

# HEAT TRANSFER EVALUATION

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## Dry Kiln Operations

The lumber drying process has been identified as the most energy intensive portion of the lumber manufacturing process. With today's energy costs and mounting process restrictions, managing the drying process in terms of cost, production time, process quality requires a manager to continuously improve his technical skills. In the process of lumber drying there are several factors involved in the process of moisture extraction. The purpose of this presentation is to identify several aspects of the drying process and to outline some techniques assist the manager in monitoring his operation.

## A Typical Process

A typical drying process is a batch operation which typically involves several dry kilns, usually a steam heated, track kiln with a holding capacities ranging from as small a 50,000 bd-ft to as much as 225,000 board feet. To clarify the issues presented we will consider 200,000 bd ft holding capacity is as a typical load in our drying process (see Figure 1). Other factors for our model include lumber conditions, kiln systems capacities, selected drying schedules. In considering the drying load itself in the drying process, we realize that the moisture content alone of the lumber can represent 40% to 200% + of the total weight of the dried product. Remembering that moisture content is defined as the weight of water in wood expressed as a fraction, usually as a percentage of the weight of oven dried wood. Coastal Hemlock, as an example, can be found to have a moisture content of 120%. From our work in wood technology we can determine that with this level of moisture and a given oven dry density of 27.5 pounds per cubic foot, this would equate to a green bd-ft weight of 5.042 pounds. ( 27.5 lb /12 bd ft per cubic foot x 220%). If we then consider a typical drying process involving a 104' double track kiln, or therefore a lumber volume of approximately 200,000 bd ft., Then the process would involve the evaporation of 2.75 pounds of water per board foot to reduce the wood moisture content to a target 15% moisture level. To consider the entire volume, this would then reflect 550,000 pounds of water removed in the entire process. Depending upon system efficiencies, process temperature, etc., typical energy requirements for evaporating one

