents of the battens in the load.

Conditioning can be applied in a number of ways. The temperature attained at the end of the schedule can be retained and the humidity or wet bulb temperature increased. Or the temperature decreased and humidity or wet bulb temperature increased. Either way, the conditions within the kiln are changed from a dry atmosphere to a moist atmosphere.

Conditioning can last anything from 4 to 24 hours, depending on what is required. Conditioning may be extended if it is known that problems have occurred during drying (excessively dry at some point in the schedule) or final moisture contents have dropped below the initial target (over-dried). It is difficult to recommend an optimum conditioning time, although somewhere between 5 and 15 hours is common.

Cooling down

Cooling down obviously occurs at the very end of the drying schedule. As with the heating-up phase, this is another important part of the drying process. It is important that cooling is allowed to happen naturally. At the end of the schedule, the heating, humidification system and fans should be closed and the vents opened. Depending on the size of the kiln (and the material it is constructed from) and load, cooling down may take more than 24 hours. The main doors should only be opened when the temperature inside the kiln reaches a similar temperature to the external ambient temperature. As a rule of thumb, the doors can be opened when the internal temperature reaches approximately 20°C.

If the main kiln doors are opened directly after drying (because the timber is required for an urgent order, or the mill is trying to speed up the turn-around process), loud cracking and creaking noises will be heard coming from stack.   This is the result of rapid heat loss from the timber surfaces along with any moisture contained in the wood surface. The noises are the development of splits and checks (both internally and externally) as rapid moisture loss occurs. This process can also cause severe stress build-up in the timber, which may lead to an increase in the development of distortion.

The main recommendation from this section is that the kiln load should be allowed to cool down naturally after drying has been completed.

Air-flow reversal

During the drying process the airflow direction is reversed at regular intervals. This ensures that the kiln load is dried in a uniform manner. During drying, the heated air passes through the timber stack losing heat to the timber and absorbing moisture from the wood surface. Depending on the width of the stack, and the percentage of heat lost from the circulating air, the rate of drying may vary quite considerably across the stack width.   Drying will be at its greatest at the air intake side, slowly reducing across the stack until it exits the stack on the opposite side.

Depending on the air velocity, and the reversal time, very harsh drying may occur on one side of the stack whilst very little drying occurs on the opposite side. When the airflow is reversed, the opposite side then receives this harsh drying treatment. During this process, moisture may be picked up by the timber on the opposite side to the harsh drying, effectively subjecting this material to a conditioning process. This type of drying process is given the name of oscillating drying. Although, this tends to apply to the process explained above, oscillations occur in all types of drying where fan reversal occurs. The peaks and troughs shown on the schedule depicted in figure 16 are effectively oscillations due to the fan direction being reversed.

Several studies have been undertaken on oscillating drying and the results show that this form of drying seems to speed up the process and either improve or retain existing wood quality in comparison to normal conventional drying. The term oscillating drying tends to be given where the fan reversal period is at intervals of 4 hours or more. Further work is required to understand this process more fully.

During the normal conventional drying of spruce, the airflow reversal times are normally in the region of between 1 and 2 hours. Several kiln manufacturers drop this to 30-minute reversal times during heat-up. Once a schedule has been proven to work well, experimentation with longer reversal times can be undertaken to assess its potential.

Airflow velocity

Air velocity parameters are calculated at the kiln design stage and are based on the maximum required drying speed. The velocity required will depend on the species being dried and the overall width of the kiln load. To provide a flexible drying system, circulation velocities for the conventional drying of spruce should be between 3.5 m/s and 5 m/s.

During the drying process, it is quite common to initiate different airflow velocities at each of the different phases of drying. Higher airflow velocities are generated during the early stages to help remove the large quantities of moisture released at this stage of drying. As drying progresses, the velocity is reduced to regulate the drying gradient and take into account the slower removal of bound water from the cells. In the later stages, this may be reduced further to prevent undue drying stress being imposed on the material.

In kilns with frequency inverters, the drop in circulation velocity of the air can be programmed with a change in fan rotation speed. The use of fan frequency inverters, as well as providing the kiln operator with a versatile system, provides considerable energy savings. Fitting over-size fan motors, coupled with frequency inverters, allows the fans to provide adequate velocity with reduced power consumption, which can provide large energy savings.

It is better to fit fans with larger circulation velocities coupled with frequency inverters, than to fit smaller fans struggling to provide adequate airspeeds at 100% capacity.

Indicative kiln schedules for UK grown spruce

A large amount of work has been undertaken over the last eight years on producing the ideal generic kiln schedule specifically for UK grown spruce. There is no doubt that material produced in the UK behaves very differently to that sourced from other European countries. UK spruce is more susceptible to developing distortion (and other drying defects) during drying than its counterparts, and for this reason care must be taken when drying.

Work undertaken on categorising and assessing kiln designs at a number of UK softwood sawmills has shown that a large variation exists between kilns from different sites. Each softwood company may have kilns from more than one manufacturer; the kilns may have very different designs, load capacity, stack widths, air speeds, heating capacity and control technology. For these reasons, it is not possible to produce one generic kiln-drying schedule, which can be used by all UK softwood mills drying spruce for the construction market. Because of the variety of designs and working capabilities of conventional kilns present in the UK, any new schedule will require various levels of adjustment to obtain the best timber quality and speed of drying.

The schedules shown in tables 4, 5 and 6, have been developed from the work undertaken at BRE over the last three years on improving the conventional kiln drying of spruce. Their production also takes into account work undertaken in previous projects on improving the quality of spruce dried in the UK. The schedules have been produced to take into account the different heating capacities of kilns in and around the UK and also dry timber with a reasonable quality, in a reasonable amount of time. Graphical representations of the schedules have also been produced in figures 17, 18 and 19.

All of the schedules have been produced so that they can be adapted to the kiln in which they are being used. For further more in-depth information , The Timber Drying Manual[5] is a useful document.

Table 3. Low temperature spruce schedule

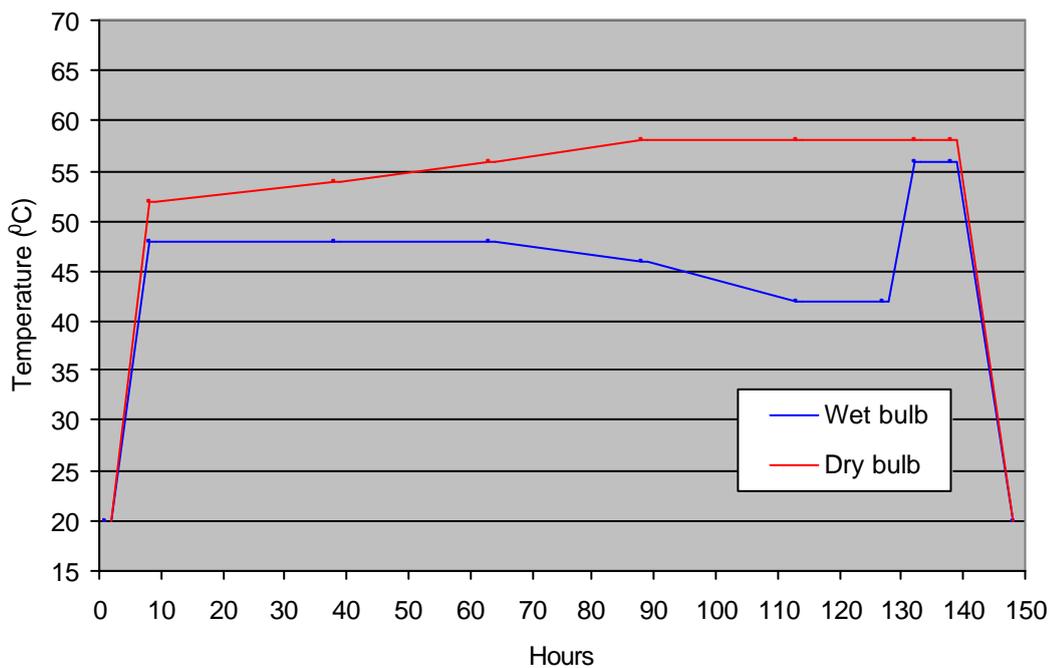| Schedule	Low temperature							
Phases	Heat up	Initial dry	Main dry	Main dry	Main dry	Main dry	Condition	Cooling
Variables	1	2	3	4	5	6	7	8
T Dry bulb (^{0}C)	20 - 52	52 - 54	54 - 56	56 - 58	58 - 58	58 - 58	58	58 - 20
T Wet bulb (^{0}C)	20 - 48	48 - 48	48 - 48	48 - 46	46 - 42	42 - 42	56	56 - 20
RH (%)	79	79 - 70	70 - 64	64 - 50	50 - 37	37 - 37	90	90
EMC (%)	15	15 -12.2	12 - 9	9 - 8.2	8.2 - 6.2	6.2	18	18
M/C (%)	95							18	Total
Time (Hrs)	8	30	25	25	25	15	10	10	148

Figure 17. Graphical representation of low temperature spruce schedule

Table 4. Medium temperature spruce schedule

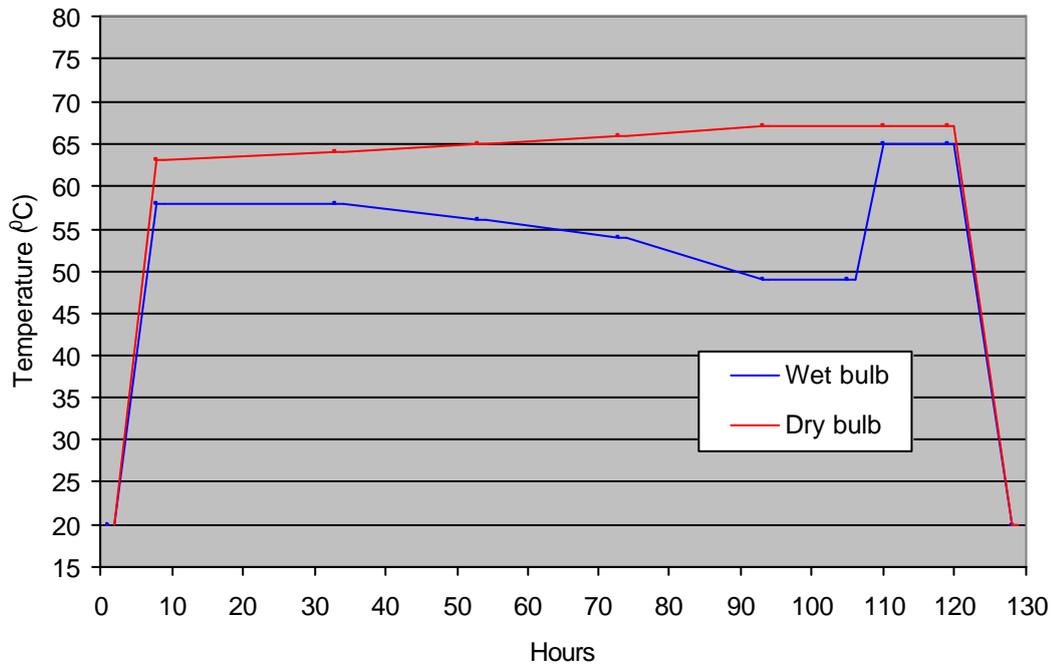| Schedule	Medium temperature								
Phases	Heat up	Initial dry	Main dry	Main dry	Main dry	Main dry	Condition	Cooling	
Variables	1	2	3	4	5	6	7	8	
T Dry bulb (^{0}C)	20 - 63	63 - 64	64 - 65	65 - 66	66 - 67	67 - 67	67	67 - 20	
T Wet bulb (^{0}C)	20 - 58	58 - 58	58 - 56	58 - 54	54 - 49	49 - 49	65	65 - 20	
RH (%)	77	77 - 74	74 - 63	63 - 53	53 - 36	36	93	93	
EMC (%)	13.4	13.4 - 12.3	13.4 - 9.8	9.8 - 8.1	8.1 - 5.6	5.6	17.7	17.4	
M/C (%)	95							18	Total
Time (Hrs)	8	25	20	20	20	15	10	10	125

Figure 18. Graphical representation of medium temperature spruce schedule

Table 5. Elevated temperature spruce schedule

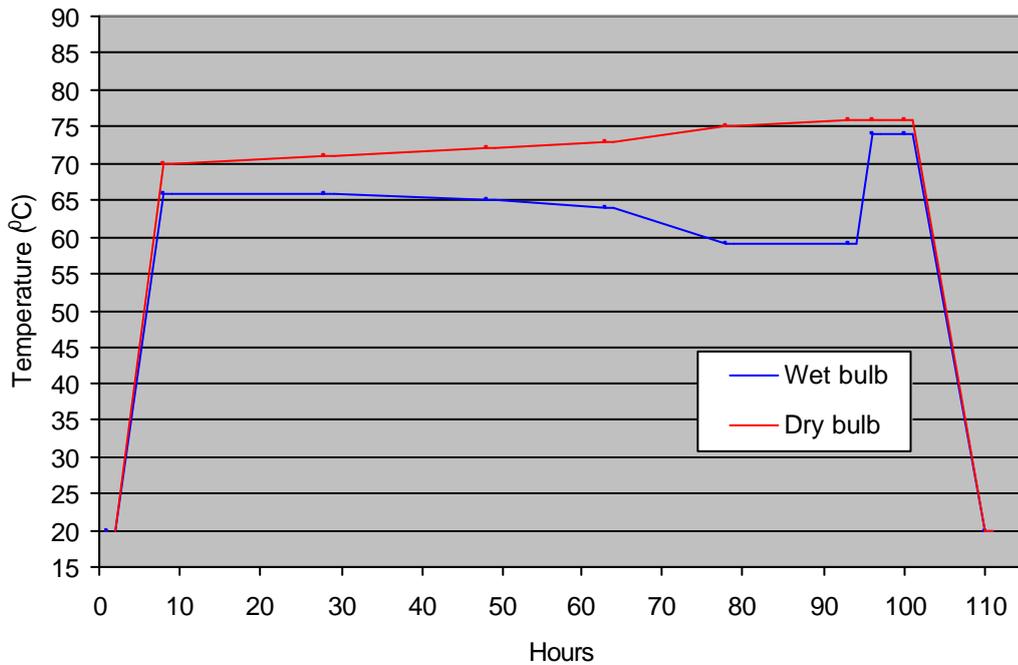| Schedule	Elevated temperature								
Phases	Heat up	Initial dry	Main dry	Main dry	Main dry	Main dry	Condition	Cooling	
Variables	1	2	3	4	5	6	7	8	
T Dry bulb (^{0}C)	20 - 70	70 - 72	72 - 73	73 - 75	75 - 76	76 - 76	76	76 - 20	
T Wet bulb (^{0}C)	20 - 66	66 - 65	65 - 64	64 - 59	59 - 59	59 - 59	74	74 - 20	
RH (%)	83	83 - 72	72 - 65	65 - 46	46 - 44	44 - 44	92	92	
EMC (%)	14.4	14.4 - 11.1	11.1 - 9.8	9.8 - 6.5	6.5 - 6.2	6.2 - 6.2	16.5	16.5	
M/C (%)	95							18	Total
Time (Hrs)	8	20	20	15	15	12	10	10	110

Figure 19. Graphical representation of elevated temperature spruce schedule

The schedules shown are specific for spruce with a nominal cross-section of 50 x 100 mm. For drying wider material (50 x 200 mm), the wet bulb values will require increasing by 1°C or 2°C. If thicker material (75 mm) is being dried, the wet bulb values will require increasing 1°C or 2°C during the initial drying stages and possibly up by 4°C later in the latter stages to prevent excessive moisture gradients developing.

