An assessment into the use of higher air-speeds during conventional kilning to improve the drying of spruce (CFS 13/06) Final report

Prepared for: James Dewar
Industry advisor
Forestry Commission

28th February 2009

Client report number 231-944

Prepared by

Name Geoff Cooper

Position Senior Consultant

Signature

Approved on behalf of BRE

Name Dr Ed Suttie

Position Director (Timber)

Date 28th February 2009

Signature

Building Technology
Group
BRE
Garston
WD25 9XX
T + 44 (0) 1923 664200
F + 44 (0) 1923 664096
E construction@bre.co.uk
www.bre.co.uk

Executive Summary

This report details the final results from the Forestry Commission funded project ‘An assessment into the use of higher air speeds during conventional kilning to improve the drying of UK spruce’ (contract number CFS 13/06) initiated in September 2006.

The main objective of the project was to investigate how increases in airflow during the drying of spruce can be utilised to reduce drying times and possibly improve wood quality. Airflow is an extremely important factor during the drying process, transferring heat from the exchangers to the timber and removing moisture from the wood surface to the air. Closely linked to the objectives above is the effect these changes may have on the energy requirements of the system.

The first task within the project consisted of undertaking a series of control/experimental drying trials. Each trial consisted of drying two near identical packs of spruce, one pack using the baseline control schedule with an air velocity of 3.5 m/s and one experimental pack with an initial step-wise increase in air velocity from 3.5 m/s up to 7.0 m/s. After drying, the timber from each completed trial then underwent measurement for distortion and uniformity of moisture content.

It became apparent very early on in the project that increasing the airflow speed by increments of 1 m/s recorded fairly small decreases in schedule length. Associated distortion values recorded on the dried material were also very similar for all trials. This may be due to the optimised kiln schedules being used or the airflow may be more closely linked to changes in drying conditions than previously thought.

A further work task was undertaken in the project to verify some of the initial results and investigate how changes in the kiln schedule and variable airflow affect wood drying. It was hoped that the results obtained from this trial series would allow more informed recommendations to be made on the best airflow levels to be used when drying spruce. Results from these additional trials indicates that even with a change in the kiln schedule (more severe) coupled with a higher airflow (7 m/s), the length of the kiln schedule or distortion levels were not significantly altered. A further trial was undertaken where the kiln schedule was again altered (more severe), whilst retaining an airflow speed of 3.5 m/s. Once again there were no significant differences recorded between the schedule lengths of the control and experimental schedules, and the distortion levels were again very similar.

A third trial was undertaken to investigate how using a kiln manufacturers recommended kiln schedule (elevated maximum drying temperatures) coupled with variable airflow rate impacted on schedule length and final wood quality. This trial recorded some interesting results and raised questions regarding the use of variable airflow during drying. The airflow recorded during the experimental schedule ranged from 5.8 m/s to 8.1m/s. There are long standing recommendations that higher airflow should be used during the early stages of the schedule when large amounts of free moisture are present in the timber when green. The airflow is then gradually reduced throughout the remaining drying stages as the moisture content reduces.

The results gained from this and the earlier set of trials tends to put the theory of using variable airflow into doubt. From the work undertaken during the project we know that raising the airflow speed does not tend to result in large reductions in schedule length. We also know that using high temperatures during the early

part of the kiln schedule will result in problems with distortion later in the schedule. During drying, the air does two jobs; it imparts heat to the timber and removes migrating moisture from the timber surface. Air with a higher temperature will hold more moisture, although subjecting the timber to higher temperatures during the early stages of the schedule will initiate problems later in the drying process. Therefore, increasing the airflow at this point in the schedule cancels itself out because higher temperatures cannot be used without causing damage to the timber.

The results from the third experimental kiln schedule undertaken with a variable air-flow speed and higher temperatures resulted in a significant increase in distortion levels in comparison to the control schedule. It is interesting to note that the control schedule resulted in a drying time of 80 .5 hours with a standard air-flow speed of 3.5 m/s throughout the schedule, whereas the experimental schedule recorded a schedule time of a 105 hours with a variable airflow between 5.8 m/s and 8.1m/s. Higher during the early phases with a general decrease during the later stages. Although not conclusive, the indications from this stage of the work do show that using variable airspeed is probably not improving the drying process other than creating higher energy costs.

During each kiln trial, the energy requirements of the drying process were monitored and recorded. This enabled a comparison to be made between the possible improvements to the drying process by increasing the airflow speed and the energy required to increase the airflow speed, plus the energy required by the boiler and associated equipment to generate these improvements.

From the recorded values, it can be concluded that any increase in airflow speed resulted in large increases in energy consumption, even taking into account the gains which occurred in the reduction drying time and the small savings made on the gas consumption.

In light of these results, it is a simple option for kiln operators to experiment with using a constant airflow when drying spruce rather than retaining the variable airflow installed as part of the kiln operating system. Depending on how each individual system is set-up, it should cause no adverse effects on the drying quality by reducing airflow to a constant 3.5 m/s throughout the schedule. This does of course depend on whether the variable airflow you are using at the moment is greater than the recommended 3.5 m/s.

Contents

Introduction

During the past five years a number of projects have been completed by BRE with regards optimising the drying of UK spruce. Almost all the large capacity kilns (between 100 m^3 and 200 m^3) used by the UK softwood sawmilling industry have upper airflow speeds of between 2.5 m/s and 3.5 m/s. From the work undertaken within recent projects, it is apparent that variations in the airflow do have an impact on the drying process, although it is not known by how much.

The objective of this project is to investigate how an increase in airspeed during the drying process affects the drying of spruce. Airflow is an extremely important factor during the drying process. The circulating air within the drying kiln imparts heat from the exchangers to the timber and in turn removes moisture from the wood surface. This project will investigate how increasing the airspeed affects drying times and the resulting quality of the timber at the end of the schedule.

Increasing the air-speeds during the drying process will also result in an increase in energy consumption. In today's climate of high energy costs, this aspect of the project is obviously very important to our industrial partners. It is possible that an increase in air-speed may significantly reduce drying times, but at what cost. During all of the experimental drying schedules, energy consumption is being closely monitored to provide comparative costs.

The UK softwood sawmilling industry is constantly investigating new methods to improve their processing technology and the quality of material produced. The use of higher air speeds has been discussed by the UK sawmillers at several of the BRE dissemination meetings. It was felt that the possible benefits to the drying process could easily be incorporated on existing equipment with an acceptable economic outlay. This project will provide evidence of the effects this process has on the quality of timber produced, the schedule length and economics of implementing the process if beneficial.

Description of the project

Background

A number of projects have been completed over the last two years on optimising the drying of UK spruce. As almost all the industrial kilns used by the UK softwood sawmilling industry have an upper ceiling to their air speeds of between 2.5 m/s and 3.5 ms, investigations into the use higher air speeds has only been minimal. From the small amount of work undertaken within previous projects, it is apparent that small changes to the airflow seem to have large influences on the drying parameters.

Work programme

The project work programme consists of undertaking a series of trials to investigate how increases in airflow affects the drying of UK spruce and how these increases can be incorporated into the drying schedules used by the industry at the moment. The changes would also be assessed for energy consumption to provide information on the economic viability of any process changes. At the start of the project, two baseline control schedules will be undertaken using schedules similar to those used by industrial partners. Depending on the results from these trials one will be selected for use as the control schedule for subsequent trials.

Task 1. Baseline control run

Two packs of 50 x 100 x 2400 mm battens will be selected from freshly processed spruce from a participating sawmill. Each of these packs will be dried using a typical spruce drying schedule with specific air speeds (2 m/s and 3.5 m/s) similar to those used in industry. The dried material from both trials will be measured for distortion and moisture content uniformity at BRE to compare similarity of drying conditions between BRE and industry. The schedule most similar to that used in industry would form the baseline schedule with which all subsequent experimental trials will be compared.

Task 2. Accelerated air speed trials

This work task will consist of approximately 8 drying trials (depending on results). Each experimental trial will see an increase in airspeed of approximately 1 m/s, from 3.5 m/s to 8 m/s (or higher if necessary). Each trial will consist of an experimental trial and control trial (undertaken using the baseline schedule). The material used in each trial will come from the same pack to allow comparisons between schedule length and drying quality to be undertaken. The timber from each trial will be measured for distortion and uniformity of moisture content.

Task 3. Further investigation

Depending on the results obtained from the Task 1 programme of trials, further trials will be undertaken to verify the initial results. This work task will also be used to optimise the airflow throughout the schedule (in normal schedules, the airflow is not constant throughout the drying cycle, but varies depending on the drying phase). Results obtained from this set of trials will allow more precise recommendations to be made on the best airflow levels to be used during the drying of spruce.

Task 4. Energy consumption

During each kiln trial, the energy requirements of both the fans and heat generation will be monitored and recorded. This will enable a comparison to be made between the expected improvements in drying and the energy requirements of both the fans and changes in heat energy requirements.

Task 5. Dissemination

Dissemination will be an ongoing process throughout the project. At it's close, a final report will be produced which summarises the results, conclusions and recommendations derived from the individual work tasks undertaken.

.

Results and discussion

The work tasks within this project were designed to investigate how increases in airflow affect the drying of UK spruce. These trials were undertaken in BRE's experimental conventional kiln which is also fitted with various energy meters to monitor and record the electricity and gas consumed during each kiln trial.

Material preparation

For each trial, approximately 120 pieces of 47 X 100 X 4800 mm freshly sawn UK grown spruce was delivered to BRE by one of our sawmill partners. Each pack of material was supplied completely wrapped in plastic to retain its 'green' moisture content. On arrival at BRE, the battens were tagged on one end using consecutive numbered blue tags and the opposite end using consecutive numbered red tags. Each batten was then cross-cut in half by removing a 50 mm portion from the centre of each batten in order to record 'green' moisture content. The two separate red and blue packs were then mixed by substituting every other batten between the two packs resulting in a red/blue red/blue series of battens in each pack. This stylised mixing ensured that both packs now contained an equal mix of top and butt sections from the original pack of material delivered.