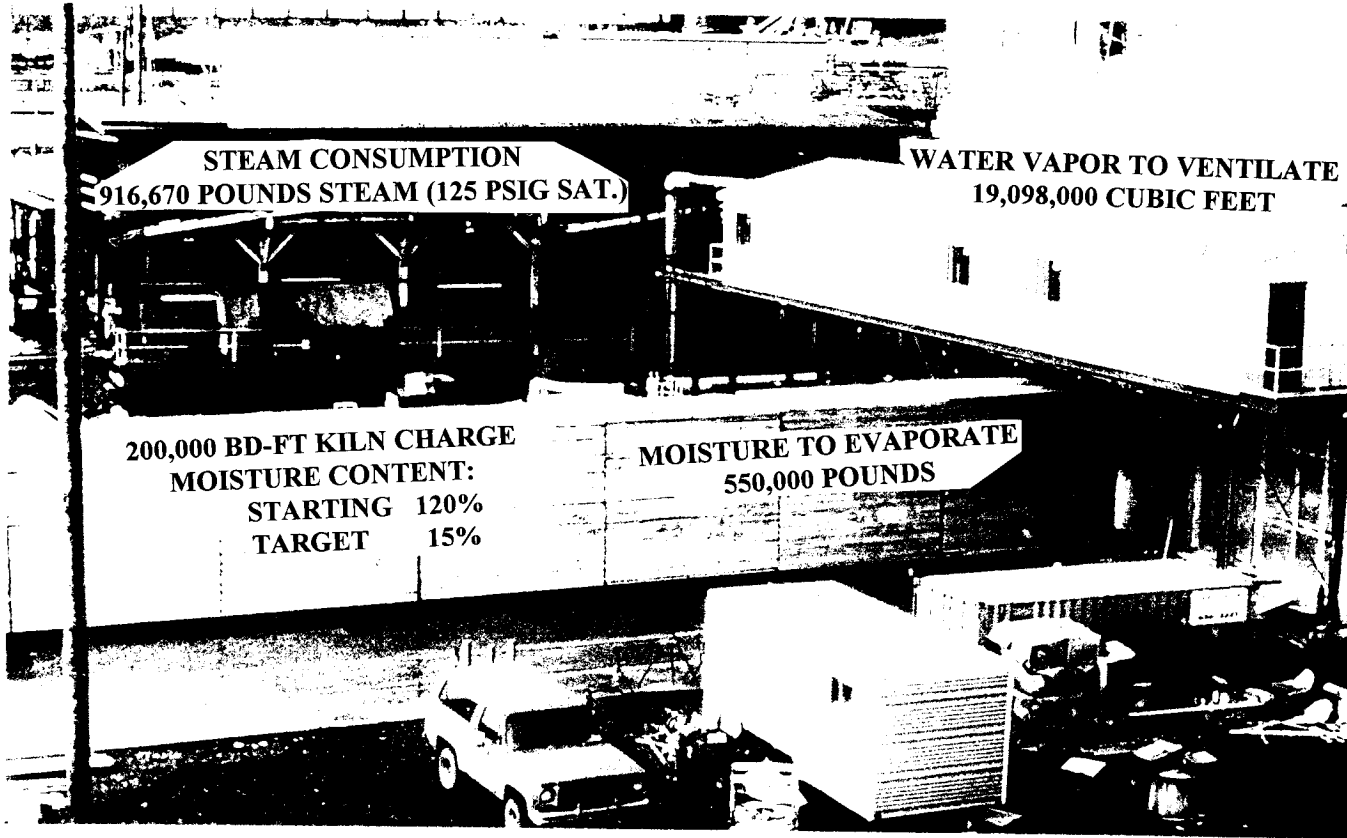


FIGURE 1. Heat transfer evaluation study model.

pound of water range from 1250 to 1600 BTU's per pound of water evaporated. (Noting that by definition 1000 BTU's per pound of water are required to convert one pound of water at 212 °F at standard conditions, from liquid to vapor state, these BTU's in excess of 1000 are consumed to raise the mass to evaporation temperature, and are consumed in ventilation and wall losses.) More exacting figures can be identified by measuring specific parameters such as wall losses, specific process variables, and other elements of a traditional "process energy audit".

However, short of engaging in an in-depth study, This 1250 to 1600 BTU "rule of thumb" can be can be very helpful to the operator in evaluating his process. It is assumed that a mild, conventional drying process would likely be in the 1250 BTU per pound energy economy, while high temperature drying will be in the 1600 BTU per pound of water area or higher, depending on how aggressive the process is.

For our model, we will assume a high temperature equipped kiln with matching schedules, and a 1450 BTU per pound of water evaporated economy of operation. Therefore, it would follow that the evaporation process for our model will require 797,500,000 BTU's to evaporate the excess moisture from our model kiln charge. Assuming that we are using 125 psig saturated steam for our process, and that from our steam tables (Figure 2) we are condensing steam at this state point, the energy released per pound of steam condensed would be approximately 870 BTU's per pound of steam. This in turn suggests that a total of 916,670 pounds of steam will be consumed for this process. If, in turn the process or drying schedule is 72 hours, the average steam flow to the system would be 12,732 pounds per hour of steam.

A 72 hour schedule would suggest at average heat release of 11,076,400 BTU, per hour released into the dry kiln circulating airflow by the heating coils. An analysis of the heat consumption of the process by the wet material absorbing the heat released by the coils and converting the moisture in the wood fiber into water vapor and dispersing into the circulating air mass can be modeled after the following mass flow heat equation:

$$\text{Heat Absorbed (BTU's/hr)} = \text{Circulating Air Mass(lb/hr)} * \text{Specific Heat Value of Air(BTU/lb-°F)} * \text{Temperature Difference Across the Load (°F)}$$

Where:

1. The circulating air mass is calculated from fan performance data.
2. The specific heat of air is determined from calculations and values from tables.
3. The temperature drop across the load is taken from the process data.

