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TB73: Estimating Heat Consumption in Kiln Drying Lumber

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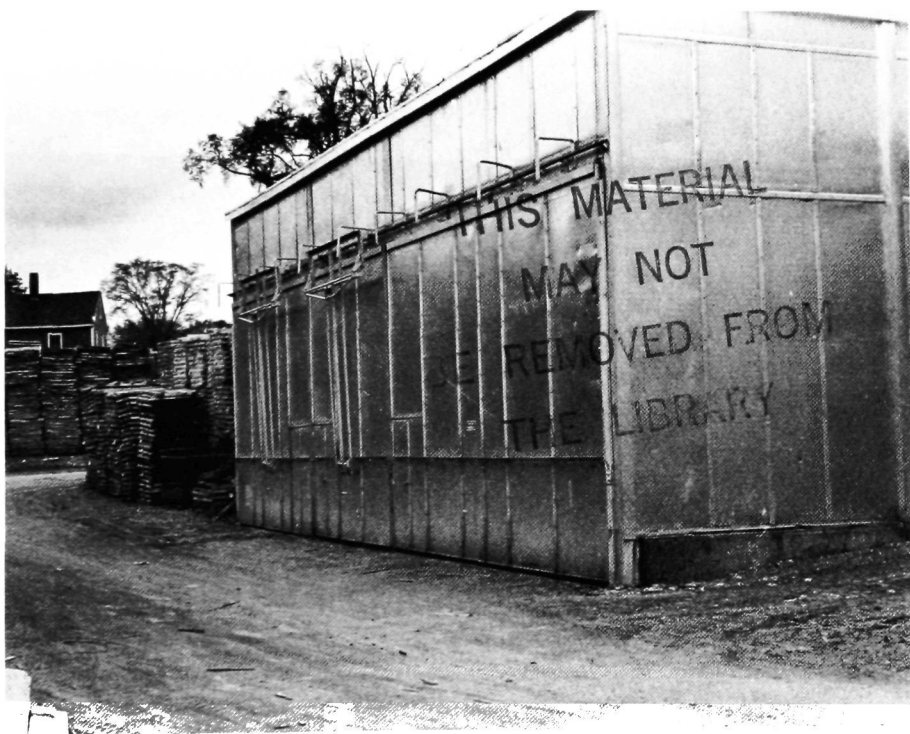 Part of the Wood Science and Pulp, Paper Technology Commons

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ESTIMATING HEAT CONSUMPTION IN KILN DRYING LUMBER

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Craig E. Shuler

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CONTENTS

ESTIMATING HEAT CONSUMPTION IN KILN DRYING LUMBER

James E. Shottafer and Craig E. Shuler[*]

INTRODUCTION

With increasing emphasis on the cost and availability
of energy, the heat consumed in the kiln drying of lumber
has become a point of immediate interest to the wood con-
version industries. The use of green, or undried lumber
is undesirable in most cases, and impossible in many others.
Modern production schedules often do not permit the elapsed
time necessary to air dry lumber to an acceptable moisture
content level, and in many areas of the Northeastern United
States, the terminal equilibrium moisture content that may
be attained is still unacceptably high. Since the use of
heat, often in significant quantities, is necessary to kiln
dry wood satisfactorily, some method should be available to
quantitatively estimate the consumption of this heat during
the drying processes. Such an estimate should provide the
kiln operator with some comparative measure of the efficiency
of the kiln and the procedures employed in its use, and per-
mit more precise estimates of potential materials processing
costs.

This report presents one method for systematically
estimating heat consumption in a dry kiln. The basis for
evaluating heat use is presented along with a description of
the specific elements of heat consumption. A necessary
physical relationships are described in detail for those who
wish to employ them. One point of interest here is the fact
that the system described will readily lend itself to the
construction of a mathematical model The operator with the
requisite skills and a small computer, or even a modern
electronic calculator, may develop a system model for his
kiln operation with which any or all of the elements of heat
consumption may be rapidly estimated.

For the operator who prefers a more practical approach
to the problem, an example is presented which describes a
step-by-step evaluation of heat consumption in a typical kiln
drying operation. By substituting the appropriate physical
values where necessary, the method may be adapted to most
conventional kiln drying processes.

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BACKGROUND

Since the objective in kiln drying wood is basically to reduce the amount of moisture in the material to a specific level, what the heat in a kiln is fundamentally used for is to increase the temperature of the air in the kiln, so that the ability of the air to hold moisture is increased. This will cause the moisture in wood to move, for various reasons, into the air until a balance, called the equilibrium moisture content (EMC), is obtained. When the EMC is at the level we wish, the work of the kiln drying process is done.

All we really wish to do, then, is heat air; but this is complicated by the fact that some of the heat introduced into the kiln does not go where we want it to. Some is absorbed by the wood, water, kiln walls and other equipment inside the kiln. Another problem is that once we have moved the water into the air, we must then move this moist air away from the wood, to prevent the water from simply returning to the wood if the air cools. We must therefore heat new, dry air to replace the moist air we remove from the vicinity of the wood. Finally, a dry kiln or any type of drying chamber will have some loss of heat that simply escapes without performing any useful drying work.

The heat used, therefore, must accomplish four basic things in the process of drying the wood in the kiln:

a). Heat the air in the kiln or entering the kiln

b). Heat any material in the kiln

c). Provide energy for any thermodynamic requirements involved in removing the moisture from the wood

d). Compensate for any loss of heat in the system

Dry kiln engineers make quite precise calculations of the heat requirements when new kilns are being designed or during critical wood drying of kiln research. The average kiln operator seldom needs such levels of precision; however, it is often useful for the operator to have some general estimate of where the heat is going during a kiln run.