Each trial consists of two drying runs, one pack being dried using the control schedule (ascertained under Task 1) with an airflow of 3.5 m/s (Figure 2, Table 1) and the second pack using the same schedule (Figure 2, Table 1), with a specific increased airflow. The final target moisture content (M/C) of each trial was 18%. Each pack of material was stacked in the kiln using 22 x 38 mm spruce stickers, set at 500 mm distances, with a top-load of 480 Kg/m^2. Before the start of each trial the airflow speed was checked in six different exit positions across the stack using a hot wire type anemometer inserted 150 mm from the stack surface between sticker spaces to ensure a uniform airflow across each pack. The drying schedule used in each trial was based partly on time and partly on moisture content monitoring of the load during drying

Task 1. Baseline control trials

Task 1 of the work programme consisted of undertaking two information collection trials to select a suitable schedule for use as a base-line control schedule for use in work task 2. Freshly processed spruce (50 x 100 x 4800 mm) was delivered to BRE where the material was coded, cross-cut and moisture content samples removed, prior to being mixed and re-stacked to form two near identical packs (as described under the section 'Material preparation'). The first pack was dried using a similar kiln schedule (figure 1) to that used by one of the industrial partners during a previous drying project.

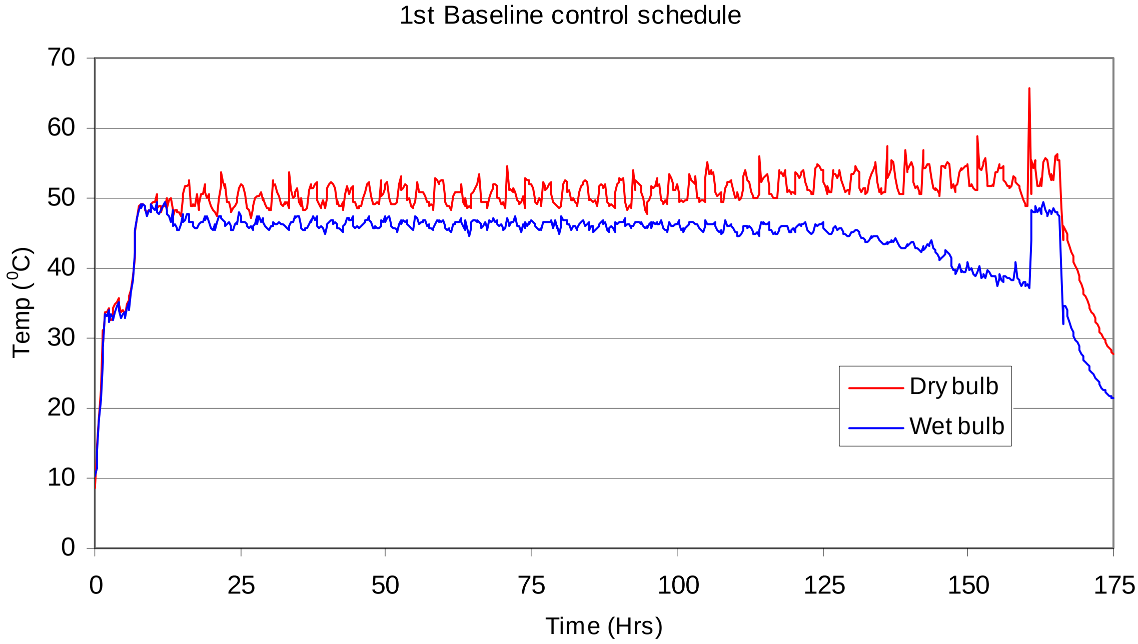

Figure 1. First baseline control schedule

On completion of this trial, it was identified that the schedule was much longer than most of those used by other industrial partners and only moderate drying was occurring during the initial phases of the programme. In light of these results, the schedule was refined by shortening the initial stages of drying programme and widening the wet and dry bulb gap during the later drying stages to speed up the overall drying time (Table 1).

Table 1. Second baseline control schedule (Input values)

Phase	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Time	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	5	10
M/C	0	0	60	50	40	37	34	31	28	24	21	20	19	18	18	0	0
Temp.	37	53	53	53	54	54	55	56	56	56	56	56	56	56	57	57	45
EMC	20	20	15.4	14.5	13.8	12.7	11.6	10.7	9.6	8.6	7.6	6.6	5.8	5.3	5.3	18	0
Fans	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5

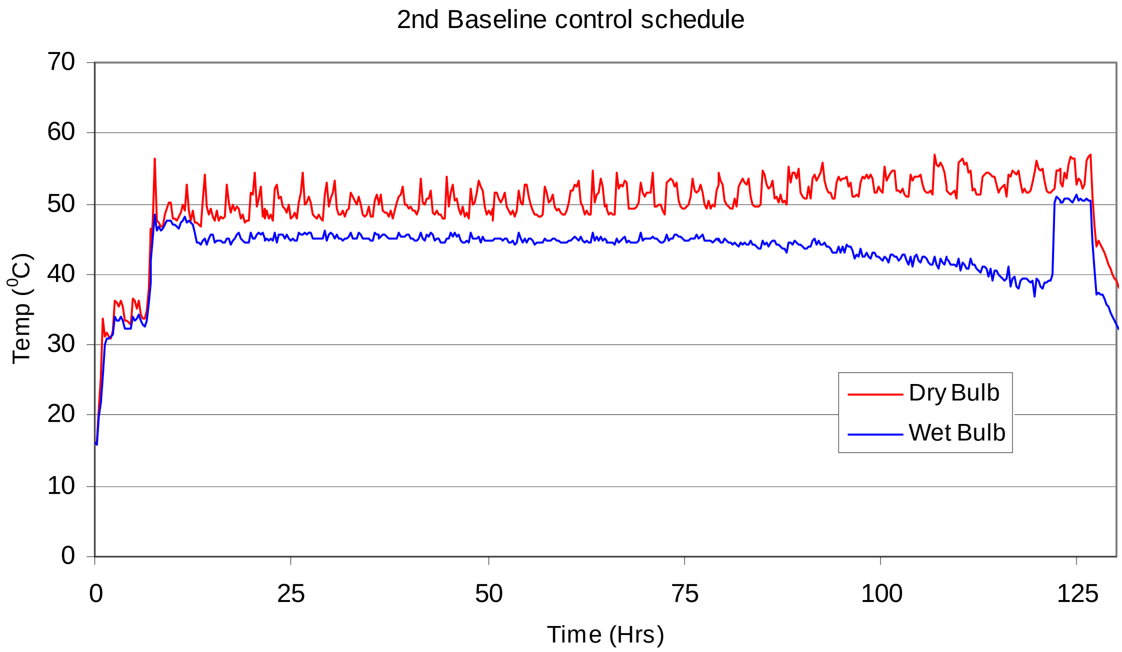

Figure 2. Second Baseline control schedule (wet & dry bulb chart)

Figure 2 shows the resulting wet and dry schedule after the inclusion of these changes. The changes resulted in an overall improvement in the drying time of approximately 30 hours, with only slight changes in the distortion values when compared with results from the first schedule (Table 2). The slight difference in the distortion values can be attributed to the difference in the final average moisture contents. The first baseline schedule was undertaken with an air-speed of 4.5 m/s and the second reduced to an air-speed of 3.5 m/s.

Table 2. Average distortion values

Kiln schedule	Twist (mm)	Bow (mm)	Spring (mm)	Cup (mm)	M/C (%)
1	3.1	1.8	1.8	0.3	16.7
2	2.2	1.3	1.5	0.3	18.2

It was felt that baseline trial 2 provided a good compromise of what was required by the control schedule. The drying was fairly fast and the maximum temperatures not excessively high. Results from the distortion assessments indicated that the schedule did not result in any adverse effects on distortion. Energy use was also reasonable (See task 4). In light of these results, baseline schedule 2 was selected as the control schedule for use throughout the remainder of the programme.

Task 2. Accelerated air speed trials

This work task consisted of undertaking a series of control/experimental drying trials, each comprising of one experimental trial (using the same baseline control schedule with a higher airflow) and one control trial (undertaken using the baseline schedule with an airflow of 3.5 m/s). The material used in each trial was processed from the same pack to allow comparisons to be made between schedule length and drying quality. The timber from each completed trial then underwent measurement for distortion and uniformity of moisture content (Annex 1).

As described above. Each trial consisted of drying two near identical packs of spruce, one pack using the baseline control schedule with an air velocity of 3.5 m/s and one experimental pack with an initial step-wise increase in air velocity starting at 3.5 m/s up to 7.0 m/s. Table 2 provides the air-speed and average green moisture content of the pack before drying, the average moisture content of the load after drying and the schedule length for each of the five completed trials.

Table 2. Air speed and schedule length of experimental and associated control trials

Trial number	Trial type	Air-speed (m/s)	Average green M/C (%)	Final average M/C (%)	Schedule length (Hrs)
A	1st Base control	4.5	73%	18.2	167
B	2nd Base control	3.5		16.7	121
1	Control	3.5	83%	18.4	120
	Experimental	**4.0**		16.7	127
2	Control	3.5	81%	19.0	127
	Experimental	**5.0**		17.8	117
3	Control	3.5	70%	13.2	144
	Experimental	**6.0**		19.3	87
4	Control	3.5	77%	17.0	122
	Experimental	**7.0**		16.7	115

It was decided at the start of the main work programme to undertake each experimental trial using 0.5 m/s incremental increases, starting from 3.5 m/s and working up to a possible 9 m/s depending on the results recorded during the programme.