Temp. Fahr. t	SPECIFIC VOLUME			ENTHALPY			ENTROPY			Abs. Press. Lb./Sq. In. p
	Sat. Liquid v <sub>l</sub>	Evap. v <sub>fg</sub>	Sat. Vapor v <sub>g</sub>	Sat. Liquid h <sub>l</sub>	Evap. h <sub>fg</sub>	Sat. Vapor h <sub>g</sub>	Sat. Liquid s <sub>l</sub>	Evap. s <sub>fg</sub>	Sat. Vapor s <sub>g</sub>	
32.00	0.01602	3305.7	3305.7	0	1075.1	1075.1	0	2.1865	2.1865	<b>0.0886</b>
40.69	0.01602	2383.7	2383.7	8.74	1070.2	1078.9	0.0176	2.1388	2.1564	<b>0.125</b>
59.31	0.01603	1235.3	1235.3	27.38	1059.5	1086.9	0.0542	2.0414	2.0956	<b>0.250</b>
79.58	0.01607	641.71	641.73	47.60	1048.0	1095.6	0.0924	1.9434	2.0358	<b>0.500</b>
101.76	0.01614	333.77	333.79	69.72	1035.5	1105.2	0.1326	1.8443	1.9769	<b>1</b>
162.25	0.01641	73.584	73.600	130.13	1000.7	1130.8	0.2347	1.6090	1.8437	<b>5</b>
193.21	0.01659	38.445	38.462	161.17	982.1	1143.3	0.2834	1.5042	1.7876	<b>10</b>
212.00	0.01672	26.811	26.828	180.07	970.3	1150.4	0.3120	1.4446	1.7566	<b>14.696</b>
213.03	0.01672	26.303	26.320	181.11	969.6	1150.7	0.3135	1.4413	1.7548	<b>15</b>
227.96	0.01683	20.093	20.110	196.16	959.9	1156.1	0.3356	1.3959	1.7315	<b>20</b>
250.34	0.01700	13.746	13.763	218.83	945.2	1164.0	0.3680	1.3312	1.6992	<b>30</b>
267.24	0.01715	10.489	10.506	236.02	933.7	1169.7	0.3919	1.2844	1.6763	<b>40</b>
281.01	0.01727	8.505	8.522	250.09	923.9	1174.0	0.4110	1.2473	1.6583	<b>50</b>
292.71	0.01738	7.162	7.179	262.10	915.4	1177.5	0.4271	1.2166	1.6437	<b>60</b>
302.92	0.01748	6.193	6.210	272.61	907.9	1180.5	0.4409	1.1905	1.6314	<b>70</b>
312.03	0.01757	5.458	5.476	282.02	901.1	1183.1	0.4532	1.1677	1.6209	<b>80</b>
320.27	0.01766	4.880	4.898	290.57	894.8	1185.4	0.4641	1.1472	1.6113	<b>90</b>
327.83	0.01774	4.415	4.433	298.43	888.9	1187.3	0.4741	1.1287	1.6028	<b>100</b>
334.79	0.01782	4.032	4.050	305.69	883.3	1189.0	0.4832	1.1118	1.5950	<b>110</b>
341.26	0.01789	3.710	3.728	312.46	878.1	1190.6	0.4916	1.0963	1.5879	<b>120</b>
347.31	0.01796	3.437	3.455	318.81	873.2	1192.0	0.4995	1.0820	1.5815	<b>130</b>
353.03	0.01803	3.202	3.220	324.83	868.5	1193.3	0.5069	1.0686	1.5755	<b>140</b>
358.43	0.01809	2.998	3.016	330.53	863.9	1194.4	0.5138	1.0560	1.5698	<b>150</b>
363.55	0.01815	2.816	2.834	335.95	859.6	1195.5	0.5204	1.0442	1.5646	<b>160</b>
368.42	0.01821	2.656	2.674	341.11	855.2	1196.3	0.5266	1.0327	1.5593	<b>170</b>
373.08	0.01827	2.514	2.532	346.07	851.1	1197.2	0.5325	1.0220	1.5545	<b>180</b>
377.55	0.01833	2.386	2.404	350.83	847.2	1198.0	0.5382	1.0119	1.5501	<b>190</b>
381.82	0.01839	2.270	2.288	355.40	843.3	1198.7	0.5436	1.0021	1.5457	<b>200</b>
385.93	0.01844	2.165	2.183	359.80	839.6	1199.4	0.5488	0.9929	1.5417	<b>210</b>
389.89	0.01850	2.067	2.086	364.05	835.8	1199.9	0.5538	0.9838	1.5376	<b>220</b>
393.70	0.01855	1.9803	1.9989	368.16	832.2	1200.4	0.5585	0.9752	1.5337	<b>230</b>
397.40	0.01860	1.8990	1.9176	372.16	828.7	1200.9	0.5632	0.9669	1.5301	<b>240</b>
400.97	0.01866	1.8244	1.8431	376.04	825.4	1201.4	0.5677	0.9590	1.5267	<b>250</b>
417.33	0.01890	1.5237	1.5426	393.85	809.3	1203.2	0.5879	0.9228	1.5107	<b>300</b>
431.71	0.01912	1.3064	1.3255	409.70	794.7	1204.4	0.6057	0.8915	1.4972	<b>350</b>