All kilns, regardless of design or type, tend to be unique, with no two exactly the same in respect to operating characteristics. Comparative estimates of the heat requirement imposed by different species, schedules, or final EMC specifications may prove of great interest to the operator Of particular use might be an occasional evaluation of the

kiln itself, in terms of the percentage of the total heat
used which is lost

ELEMENTS OF HEAT CONSUMPTION IN A DRY KILN

The four basic uses of heat, can be considered as six
specific elements. These are discussed separately, since
they are treated somewhat differently in calculations.

1. The heat required to raise the temperature of wood
    substance (H_1)

All materials have the ability to absorb heat. How
much heat is absorbed as the temperature is raised is de-
pendent upon the change from initial to final temperature,
the amount of material present, and a unique material pro-
perty known as the thermal capacity (or specific heat). The
thermal capacity of a material is found experimentally and
is a constant for any temperature.

For wood substance the thermal capacity (c) in $Btu/lb^{O}F$
is:

$$c = 0.266 + 0.000644 (T   32)$$

(Where T is the average temperature in ^{O}F.)

For any temperature range this expression becomes:

$$c = 0.266 + 0.000322 (T_1 + T_o   64)$$

(Where T_1 is the final temperature of the wood and
T_O is the initial temperature, both in ^{O}F.)

The heat requirements of the wood in the kiln are found
by the relationship of:

H_1 *Weight of wood substance $\times$ thermal capacity $\times$
        change in temperature*

2. The heat required to overcome hygroscopic forces
    (H_2)

The chemical structure of wood is such that water vapor
is readily attracted to it and held by relatively weak
chemical bonds. When the wood is nearly oven dry, the bonds
are relatively quite strong while for the free water above
the fiber saturation point, there are zero hygroscopic forces.
Experiments have indicated that 34 Btu are required to over-
come hygroscopic forces whenever one pound of wood substance
is dried from green condition to oven dry. This heat require-

-3-

ment, known as the heat of desorption, drops off rapidly as higher final moisture contents are desired.

H_2 = ovendry weight of wood $\times$ heat of desorption

3. The heat required to raise the temperature of any water remaining in the wood (H_3)

Kiln operations do not dry wood to zero moisture content. Thus at the end of the kiln run there is still some water remaining in the wood. Since during the run the temperature of the kiln has been increased, some of the heat has gone to raising the temperature of this water. The heat requirement designated as H_1 is concerned only with the heat absorbed by the wood substance itself. The heat absorbed by the residual water is found in the same manner.

H_3 = weight of residual water $\times$ thermal capacity $\times$ temperature change

The thermal capacity of water is not truly constant but is dependent upon the temperature when the measurement is made. For practical considerations, however, the thermal capacity of water can be considered to be 1 Btu/lb°F.

4. The heat required to raise the temperature and evaporate the water removed from the wood (H_4)

The heat absorbed by the water which is actually removed from the wood is also the product of the weight of the water, thermal capacity, and the temperature involved. Before the water can be removed by the air circulating in the kiln, however, it must also be evaporated. To cause this change from liquid to vapor at a given temperature requires a considerable amount of energy. This energy is effective only in bringing about the change in the physical state of the material and does not function in raising the temperature of the material. This energy is known as the latent heat of vaporization. The latent heat of vaporization for water is not a constant but is dependent upon the particular temperature at which evaporation occurs. Consequently, the heat requirement for this element must be calculated for each temperature step of the kiln schedule. The total heat consumption is simply the sum of that used in all the steps. The heat consumption H_4 at any step "a" in the kiln schedule may be calculated as:

H_4 (a)   (weight of water removed at step "a" $\times$ thermal capacity $\times$ temperature change) + (weight of water removed at step "a" $\times$ latent heat of vaporization "a")

-4-

$H_4 = H_4$ (a) $+ H_4$ (b) $+ H_4$ (c) etc. for <u>all</u> the
schedule steps.

5. The heat required to raise the temperature and
humidify the incoming vent air (H_5)

As water is removed from the wood, it becomes water
vapor in the air circulating within the kiln. When the air
becomes saturated with water vapor, new dry air must be
introduced into the kiln or the drying process will cease.
This new air must then be elevated to the temperature in the
kiln. Since kiln controls are not sufficiently precise to
allow only the exact amount of necessary air into the kiln,
a certain amount of excess air will also be admitted. The
incoming air already contains some moisture, depending on the
outside temperature and relative humidity conditions. This
moisture also absorbs some heat The excess air behaves
like the required air, but since it is just excess it must
be humidified to be brought up to the humidity conditions
of the required kiln air, which is being humidified by water
vapor from the wood. This humidification is brought about
by the direct spraying of steam into the kiln. The total
heat consumption of this element is dependent upon: the
weight of the air brought into the kiln, the weight of water
held in the vent air, the thermal capacities of the air and
the water vapor, the temperature change, and the latent heat
of vaporization needed for the production of the humidifying
vapor

6. The heat required to replace losses from the
system (H_6)

Some heat will be absorbed by the kiln structure itself
This heat will be conducted through the structure to the out-
side. In order to maintain the desired temperature in the
kiln, these losses must be replaced. The amount of loss in
this manner is dependent upon the thermal conductivities of
the various materials making up the kiln walls, roof, floor,
and other items such as doors. The combination of several
materials in a single unit (such as a wall) makes it difficult
to evaluate each thermal conductivity. As a result, a co-
efficient of heat transmission is used for the component as
a whole unit. These coefficients are determined for most
types of kiln construction and may be obtained from the kiln
construction company. The heat consumption for this element
is dependent upon the heat transmission coefficients of the
kiln materials, the surface area in question, the temperature
change, and the total time involved.

