WHITE PAPER: Dry Kiln Fan Speed Reduction

By Todd M. Bennett P.E.

Introduction

Dry kilns are an integral part of manufacturing of wood products – they can also be one of the largest electrical power consumers in a modern sawmill. Dry kilns operating at suboptimal performance can increase drying cycle time, as well as waste thousands of dollars of electricity. Small cost savings in the dry kiln process can quickly add up!

Background

At a typical single-shift sawmill, the electrical requirements of the kiln operation may only be around 15% of the facility's instantaneous power usage. However, because the kiln operation is a 24 hour process, the kiln power consumption can total nearly 70% of the total kilowatt-hours purchased. While a typical kiln fan may only be 10 HP, a facility with large track kilns can use upwards of 600 HP total. These fans running for over 8600 hours per year can consume over 3,850,000 kilowatt hours (kWh).

If these fans are operated at or near full speed for the entire drying cycle, they are probably providing more air flow than required to sufficiently dry the lumber, and therefore, are using more power than necessary. Research by William T. Simpson for the U.S. Department of Agriculture was published in a 1997 Research Note (FPL-RN-266) called "Effect of Air Velocity on the Drying Rate of Single Eastern White Pine Boards." Simpson concluded that "[t]he rate of increase in drying rate with air velocity gradually decreased and tended to level off with air velocities above approximately 600 to 700 ft/min and moisture contents below 80% to 90%." (Simpson, p. 4.)

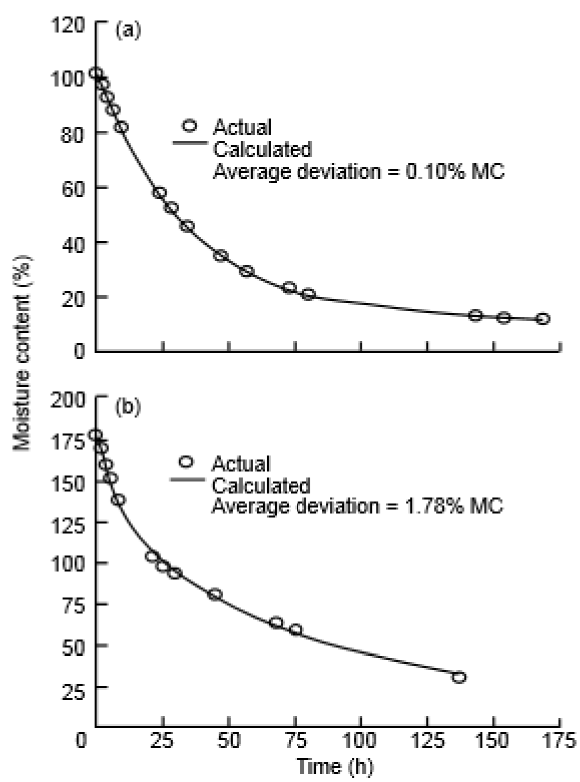


Figure 1 – Moisture content – time drying curves (Simpson, p. 3)

Simpson says that "…at any stage of drying, there is an optimum air velocity. Slowing the drying process below these optimum values wastes kiln capacity, increases heat loss from the kiln, and risks lumber stain. Accelerating the drying process by using higher than optimum values wastes electrical energy for operating fans and imposes unnecessary wear on the fan-motor-shaft system. Because of fan characteristics, modest reductions in air velocity cause great reductions in electrical power." (Simpson, p.1.)

Further analysis of Simpson's data suggests additional support for fan speed reduction. In his conclusions, Simpson states, "[t]he rise in drying rate with air velocity is gradual, with the greatest increases at low air velocities. At moisture contents below approximately 60%, air velocity has little effect on drying rate." (Simpson, p. 3.) His results are shown in Figure 2.