Although the schedules shown in tables 3, 4 and 5 have been produced with increasing dry bulb temperatures and decreasing wet bulb temperatures, it is possible to produce schedules with one or the other remaining constant. In theory, this type of schedule should produce exactly the same results as for the increasing dry bulb and decreasing wet bulb type schedules. Table 6 and figure 20 show an elevated temperature schedule suitable for 50 x 100 mm spruce, based on the constant dry bulb theory.

Table 6. Elevated temperature spruce schedule (constant dry bulb type)

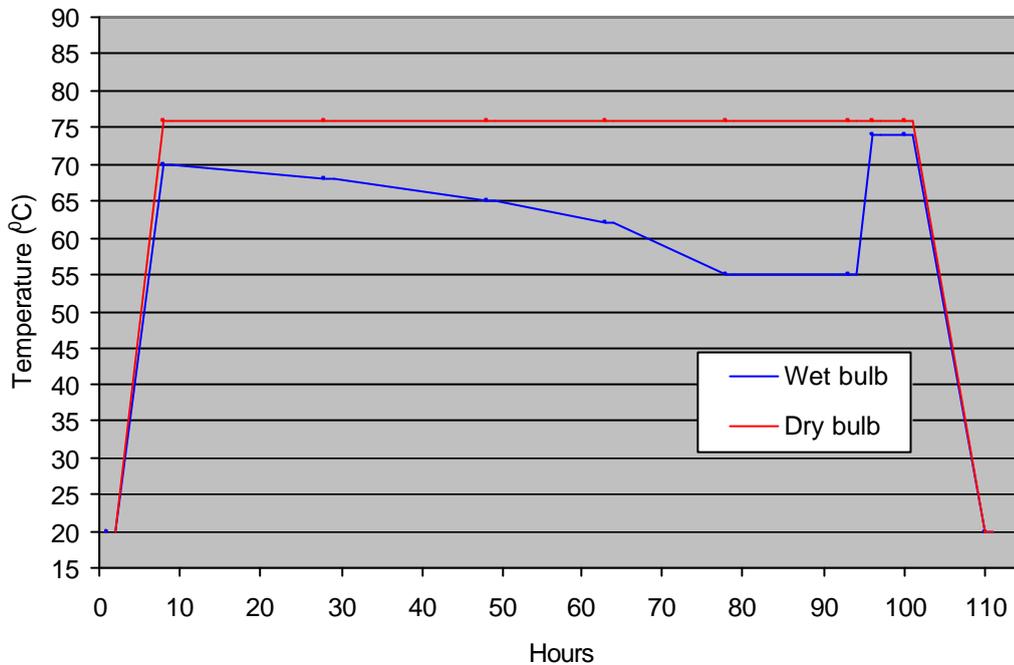| Schedule	Elevated temperature								
Phases	Heat up	Initial dry	Main dry	Main dry	Main dry	Main dry	Condition	Cooling	
Variables	1	2	3	4	5	6	7	8	
T Dry bulb (^{0}C)	20 - 76	76	76	76	76	76	76	76 - 20	
T Wet bulb (^{0}C)	20 - 70	70 - 68	68 - 65	65 - 62	62 - 55	55	74	74 - 20	
RH (%)	76	76 - 69	69 - 60	60 - 51	51- 37	33	92	92	
EMC (%)	11.6	11.6 - 10.5	10.5 - 8.5	8.5 - 7.1	7.1 - 5.2	5.2	16.5	16.5	
M/C (%)	95							18	Total
Time (Hrs)	8	20	20	15	15	12	10	10	110

Figure 20. Graphical *representation of elevated temperature spruce schedule (constant dry bulb type)*

The total drying time shown on each of the schedules is only an indicative figure. Drying may take longer than shown and inversely may be quicker than shown. Much will depend on the kiln in which the timber is being dried, the initial moisture content of the material and the stacking regimes employed.

The schedules have been developed using an average air velocity of 3.5 m/s throughout the schedule. If experimentation with different air velocities is required, it is recommended that changes are made in individual specific sections of the schedule, and the material assessed before making further changes. The use of air velocity is one area which should not be overlooked as a tool for adjusting the drying schedule. Subtle adjustments will allow you to either speed the drying process up or down. These types of adjustment will also affect the drying gradient, so any changes must be made carefully.

One point which is worth remembering; **Do not** **make excessive numbers of changes to the drying schedules at any one time.** It is very difficult to identify where a problem has occurred if a whole raft of changes has been made in one go.   **Happy drying.**

References

(1) Skaar, C. (1988). Wood-water relations. Springer-Verlag. Berlin, Heidelberg, New York.

(2) Kollmann, F. F. P. & Cote, W. A. (1968). Springer-Verlag. Berlin, Heidelberg, New York.

(3) U.S Forest Products Laboratory (1987). Wood Handbook. U.S.D.A., Ag Handbook No 72 (revised).

(4) BS EN 13183-1:2002. Moisture content of a piece of sawn timber – Part 1: Determination by oven dry method.

(5) Pratt, G. H. (1997). The timber drying manual. Building Research Establishment.

Annex A – 'Enhancing the quality and adding value to UK timber by improved conventional kiln drying'

Introduction

This report is the experimental section of the final output from the project 'Enhancing the quality and adding value to UK timber by improved conventional kiln drying', the results of which have been used to complete several sections in the main guidance manual. The project was funded by the Forestry Commission under contract number PPD 94, and was due for completion at the end of October 2005. This research programme complements work previously carried out under both Forestry Commission and European Commission funded projects and forms part of the extensive BRE and UK sawmilling industry research programme, targeted at optimising drying efficiency and improving the quality of kiln dried softwood timber.

The project specifically targeted the improvement and optimisation of conventional drying techniques using current drying equipment present in the UK. The main objective of this project was to investigate how increases in drying temperature (and changes in other drying parameters) affect drying times, and the final quality of UK kiln dried spruce. From the analysed information, a series of kiln drying schedules have been produced specifically targeted at complementing existing schedules and improving the overall drying of UK spruce.

Description of the project

The main objective of this project was achieved by undertaking a series of accelerated drying trials in BRE's experimental wood drying kiln. The trials incorporated a number of different drying parameters to speed up the drying process, whilst attempting to retain or reduce distortion on dried material. Each experimental trial in the series consisted of one control and one experimental drying run.

The first trial in the work programme was a baseline control trial, against which all other control packs within the project could be compared.   To complete this trial a single pack of 'green' spruce, supplied by a UK sawmill, was coded at both ends, cross-cut into two, then mixed to provide two almost identical packs. One pack was dried by the industrial partner using their own kiln and schedule and one dried using the experimental kiln at BRE. Both using the same schedule as that of the industrial partner. The results from each kiln trial were then compared to ensure similarity between the drying parameters. This would ensure that any subsequent improvements generated by the following experimental trials undertaken at BRE could be transferred directly to industrial units without any problems.

This trial was used as the main control trial against which all the experimental trials would be compared.

The next phase of the work programme consisted of undertaking six accelerated drying trials. Each of these trials would have a stepwise increase in maximum temperature of 5ºC increments from 62ºC up to a maximum temperature of 87ºC. The other drying parameters (airflow, sticker dimension etc) would be kept

constant, whilst maintaining a similar schedule shape in accordance with the stepwise increase in the dry bulb temperature. The target moisture content for all trials was set at 18%. After drying, the timber from each of the trials was measured for distortion and uniformity of moisture content. Each drying schedule was also monitored using external electronic equipment to verify the kiln control unit figures.

Using the results obtained from the first programme of trials, described above, two further experimental trials were undertaken. These aimed to investigate how a change in drying parameters affected timber quality and drying time. All the trials undertaken provided information on how wood quality and moisture content uniformity is affected by increasing temperatures during the drying schedule and how other drying parameters interact as drying time is reduced.

All the trials were undertaken used timber with a dimension of 50 mm x 100 mm. Past trials have indicated that this dimension is the worst affected by distortion.

From the completed programme of experimental trials, three kiln schedules were produced for use by the UK sawmilling industry, each utilising progressively higher temperatures. These schedules were not produced to replace those already in use, but to complement existing information and knowledge, and improve the drying of spruce.

All the drying experiments undertaken were used to assess the impact of top-loading on drying quality, and in turn how this was affected by increases in drying temperature. Each full trial consisted of one experimental and one control trial. In each of these trials, half the load was top-loaded, whilst the other half was left un-loaded.

Test material

All the material used in the programme was sourced in the UK (Sitka spruce, *Picea sitchensis*), and was supplied by a consortium of the UK's largest softwood sawmills (James Jones & Sons Ltd, BSW Timber plc, Adam Wilson & Sons Ltd, James Callander & Son Ltd, Balcas Timber Ltd, John Gordon & Son Ltd and Howie Forest Products). As already described, each trial consisted of taking one pack of 'green' 50 mm x 100 mm x 4800 mm material (approximately 150 battens per pack) and applying sequentially numbered plastic tags to either end of every batten (different colours either end). The parcel was then cross-cut into two equal lengths and a moisture content sample (for green moisture content) removed from the central portion. The two packs of battens were then mixed (figure 1) equally into two packs (this prevented all the 'tops' or 'butts' remaining in one parcel and affecting result comparability). This process involved exchanging or substituting every other batten between the two parcels. After the mixing process was complete, two almost identical packs of 50 mm x 100 mm x 2350 mm material remained. Each full size pack was then used to complete one trial. Each trial consisting of an experimental portion and one control portion.
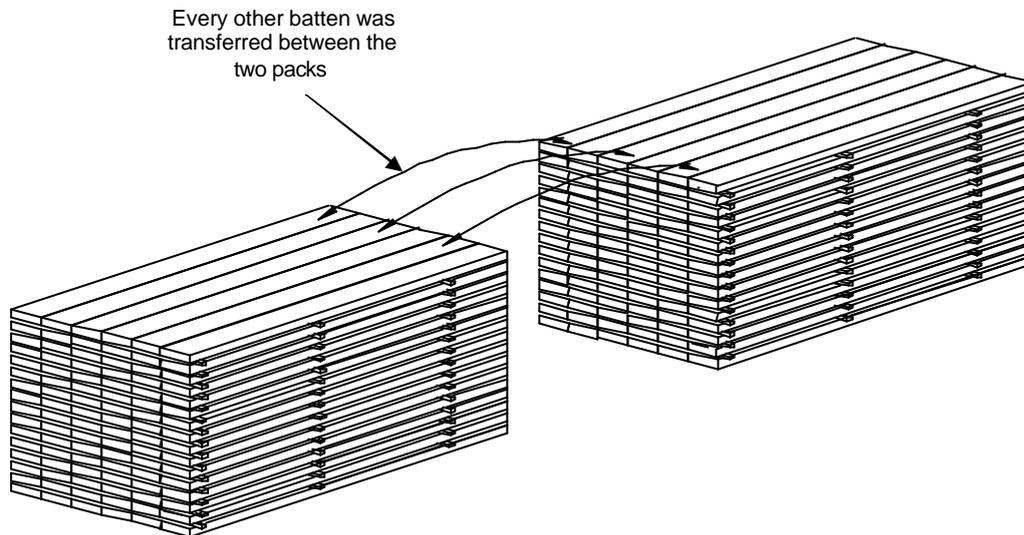
Figure 1. Batten substitution process. This prevented all the top or butt sections occurring in one pack and skewing results. Two approximately equal packs are produced by this process. One control & one experimental.

Baseline Control Trial

Method

The kiln schedule used for the baseline control trial was selected from the sawmill of James Jones and Sons, Aboyne, Scotland. This schedule is one normally used to dry 50 x 100 mm spruce at the mill in Aboyne.

One pack of 'green' spruce (50 mm x 100 mm x 4800 mm, approx. 150 battens per pack) was selected from freshly sawn material. Each batten was consecutively numbered with plastic tags (same number both ends, blue tags one end, red the other) and the pack cross-cut into two (50 mm x 100 mm x 2400 mm battens). From the centre of each batten, a moisture content sample was removed to ascertain its 'green' moisture content. Every other batten in the two packs was then exchanged to provide two almost identical packs (a mixture of butt and top battens). One pack was then dried by James Jones using one of their normal drying schedules and the remaining 'green' pack was wrapped in plastic and sent to BRE. Once received, this pack was stacked into the experimental kiln and dried (after entering the schedule into the kiln control unit) using the same schedule as that used by James Jones. Both packs were dried to a target moisture content of 18%. When the drying at both sites was completed, the battens were assessed for moisture content and measured for twist, bow, spring and cup.