The estimate of the heat consumption during a kiln run is the sum of the heat requirements imposed by these six elements.

PROCEDURE FOR ESTIMATING HEAT CONSUMPTION IN A DRY KILN

Since each of the elements of heat consumption is responsible for some of the heat used by the kiln during a drying run, some estimate of each element must be made in order to determine the total amount of heat used. The particular method for calculating the amount of heat consumed by each element is somewhat different, but certain information is needed throughout the procedure.

The dry bulb temperature (DBT), wet bulb temperature (WBT), moisture content (MC), and the various time relationships during the kiln run must be known. All of these are available, of course, from the particular drying schedule used. An actual schedule, such as those recommended in the Dry Kiln Operators Manual, a schedule developed and followed by the kiln operator, or a graph of the schedule, such as Figure 1, may be used.

The schedule used as an example is only one of numerous possibilities. It is recognized that in many mills, eastern white pine is being dried at temperatures of at least 180°F. Also, this example does not show any equalizing or conditioning treatments. The only effect this has on heat consumption is to increase the element replacing heat losses. Since the temperatures and moisture content are no longer changing, the other elements are effectively zero.

The following thermal capacity values are used as constants throughout the entire procedure:

Air	c_a = 0.24 Btu/lb°F
Water vapor	c_{wv} = 0.45 Btu/lb°F
Water	c_{H_2O} = 1.0 Btu/lb°F

All temperatures are expressed as degrees Fahrenheit (°F), and thermal capacity or heat capacity values as British thermal units per pound per degree Fahrenheit (Btu/lb°F).

1. Determine H_1 The heat required to raise the temperature of the wood substance (Btu)

A. Determine the temperature of wood
   in the yard (°F) T_o

B. Determine the maximum temperature
   reached during the kiln run (°F) T_1

C. Calculate the average heat capacity
   of the wood substance (Btu/lb°F) c_w
   $c_w = 0.266 + 0.000322 (T_1 + T_o \quad 64)$

D. Determine the specific gravity of
   wood, based on green volume. (See
   Wood Handbook or Dry Kiln Operator's SG_{gr}
   Manual).

E. Determine the volume of wood in the
   kiln (ft^3) assuming the kiln is V_w
   filled to capacity:
   $V_w \quad \dfrac{\text{bd. ft. capacity of the kiln}}{12}$

F. Calculate the ovendry weight of the
   wood substance in the kiln (lb)   ODW
   ODW $V_w \times SG_{gr} \times 62.4$ (lbs/ft^3)

G. Determine the maximum change in tem-
   perature (°F) ΔT
   $\Delta T \quad T_1 \quad T_o$

      and:

   $H_1 \quad$ ODW $\times c_w \times \Delta T$

2. Determine H_2 The heat required to overcome
   hygroscopic forces (Btu)

   A. Using Figure 2, determine the heat
      of desorption at final moisture con-   D
      tent in the kiln schedule
      (Btu/lb of ovendry wood)

            and:

      $H_2 =$ ODW $\times$ D

3. Determine H_3 The heat required to raise the
   temperature of any water remaining in the
   wood (Btu)

A. Calculate the amount of water re-
maining in the wood at the final
moisture content in the kiln
W = ODW x final MC expressed as a decimal

and

H_3 $W \times c_{H_2O} \times \Delta T$

W

4. Determine H_4 - The heat required to raise the
temperature of the water removed from the wood,
and to evaporate it (Btu)
Note: The first four steps in this section
of the procedure must be repeated for
each dry bulb temperature stage in
the kiln schedule.

A. Using Figure 3, determine the latent
heat of vaporization of water at
dry bulb temperature level concern-
ed (Btu/lb of water)

h

B. Using the kiln schedule, determine
the moisture content change during
the dry bulb temperature period
concerned (%). Express as a
decimal.
ΔMC - (MC at start of period)
    (MC at end of period)

ΔMC

C. Determine the change in temperature
represented by the dry bulb tempera-
ture level concerned (°F)
Δt = DBT - T_o

Δt

D. Calculate H_{4i} at x °F DBT level (Btu)
(i indicates only the particular DBT
level at which the value is being
calculated)
H_{4i} = ODW x $\Delta MC \times [(C_{H_2O} \times \Delta t) + h]$

H_{4i}

REPEAT FOR EACH DBT LEVEL IN THE KILN SCHEDULE

and:

H_4 = ΣH_{4i} values, i.e. the sum of
all the H_{4i} values, or the H_4
values calculated at each DBT level
in the kiln schedule.

5. Determine H_5 The heat required to raise the temperature and humidify the incoming vent air (Btu)

   A. Using Figure 4, determine the pounds of water vapor contained in each pound of incoming vent air, based on outside temperature (T_o) and relative humidity. (lb/lb)

          b

   B. The following calculations must be made for EACH COMBINATION OF WET AND DRY BULB TEMPERATURES, OR STAGE, IN KILN SCHEDULE.

      a) Using the kiln schedule, determine the relative humidity in the kiln at the WBT-DBT combination concerned.

      b) Using Figure 4, determine the pounds of water vapor that can be held by a pound of heated air in the kiln (lb/lb)

          j

      c) Calculate the amount of water vapor that can be absorbed by the incoming vent air (lb/lb of air)
         $d = j - b$

          d

      d) Using the kiln schedule, determine the moisture content change in the wood during the WBT-DBT period concerned (%). Express as a decimal.
         Δmc (MC at start of period) – (MC at WBT or DBT change)

          Δmc

      e) A certain percentage of excess air will be required ranging from 5 to 25%, depending on the kiln. If specifications are not available for the individual kiln, a value must be assumed (%). Express as a decimal.