FIGURE 2. Steam table: Pressure table.

## Air Circulation System

Typical circulation air flow for a kiln of this size would be composed of 10 fans with a range of 75 to 250 connected fan motor horsepower. For our model we will assume 150 connected horsepower, or 15 horsepower per fan. Kiln fans are typically 72" diameter, 6 bladed, aluminum cast, adjustable pitch airfoil assemblies. Typical fan performance curves for this style propeller fan suggest .6" water column static pressure across the fan wall and a typical corresponding fan volume of 64,000 cfm or a combined volume of 640,000 cfm. (Such a fan package would likely produce an average crib exiting velocity in the area of 950 ft per minute.) 640,000cfm at 200°F has a density of 0.06 pounds per cubic foot (Figure 3) and can be expressed in terms of pounds per hour by the following equation:

$$\text{Circulating Air Mass (lb/hr)} = 640,000 \text{ cu-ft/minute} \times 60 \text{ min/hr} \\ \times 0.06 \text{ lb/cu-ft}$$

$$\text{Circulating Air Mass} = 2,304,000 \text{ lb/hr}$$

### Specific Heat Value for Air (as a mixture of air and water vapor)

The specific heat value from air can be obtained by calculation per the following equation:

$$\text{Specific Heat Air or } C_v \text{ (BTU/lb-°F)} = .240 + 0.44(W) \text{ BTU/lb dry air}$$

Where "W" is defined as specific humidity or Water Vapor Mass/Pound Dry Air. This value is normally found in psychometric tables (Figure 5). For our purposes, this value at process temperature (200°F Dry Bulb, 180°F Wet Bulb) has been determined to be 0.6 .pounds of water vapor per pound of dry air.

Therefore the specific heat of the circulating air mass at this process condition is determined to be (0.240 + 0.44(0.6) BTU/lb dry air - °F) or

$$\text{Specific Heat of Air is } 0.504 \text{ ( BTU/lb dry air - °F).}$$

(It is interesting to notice that as the specific humidity increases, so does the specific heat value, or the ability of the air mass to transfer heat.)

### Temperature Difference Across the Load

This value is normally displayed by all the microprocessor based controllers now on the market. Older kilns will require some additional equipment to allow the operator to observe crib exiting temperature values.