Results from the baseline drying schedule

The final drying time from both schedules was approximately 165 hours and attained a maximum dry bulb temperature of 57°C. The graphical representation of the schedule used to dry material at BRE is shown in figure 2. The final mean moisture content recorded from the trials was 20.6% (BRE) and 19.4% (James Jones).
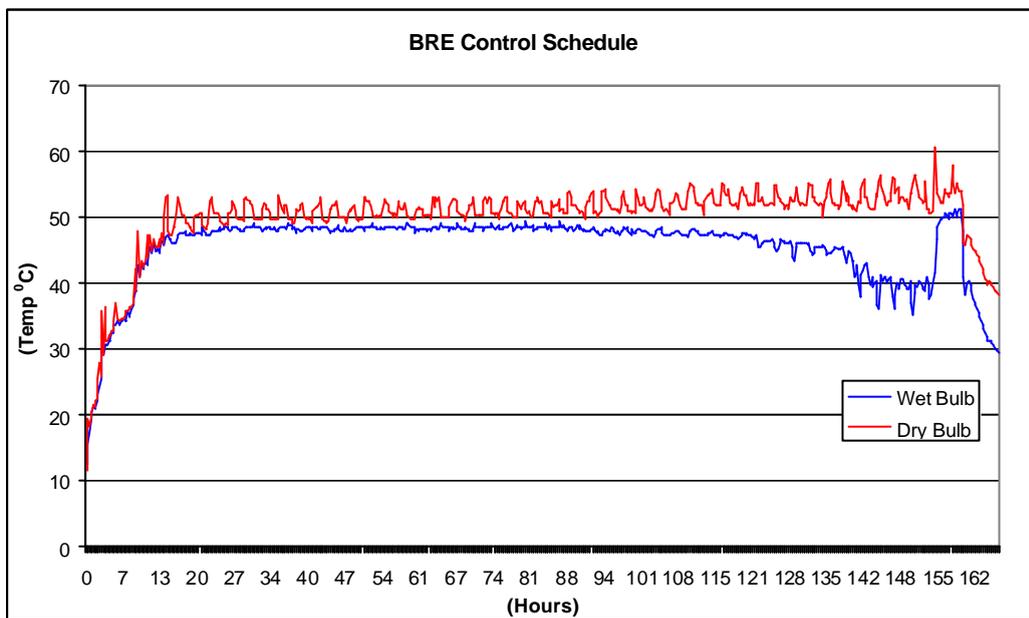

Figure 2. BRE control schedule

Figure 3 indicates the similarity between the average distortion values recorded from both trials. Both batches shown were dried under load.
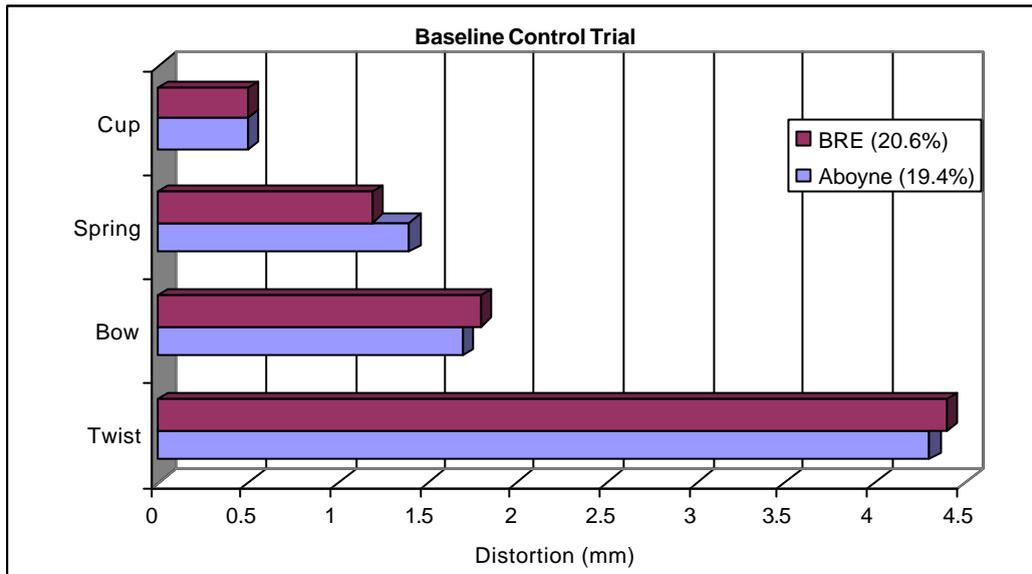
Figure 3. Average distortion results recorded from the baseline control trial

The similarity of results, both from the drying schedules and distortion values indicate that any subsequent improvements generated by the experimental trials could be transferred directly to industrial units with very few problems.

Accelerated Drying Trials

Method

Six sets of accelerated drying trials were planned with a target moisture content for all timber set at 18%. The first experimental trial was programmed to reach a maximum dry bulb temperature of 62ºC. The maximum temperature attained in each subsequent trial would be increased by 5ºC, up to a maximum temperature of 87ºC as shown below:

- **Control Run: 57ºC**

  - Exp. Series 1:   62ºC
  - Exp. Series 2:   67ºC
  - Exp. Series 3:   72ºC
  - Exp. Series 4:   77ºC
  - Exp. Series 5:   82ºC
  - Exp. Series 6:   87ºC

All the schedules were programmed to follow a similar schedule shape, and retain the same relative humidity values as those used in the baseline control schedule, in accordance with the rise in dry bulb temperature. The drying parameters also remained constant. These consisted of:

- Utilising one pack of 50 mm x 100 mm x 4800 mm freshly cut UK grown spruce, split into two, to form one control pack and one experimental pack as described earlier.

- Each trial pack was further split into two, half the pack being top-loaded and half left without top-load.

- Airflow velocity would be approximately 3.5 m/s throughout the schedule.

- Sticker thickness was: 22 mm x 38 mm and placed every 500 mm.

- Airflow reversal time was set for 2 hours (30 minutes during heat-up).

As previously stated, each experimental and control trial was further split into two sets for each trial, one set of battens being dried under top-load (480 kg/m^2) and one dried without top-load (see figure 4). Following each kiln trial, twist, bow, spring, cup, moisture content, slope of grain and the position of the piece in the log was measured on each individual piece. During the drying process, the moisture content was monitored by electrical resistance type measuring probes.

Figure 4. Experimental kiln trial showing loaded and un-loaded material

Twist bow and spring were measured on a specially designed aluminium distortion rig. Twist, bow and spring were measured over the central 2000 mm portion of each batten, and twist at a height of 100 mm. Cup was measured using a special dial gauge jig, the measurement being taken from the centre of each batten, 50 mm from one edge. Twist bow and spring were measured to an accuracy of 0.5 mm and cup to 0.1 mm. To obtain 'green' moisture content, oven dry samples (50 mm x 100 mm x 50 mm blocks) were removed from battens during the initial cross-cutting stage.

Results from the accelerated trials

Comparison of moisture content and drying time

Average 'green' and final moisture content values recorded from both the control and experimental trials is presented in table 1. 'Green' moisture content was assessed according to BS EN 13183-1:2002[4]. The final dry moisture content values were determined using calibrated electrical resistance type moisture meter (one measurement per batten, measuring 1/3 of the width from one edge and at a depth of 1/3 of its thickness).

Average green moisture content values varied between an average of 66% and 93%. Final moisture contents recorded from the control and experimental battens were fairly close at around an average of 20%. Trial 6 battens were over-dried in both the control (15%) and experimental schedules (13%).

Table 1 Average initial & final moisture contents of all trial material

Trial No.	No. of battens in pack	Average M/C 'Green' (Std)	Average final M/C Control battens (Std)	Average final M/C Experimental battens (Std)
1	134	70% (18)	20.2% (2.3)	16.1% (1.2)
2	142	74% (25)	19.5% (1.8)	21.0% (2.7)
3	154	93% (38)	19.7% (3.9)	18.4% (2.6)
4	100	78% (44)	18.7% (3.4)	18.5% (3.0)
5	143	66% (27)	20.0% (2.7)	20.0% (2.8)
6	165	73% (29)	15.0% (2.0)	13.0% (2.1)

Table 2 shows the drying times of the control and comparative experimental drying runs. Results indicate that the control schedule length varied between 165 hours and 182 hours, for trials 1 to 5, with a maximum difference of 17 hours. Trial 6 (both control and experimental) exhibited a much longer drying time than any of the other recorded schedules, partly due to over-drying. Trial 1 experimental also shows an extended drying time. It is not known why this occurred. Comparing tables 1 and 2 indicates that the longest control schedule (between 1 and 5) does not always correspond to the highest initial 'green' average moisture content.

Table 2 Drying time variations at different maximum dry bulb temperatures

	Drying time (hrs)	Max temp (ºC)	Drying time (hrs)	Max temp (ºC)
Trial No	Control schedules		Experimental schedules	
1	165	57	225	62
2	167	57	155	67
3	175	57	144	72
4	182	57	136	77
5	171	57	113	82
6	238	57	215	87

If anomalous results from the experimental schedules 1 and 6 are removed from the calculation, the indications are that raising the maximum dry bulb temperature, whilst keeping all other drying parameters constant, reduces the drying time (table 2 & figure 4). This trend does not seem to be overly affected by quite large variations in initial moisture content. It is expected that if a large number of trials were undertaken at each of the temperatures the trend line would remain fairly similar, although outliers would still occur
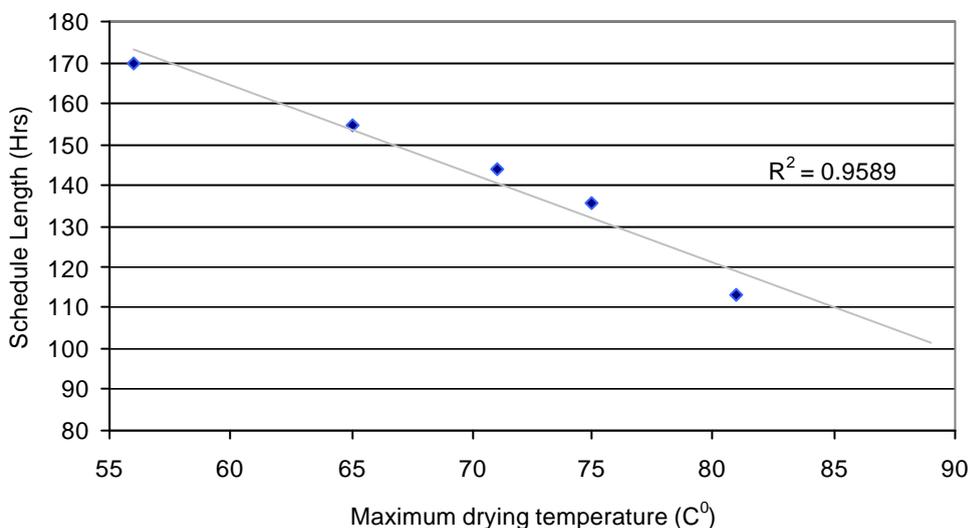
Figure 4 Correlation between maximum temperature and drying time (anomalous values removed).

The aim of the experimental procedure was to determine the effect of top-loading in conjunction with the effects of raising the maximum drying temperature. The effect this has on the development or variation in drying distortion was also of importance.

The control packs were dried using a set drying schedule (figure 2), where the maximum dry bulb temperature was capped at 57ºC. Each of the following experimental trials utilised a similar shaped schedule to that of the control schedule, but with an increased in maximum temperature from a target of 62ºC to 87ºC in 5ºC increments (table 2).

Figures 5 - 16 show the twist distribution frequency as a percentage of the battens for both control and experimental trials, from 62ºC to 87ºC in 5ºC increments. Tables 3 - 8 show the percentage of battens falling within a 0 mm – 4 mm and 4 mm – 8 mm twist range, for both loaded and un-loaded battens.

In both the control and experimental drying trials, the application of top-load was found to have a considerable influence on reducing the incidence of twist. The trials also provided firm evidence that top-loading is more effective at reducing twist levels on battens which show a higher tendency to twist, when compared to those battens with a lower tendency to twist. The reduction in average twist values by the application of top-weight can be extremely variable, being as much as 100% or as little as 10%. The reasons for this variation are still un-clear.
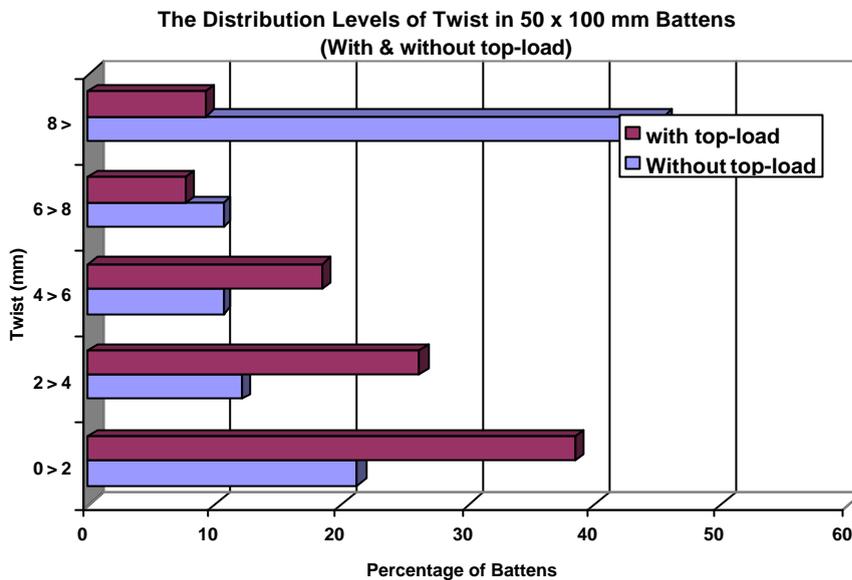
The Distribution Levels of Twist in 50 x 100 mm Battens
(With & without top-load)

Figure 5. Distribution levels of twist in trial 1 control battens

The Distribution Levels of Twist in 50 x 100 mm Battens
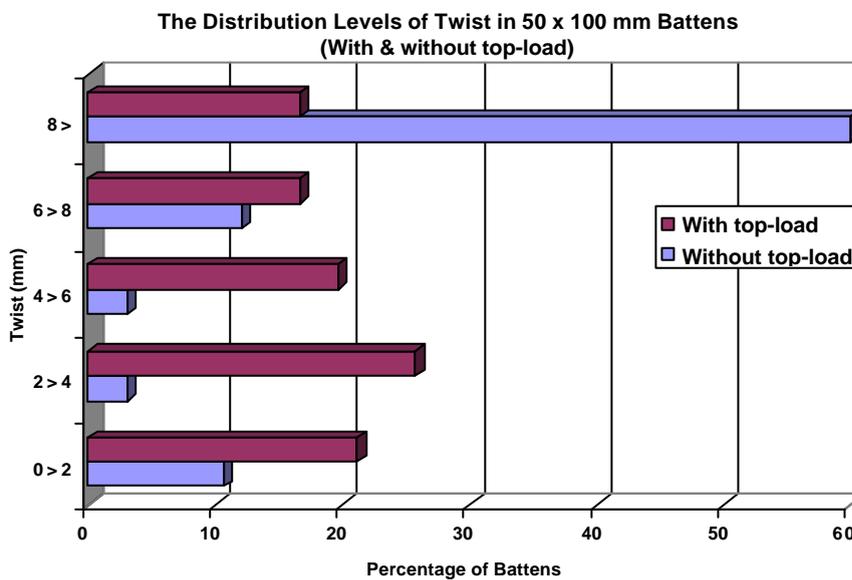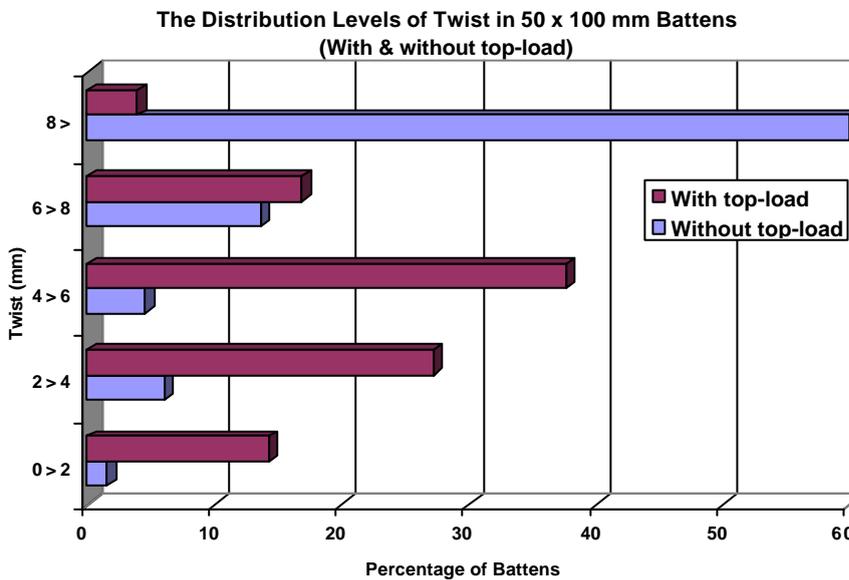**(With & without top-load)**