          E

      f) Determine the temperature of the cold water going to the boiler. (°F)

          S_o

      g) Calculate the change in temperature of the humidifying air (°F)
         ΔS DBT S_o

          ΔS

Table 1. Procedure for Calculating Total H_5 Element
(Heat Consumed in Heating and Humidifying Vent Air)

a) Calculate K, a factor used only as a convenience in completing the calculation   K

$$K = (ODW) (1 + E) [c_a + (b) (c_{vw})]$$

b) Calculate A, a factor used only as a convenience in completing the calculation   A

$$A = (ODW) (E)$$

and:

$$H_5 = K \left[\frac{\Delta mc_1 (\Delta t_1)}{d_1} + \frac{\Delta mc_2 (\Delta t_2)}{d_2} + \ldots \text{ etc} \right] + A \left[\Delta mc_1 (\Delta S_1 \, c_{H_2O} + h_1) + \Delta mc_2 (\Delta S_2 c_{H_2O} + h_2) + \ldots \text{ etc.} \right]$$

Note that the subscripts 1 and 2, etc. refer to stages 1 and 2 etc. in the kiln schedule.

C. If only the total heat consumption by
    this element, H_5, is needed it may be
    calculated by following the procedure
    in Table 1.
    If the heat consumption by this element,
    H_5, is needed for each stage, or set of
    conditions, in the kiln schedule, the
    calculations outlined in the following
    steps of the procedure must be completed.

D. For each stage in the kiln schedule, or
    combination of wet and dry bulb tem-
    perature conditions, the heat required
    for the following must be calculated:

    a) Heat the required vent air (Btu) H_a
       $$H_a \quad \frac{ODW \times \Delta mc \times c_a \times \Delta t}{d}$$

    b) Heat any water vapor entering with H_b
       the vent air (Btu)

       $$H_b = \frac{ODW \times \Delta mc \times b \times c_{wv} \times \Delta t}{d}$$

    c) Heat any excess vent air, and any H_e
       water vapor in the excess vent air
       (Btu)
       $$H_e = (H_a + H_b)\, E$$

    d) Vaporize the water needed to humidify H_h
       the excess vent air (Btu)
       $$H_h = ODW \times \Delta mc \times E \left[(c_{H_2O} \times \Delta S) + h \right]$$

E. For each stage in the kiln schedule, H_{5i}
    the heat required to raise the tem-
    perature and humidify the incoming
    vent air must be determined (Btu)
    $$H_{5i} \quad H_{ai} + H_{bi} + H_{ei} + H_{hi}$$
    Where i indicates only the par-
    ticular kiln schedule stage at
    which the H_5 value is being cal-
    culated.

    REPEAT FOR EACH STAGE IN THE KILN SCHEDULE

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and:

$H_5 = \Sigma \ H_{5i}$ values   i.e. the sum of all
the H_{5i} values calcu-
lated at each stage of
the kiln schedule.

6.   Determine H_6 - The heat required to replace
any losses from the system (Btu)

    A.   Calculate the weighted average DBT
for the entire kiln run (°F) T_{avg}

$$T_{avg} \quad \frac{(DBT_1)(n_1) + (DBT_2)(n_2) + \ldots \text{ etc.}}{n_1 + n_2 + \ldots\ldots\ldots \text{ etc.}}$$

Where n_x is the elapsed time at DBT_x

    B.   For each kiln component (walls, floor,
roof, etc.) determine the difference in ΔT_L
temperature inside and outside the kiln
(°F)
$\Delta T_L = T_{avg} - T_y$
Where T_y is the ground or air temperature
outside the kiln, depending on the loca-
tion of the component.

    C.   Determine the coefficients of heat trans-
fer for each of the kiln components U_i
(Btu/ft^2 hr). These values, for different
materials are available from a variety
of handbooks, the kiln specifications,
or FPL report R1646.

    D.   Determine H_{6i} the heat loss through
kiln component i (Btu/hr) H_{6i}
$H_{6i} = U_i \times \text{Area (ft}^2) \times \Delta T_L$
Where U, Area, and ΔT_L are for com-
ponent i

REPEAT FOR EACH KILN COMPONENT

and:

$H_6 = \Sigma H_{6i} \times$ Total drying time (hrs)

     eg: The sum of the H_{6i} values
for each kiln component,
multiplied by the length
of the kiln run in hours.

Total heat consumption may now be de-
termined, as indicated in the description
of the various elements.

$$H_{total} = H_1 + H_2 + H_3 + H_4 + H_5 + H_6$$

While the calculations appear complex,
they are actually quite simple, provided
one proceeds through them carefully, step-
by-step. An example illustrating the use
of the formulas may also prove helpful.

EXAMPLE OF ESTIMATING HEAT CONSUMPTION IN A DRY KILN

Assume a dry kiln is located in the northeast region of
the country. The kiln is 18 feet wide, 33 feet deep, and
27 feet high. The walls, roof and door are prefabricated
sheet aluminum with insulation, and the concrete slab floor
is 6 inches thick.

The proposed kiln charge is 25,000 board feet of 4/4
eastern white pine (*Pinus strobus*), with initial moisture
content in the yard of 120 percent The drying schedule
used will be Forest Products Laboratory Schedule T7-E6
(modified). The temperature of the water going to the
boilers that will heat the kiln is 45°F, and it is estimated
that 5 percent excess ventilation air will be required.

The temperature of the air outside the kiln is 35°F.
and the relative humidity is 69 percent The ground tem-
perature is estimated to be about 45°F.