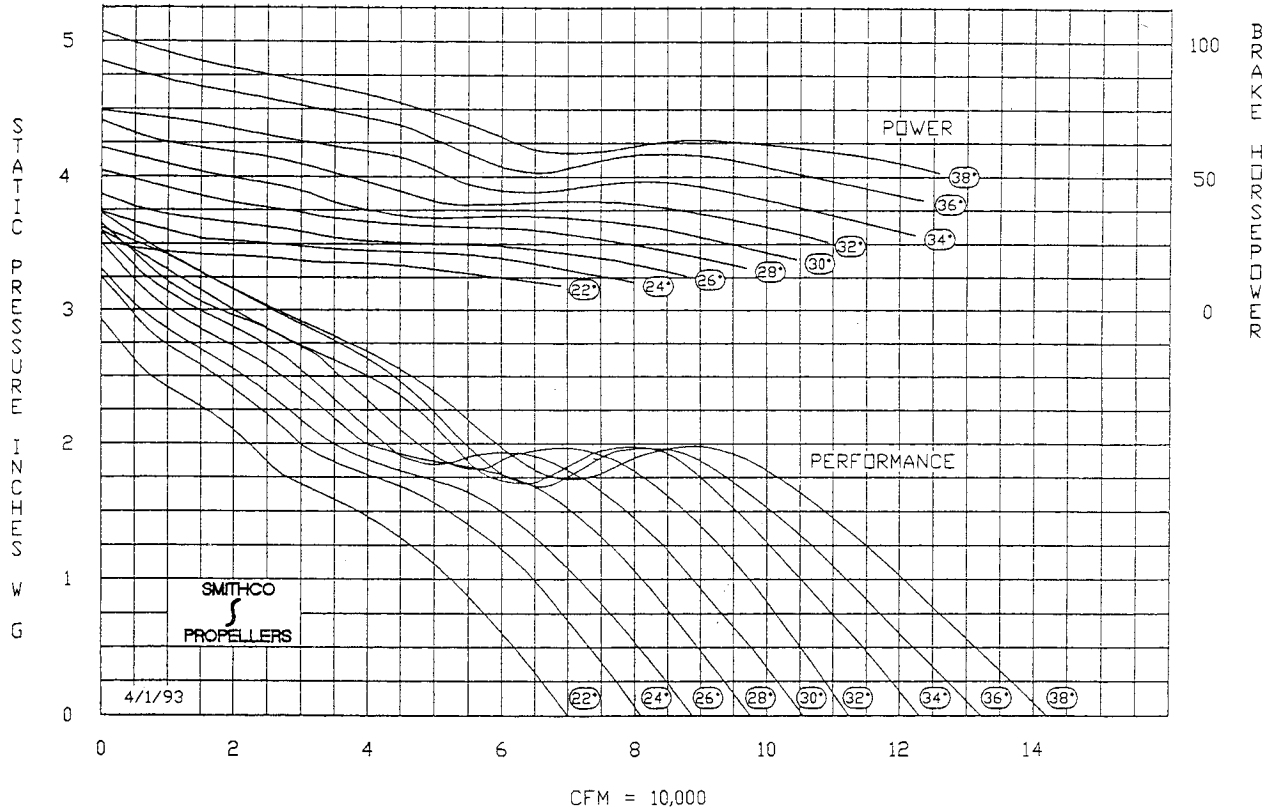


FIGURE 3. 875 rpm curve for Smithco SMI-72-6 blade propeller.