Table 2 includes data from the first set of baseline control trials (A & B). As previously described, schedule B was selected for use throughout the experimental phase of the programme as a control schedule. The schedule length data in Table 2 indicates that most of the control trial schedule lengths fell within a fairly small range (120 hours to 127 hours) of the original baseline control schedule (B). Trial 3 being the exception to this rule, the material being over-dried due to the program not automatically switching off at the target moisture content of 18%. This resulted in a schedule length of 144 hours and a final average moisture content of 13.2%.

It became apparent very early on in the project that raising the airflow by 0.5 m/s increments did result in a reduction of the overall drying times, although these reductions were generally quite small. In fact, increasing the airflow rate by increments of 1 m/s also recorded fairly small decreases in schedule length as data in Table 2 indicates. There may be several reasons for this. Many of the kiln schedules for spruce have been adjusted and optimised by the industry (and through projects by BRE) over a fairly long period of time. Therefore the kiln schedules in use at the moment may be at there optimum. Although more likely is that airflow is more closely linked to changes in the drying conditions than previously thought.

Results from this work task indicates that increasing the air-flow speed results in a reduction in drying times when compared to associated control trials. Although the extent of these reductions was not a great as was expected. Due to the small reductions in schedule length, especially when energy and final wood quality was taken into account, the trials were halted at 7 m/s.

Distortion after drying

After each trial both the control and experimental material was assessed for twist, bow, spring, cup and moisture content (the distortion measurement processes is described in Annex A of this document) and the values recorded. The average values from each set of trials is shown in figures 3, 4, 5, 6 and 7. Each chart depicts the average distortion values from both control and experimental material dried during the trials along with the average moisture content from each group which is contained in the legend.

Figure 3. Average distortion values recorded from trial A material (baseline control material shows the distortion values obtained from the two baseline control trials undertaken at the start of the program. Trial 1 was undertaken with an airflow of 4.5 m/s and a schedule length of 167 hours and trial 2 with an airflow of 3.5 m/s and a schedule length of 121 hours. It is interesting to note that although trial 2 was undertaken with a lower airflow speed and a slightly harsher kiln schedule, timber quality still returned distortion values well below those exhibited by material from trial 1, even when taking into account the slight disparity between final moisture contents. Considering that the drying time of trial 2 was reduced by over 40 hours in comparison to trial 1, the results are difficult to explain.

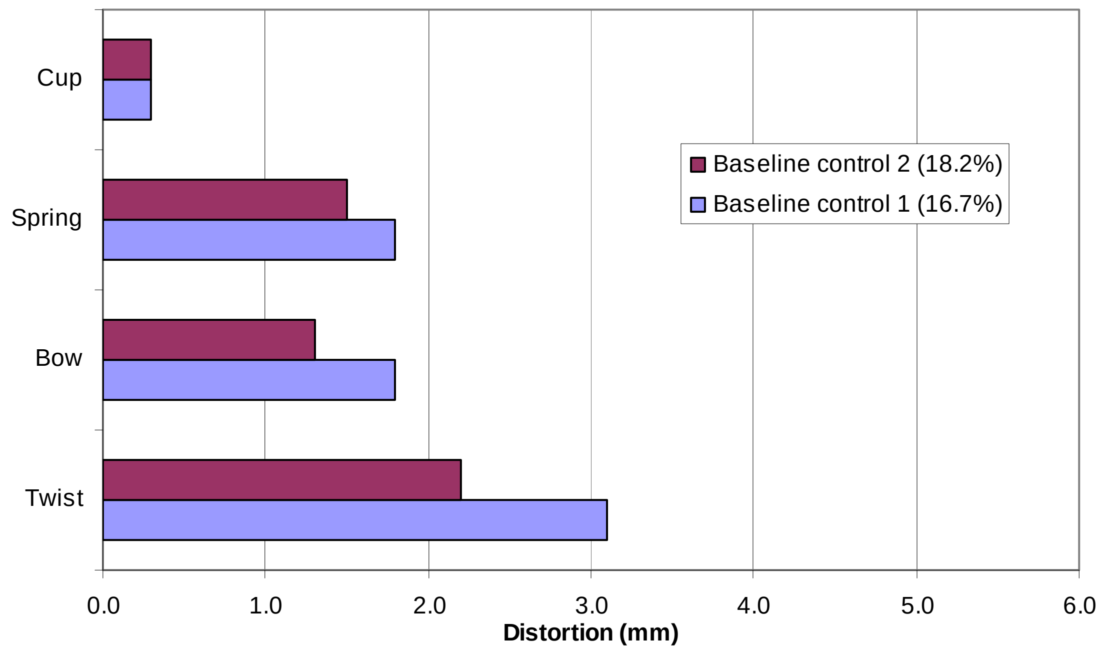

Figure 3. Average distortion values recorded from trial A material (baseline control material)

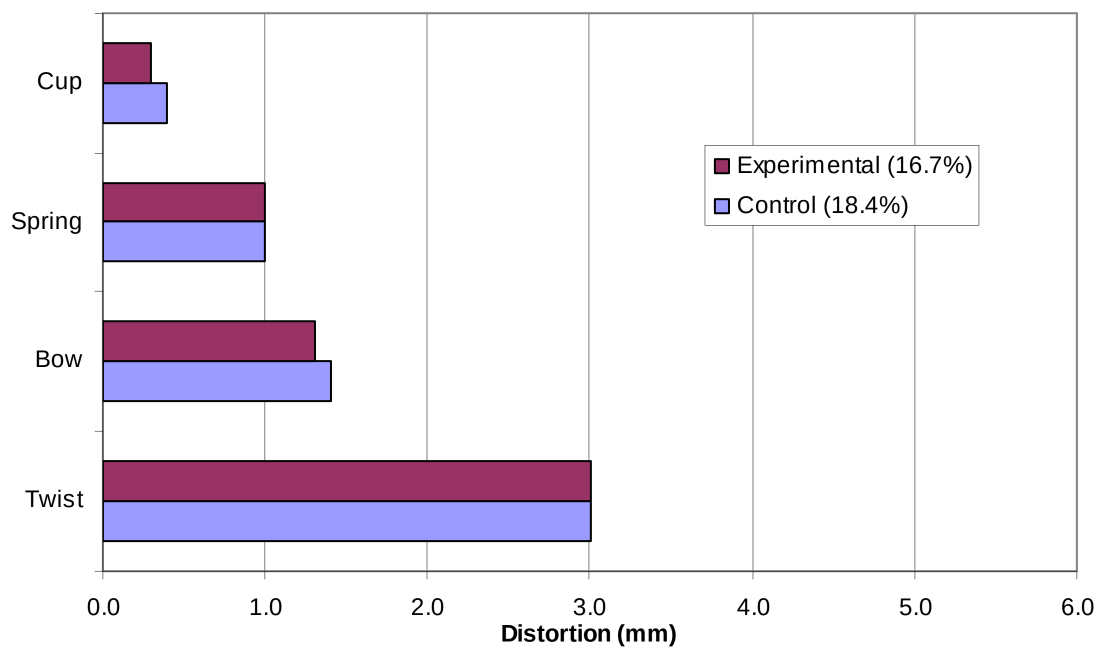

Figure 4. Average distortion values recorded from trial 1 material (4 m/s)

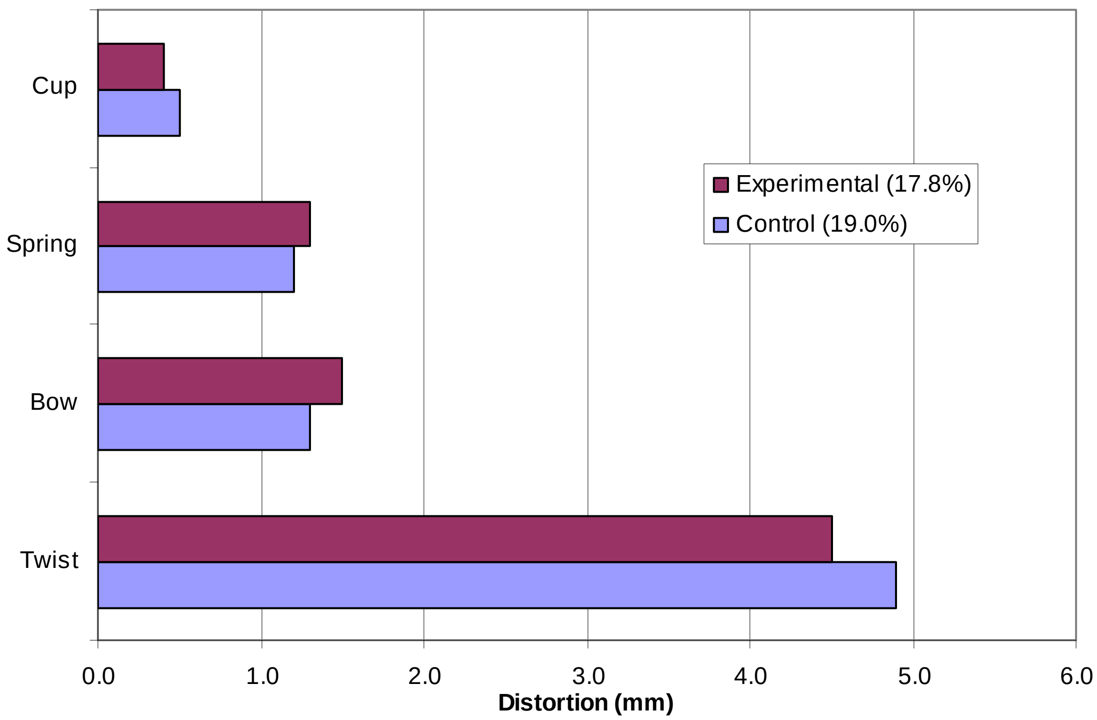

Figure 5. Average distortion values recorded on trial 2 materials (5 m/s)