1. Determine H_1 The heat required to raise the tem-
perature of the wood substance.

The initial temperature of the wood is 35°F, and the
maximum temperature reached during the kiln run is 160°F
The heat capacity of the wood is calculated:

c_w = 0.266 + 0.000322(160 + 35   64) = 0.31 Btu/lb°F

Specific gravity of the wood on green volume basis is 0.34
(Dry Kiln Operator's Manual)

V_w $\dfrac{25000}{12}$ 2083.33 cu. ft. of wood in the kiln

ODW   2083.33(0.34)(62.4) = 44,200 lbs of oven dry wood
in the kiln

Maximum change in temperature, ΔT is found by:

ΔT 160   35 = 125 °F

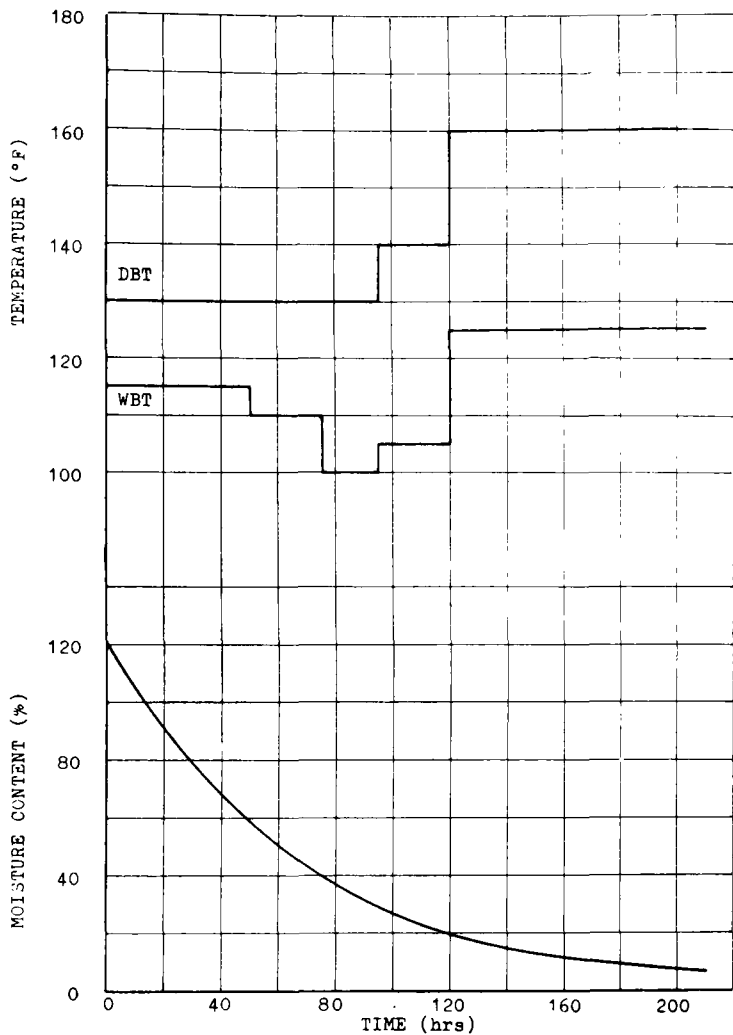H_1 ODW × c_w × ΔT (44,200)(.31)(125)   1,712,750 Btu

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Figure 1.   Temperature and moisture content for drying 4/4
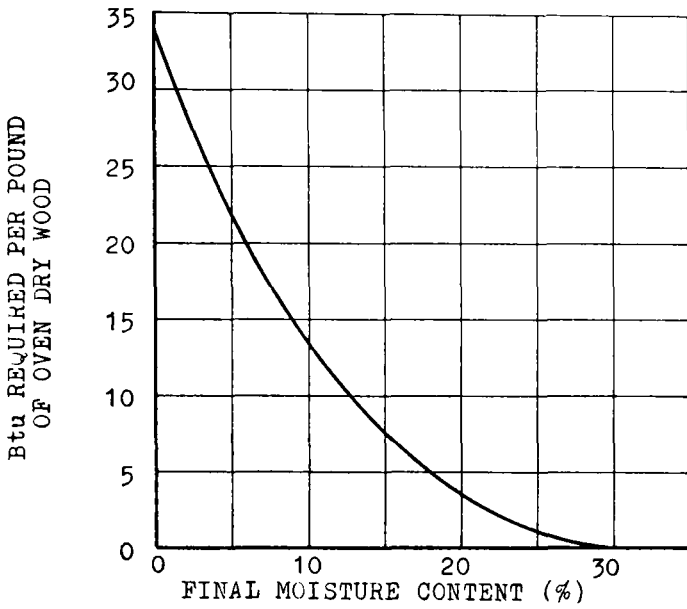eastern white pine (Schedule T7-E6, modified)

Figure 2. Heat required to overcome hygroscopic forces as related to final moisture content
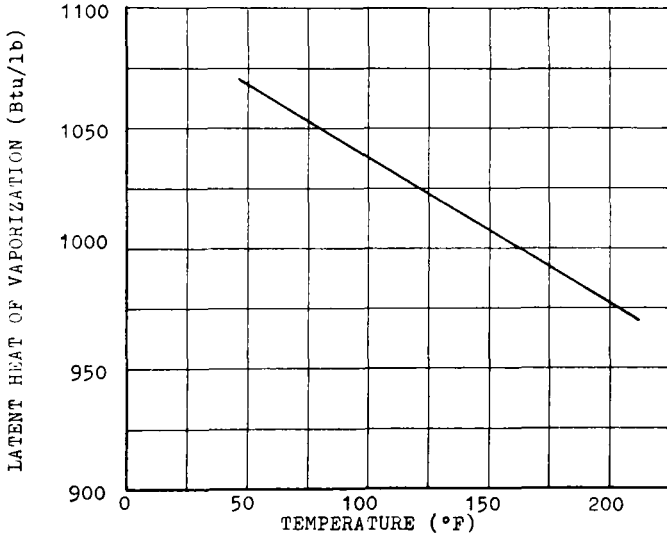