Figure 6. Distribution levels of twist in trial 1 experimental battens

Table 3 Frequency distribution of twist within 0–4 mm & 4–8> mm (Trial 1)

	% Of battens with twist levels within 0 – 4 mm range		% Of battens with twist levels within 4 – 8> mm range	
	Top-loaded	Un-loaded	Top-loaded	Un-loaded
Control	65	33	35	67
Experimental	47	14	53	86

The Distribution Levels of Twist in 50 x 100 mm Battens (With & without top-load)
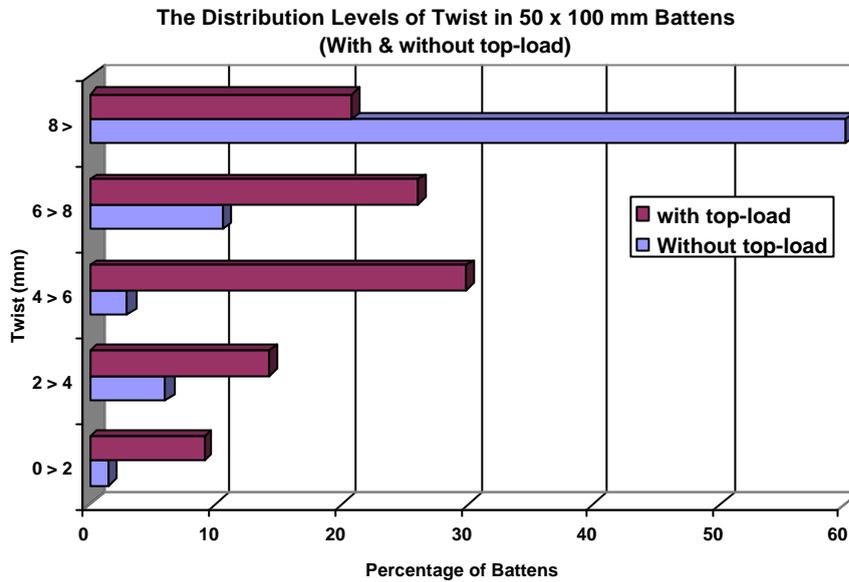
Figure 7 Distribution levels of twist in trial 2 control battens

The Distribution Levels of Twist in 50 x 100 mm Battens (With & without top-load)
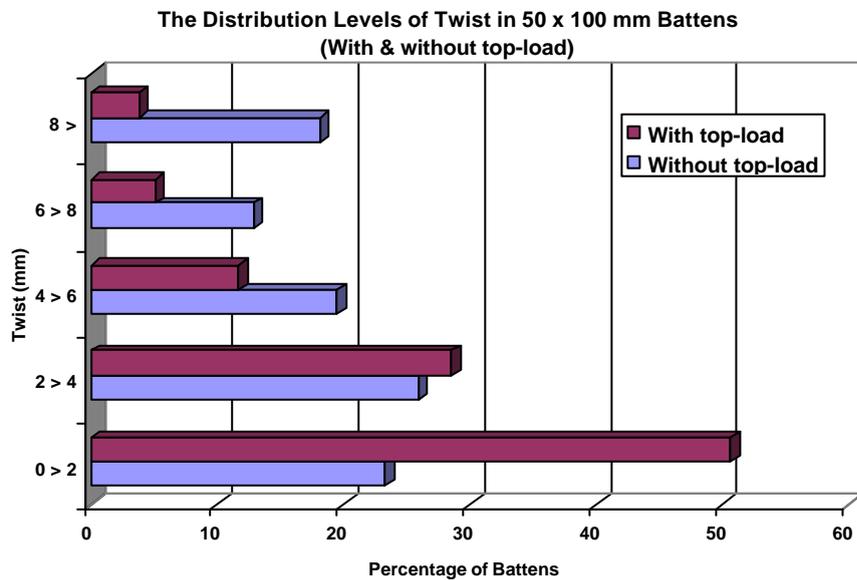
Figure 8 Distribution levels of twist in trial 2 experimental battens

Table 4 Frequency distribution of twist within 0–4 mm & 4–8> mm (Trial 2)

	% Of battens with twist levels within 0 – 4 mm range		% Of battens with twist levels within 4 – 8> mm range	
	Top-loaded	Un-loaded	Top-loaded	Un-loaded
Control	23	8	77	92
Experimental	41	8	59	92

**The Distribution Levels of Twist in 50 x 100 mm Battens
(With & without top-load)**
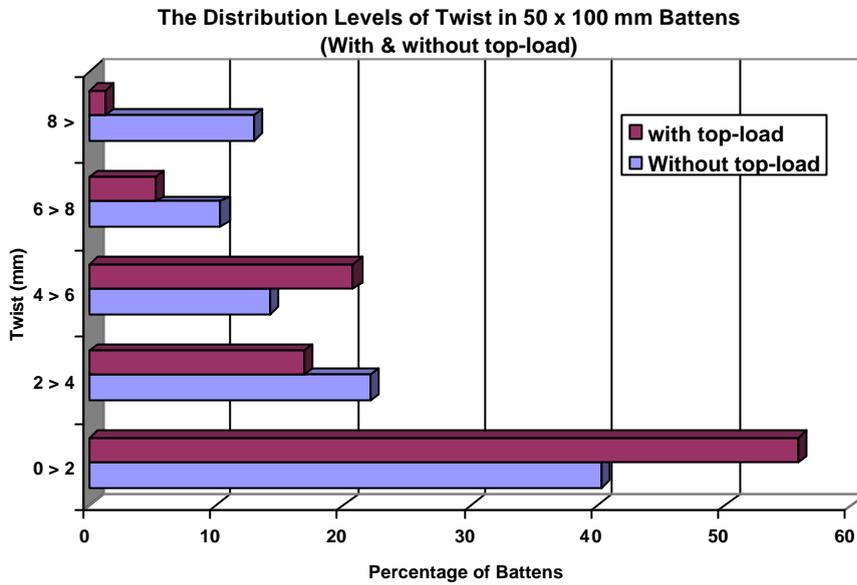
Figure 9 Distribution levels of twist in trial 3 control battens

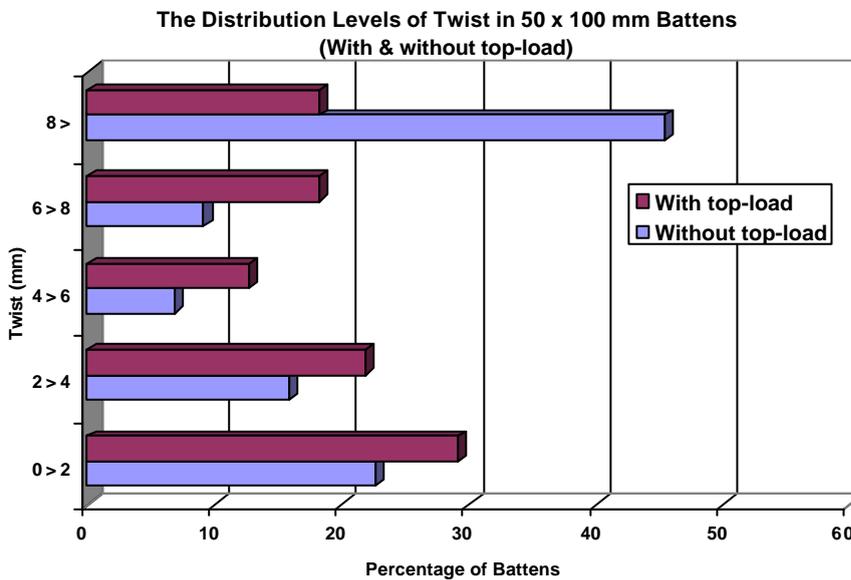**The Distribution Levels of Twist in 50 x 100 mm Battens
(With & without top-load)**

Figure 10 Distribution levels of twist in trial 3 experimental battens

Table 5 Frequency distribution of twist within 0–4 mm & 4–8> mm (Trial 3)

	% Of battens with twist levels within 0 – 4 mm range		% Of battens with twist levels within 4 – 8> mm range	
	Top-loaded	Un-loaded	Top-loaded	Un-loaded
Control	73	62	27	38
Experimental	80	49	20	51

**The Distribution Levels of Twist in 50 x 100 mm Battens
(With & without top-load)**
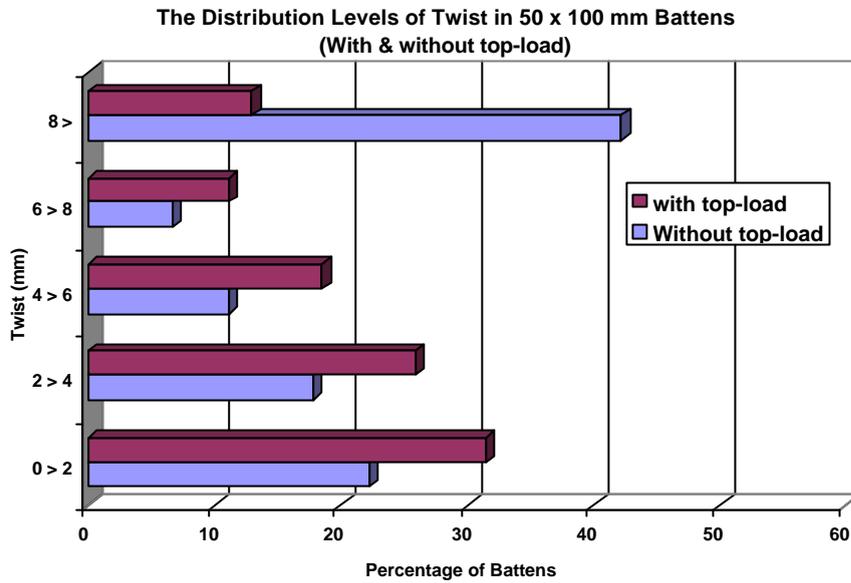
Figure 11 Distribution levels of twist in trial 4 control battens

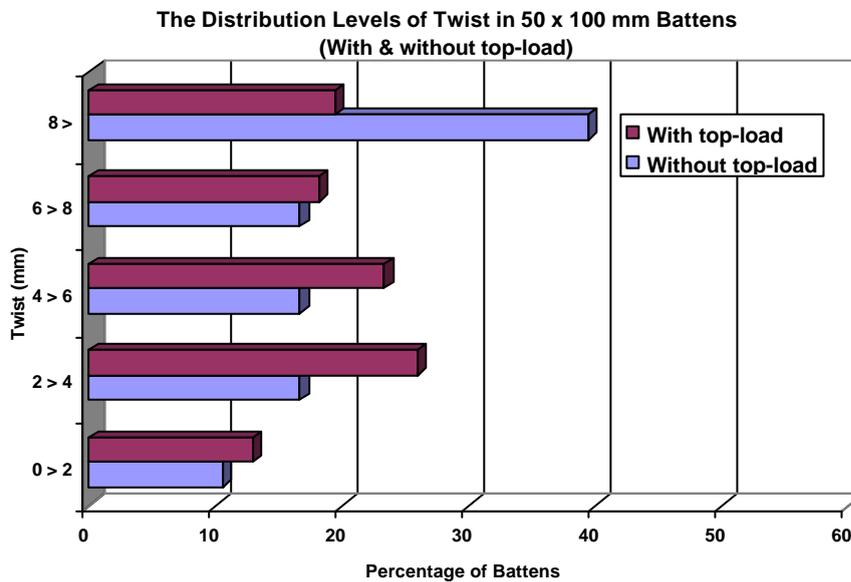**The Distribution Levels of Twist in 50 x 100 mm Battens
(With & without top-load)**

Figure 12 Distribution levels of twist in trial 4 experimental battens

Table 6 Frequency distribution of twist within 0–4 mm & 4–8> mm (Trial 4)

	% Of battens with twist levels within 0 – 4 mm range		% Of battens with twist levels within 4 – 8> mm range	
	Top-loaded	Un-loaded	Top-loaded	Un-loaded
Control	57	40	43	60
Experimental	51	39	49	61

The Distribution Levels of Twist in 50 x 100 mm Battens
(With & without top-load)
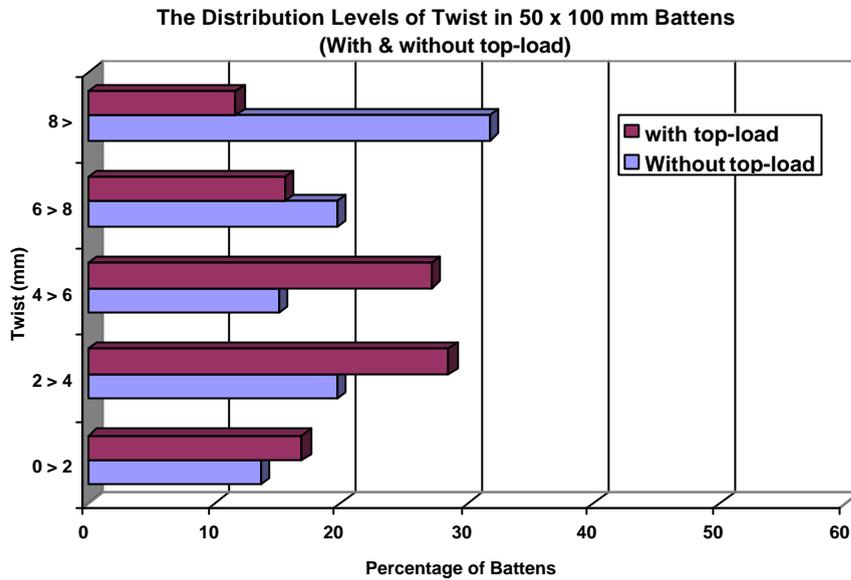
Figure 13 Distribution levels of twist in trial 5 control battens