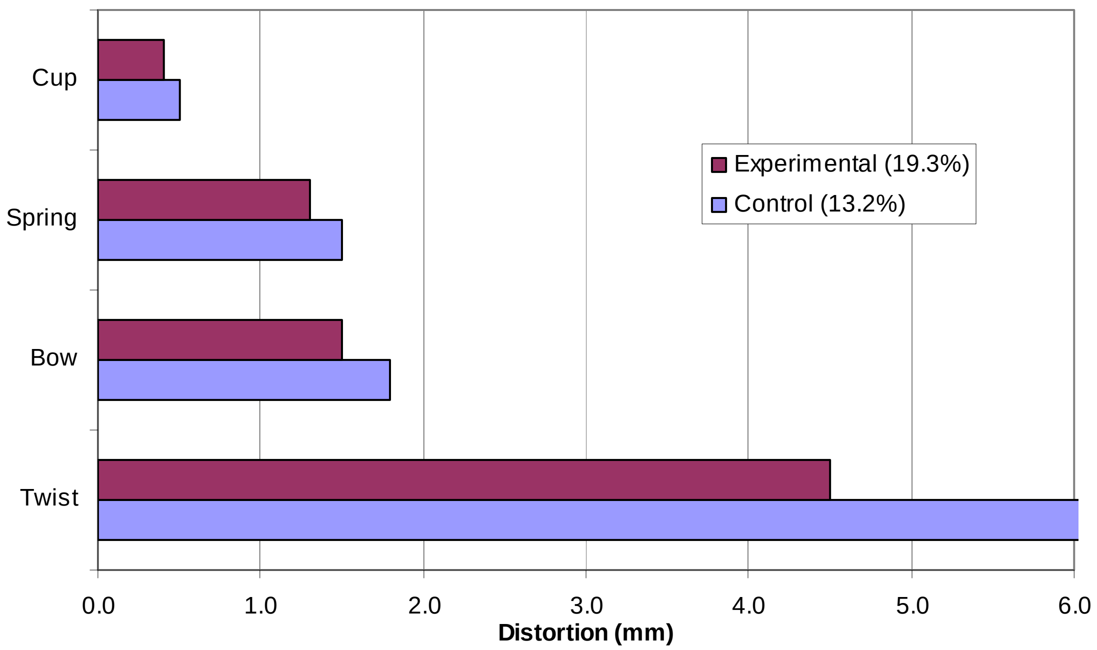

Figure 6. Average distortion values recorded on trial 3 materials (6 m/s)

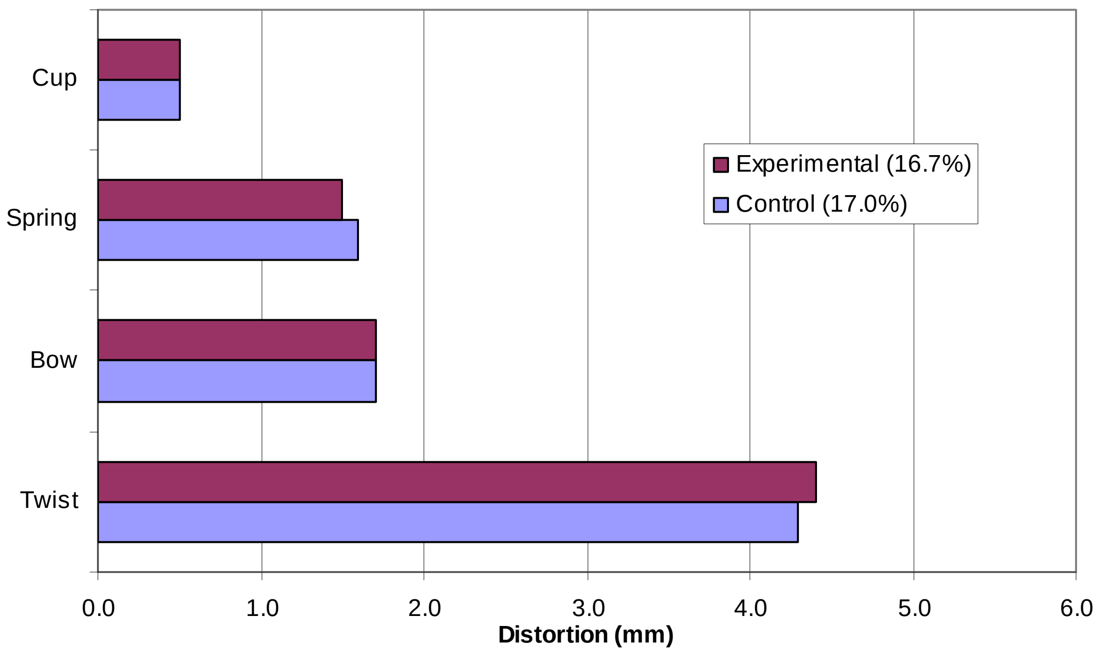

Figure 7. Average distortion values recorded on trial 4 materials (7 m/s)

Figures 4, 5, 6 and 7 show the average distortion values for both the control and experimental material from the first, second, third and fourth trials, the experimental material from these trials being dried using airflows of 4 m/s, 5 m/s, 6 m/s and 7 m/s respectively.

Considering the significant increase in airflow from 3.5 m/s to 7 m/s, distortion values remain very similar for each individual control and experimental set on all material. Figure 6 is the only graph deviating from this trend, but this can be directly attributed to the control material being over-dried due to a problem at the end of the schedule. The values shown indicate very little change has occurred in the final wood quality after increasing the air velocity from 3.5 m/s to 7 m/s.

Task 3. Further investigation

This work task was included in the project to verify initial results (three duplicate trials were undertaken in Task 2 to verify and clarify some of the initial results), and investigate changes in kiln schedule and variable airflow. It was hoped that the results obtained from this set of trials would allow more informed recommendations to be made on the best airflow levels to be used when drying of spruce.

Trial 1a

The first trial to be completed in this work task (Trial 1a) was undertaken to investigate how an increase in the wet and dry bulb gap (one degree depression of the wet bulb temperature) incorporated with a high airflow speed affected the drying time and final timber quality.

Trial 2a
The second trial in this series consisted of investigating whether an increase in the wet and dry bulb gap (one degree depression of the wet bulb temperature), but retaining an airflow speed of 3.5 m/s resulted in any significant changes in the length of schedule and/or final wood quality

Trial 3a
The third trial was undertaken to investigate how using a kiln manufacturers recommended kiln schedule coupled with variable airflow rate impacted on schedule length and final wood quality.

Table 3. Air speed and schedule length of experimental and associated control trials

Trial number	Trial type	Air-speed (m/s)	Average green M/C (%)	Final average M/C (%)	Schedule length (Hrs)
1a	Control	3.5	92%	17.5	122
	Experimental	**7.0**		14.9	113
2a	Control	3.5	71%	19.5	122
	Experimental	**3.5**		17.0	120
3a	Control	3.5	77%	19.6	80.5
	Experimental	**variable**		15.3	105

Table 3 indicates the air-speed, average green moisture content of the timber before drying, final average moisture content of the timber after drying and the schedule length in hours of the three trials undertaken in this work schedule.

The results from Trial 1a indicates that even with a change in the kiln schedule (more severe) and a higher airflow, did not alter kiln schedule length to any significant degree (the experimental schedule would have been shorter if the final moisture content had been higher). This result is also borne out by similarity between distortion levels from both the control and experimental material recorded from the trial (Figure 8).

The results from Trial 2a indicate that altering the kiln schedule (more severe), whilst still retaining an airflow speed of 3.5 m/s results in no significant differences occurring between the schedule lengths of the control and experimental schedules (Table 3). This similarity trend continues when viewing distortion levels from both the control and experimental material recorded from this trial (Figure 9).

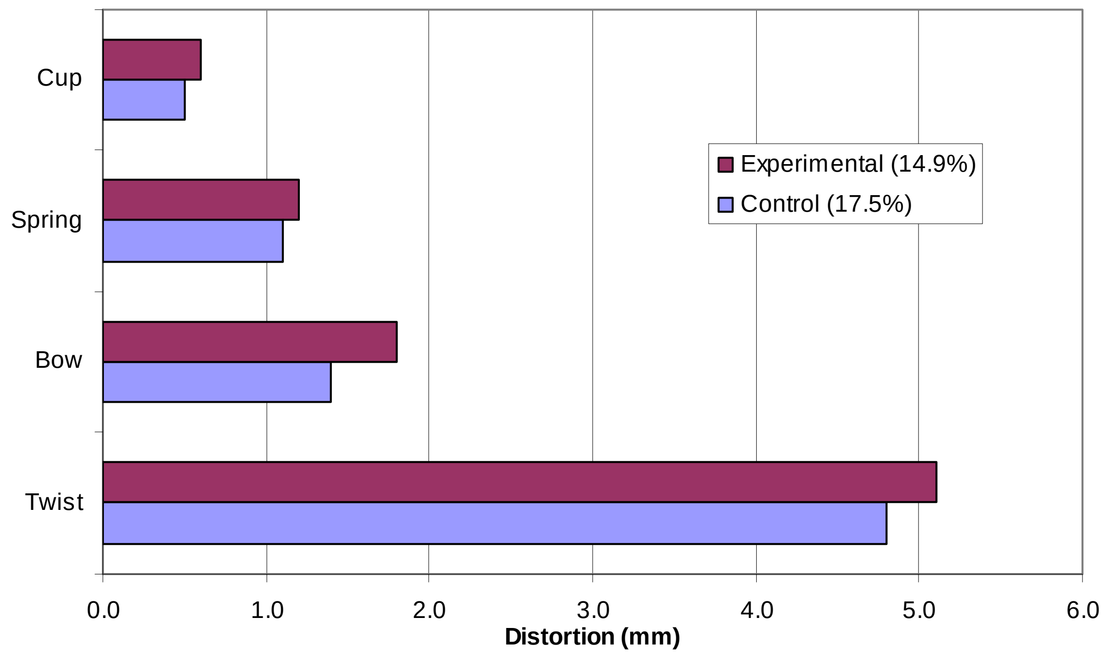

Figure 8. Average distortion values recorded on trial 1a material (7 m/s)