Figure 3. Latent heat of vaporization of water for various temperatures.
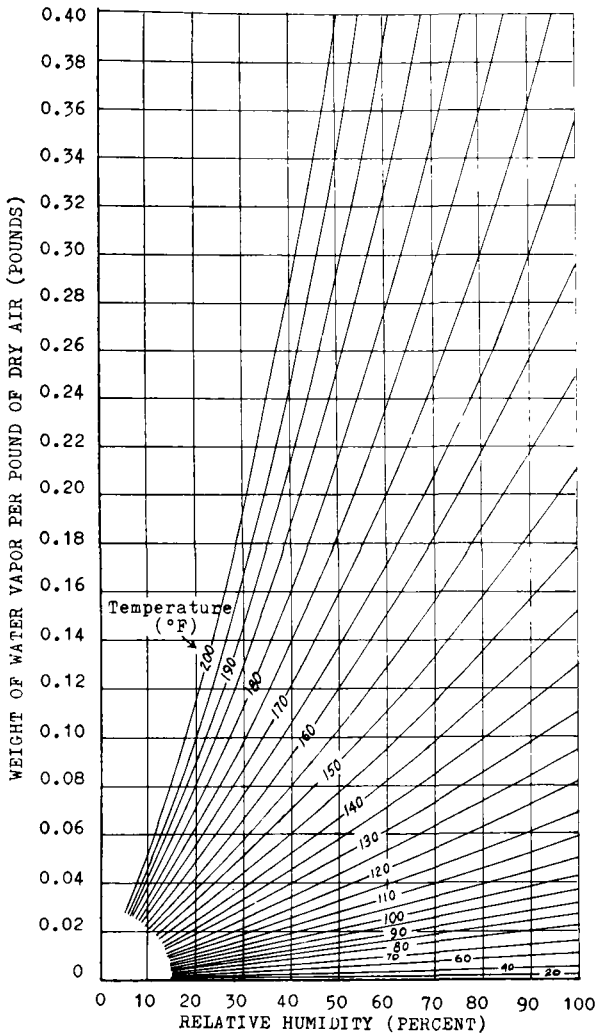
Figure 4. Weight of vapor per pound of dry air
at various combinations of temperature
and relative humidity. (From U.S. FPL
Report No. R1265, March, 1954)

2. Determine H_2 - Heat required to overcome hygroscopic forces. From Figure 2, the heat desorption at the final moisture content in the Schedule (D) is 18.5 Btu/lb (Final moisture content is 7%.)

$$H_2 = ODW \times D = (44,200)(18.5) = 817,700 \text{ Btu}$$

3. Determine H_3 The heat required to raise the temperature of any water remaining in the wood.

The water remaining in the wood at the final moisture content in the schedule (W) is calculated: (MC expressed as a decimal)

$$W = ODW \times \text{Final MC} = (44,200)(.07) \quad 3094 \text{ lbs}$$
$$H_3 = W \times c_{H_2O} \times \Delta T = (3094)(1)(125) \quad 386,750 \text{ Btu}$$

4. Determine H_4 The heat required to raise the temperature of the water removed from the wood, and to evaporate it.

First determine the latent heat of vaporization of water (h) at each dry bulb stage in the schedule, using Figure 3. Next, from the kiln schedule, determine the moisture content change (ΔMC) during each dry bulb stage in the schedule. Next, determine the temperature change (Δt) from the initial temperature at each dry bulb stage in the schedule.

DB Stage	DBT	h	ΔMC		Δt	
1	130	1020	1.20	.30 = .90	130 - 35 = 95	
2	140	1014	.30	.20 = .10	140 - 35	105
3	160	1002	.20	.07 = .13	160 - 35	125

$$H_{4i} = ODW \times \Delta MC \times [(c_{H_2O} \times \Delta T) + h] \text{ at each DB stage}$$

$$H_{41} = (44,200)(.9)[(1)(95) + 1020]$$
$$= 44,354,700 \text{ at DB stage 1}$$

$$H_{42} \quad (44,200)(.1)[(1)(105) + 1014]$$
$$4,945,980 \text{ at DB stage 2}$$

$$H_{43} \quad (44,200)(.13)[(1)(125) + 1002]$$
$$6,475,742 \text{ at DB stage 3}$$