The Distribution Levels of Twist in 50 x 100 mm Battens
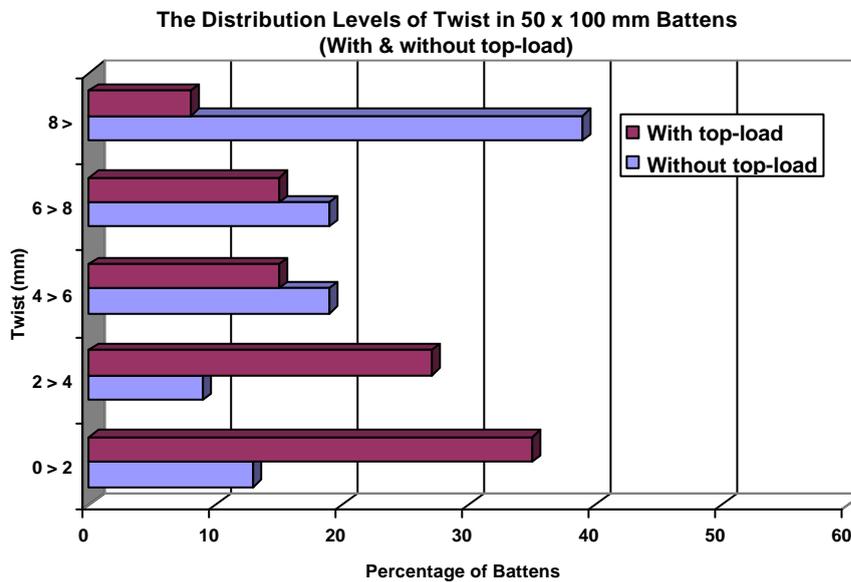**(With & without top-load)**

Figure 14 Distribution levels of twist in trial 5 experimental battens

Table 7 Frequency distribution of twist within 0–4 mm & 4–8> mm (Trial 5)

	% Of battens with twist levels within 0 – 4 mm range		% Of battens with twist levels within 4 – 8> mm range	
	Top-loaded	Un-loaded	Top-loaded	Un-loaded
Control	46	34	54	66
Experimental	39	28	61	72

The Distribution Levels of Twist in 50 x 100 mm Battens
(With & without top-load)
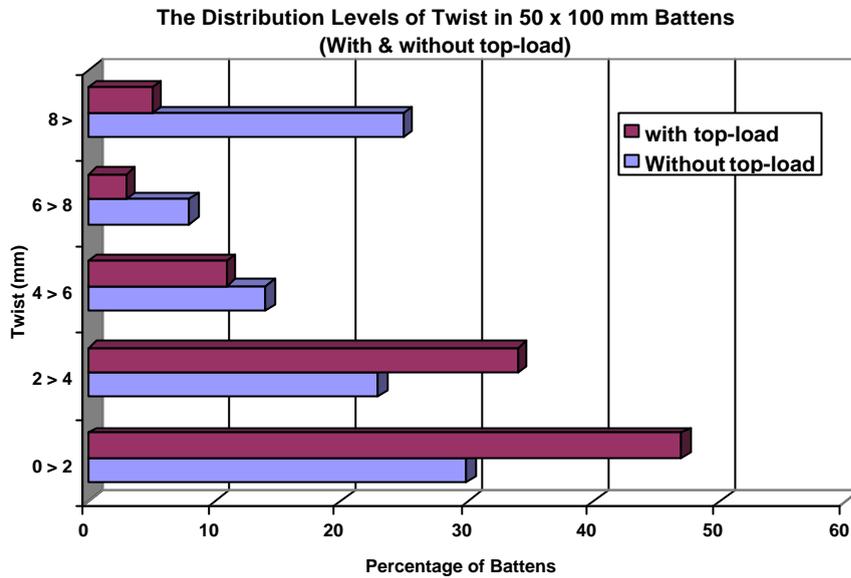
Figure 15 Distribution levels of twist in trial 6 control battens

The Distribution Levels of Twist in 50 x 100 mm Battens
(With & without top-load)

Figure 16 Distribution levels of twist in trial 6 experimental battens

Table 8 Frequency distribution of twist within 0–4 mm & 4–8> mm (Trial 6)

	% Of battens with twist levels within 0 – 4 mm range		% Of battens with twist levels within 4 – 8> mm range	
	Top-loaded	Un-loaded	Top-loaded	Un-loaded
Control	81	53	19	47
Experimental	62	23	38	77

If a twist acceptance level of 0 mm - 4 mm over a 100 mm width and a 2000 mm length is set, the percentage of battens falling within this range (and dried using control schedules) increased from an average of 8% in un-loaded battens to 81% for loaded battens. The acceptance percentage in battens dried using experimental schedules increased from an average of 8% in un-loaded battens to 80% for loaded battens. This shows that very little difference between the results obtained for control and experimental schedules was observed. These results indicate that both sets of figures are very similar and the use of elevated drying temperatures has no detrimental effect on distortion levels when compared to material dried using lower temperature schedules. Even so, the twist frequency distribution graphs shown on the following pages (figures 5 -16), indicate that as a general rule, higher twist values do occur when using elevated temperatures and lower values occur using lower temperatures.

The effects of top-loading on other forms of distortion

Figures 17 - 22 show the average values for all types of distortion on material dried within the work programme. The graphs clearly show that the application of a top-load significantly reduces the incidence of twist when compared to battens dried without any form of top-loading. This trend is seen in both control and experimentally dried material.
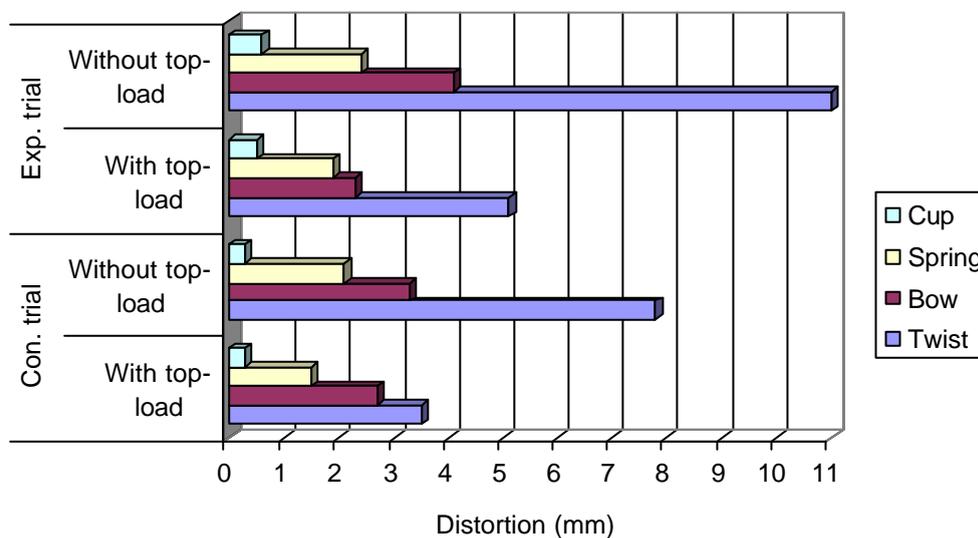
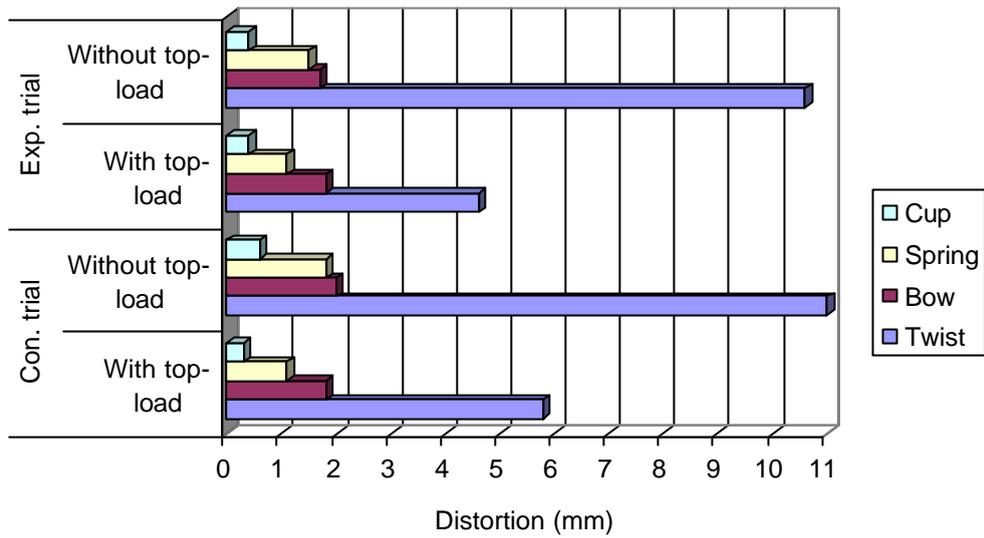*Figure 17 Average distortion values for trial 1 material, control & experimental*

Figure 18 Average distortion values for trial 2 material, control & experimental
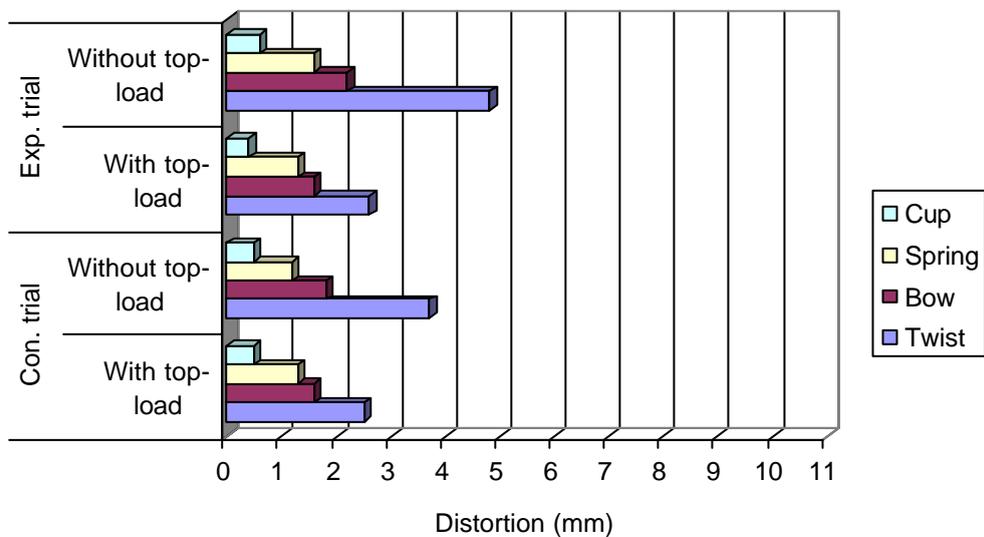

Figure 19 Average distortion values for trial 3 material, control & experimental
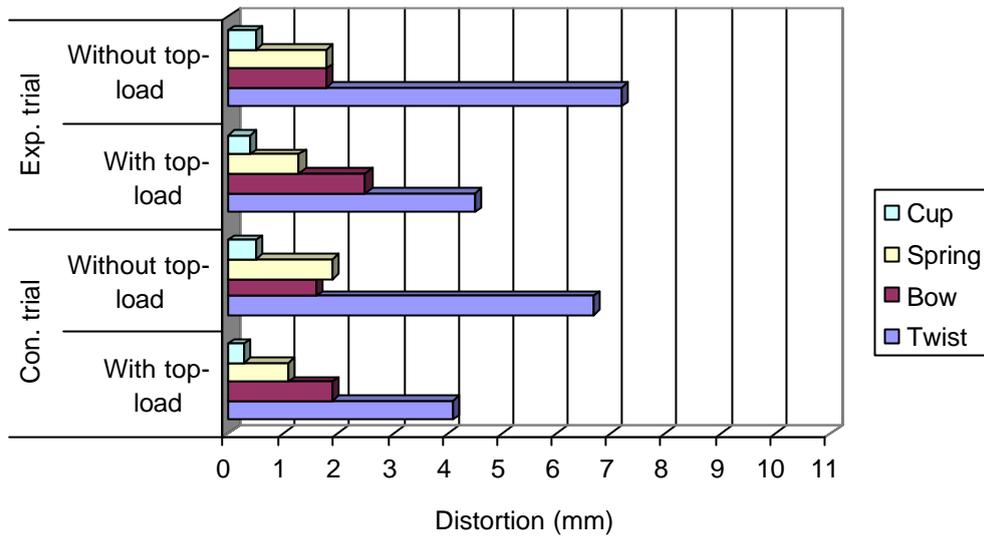
Figure 20 Average distortion values for trial 4 material, control & experimental
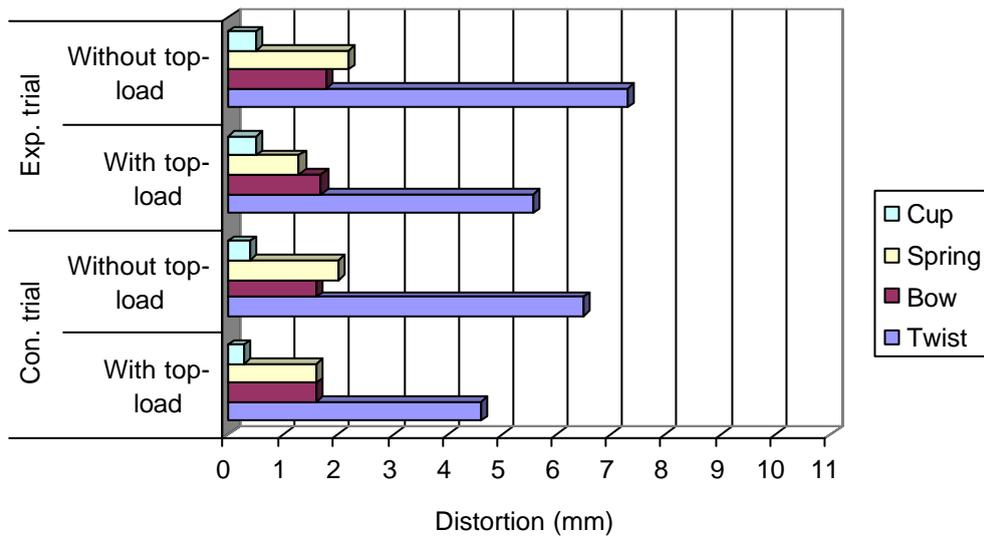