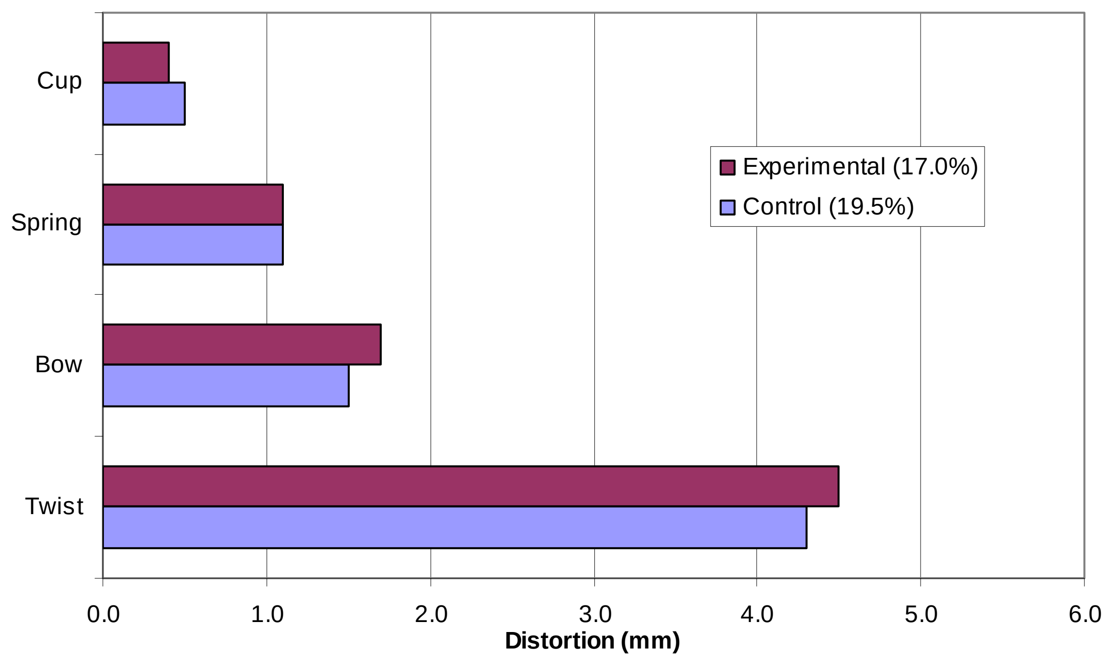

Figure 9. Average distortion values recorded on trial 2a material (3.5 m/s))

Trial 3a recorded some interesting results and raised questions regarding the use of variable airflow during drying. Table 4 shows the input data for the 3a experimental schedule. The input data used for the control schedule is shown in Table 1. Airflow during the experimental schedule was variable and ranged from 5.8 m/s to 8.1m/s. The theory behind using variable airflow during wood drying is related to the large amount of moisture present in the timber when green and the amount of moisture being given off from the timber during the early phases of the drying, i.e. you require a higher airflow to remove the large amounts of free water being lost by the timber during the early phases of drying, gradually tailing off towards the end of the schedule.

The results gained from this and the earlier sets of trials tends to put this theory into doubt. From the work undertaken during the project we know that raising the airflow speed does not tend to result in large reductions in schedule length (without altering the conditions). We also know that using high temperatures during the early part of the kiln schedule will result in either the timber developing severe collapse or causing problems with distortion. During drying, the air does two jobs; it imparts heat to the timber and removes migrating moisture from the timber surface. Air with a higher temperature will hold more moisture, although subjecting the timber to high temperatures during the early stages of the schedule will initiate problems later in the drying process. Therefore, increasing the airflow at this point without altering the schedule (raising the temperature or widening the wet and dry bulb gap) is in some question.

Table 4. kiln manufacturers recommended kiln schedule for European spruce

Phase	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Time	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	5	10
M/C	0	0	60	50	40	38	36	34	32	29	27	25	23	21	18	0	0
Temp.	37	56	56	56	56	58	61	64	66	69	75	75	75	75	75	67	45
EMC	15.2	13.7	12.2	12.2	11.5	11.3	11.2	11.0	10.9	10.2	9.2	8.2	7.4	6.5	5.3	14	0
Fans	6.5	7.5	8.1	7.5	6.7	6.6	6.4	6.5	6.4	6.3	6.2	6.1	6.0	5.9	5.8	5.8	6.1

It is interesting to note that the control schedule undertaken in Trial 3a resulted in a drying time of 80 .5 hours with a standard airflow speed of 3.5 m/s throughout the schedule, whereas the experimental schedule recorded a schedule time of a 105 hours with a variable airflow between 5.8 m/s and 8.1m/s.

Figure 10 shows the different levels of distortion recorded in Trial 3a. It is apparent that the experimental kiln schedule undertaken with a variable airflow speed and higher temperatures results in a significant increase in distortion levels in comparison to the control schedule. It would be expected that this would still be the case even if the experimental schedule had attained the target moisture content of 18% rather than the 15.3% average it did attain.

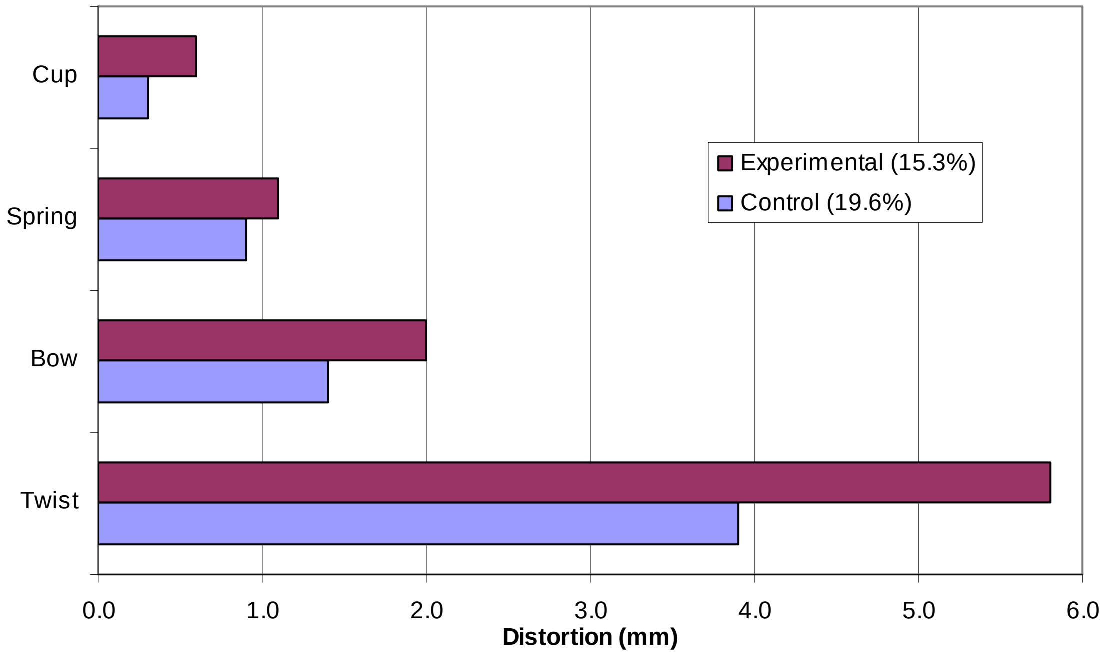

Figure 10. Average distortion values recorded on trial 3a material (variable airspeed)

Task 4. Energy consumption

It was planned at the proposal stage that during each kiln trial, the energy requirements of the drying process would be monitored and recorded. This would enable a comparison to be made between the expected improvements in the drying process by increasing the airflow speed and the energy requirements of fans, boiler and associated equipment required to generate these improvements.

The heat for the kiln is generated by a gas fired hot water boiler system (measured in m^3 of gas consumed). The two 3 kilowatt (Kw) fans and associated equipment (pumps, control unit & humidification unit) are powered by electricity. The legend contained in the following graphs identifies the trial number and is followed by the drying time in hours.