Total $H_4 = H_{41} + H_{42} + H_{43}$

Total H_4 55,776,422 Btu

Table 2. Example Calculation of Total H_5 Element
(Energy Required to Heat and Humidify Vent Air)

$$H_5 = K \left[\frac{\Delta mc_1 \ (\Delta t_1)}{d_1} + \frac{\Delta mc_2 \ (\Delta t_2)}{d_2} \ \ldots \ \text{etc.} \right] + A \left[\Delta mc_1 \ (S_1 \times c_{H_2O} + h_1) + \Delta mc_2 \ (\Delta S_2 \times c_{H_2O} + h_2) \ \ldots \ \text{etc.} \right]$$

$$K = ODW \ (1 + E) \left[c_a + (b) \ (c_{wv}) \right] = 44,200 \ (1 + .05) \left[.24 + (.003) \ (.45) \right] = 11,201.05$$

$$A = ODW \times E = 44,200 \times .05 = 2210.00$$

$$c_{H_2O} = 1.0$$

$$H_5 = 11,201.05 \left[\frac{(.6)(95)}{.062} + \frac{(.2)(95)}{.051} + \frac{(.1)(95)}{.031} + \frac{(.1)(105)}{.037} + \frac{(.3)(125)}{.083} \right]$$

$$+ \ 2210 \left[(.6)(85 + 1020) + (.2)(85 + 1020) + (.1)(85 + 1020) + (.1)(95 + 1014) + (.13)(115 + 1002) \right]$$

$$H_5 = 26,038,761 \ \text{Btu}$$

5. Determine H_5 - The heat required to raise the temperature and humidify the incoming vent air

Determine the weight of water vapor per pound of incoming vent air (b) using Figure 4. At an outside temperature of 35^OF, and 69% RH, b = 0.003 lbs/lb. At each stage in the kiln schedule, or combination of wet and dry bulb temperatures, determine:

(a) the relative humidity in the kiln

(b) the weight of water vapor per pound of air in the in the heated kiln (j) using Figure 4.

(c) the amount of water vapor that can be absorbed by the incoming vent air (d) d = j - b

(d) from the kiln schedule, determine the moisture content change (Δmc) during the drying stage. Express as a decimal (MC%/100)

Schedule Stage	DBT (^{O}F)	WBT (^{O}F)	RH (%)	j (lbs/lb)	d (lbs/lb)	Δmc %MC/100
1	130	115	62	0.065	0.062	0.60
2	130	110	52	0.054	0.051	0.20
3	130	100	35	0.034	0.031	0.10
4	140	105	31	0.040	0.037	0.10
5	160	125	37	0.086	0.083	0.13

The kiln manufacturer has estimated the excess air required (E) as 5 percent (0.05). The temperature of the cold water going to the boiler is measured as 45^OF (S_0).

Determine the change in temperature of the humidifying air (ΔS = DBT - S_0).

In the manner shown for the calculation of H_4, determine $\angle$t for each stage of the kiln schedule.

Schedule Stage	DBT (^{O}F)	S_0 (^{O}F)	ΔS (^{O}F)	Δt (^{O}F)
1	130	45	85	95
2	130	45	85	95
3	130	45	85	95
4	140	45	95	105
5	160	45	115	125

Since only the total heat consumption by H_5 is needed, it may be calculated directly. This computation is shown in Table 2.

H_5 26,038,761 Btu

6. Determine H_6 - The heat required to replace any losses from the system. The weighted average DBT for the the entire kiln run must be calculated.

$$T_{avg} = \frac{DBT_1 (n_1) + DBT_2 (n_2) + DBT_3 (n_3) + \ldots \text{ etc.}}{n_1 + n_2 + n_3 \ldots \ldots \ldots \ldots \text{ etc.}}$$

Where n is the time in hours

$$T_{avg} = \frac{130 (95) + 140 (25) + 160 (90)}{95 + 25 + 90}$$

$$T_{avg} = 144 \ ^oF$$

The difference between the average DBT in the kiln and the temperature of the air and the ground (ΔT_L) must be calculated.

$\Delta T_2 \quad 144 \quad 35 = 109^oF$ for walls, door and roof

$\Delta T_2 \quad 144 \quad 45 = 99^oF$ for floor

The coefficients of heat transfer (U) for the various structural components of the kiln are provided by the kiln manufacturer:

walls - U = 0.118   door   U = 0.220
roof - U = 0.116   floor - U = 0.900

The variations in the coefficients of heat transfer are due to structural difference, such as metal rein- forcement parts, in the kiln components. The heat loss through each structural component of the kiln is calculated as:

$H_6 = U \times \text{area} \times \Delta T_2$, for each component

$H_{61} = (0.118)[(2 \times 27 \times 33) + (18 \times 27)] (109)$
$\quad = 29,171$ Btu through the walls

$H_{62} = (0.116)(18 \times 33)(109) = 7,510$ Btu through the roof

$H_{63} \quad (0.220) (18 \times 27)(109)$
$\quad 11,654$ Btu through the door

$H_{64} \quad (0.900)(18 \times 33)(99)$
$\quad 52,925$ Btu through the floor

H_6 (total) = $H_{61} + H_{62} + H_{63} + H_{64} \quad 101,260$ Btu/hr

H_6 (total) = 101,260 (210)
$\quad\quad\quad = 21,264,600$ Btu for the kiln run

Total Heat Consumption		Btu	Percent
H_1	– Heat the wood substance	1,712,750	1.6
H_2	– Overcome hygroscopic forces	817,700	0.8
H_3	Heat residual water in wood	386,750	0.4
H_4	Heat and evaporate water removed from wood	55,776,422	52.6
H_5	– Heat and humidify vent air	26,038,761	24.5
H_6	Replace heat losses	21,264,600	20.1
	Total	105,996,983	100.0

For purposes of comparison two other examples have been worked out. The summaries of these examples are given below.