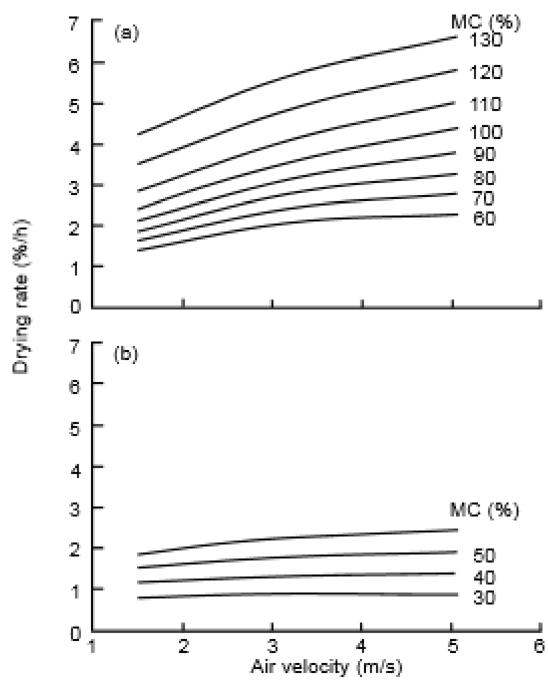


Figure 2- Effect of air velocity and moisture content on drying rate (Simpson, p. 5)

Simpson found that the drying rate decreased as the moisture content was reduced. As the drying rate is decreased, less air flow is required to remove that moisture from the surface of the wood. Therefore, the fan speed can be reduced as the drying process progresses, thereby reducing the cost to run the fan.

This also supports the idea of larger fan speed reductions during the "conditioning" stages of the drying cycle, when the moisture content has been significantly reduced.

Solutions

Theoretical Savings

The Affinity Laws for fans are used to express the influence on volume capacity and power consumption due to

1. change in **fan speed** - revolutions per minute (*rpm*); and/or
2. geometrical similarity by change in **impeller diameter**.

The power consumption of a centrifugal fan can be expressed as

$$P_1 / P_2 = (n_1 / n_2)^3 (d_1 / d_2)^5$$

Where
P = power (watts, horsepower)
n = fan speed - revolution per minute - (rpm)
d = impeller diameter