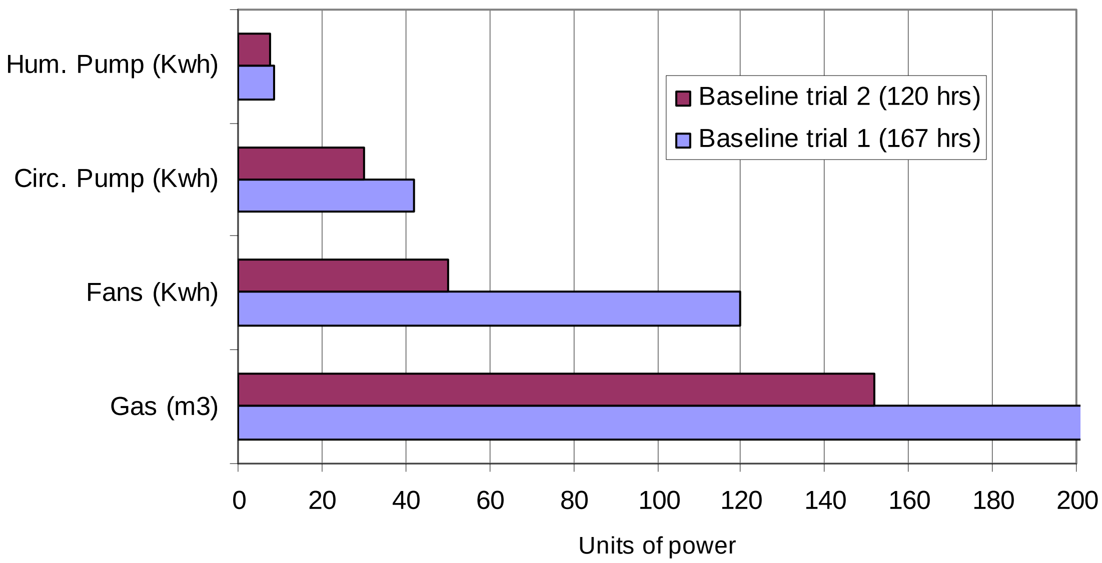

Figure 11. Comparison of energy consumption during the baseline control trials

Figure 11 indicates how much more energy is required when a kiln schedule is extended for any significant period. Baseline schedule 1 was completed in 167 hours and baseline schedule 2 in 120 hours. As expected, gas consumption in schedule 1 has increased due to the extra heat requirement of a longer schedule. Although the most significant factor shown is the increase in fan kilowatt hours (Kwh) required due to schedule 1 being undertaken with a constant air velocity of 4.5 m/s and schedule 2 with 3.5 m/s. As the fans in the experimental kiln are fitted with frequency inverters, a reduction in air velocity equates to a large saving in electricity consumption (Annex 2).

Figure 12 shows the energy consumption recorded from both the first control and experimental schedules. The air velocity used on the control schedule was 3.5 m/s and the experimental schedule undertaken with 4.0 m/s. As expected, the energy use of the fans has increased slightly due to the velocity increase, whilst the gas consumption has decreased. It is not certain why the experimental trial required 127 hours of drying time, whilst the control trial was completed in 120 hours.

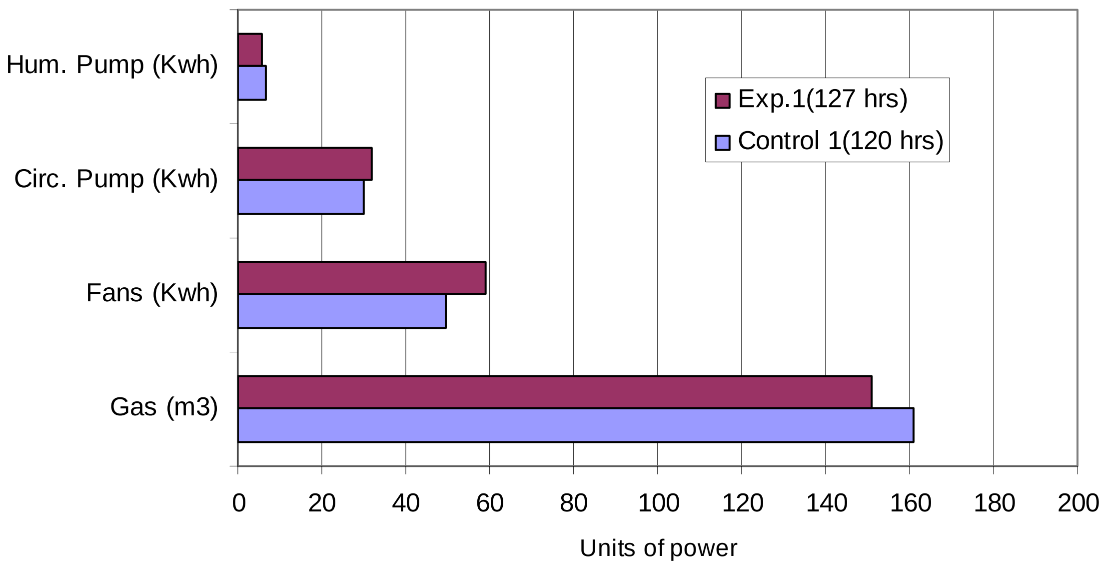

Figure 12. Comparison of energy consumption from trial 1 (Airflow speed - 4 m/s)

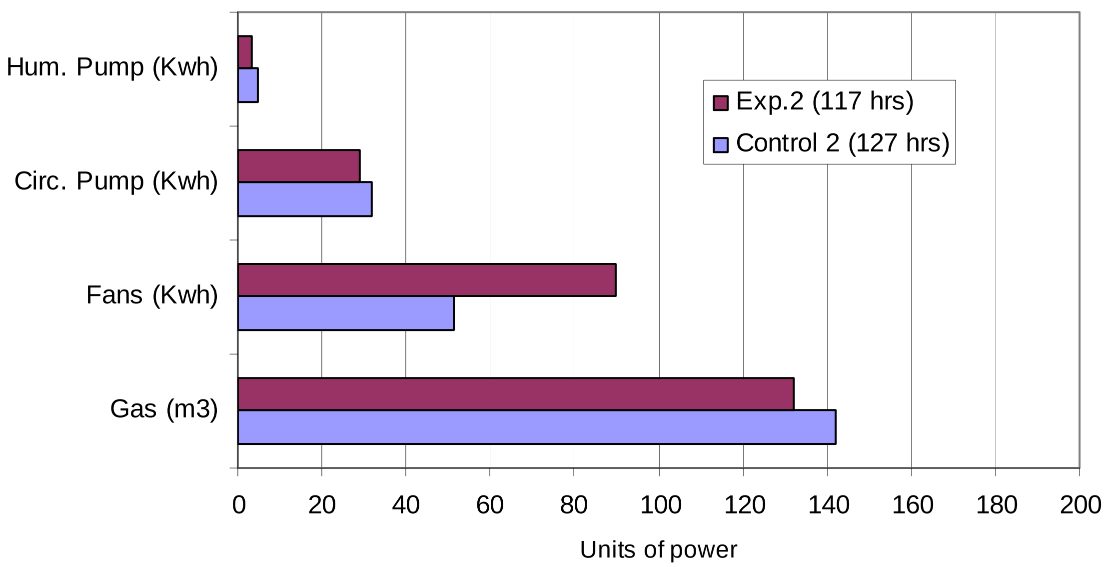

Figure 13. Comparison of energy consumption from trial 2 (Airflow speed - 5 m/s)

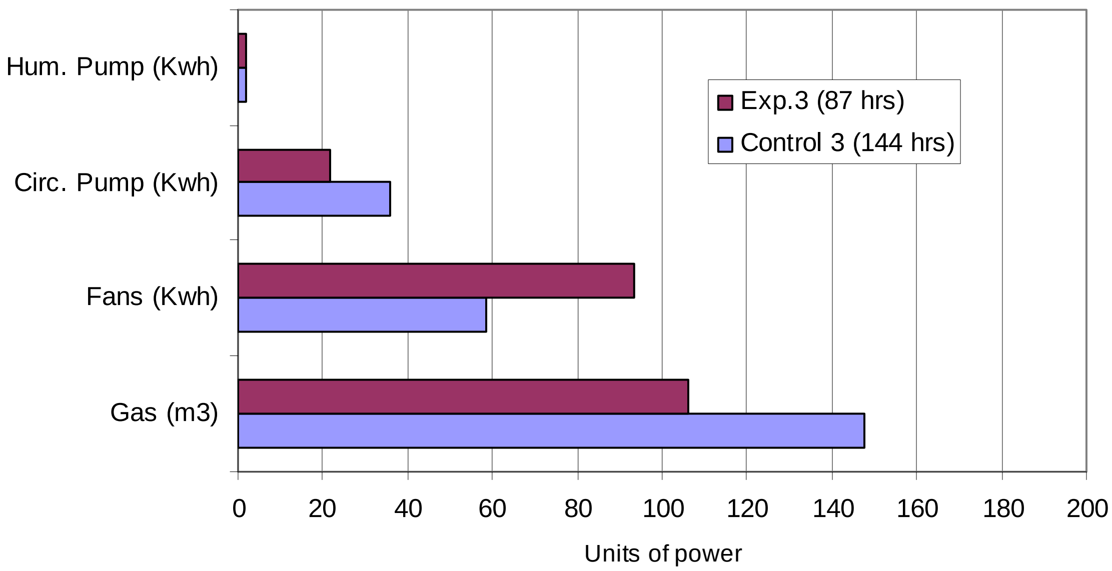

Figure 14. Comparison of energy consumption from trial 3 (Airflow speed - 6 m/s)

Figure 13 shows the energy consumption recorded from both the second control and experimental schedules. The air velocity used on the control schedule was 3.5 m/s and the experimental schedule, 5.0 m/s. As expected, the energy use of the fans has shown a significant increase over the previous experimental schedule due to the increase in velocity. As expected, gas consumption has decreased, mainly due to the decrease in kiln schedule length and the increase in the speed of drying.

Figure 14 shows the energy consumption recorded from both the third control and experimental schedules. The air velocity used on the control schedule was 3.5 m/s and the experimental schedule, 6.0 m/s. As expected, the energy use of the fans has shown another significant increase over the previous experimental schedule due to the stepwise increase in velocity. Again, gas consumption has decreased, mainly due to the decrease in kiln schedule length and the increase in the speed of drying.

Figure 15 shows the energy consumption recorded from both the fourth control and experimental schedules. The air velocity used on the control schedule was 3.5 m/s and the experimental schedule, 7.0 m/s. Increasing the airspeed to 7 m/s has resulted in an almost exponential increase in energy use over that of the control schedule. This example clearly shows how much energy can be saved when frequency inverters are fitted to the fan motors and the fan speed ramped down to produce a lower air-flow velocity. This is clearly explained in Annex 2 where examples are provided to describe the process.