I   If the same load of eastern white pine is dried under the same conditions except that the initial moisture content is 80%, the heat requirements are:

		Btu	Percent
H_1	Heat the wood substance	1,712,750	2.3
H_2	Overcome hygroscopic forces	817,700	1.1
H_3	– Heat residual water in the wood	386,750	0.5
H_4	– Heat and evaporate water removed from wood	36,063,222	47.6
H_5	– Heat and humidify vent air	18,196,785	24.0
H_6	Replace heat losses	18,546,551	24.5
	Total	75,723,758	100.0

II. A kiln charge (25,000 bd. ft.) of 4/4 sugar maple is dried from 70% MC to 10% MC in 14 days using schedule T 8-C3. The heat requirements are:

		Btu	Percent
H_1	– Heat the wood substance	3,271,821	3.0
H_2	– Overcome hygroscopic forces	982,638	0.9

		Btu	Percent
H_3 – Heat residual water in wood		1,055,455	1.0
H_4 – Heat and evaporate water removed from wood		48,855,306	45.3
H_5 – Heat and humidify vent air		17,964,494	16.7
H_6 – Replace heat losses		35,666,736	33.1
	Total	107,796,450	100.0

SUMMARY

There are several points that should be discussed regarding the manner in which this procedure can best be utilized. First of all, it is essential that good records are kept of each kiln charge in order to have the necessary data to satisfactorily estimate the active heat consumption in a plant kiln. These records provide a means of constructing a good picture of the kiln run (such as shown in Figure 1). They are also necessary in order to have a reference point for making schedule modifications, which is the next point of discussion.

Any schedule modifications will have to be tried in order to check for degrade, but in some instances it will be beneficial to do some theoretical heat consumption calculations before the kiln runs are made in order to see which alternatives may be the most favorable.

The Dry Kiln Operator's Manual suggests that the first step in systematic·schedule modification is to change wet-bulb depression. This is followed by shifting temperatures, and the last step is to modify certain steps with the schedule.

Some factors to be considered in analyzing the results are:

1. It is obvious from all the examples that over ninety percent of the heat consumed is used to heat and evaporate the water, heat and humidify the vent air, and replace losses.

2. As the outside air temperature increases, kiln heat requirements decrease.

3. For the same moisture content percentage, higher specific gravity woods contain more water and result in

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higher consumption.

4. For a particular kiln charge, all the elements of heat consumption, except one, are essentially fixed values since they are dependent primarily upon the amount of wood and the amount of water present The exception is heat loss which is time-dependent. This effect of time may be adjusted by either using lower temperature for longer times or using higher temperatures for shorter times.

As a final suggestion, a reprint of a Forest Products Research Society news bulletin is presented on the following page. It contains many practical ideas for reducing kiln fuel costs.

SOME SUGGESTED REFERENCES

Wood and Cellulose Science. A. J. Stamm. Ronald Press, New York. 1964

Principals of Wood Science and Technology. F F. P. Kellmann and W. A. Cote. Springer-Verlag, New York. 1968.

Dry-Kiln Building Materials and Construction. Forest Products Laboratory Report No. R 1646. USDA, Madison. 1950.

Properties of Wood Related to Drying. Forest Products Laboratory Report No. R 1900-1. USDA, Madison. 1951.

Function and Calculation of Ventilation in Drying Compartments. Forest Products Laboratory Report No. P 1265. USDA, Madison. 1941.

Handbook of Chemistry and Physics. Chemical Rubber Publishing Co., Cleveland.

Dry Kiln Operators' Manual. Agriculture Handbook No. 188, U. S. Forest Products Laboratory, Madison. March 1961.

How to Reduce Energy Consumption in Kiln-Drying Lumber. Forest Products Laboratory Research Note FPL-0228. USDA, Madison. 1974.

"How to Save Fuel This Winter"

This winter, and probably for several winters to come, the fuel supply for heating dry kilns is quite low. Therefore, in order to keep the kilns running as economically as possible, kiln operators and foremen should look at their operations and improve them as necessary. Without delving into the why's and wherefore's, the list below presents several ideas on where to improve typical drying operations with the aim of reducing fuel consumption.

(1) Get as much air drying done as possible. Improve the air-drying yard as necessary. (See your June 1973 News-Digest.) With a hardwood, each 2 percent moisture content loss in air drying will save about 3 percent in fuel compared with drying green from the saw. This is probably the most profitable area.

(2) Do not use steam spray or water spray in the kiln except during conditioning. Keep the vents tightly closed and let the moisture coming out of the wood build up the humidity to the desired level. Remember that when the vents open, hot air is exhausted.

(3) Repair and caulk all leaks and holes in the kiln structure to prevent unnecessary venting and loss of heat.

(4) For brick or cinder block kilns, coat the inside of the kiln with a vapor-resistant coating. This will prevent the walls from getting wet since dry walls will conduct less heat outside.

(5) For aluminum kilns ONLY, paint the exterior walls and roof a dark color to increase the wall temperature by solar heat and reduce heat loss from the kiln. This will be disastrous for permeable walls like brick or cinder block.

(6) Install better baffling and obtain uniform air velocity in the kiln. This is a high payoff item. Reverse circulation only every 6 hours or longer, if possible.

(7) Have the recorder-controller calibrated and checked for proper operation. Another $ Saver   In a steam kiln, check your traps.

(8) Unload and reload the kiln as fast as possible. Try
not to do this until the air temperature has warmed up a
little from the morning low--don't cool the kiln un-
necessarily.

(9) During non-use periods, close all valves tightly.

(10) In a battery of adjacent kilns, try not to have one
kiln being unloaded or loaded while the adjacent kiln
is at 180°F. or other high temperature.

(11) Use advanced schedules. Check your manuals to see
how to accelerate schedules without risk. This can be a
big savings area. Also note that the higher the tempera-
ture at which drying is done, the more effecient the use
of energy.

(12) Accurately determine the moisture content of the wood
you're drying. Don't waste energy by overdrying or by
taking too long because your samples are not adequate.

(13) Finally, check with the manufacturer of your equip-
ment and see if you can lower steam pressures or reduce
gas or oil flow rates during periods of constant dry-bulb
temperature.