Figure 21 Average distortion values for trial 5 material, control & experimental
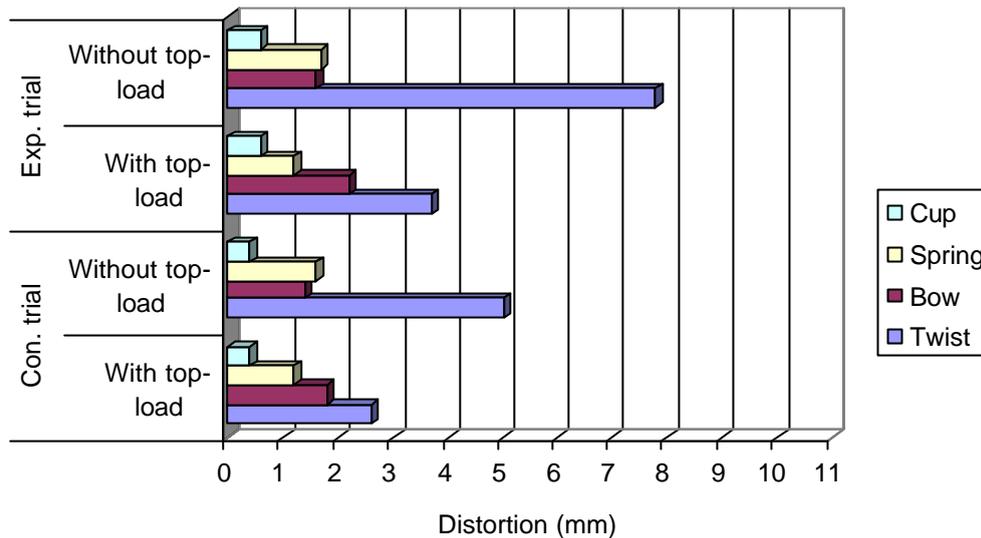
Figure 22 Average distortion values for trial 6 material, control & experimental

These charts also show that the application of top-load reduces the severity of bow, spring and cup, although, not to the extent of twist. If the charts are viewed in sequence (increasing maximum temperature), from figure 17 to figure 22, the results show that raising the maximum dry bulb temperature (experimental trials) in comparison to the control trials (maximum temperature 57°C) results in the average twist values increasing slightly, in comparison to material dried under the lower control schedule temperatures. This trend is replicated in both material with and without top-load, although no explanation can be given for the values shown in figure 18, where the figures show a complete reversal of this trend.

The results from this experimental series indicate a number of points:

- If all drying parameters remain constant (airflow, sticker dimension, EMC levels etc), increasing the dry bulb temperature will result in a faster drying times (although even under these conditions, you will always get anomalies which will not adhere to this rule).

- Under the circumstances above, raising the maximum drying temperature will result in an increase in the level of twist

- Results clearly show that the application of a top-load (480m^2) significantly reduces the incidence of twist when compared to battens dried without top-loading.

Further optimised trials

Optimised trial 1.

Using the results from the experimental trials, several further optimised trials were undertaken to assess whether improvements in drying time and wood quality could be achieved by altering the schedule.

Optimised schedule 1 was developed using the VTT Building and Transport Institute, Finland, optimising tool. Over the last three years, BRE has worked closely with this organisation on several drying projects. Data from the experimental trials was supplied to VTT and entered into their kiln drying optimising programme (Laatukamari optimising) which was developed by their timber department. The main criteria for the optimisation schedule was to produce a fairly short schedule with relatively low drying distortion.

The optimised schedule produced by the optimising tool is shown in table 9 and a graphical representation shown in figure 23.

Table 9. Optimised schedule 1.

Schedule	Optimised schedule 1.								
Phases	Heat up	Initial dry	Main dry	Main dry	Main dry	Main dry	Condition	Cooling	
Variables	1	2	3	4	5	6	7	8	
T Dry bulb (^{0}C)	20 - 70	70 - 70	70 - 70	70 - 70	70 - 70	70 - 70	70	70 - 20	
T Wet bulb (^{0}C)	20 - 64	64 - 58	58 - 54	54 - 48	48 - 40	40 - 40	69	74 - 20	
RH (%)	74	73 - 58	58 - 44	44 - 32	32 - 17.6	17.6 - 96	96	96	
EMC (%)	11	11 – 6.9	6.9 - 5.8	5.8 - 4.3	4.3 - 2.7	2.7 - 20	20	16.5	
M/C (%)	95							18	Total
Time (Hrs)	14	18	10	10	10	12	20	**10***	94

* During optimisation, cooling down is not included in the total number of hours
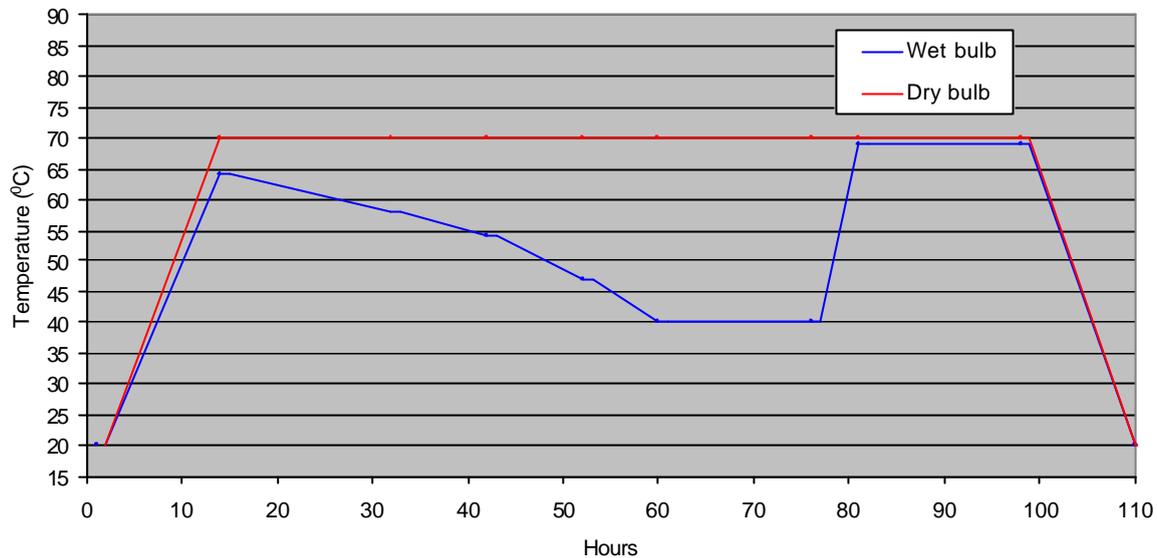
Figure 23. Graphical representation of optimised schedule 1.

The optimised schedule produced by VTT was entered into the kiln control unit at BRE and UK spruce loaded into the kiln as detailed for the previous experimental series. When the first optimised trial was completed, a further trial was undertaken on the remaining half pack using the control schedule. Throughout both of the schedules, the air velocity was kept constant at 3.5 m/s. The first optimised schedule was completed in 98 hours (not including 12 hours for cooling) and returned an average final moisture content for the load of 18.9%. The control schedule was completed in 169 hours (including cooling down) and returned an average final moisture content for the load of 18.5%. Figure 24 shows the distribution levels of twist from the control schedule. Figure 25 shows the distribution levels of twist from the first optimised schedule. Table 10 shows the percentage of battens with twist levels between 0 mm and 4 mm and between 4 mm and 8 mm for the control and experimental material, dried with and without top-load.

When comparing the top-loaded twist levels between 0 mm and 4 mm, from both the optimised and control schedule (table 10), it is apparent that the percentage of battens from the higher temperature optimised schedule returns a lower percentage of battens in this quality group (67%), than produced in the control schedule (75%). Although this difference is not large at 8%, this result follows the same trend as observed in the previous experimental trials where a raise in the maximum drying temperature normally results in an increase in the severity of twist.
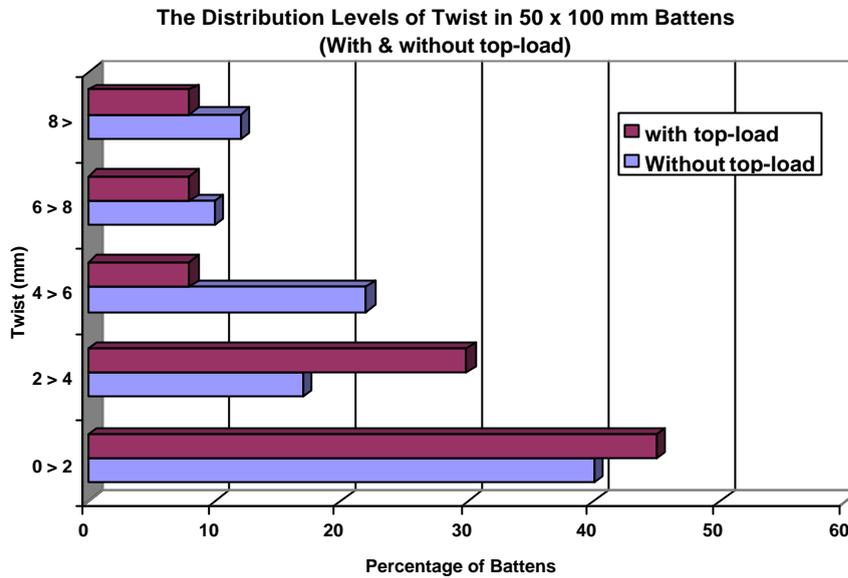
The Distribution Levels of Twist in 50 x 100 mm Battens
(With & without top-load)

Figure 24. Distribution levels of twist in the first optimisation trial control battens

The Distribution Levels of Twist in 50 x 100 mm Battens
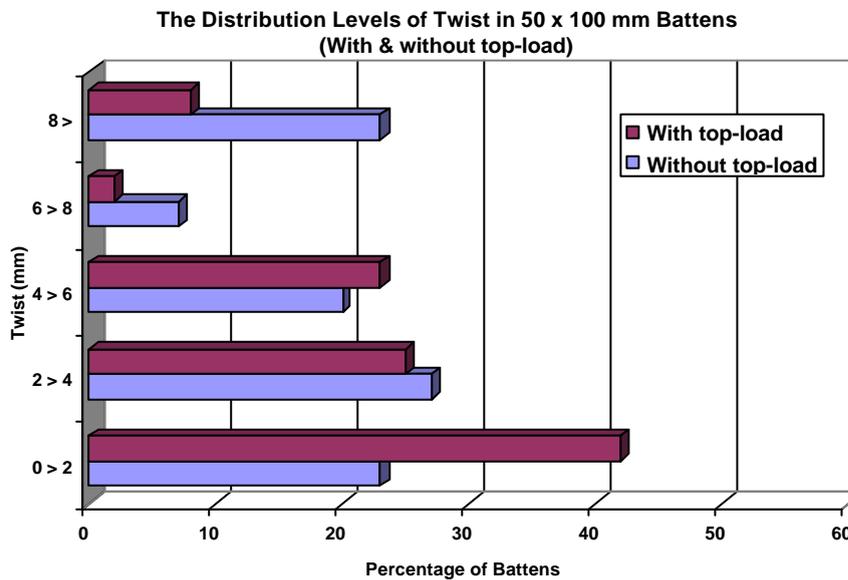**(With & without top-load)**

Figure 25. Distribution levels of twist in the first optimisation trial battens

Table 10 Frequency distribution of twist within 0–4 mm & 4–8> mm (Optimisation trial 1)

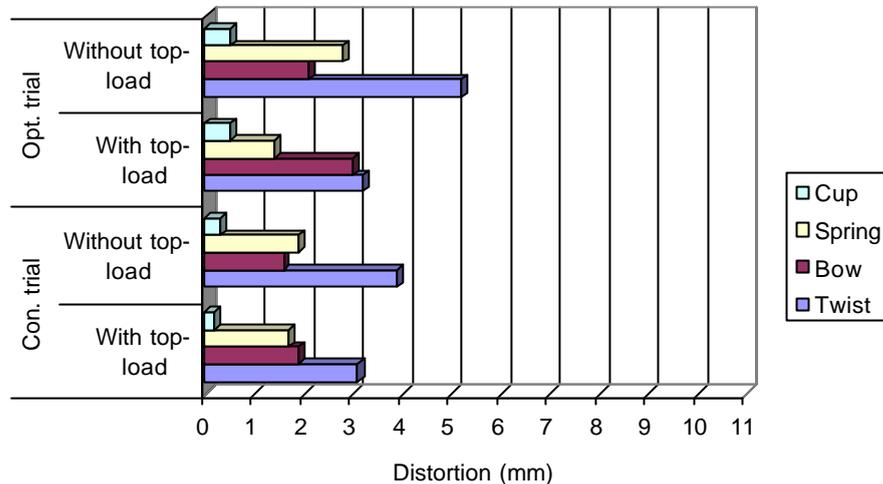|	% Of battens with twist levels within 0 – 4 mm range		% Of battens with twist levels within 4 – 8> mm range	
	Top-loaded	Un-loaded	Top-loaded	Un-loaded
Control	75	57	25	43
Experimental	67	50	23	50

Figure 26. Average distortion values for optimisation trial 1, control & optimised

Figure 26 shows the average values for all distortion types from both the control and optimised trial. Overall, the two sets showed very similar values across the range, although the optimised schedule showed a slight increase in the level of bow compared to the control.

Optimised trial 2.

The second optimised schedule was formulated using a combination of optimisation trial 1 and schedules from industry. Again the maximum temperature remained constant, whilst the wet bulb temperature was decreased at a slower rate than optimisation trial 1. Once the second optimised trial was completed, a further trial was undertaken on the remaining half pack using the control schedule. One change made to this optimisation schedule was airflow (airflow in the control schedule remained constant at 3.5 m/s). The air velocity was ramped up to 4.8 m/s in the first quarter of the schedule, 4.2 m/s in the second quarter, 4.0 m/s in the third quarter and 3.6 m/s in the final quarter. The second optimised schedule was completed in 130 hours and returned an average final moisture content for the load of 15.8%. The control schedule was completed in 171 hours and returned an average final moisture content of 16.7% for the load.

The second optimised schedule produced using the optimising tool and a combination of industry schedules is shown in table 11 and a graphical representation shown in figure 27.

Table 11. Optimised schedule 2.