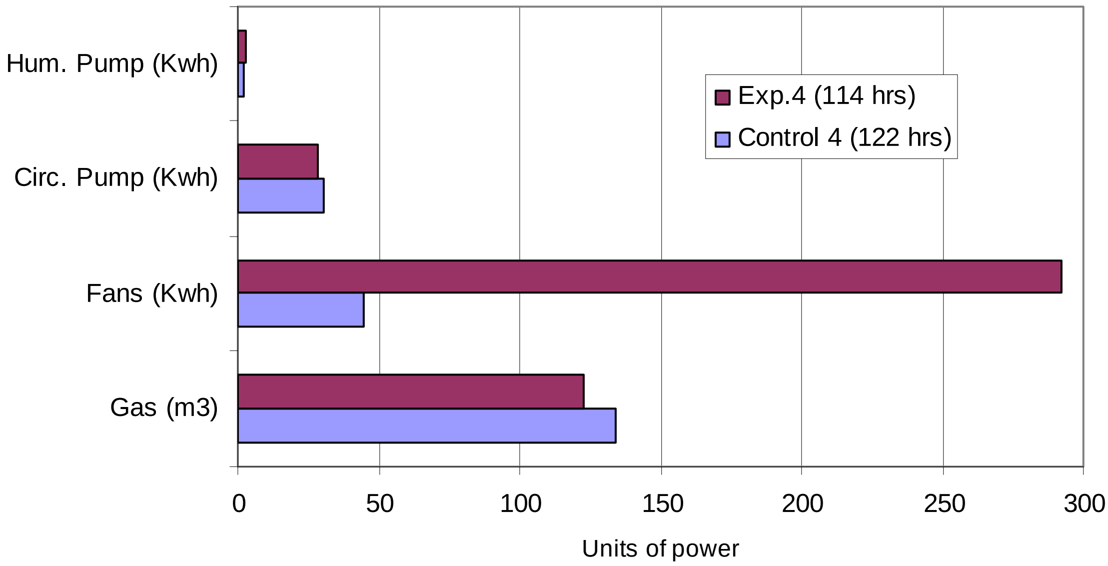

Figure 15. Comparison of energy consumption from trial 4 (Airflow speed - 7 m/s)

Figure 16 shows the energy consumption recorded from the first set of additional trials (Trial 1a). The velocity used during the control schedule was 3.5 m/s and the experimental schedule, 7.0 m/s. The experimental trial also included a one degree increase in the wet and dry bulb gap which effectively increases the drying occurring during the schedule. As expected, the use of an airflow speed of 7 m/s has resulted in a significant increase in energy use by the fans compared to the control schedule. Even with an increase in the in the wet and dry bulb gap, gas consumption has only decreased by approximately 50 m^3.

Figure 17 shows the energy consumption recorded from the second set of additional trials (Trial 2a). The second trial in this series consisted of investigating whether an increase in the wet and dry bulb gap (one degree depression of the wet bulb temperature), but retaining an airflow speed of 3.5 m/s resulted in any significant changes in the length of schedule, final wood quality or energy consumption. As the energy consumption graph shows, gas consumption and fan energy consumption is slightly reduced on the experimental trial mainly due to the slight decrease in schedule length (attributed to the one degree depression of the wet bulb temperature).

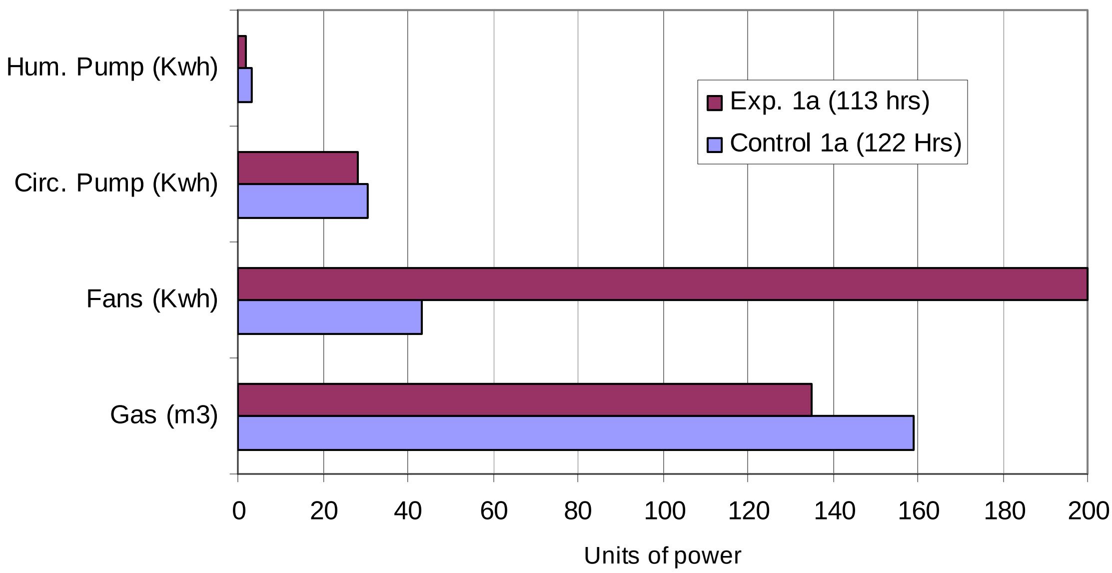

Figure 16. Comparison of energy consumption from trial 1a

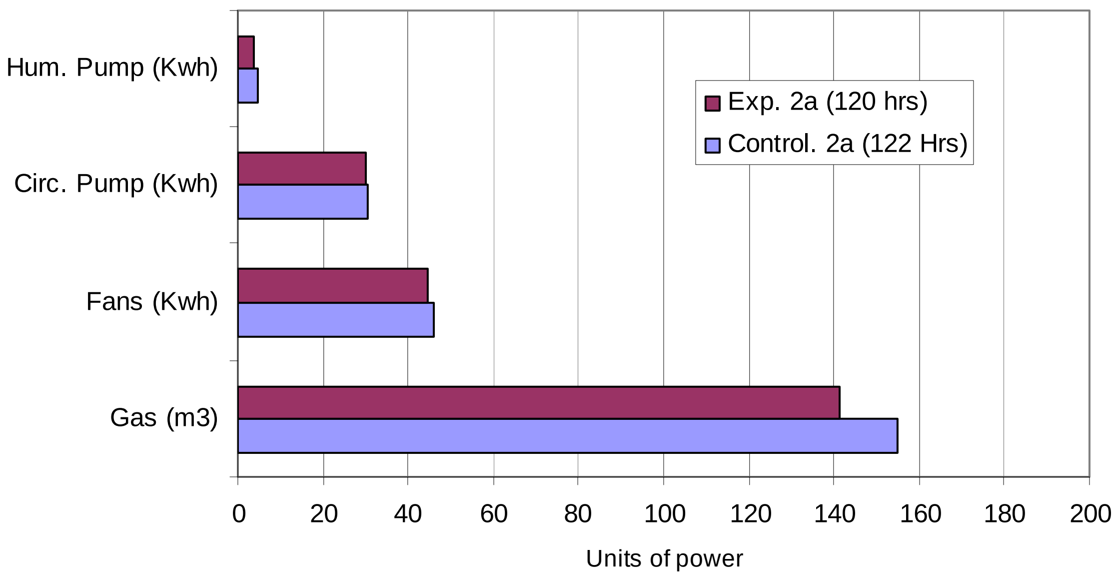

Figure 17. Comparison of energy consumption from trial 2a

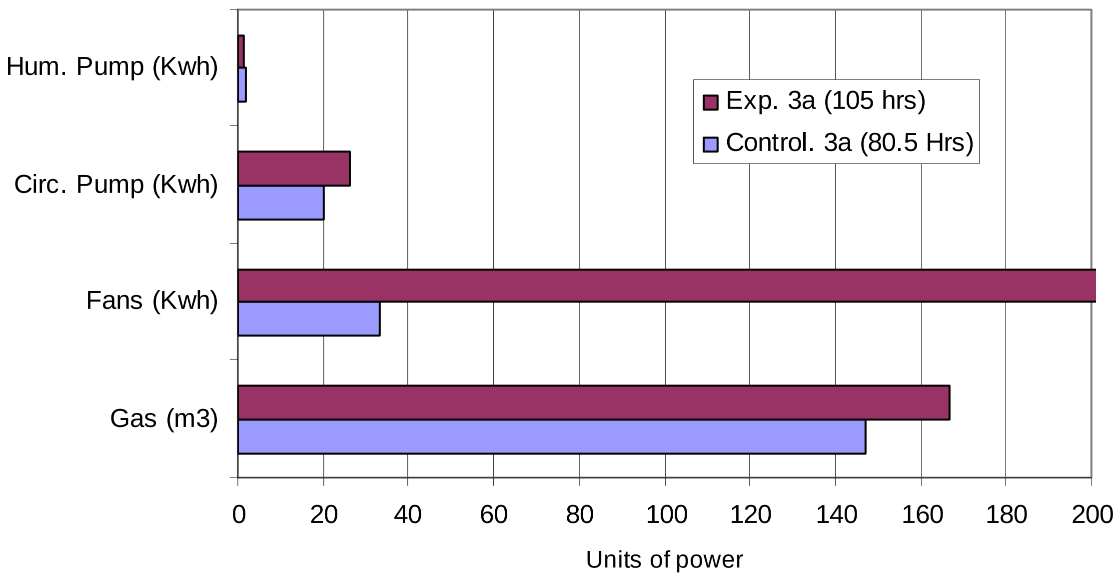

Figure 18. Comparison of energy consumption from trial 3a

Figure 18 shows the energy consumption recorded from the third set of additional trials (Trial 3a). The third trial in this series consisted of investigating whether the use of variable airflow (ranging from 5.8 m/s to 8.1m/s) and an increase in maximum kiln temperature resulted in any significant changes in the length of schedule, final wood quality or energy consumption in comparison to the control schedule. As the energy consumption graph shows, some interesting results were recorded. The most notable being the high energy consumption of the fans during the experimental phase of the programme when compared to the energy used during the control schedule.