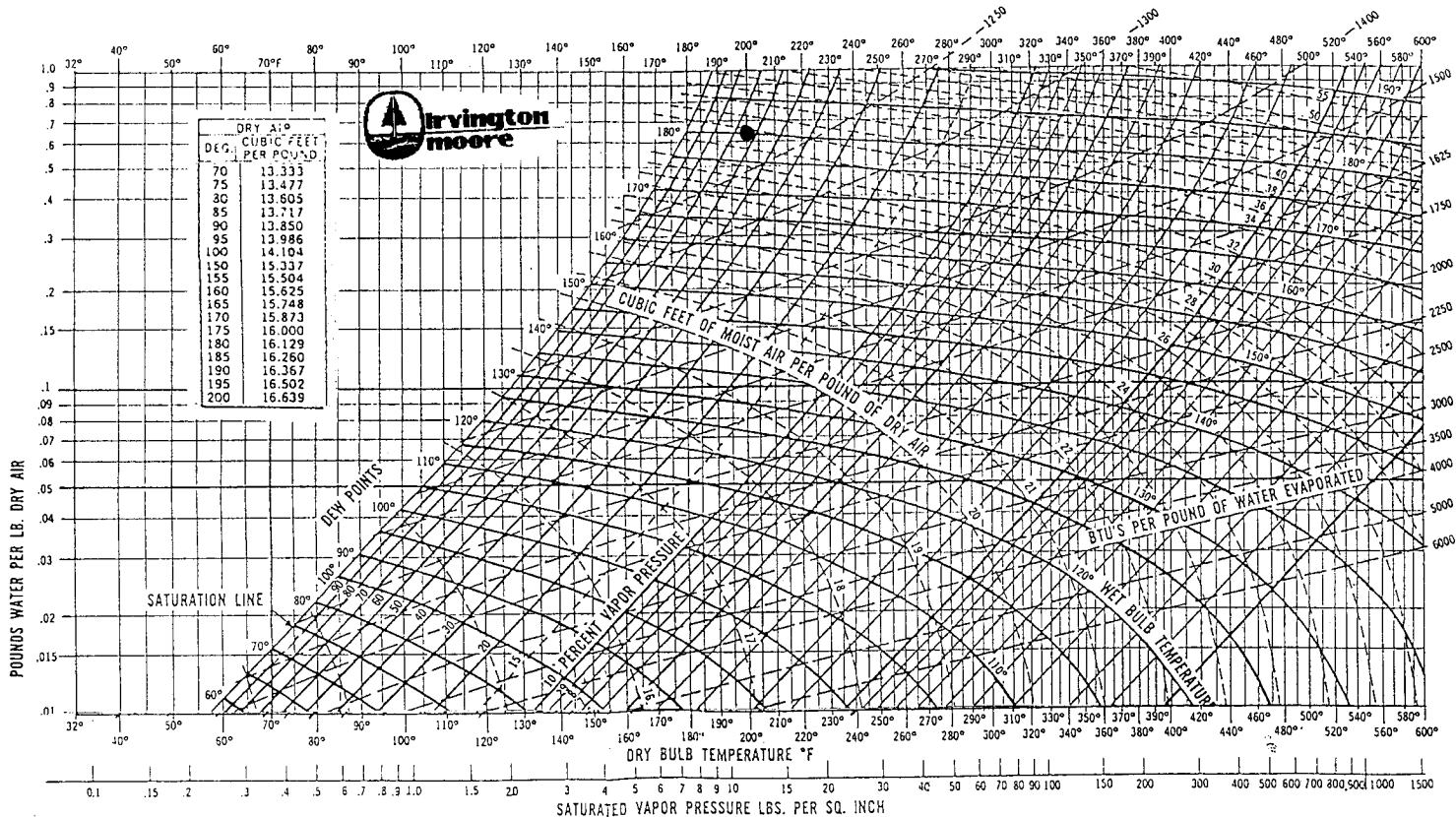


FIGURE 4. Psychrometric chart for 32 to 600°F.

The difference in the inlet and discharge temperatures is then simply tabulated. For a kiln of this type a typical temperature measurements would be:

Temperatures            inlet side = 200°F  
                                  outlet side = 190°F  
                                  differential = 10°

Once these values are determined, the operator has the ability to then calculate the average heat absorbed by the lumber charge. For our model, the following values would have been developed:

Circulating Air Mass = 2,304,000 (lb/hr)  
 Specific Heat of Air = 0.504 (BTU/lb dry air - °F).  
 Temperature differential = 10°F

Therefore, for these conditions, the following kiln thermal load is calculated:

Heat Absorbed (BTU's/hr) = Circulating Air Mass(lb/hr) \* Specific Heat Value of Air(BTU/lb-°F) \* Temperature Difference Across the Load (°F)

Heat absorbed = 2,304,000 (lb/hr) x 0.504 (BTU/lb - °F) x 10°F  
 = 11,612,000 BTU/hr