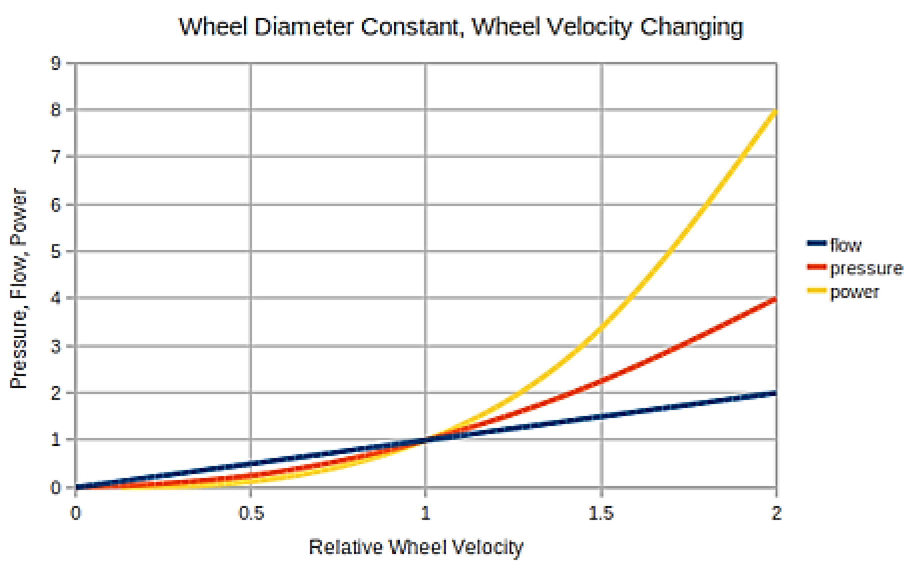


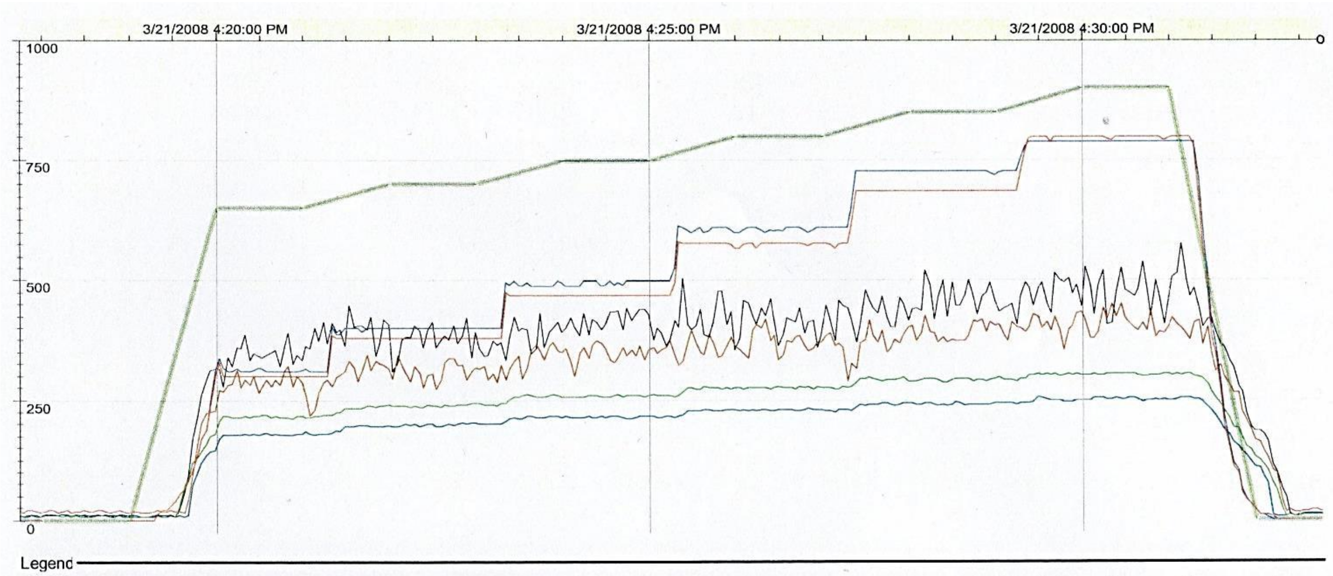
Figure 3 – Fan Affinity Laws (EngineeringToolbox.com)

It can be seen from the graph in Figure 3 that the air flow is directly proportional to the fan speed. In other words, if the relative fan speed doubles, the air flow also doubles. Similarly, Figure 3 shows that the air pressure is proportional to the square of the fan speed. Therefore, if the fan speed is doubled, the air pressure is multiplied by a factor of 4. Lastly, the fan power consumption is proportional to the cube of the fan speed, so if the fan speed is doubled, the power consumption is multiplied by a factor of 8!

Obviously, this concept works in the reverse, as well. While reducing the fan speed by only 12%, or slowing the fans down from a base speed of 900 RPM to a speed of 800 RPM, the power consumption can be cut in half. In other words, running a 10 HP fan at a reduced speed of about 800 RMP, a power savings of about 3.75 kW should theoretically be realized. With the number of fans required at a large facility, this cost savings can add up quickly.

Real-world Savings

To test the feasibility of fan speed reduction, Progress Engineering conducted an experiment at a large eastern white pine sawmill. Air flow anemometers were installed inside a kiln to measure the effect of fan speed on air flow and power consumption. By using four velocity sensors moved to three incremental elevations, and in both forward and reverse fan directions, 24 air velocity readings were available to be averaged for each fan speed. Fan speeds between 700 and 900 RPM were incremented and allowed to stabilize, before incrementing to the next fan speed, during each run. A single incremental fan speed test run is shown in Figure 4:



	Name	Start	End	Duration	Scale	Units	Min	Max	Avg
	Kiln #06 Air Velocity Study Sensor #1	3/21/2008 4:17:44 PM	3/21/2008 4:32:44 PM	00:15:0	0 - 150	ft/min	9.775	864.23	510.58579
	Kiln #06 Air Velocity Study Sensor #2	3/21/2008 4:17:44 PM	3/21/2008 4:32:44 PM	00:15:0	0 - 150	ft/min	8.2875	383.35	269.37116
	Kiln #06 Air Velocity Study Sensor #3	3/21/2008 4:17:44 PM	3/21/2008 4:32:44 PM	00:15:0	0 - 150	ft/min	20.329	675.60	432.81779
	Kiln #06 Air Velocity Study Sensor #4	3/21/2008 4:17:44 PM	3/21/2008 4:32:44 PM	00:15:0	0 - 150	ft/min	8.2875	458.717	325.62410
	Kiln #06 Fan #1 Power Consumption	3/21/2008 4:17:44 PM	3/21/2008 4:32:44 PM	00:15:0	0 - 10	kW	0	7.87421	4.462018
	Kiln #06 Fan #2 Power Consumption	3/21/2008 4:17:44 PM	3/21/2008 4:32:44 PM	00:15:0	0 - 10	kW	0	7.9992	4.302972
	Kiln #06 Fan Speed Setpoint	3/21/2008 4:17:44 PM	3/21/2008 4:32:44 PM	00:15:0	0 - 100	RPM	0	900	619.94626

Figure 4 – Test Results for a Single Fan Speed Incremental Run (Progress Engineering)

The graphical data confirms that, while the air velocity rises proportionally with the fan speed, the fan power consumption rises exponentially with fan speed. The average values of the recorded data provided the results in Table 1:

Fan Speed (RPM)	Average Air Velocity (FPM)	Average Power (kW)
650	316.0	2.61
700	387.4	3.89
750	416.5	4.81
800	444.0	5.87
850	466.4	7.04
900	487.6	7.87

Table 1 – Average Air Velocity and Power Consumption Data (Progress Engineering)

The graph in Figure 5 was created from the average data and shows the non-linear relationship between the air velocity and the power consumption. As speed is increased, there is a gradual increase in air velocity, while the power consumption increases sharply as fan speed is increased. The test results showed that sufficient air flow velocities, as suggested by Mr. Simpson, might be achieved in a square box package kiln with fan speeds as low as 700 RPM. Furthermore, the actual power consumption of 5.87 kW (23% power reduction) measured at 800 RPM (12% fan speed reduction), while not as much as the Affinity Laws suggested, was still significant:

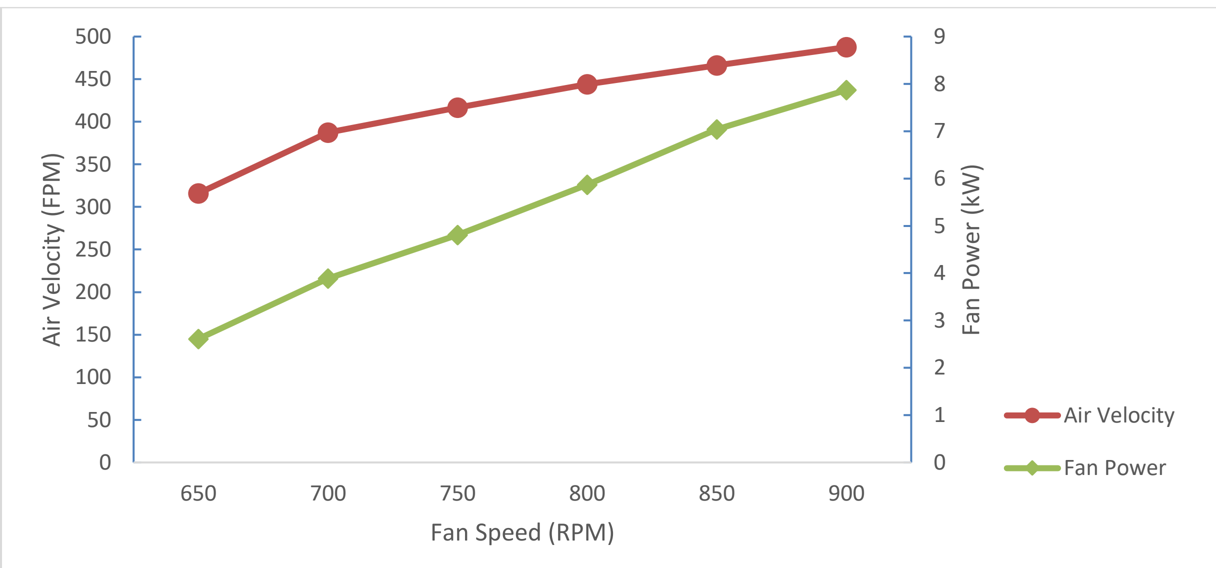


Figure 5 – Effect of Fan Speed on Air Velocity and Power Consumption (Progress Engineering)