Figures 19 and 20 show the relationship between schedule length and fan energy consumption for the five experimental and control schedules undertaken in task 2. Figure 20 clearly shows how uniform the fan energy consumption and schedule length are when a constant air-flow is utilised. In comparison, the experimental trials clearly show a gently reducing schedule time against increasing airflow in relation to an almost exponential rise in fan energy consumption.

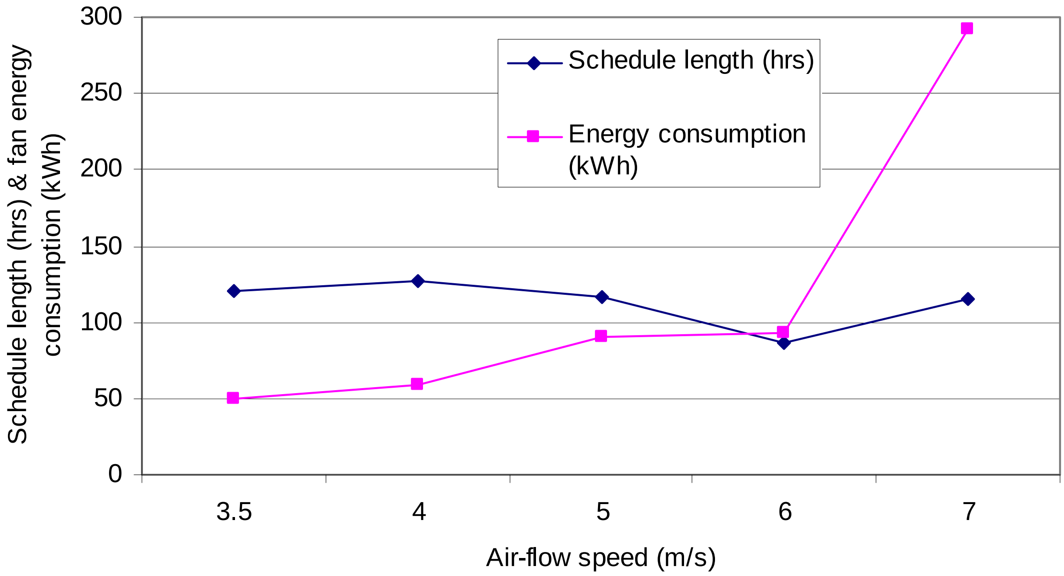

Figure 19. Experimental schedule length versus air-speed versus fan energy consumption

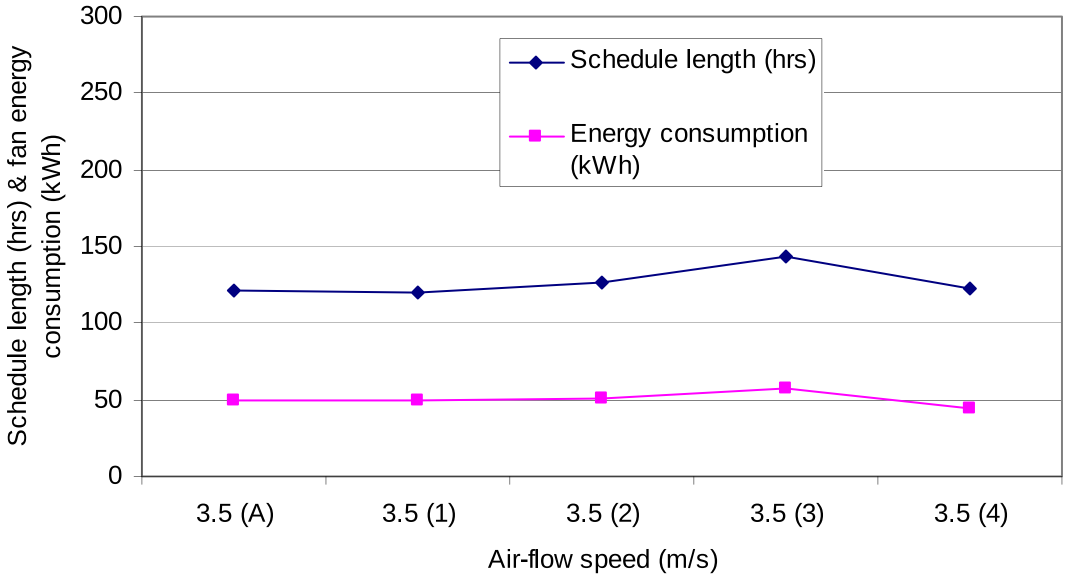

Figure 20. Control schedule length versus air-speed versus fan energy consumption

Conclusions

The main objective of this project was to investigate how increases in airflow affect drying times and the quality of UK spruce after drying. Closely linked with these objectives was how these changes affect the energy requirements of the system.

Trials carried out during the project indicate that:

- Increases in airflow speed reduce drying times (whilst retaining the same drying schedule), although not by any significant amounts
- Increases in airflow speed (whilst retaining the same drying schedule) do not cause significant increases in twist, bow or spring when compared to matched control material
- The trials undertaken within this project has raised reasonable doubt with regards the effectiveness of using variable airflow to dry UK grown spruce
- As expected, increases in airflow will result in significant increases in energy consumption

Although the work undertaken during the project was not exhaustive, the results do indicate that increasing the airflow speed during an existing drying schedule will not result in significant savings in drying times. It will however result in significant increases in energy costs.

Annex 1 – Distortion Measurement Processes

After the material is dried, distortion is measured and recorded by clamping each batten onto a special rig set up with a series of transducers at specific points along the batten:

Twist

Twist is measured over a length of 2000 mm and at a height of 100 mm. Twist is recorded to the nearest 0.5 mm and whether it occurs at the upper or lower point of the batten (fig. 1).

Bow

Bow is measured on the broad face of each batten at the central position of a 2000 mm span. The amount of bow is measured as the deflection (mm) of the piece (inner or outer) away from the central portion of the straight edge to the nearest 0.5 mm (fig. 1).

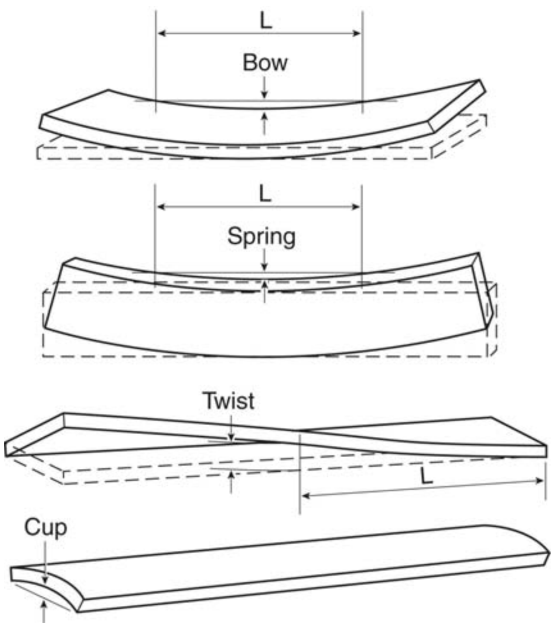

Figure 1. Distortion Types

Spring

Spring is measured in a similar manner to bow, except measurements are recorded on the narrow face only.

Cup

Cup was measured using a short straight edge and an engineer's rule. Each batten was marked in the central position and a straight edge was placed on the marked area and the deflection at the centre measured to the nearest 0.5 mm.

Moisture Content Measurement

Moisture content was measured, using a calibrated electrical resistance type moisture meter at the central position of the board at a depth of 15 mm. The reading was calibrated using wood temperature at the time of measurement.

Annex 2. Frequency inverters and energy consumption

Kiln Air Circulating Fans

The two major consumers of energy used in wood drying kilns are in the production of heat, and the movement of air.

There may be as many as 10 fans present in a medium/large size batch kiln (190 m^3). Based on a presentation by Groupe Schneider, 3 kW fans running at 100%, 90 hours per week, 48 weeks per year, with an electricity price of 4p (£0.04) per kWh, indicate that the fan running costs can be quite considerable (table 1).

Power	**x**	**Hrs**	**x**	**kWh**	
30	x	4320	x	0.04	= £5184 per year

Table 1. Air circulating fan running costs (fans running at 100%)

This cost can be significantly reduced by fitting a speed controller (frequency inverter). Although this may increase the initial capital outlay (by approximately £2500), the savings made within the first year should more than pay for this addition.

If the speed controller was set to run the fans as described above at 80% of their full power, considerable savings are possible (table 2).

Power	**x**	**Hrs**	**x**	**kWh**	**x**	**speed^3**
30	x	4320	x	0.04	x	0.8^3 = £2654 per year

Table 2. Air circulating fan running costs (fans running at 80%)

If the frequency inverter was set to run the fans at 60% of their full power, even greater savings are possible (figure 3).

Power	**x**	**Hrs**	**x**	**kWh**	**x**	**speed^3**
30	x	4320	x	0.04	x	0.6^3 = £1120 per year

Table 3. Air circulating fan running costs (fans running at 60%)

Most modern kilns (batch kilns constructed within the last 10 years) are generally supplied with slightly oversize fans to ensure the correct air velocity is achieved. During a normal kiln schedule, higher air velocities are generated during the earlier stages of the schedule (large movement of moisture), gradually reducing in the later stages of drying as the moisture content decreases. Most computer controlled drying operations have a variable fan speed unit built into the programmed schedules and is generally available as part of the operating system. As the calculations above illustrate, the addition of a speed controller when purchasing a new kiln can provide significant energy savings.