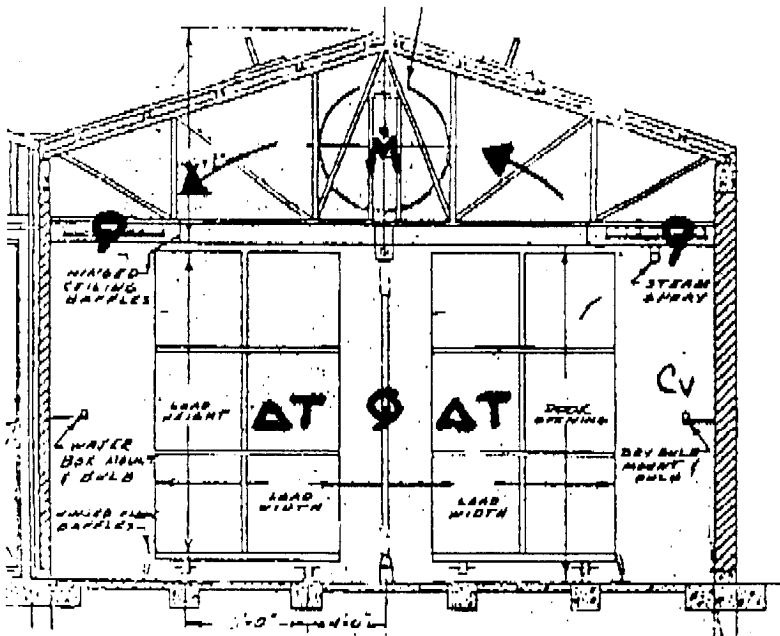


FIGURE 5. Diagram for calculation of heat absorbed.



## Ventilation Evaluation

Assuming that the moisture laden air mass is vented to atmosphere and replaced by ambient air, the following considerations can be made. From standard steam tables (Figure 2), it can be determined that one pound of water in the liquid phase will expand to a volume of 33.67 cubic feet when evaporated into the vapor phase at the process temperature of 200°F. Therefore, in this process the water mass in liquid phase will absorb thermal energy, go through a phase change and expand. The total volume of water to be evaporated in this process represents 550,000 pounds, or 18,519,000 cubic feet of vapor. When maintained as a mixture as prescribed by the drying schedule state point of 200 °F dry bulb, 180°F wet bulb, the specific humidity conditions define a ration of 32 cubic foot of water vapor per cubic foot of dry air (Figure 4). Therefore, this vapor volume then is to be diluted by dry air to maintain this air to water vapor ratio. Therefore, the circulating air mass is composed of a mixture of water vapor and dry air, that, must be represented by a vented volume of 19,098,000 cubic feet. Sustained over a 72 hour drying schedule, this would represent an average ventilation rate of 4,421 cfm. By determining the average volume of air vented per unit time that can be exhausted through the roof vent system, a ventilation cycle rate can be calculated for this process condition. This ventilation rate should therefore balance with the calculated moisture extraction rate, at the prescribed psychometric state point , and this in turn should relate to the temperature differential measured across the kiln charge.

### Model Analysis

Based upon the heat absorption rate we have calculated, the following observations can be made:

The steam condensing rate at for these conditions is 13,347 pounds per hour. (11,612,000 BTU/hr / 870 BTU/pound of steam -from steam tables)

The evaporation rate of the moisture for these conditions, including factor for process heat losses is 8,008 lb per hour. (11,612,000 BTU/hr / 1450 BTU per pound water)

The ventilation system for these conditions should cycle so as to exhaust an average 4,441 cfm.

### Summary

The dry kiln operator can be better equipped to monitor and anticipate the existing wood moisture content, the approximate moisture evaporation and therefore the water vapor generation rate, and the subsequent ventilation

cycle rates through the kiln schedule by obtaining and monitoring average air temperatures across the kiln charge, determining the capacity of the circulation system (at various speeds, if variable speed drives are utilized), boiler firing rate or steam flow rate, lumber properties and entering moisture content, roof ventilator ventilation capacity. Your kiln manufacturer, and related systems vendors can be of great assistance in gathering this performance data. All these parameters are inter-related. As they are studied observed, and understood by the operator, they will combine to form a clear picture of the drying process. When variables such as changes in the type or condition of the lumber, weather, boiler, or kiln system malfunctions occur affecting the drying process, the operator can be better equipped to detect problems, and monitor the effects of corrections by observing the effects of these variables. By observing these conditions, the operator can better monitor his process and be better prepared to deal with the continuously changing requirements of the managing of lumber drying operations.