Cost Saving Analysis

The preceding data results are the basis for the computation of the cost savings expected by reducing fan speeds by various amounts, during the entire cycle. The following assumptions are used for the cost savings analysis:

- 10 HP, 900 RPM fans
- Kilns run for 8640 hours per year (180 hour drying cycle, 45 cycles per year)
- Kilns are in conditioning mode for 3480 hours per year (80 hours per cycle, 45 cycles per year)
- Electrical energy cost is $0.14 per kWh, delivered to the mill
- Current fan velocity is 850 RPM for the entire cycle

Fan Speed Reduction during the Full Drying Cycle

Reduced fan speeds of 800 RPM, 750 RPM, and 700 RPM all produced air velocities within 100 FPM (20%) of the air velocity at 850 RPM, so these values were used in the analysis. The following equation, based on the assumptions listed above, was used to calculate the cost savings for each fan:

$$\text{\$ Saved/yr} = (kW_{850\ RMP} - kW_{x\ RPM}) \times \$0.14/kWh \times 8640\ hrs/yr$$

To calculate savings for the entire kiln operation, the calculated number was multiplied by 60 (the number of fans at the facility). Table 2 uses the above equation to calculate the cost savings for each applicable speed reduction:

Fan Speed (RPM)	Average Power (kW)	Reduced Air Flow (%)	Savings per Fan per Year	Facility Savings per Year
850	7.04	---	---	---
800	5.87	4.8	$1415	$84,913
750	4.81	10.7	$2697	$161,844
700	3.89	16.9	$3810	$228,614

Table 2 – Cost Savings for Different Fan Speeds for Kiln Full Cycle (Progress Engineering)

This should be considered to be a best case scenario. As there will be some reduction in air velocity with the reduced fan speed, the optimal velocity should be determined for best results.

Cost Savings Analysis during Conditioning Only

A more conservative place to start saving is based on Mr. Simpson's statement that "at moisture contents below 60%, air velocity has little effect on drying rate." Because of this, we calculated the cost savings if the fan speed was reduced during conditioning only. To calculate cost savings per fan, the following equation was used:

$$\$\ Saved/yr = (kW_{850\ RMP} - kW_{x\ RPM}) \times \$0.14/kWh \times 3840\ hrs/yr$$

By using this equation, which accounts for only 3840 hours of the yearly drying cycles, the cost savings shown in Table 3 could be realized:

Fan Speed (RPM)	Average Power (kW)	Reduced Air Flow (%)	Savings per Fan per Year	Facility Savings per Year
850	7.04	---	---	---
800	5.87	4.8	$629	$37,739
750	4.81	10.7	$1199	$71,930
700	3.89	16.9	$1693	$101,606

Table 3 – Cost Savings for Different Fan Speeds for Kiln Conditioning Only (Progress Engineering)

With Mr. Simpson's conclusions in mind, this table could be extrapolated down to as low as 300 RPM, just to keep air circulating. However, the optimal velocity should be determined for best results.

Conclusion

Clearly, small fan speed reductions can yield large cost savings. Our testing shows that reducing the fan speed from 900 RPM to 800 RPM reduced the power consumption by 23%, while only reducing the air velocity by 8.8%. For fans running at full speed using full voltage starters, installation of Variable Frequency Drives (VFDs) can yield substantial returns. Furthermore, our testing shows that a reduction of fan speed from 850 RPM to 800 RPM reduced the power consumption by 16.7%, while it only reduced the air velocity by 4.8%. In the case of our test mill, which was already using VFDs, significant cost savings could be realized with no financial investment.

Simpson's research, along with many others, has led to his profound statement that "[k]nowledge of air velocity effects on drying rate is useful for determining optimum air velocity. In fact, if the optimum air velocity were known for each step in a kiln schedule, air velocity specifications could be added to dry- and wet-bulb temperatures for each step." (Simpson, p.3.) In this way, kiln schedules could be tuned for optimal performance.