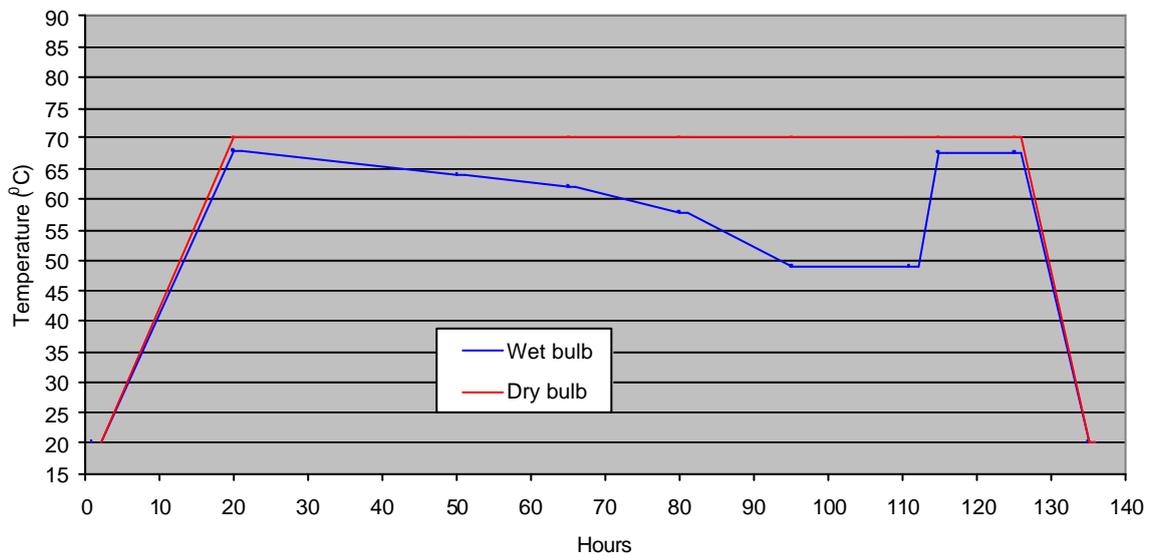| Schedule	Optimised schedule 2.								
Phases	Heat up	Initial dry	Main dry	Main dry	Main dry	Main dry	Condition	Cooling	
Variables	1	2	3	4	5	6	7	8	
T Dry bulb (^{0}C)	20 - 70	70 - 70	70 - 70	70 - 70	70 - 70	70 - 70	70	70 - 20	
T Wet bulb (^{0}C)	20 - 68	68 - 64	64 - 62	62 - 58	58 - 53	53 - 49	67.5	67.5	
RH (%)	92	92 - 77	77 - 70	70 - 57	57 - 42	42 - 34	90	90	
EMC (%)	18	18 - 11	11 - 10	10 - 8	8 - 6	6 - 5	17	17	
M/C (%)	95							18	Total
Time (Hrs)	20	30	15	15	15	15	10	10	130

Figure 27. Graphical representation of optimised schedule 2

Figure 28 shows the distribution levels of twist from the control schedule. Figure 29 shows the distribution levels of twist from the second optimisation schedule. Table 12 shows the actual figures for the percentage of battens with twist levels between 0 mm and 4 mm and between 4 mm and 8 mm for the control and optimised material, dried with top-load and without top-load.

When comparing the top-loaded twist levels between 0 mm and 4 mm, from both the optimised and control schedule (table 12), it is once again apparent that the percentage of battens from the higher temperature optimised schedule return a lower percentage of battens in this quality group (41%), when compared to those produced in the control schedule (58%). The difference between the two is considerably larger (17%) than observed in optimisation trial 1. This result still follows the same trend as observed in most of the previous experimental trials, where a raise in the maximum drying temperature normally results in an increase in the severity of twist.
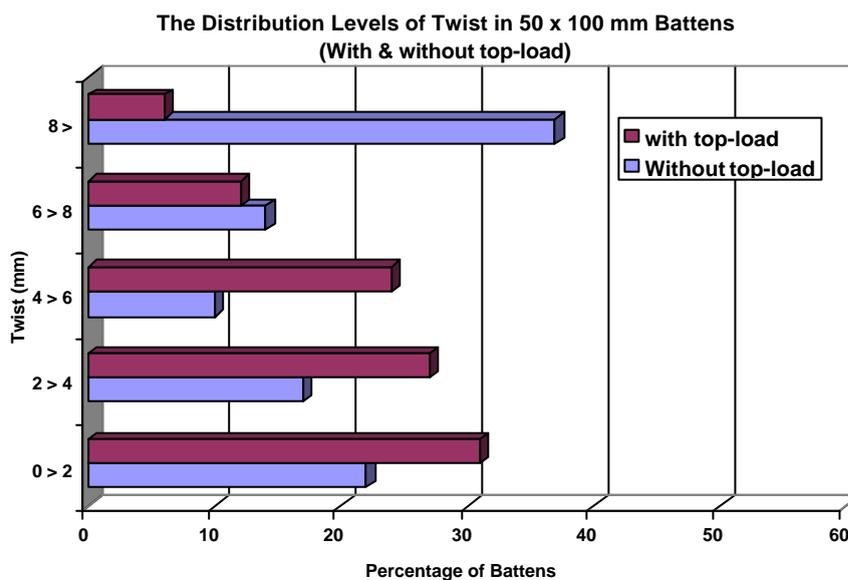
The Distribution Levels of Twist in 50 x 100 mm Battens
(With & without top-load)

Figure 28. Distribution levels of twist in the second optimisation trial control battens

The Distribution Levels of Twist in 50 x 100 mm Battens
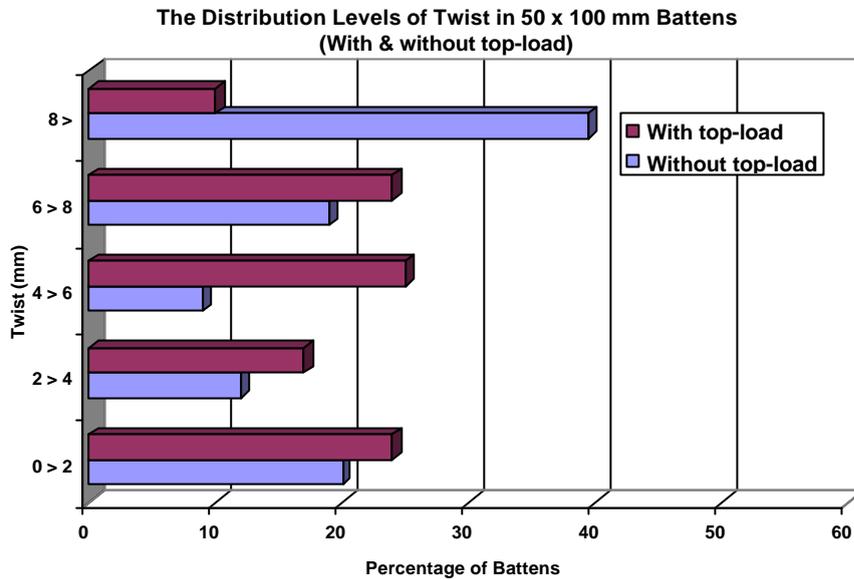**(With & without top-load)**

Figure 29. Distribution levels of twist in the second optimisation trial battens

Table 12 Frequency distribution of twist within 0–4 mm & 4–8> mm (Optimisation trial 2)

	% Of battens with twist levels within 0 – 4 mm range		% Of battens with twist levels within 4 – 8> mm range	
	Top-loaded	Un-loaded	Top-loaded	Un-loaded
Control	58	39	42	61
Experimental	41	33	59	67

Figure 30 shows the average values for all distortion types from both the control and second optimised trial. Overall, the material from the second optimised trial shows a general increase in the severity of all forms of distortion when compared material from the control schedule.
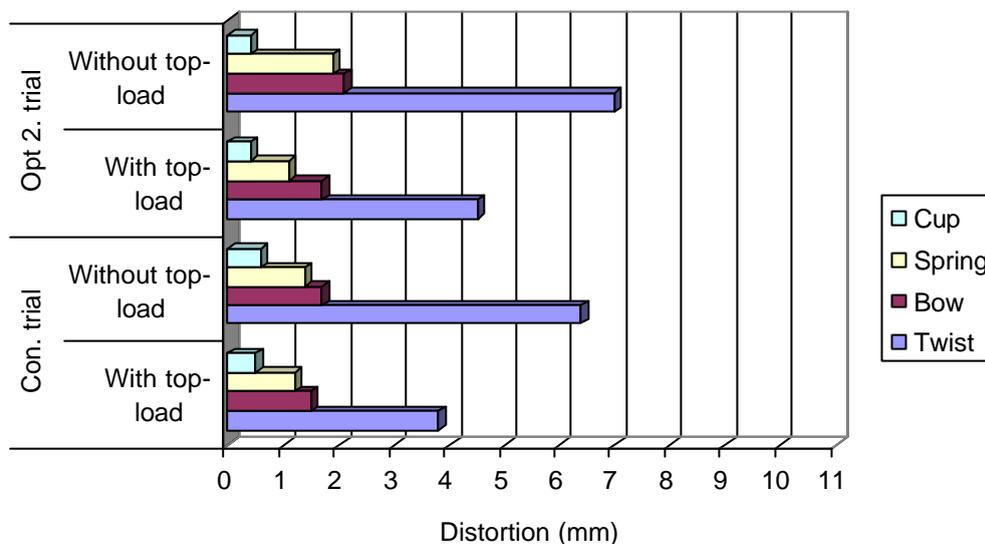

Figure 30. Average distortion values for optimisation trial 2, control & optimised

Slope of grain and its influence on distortion

In addition to the measurements undertaken on distortion and moisture content, slope of grain measurements were also recorded on a majority of the battens dried within this experimental program. Slope of grain is the spiral arrangement of wood cells in relation to the stem axis. The severity of this deviation is highly variable and is thought to be closely related to the development of twist on battens after drying. As part of this study slope of grain measurements were recorded to investigate how relevant slope of grain is in the development of twist.

Slope of grain was measured using the traditional scribing method on most of the battens dried during the experimental programme. Between three and six scribe marks were marked on each batten face. The inner face is the face closest to the centre of the tree and outer face is facing the outer part of the tree. The average slope of grain angle was then calculated from the marks on that face. All battens with inconsistent slope of grain (i.e. grain angles which change direction to give an average of ^{0}) measurements were removed from the group before further analysis. Figure 31 and figure 32 show the results recorded from trial 2 battens using twist values obtained from the control schedule programme. The battens were dried to an average moisture content of 19.5%. The results shown in both figures are very similar for all groups of battens used in this programme.

The graphs indicate that there is a link (although weak) between the increase in slope of grain and the increase in twist after drying. This correlation is further enhanced by the application of top-weight. The variability of twist seems to be reduced in comparison with the large spread of results found in the battens without the application of top-load. Although the graphs are not shown, the link shown between the increase in slope of grain and the increase in twist after drying is considerably worse when measurements recorded on the outer face of the same battens are used to form the graphs.
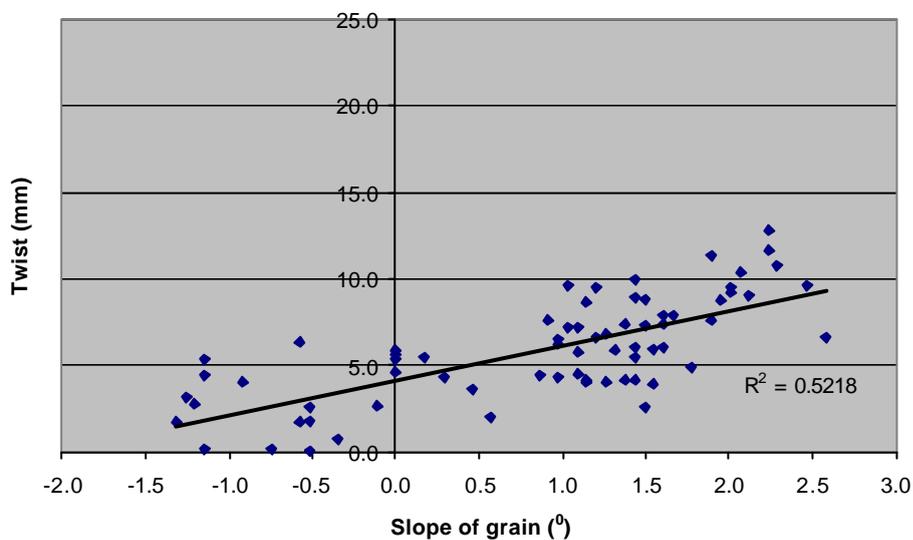

$R^2 = 0.5218$

Figure 31. Correlation between slope of grain & twist on battens top-weighted during drying (Trial 2 battens, inner face slope of grain measurements used)

A comparison between figures 31 and 32 show that the application of top-weight has a beneficial effect on the development and severity of twist, especially on those battens showing relatively high slope of grain values. Figure 31 also shows that top-loaded battens with a grain angle between -1.5º to 0.5º develop the lowest twist values within this group.
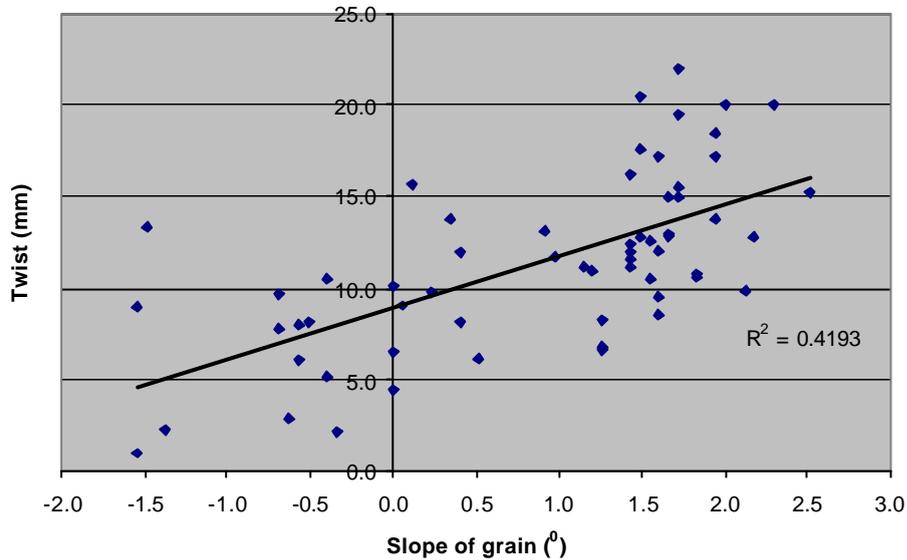
Figure 32. Correlation between slope of grain & twist on battens un-weighted during drying (Trial 2 battens, inner face slope of grain measurements used)

No mention has been made so far regarding the relationship, if any, between slope of grain and log size. All the battens used in these trials have, as far as I am aware, been cut from relatively small diameter logs (140–170 mm). As only small logs were used in this work, it is not known if the correlation between slope of grain and twist remains the same or improves with differences in log dimension. There may also be some differences between timber species within Europe.

Indicative kiln schedules

In every kiln charge of UK spruce, there will always be a percentage of the material that will develop distortion or other drying defects. The reasons for the development of distortion are complex and include such variables as genetic make-up of the tree, its position in the stand, position in the tree, growing conditions and even how a batten is cut from the log. The level to which the inherent distortion within a processed batten develops hinges closely on how the material is dried. In any commercial drying process the economies of drying are very important. Drying timber costs money. In effect, we require the best quality of dried timber in the shortest possible drying time. The problem arises because the speed of drying and the final timber quality are also closely linked. If the timber is dried quickly in a harsh environment, the quality of dry timber will be poor and will be less marketable. In contrast, timber dried with a long gentle schedule may result in timber with very high final quality. However, the increased process costs may be greater than the added value achieved. Therefore, a fine line exists between the speed of drying and the final quality of the timber being produced.

From the work undertaken in this and several other drying projects, plus information gleaned from the schedules in use by UK sawmillers and personal experience, three indicative drying schedules for UK spruce have been developed. These schedules have not been produced to replace existing schedules, but to complement those already in use and also to provide a starting point for those new to drying.

Many sawmills may have kilns from more than one manufacturer. Due to the design and workings of the kiln, each type of kiln will dry differently. Therefore, a drying schedule is only effectively a starting point in drying your timber. Each schedule will require a degree of optimising to work effectively in that kiln.

Each of the three schedules has been produced with a different maximum dry bulb temperature. The economies of drying are such that it may be more economical to dry at a low temperature and take longer to dry, than dry quickly at a high temperature with higher costs. This type of decision can only be made by the kiln operator.

Each of the three schedules (low temperature (table 13, figure 33), medium temperature (table 14, figure 34), and elevated temperature (table 15, figure 35)), has been produced as a rising dry bulb and reducing wet bulb type schedule. It is possible to change these schedules to a constant dry bulb and reducing wet bulb type schedule, although the conditions will vary slightly because of the transition from one to the other. The three schedules have all been produced to be used with a constant air velocity of approximately 3.5 m/s. Many schedules have higher air velocities during the initial phases, medium during the central portion and low during the last phase. It is possible to programme this into most modern kiln control programmes, although correct assessment of how this affects the drying quality should be undertaken.

Table 13. Low temperature spruce schedule

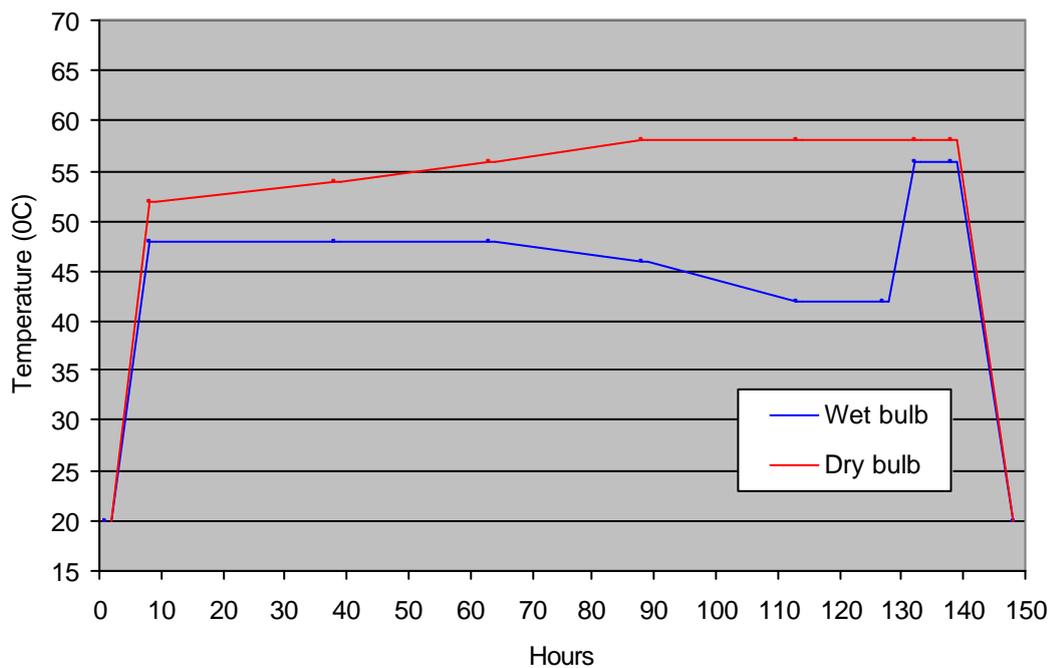| Schedule	Low temperature							
Phases	Heat up	Initial dry	Main dry	Main dry	Main dry	Main dry	Condition	Cooling
Variables	1	2	3	4	5	6	7	8
T Dry bulb (^{0}C)	20 - 52	52 - 54	54 - 56	56 - 58	58 - 58	58 - 58	58	58 - 20
T Wet bulb (^{0}C)	20 - 48	48 - 48	48 - 48	48 - 46	46 - 42	42 - 42	56	56 - 20
RH (%)	79	79 - 70	70 - 64	64 - 50	50 - 37	37 - 37	90	90
EMC (%)	15	15 -12.2	12 - 9	9 - 8.2	8.2 - 6.2	6.2	18	18
M/C (%)	95							18	Total
Time (Hrs)	8	30	25	25	25	15	10	10	148

Figure 33. Graphical representation of low temperature spruce schedule

Table 14. Medium temperature spruce schedule

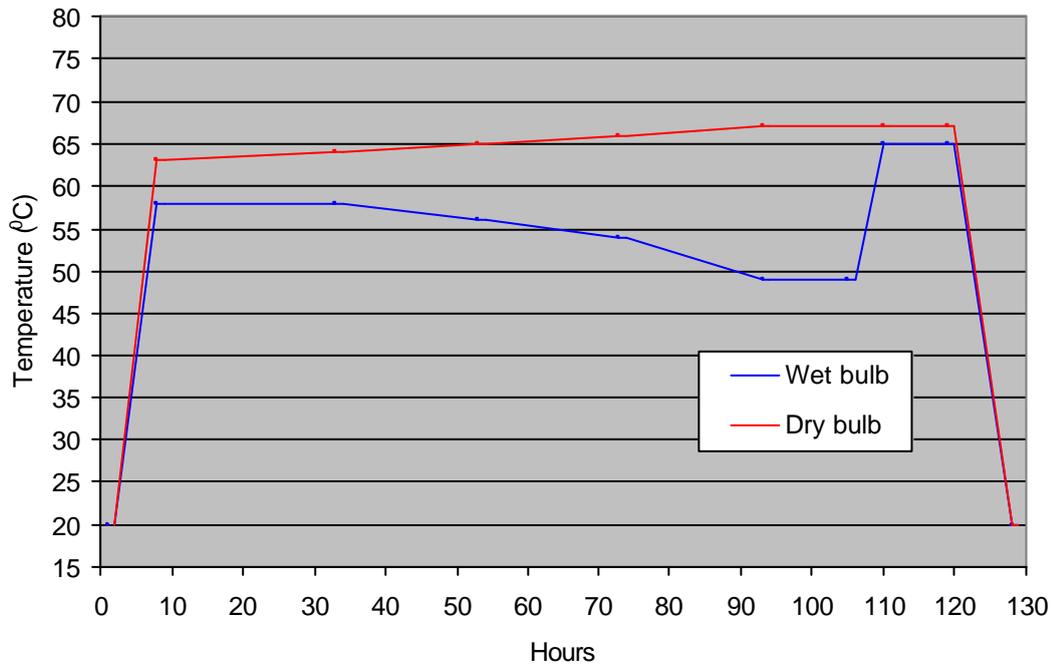| Schedule	Medium temperature								
Phases	Heat up	Initial dry	Main dry	Main dry	Main dry	Main dry	Condition	Cooling	
Variables	1	2	3	4	5	6	7	8	
T Dry bulb (^{0}C)	20 - 63	63 - 64	64 - 65	65 - 66	66 - 67	67 - 67	67	67 - 20	
T Wet bulb (^{0}C)	20 - 58	58 - 58	58 - 56	58 - 54	54 - 49	49 - 49	65	65 - 20	
RH (%)	77	77 - 74	74 - 63	63 - 53	53 - 36	36	93	93	
EMC (%)	13.4	13.4 - 12.3	13.4 - 9.8	9.8 - 8.1	8.1 - 5.6	5.6	17.7	17.4	
M/C (%)	95							18	Total
Time (Hrs)	8	25	20	20	20	15	10	10	125

Figure 34. Graphical representation of medium temperature spruce schedule

Table 15. Elevated temperature spruce schedule

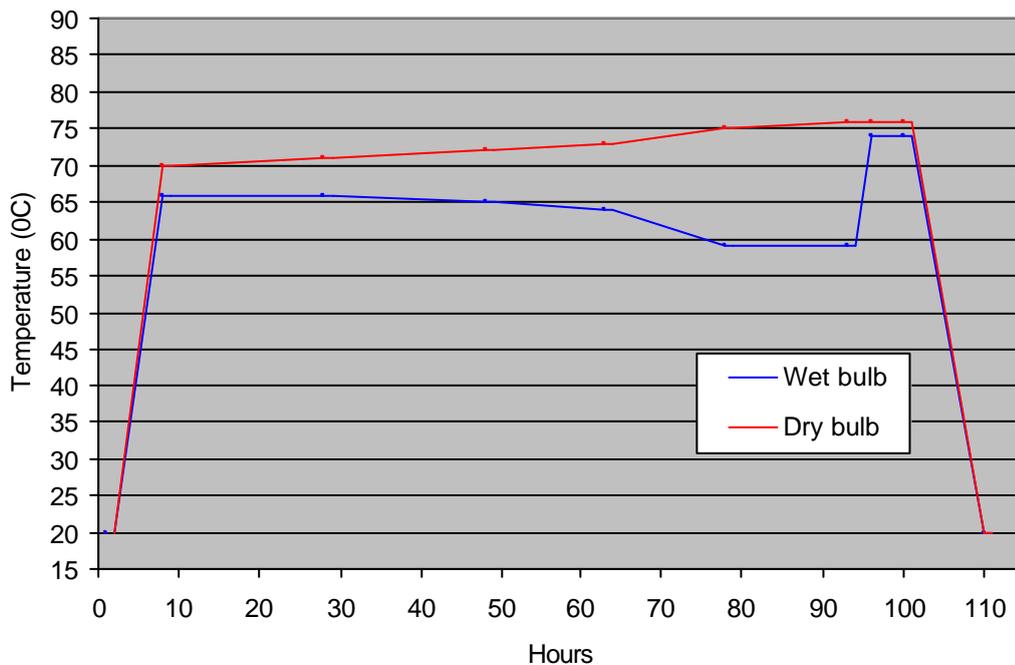| Schedule	Elevated temperature								
Phases	Heat up	Initial dry	Main dry	Main dry	Main dry	Main dry	Condition	Cooling	
Variables	1	2	3	4	5	6	7	8	
T Dry bulb (^{0}C)	20 - 70	70 - 72	72 - 73	73 - 75	75 - 76	76 - 76	76	76 - 20	
T Wet bulb (^{0}C)	20 - 66	66 - 65	65 - 64	64 - 59	59 - 59	59 - 59	74	74 - 20	
RH (%)	83	83 - 72	72 - 65	65 - 46	46 - 44	44 - 44	92	92	
EMC (%)	14.4	14.4 - 11.1	11.1 - 9.8	9.8 - 6.5	6.5 - 6.2	6.2 - 6.2	16.5	16.5	
M/C (%)	95							18	Total
Time (Hrs)	8	20	20	15	15	12	10	10	110

Figure 35. Graphical representation of elevated temperature spruce schedule

Conclusion

The main objective of this project was to investigate how increases in drying temperature (and changes in other drying parameters such as top-loading) affect drying times and the final quality of kiln dried UK spruce

Results from the six sets of trials clearly show that the application of top-loading (480kg/m^2) significantly reduces the incidence of twist when compared with battens without top-load. The trials also provided firm evidence that top-loading is more effective at reducing twist levels on battens which show a higher tendency to twist, than those with a lower propensity to twist. It should be noted that reductions in twist by the application of top-loading can be very variable. Top-loading has also been shown to reduce the incidence of bow, spring and cup, although not to the extent of twist.

If a twist acceptance level of 0 mm - 4 mm over a 100 mm width and a 2000 mm length is set, the percentage of battens falling within this range (dried using control schedules) increased from an average of 8% in un-loaded battens to 81% for loaded battens. The acceptance percentage in battens dried using experimental schedules increased from an average of 8% in un-loaded battens to 80% for loaded battens. This shows that very little difference between the results obtained for control and experimental schedules was observed. These results indicate that both sets of figures are very similar and the use of elevated drying temperatures has no detrimental effect on distortion levels when compared to material dried using lower temperature schedules. Even so, the twist frequency distribution graphs indicate that as a general rule, higher twist values do occur when using elevated temperatures and lower values occur using lower temperatures.

As expected, (excluding anomalous readings) drying times were reduced when the maximum dry bulb temperature was increased (when all drying parameters remaining constant). Results from the experimental trials indicate that a good correlation existed between a stepwise increase in maximum dry bulb temperature and the reduction in drying time. This was true even though quite large variations occur in initial moisture content of the battens from one trial to the next.

Slope of grain measurements were recorded on all timber within this work programme using the traditional scribing method. The results obtained indicate that there is a link (although weak) between the increase in slope of grain and the increase in twist after drying. This correlation is further enhanced by the application of top-weight, which seems to reduce the variability of the twist values in comparison with the large spread of results found in the battens without the application of top-load. The slope of grain/twist results obtained from UK Sitka spruce do not seem to follow the good correlations exhibited by other species of spruce from other European countries.

From the work undertaken in this and several other drying projects, plus information gleaned from the schedules in use by UK sawmillers and personal experience, three indicative drying schedules for UK spruce have been developed. These schedules have not been produced to replace existing schedules, but to complement those already in use and also provide a starting point for those new to drying. Minor changes may need to be made to these schedules in order to adapt them to specific industrial requirements and scenarios.