HEAT TRANSMISSION LOSSES IN DRY KILN STRUCTURES

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Introduction

The increasing cost of processing forest products materials and in particular increasing fuel costs, whether the fuel be oil, natural gas or wood residues, are a now well recognized fact. These increasing costs are demanding that our industry improve its process efficiency. Although data is limited and somewhat questionable, the kiln drying of lumber is a rather inefficient process from an energy point of view as can be seen from the following energy partition data of Wengert (1978):

      Energy for evaporation   45-50%
      Energy lost in venting   15-20%
      Heat losses through walls   30-40%
         and roof

Most work done in the past on transmissional heat losses in kiln structures has largely been based upon calculated or theoretical estimates of total energy consumption and loss (Anon 197?; Villiére, 1969, 1975; Shotlafer and Schuler, 1974). These studies also indicate that significant heat losses are probably occurring in kilns. A search of the literature failed, however, to find a case where heat losses had been actually measured in a commercial setting so that the real magnitude of this problem could be more accurately assessed.

Objectives

The objectives of the study described here were as follows:
1. On a limited sample to measure the amount of energy being lost by thermal conduction through different kiln components.
2. To then compare these actual measured values with theoretical calculated values of rate of heat loss.
3. Based upon the above results to verify whether further investigation is justifiable in order to reduce heat losses by changing design criteria for new kilns or retrofitting of existing kilns.

Measurement of Heat Losses

Actual heat losses in kilns were measured using a commercially available flat-plate type thermal flux meter. The operating characteristics of the meter used are given in Table 1. This type of transducer measures either heat flow to or from any surface being tested, and generates a DC electrical signal which increases

linearly as heat flow increases. The meter was attached to a surface using thermal conducting paste and all measurements were made in the shade and still air unless otherwise noted.

Kilns Tested

Measurements were made on two aluminum sandwich wall prefabricated kilns; one less than 1 year old and the other about 6 years old. The wall and floor construction of these kilns is shown schematically in Figure 1. Using a 104 ft double track kiln as a reference base (Figure 2) the surface areas through which heat loss can occur are given in Table 2. It should be noted that for such a kiln the total surface area involved is 12,250 ft^2.

Calculated Conductive Heat Transfer

Heat flow through a single or composite material is controlled by:
1. The temperature difference between the air on the inside and outside of the wall = $T_{int.} - T_{ext.}$
2. The convective heat transfer coefficients for the inside and outside surfaces which are controlled by the wall surface geometry and air velocity – $\overline{h}_{c,\ interior}$ and $\overline{h}_{c,\ exterior}$
3. The thickness and coefficient of thermal conductivity of each material comprising the wall.

The interrelationship of these variables to heat flow (q) is shown in Figure 3.

Once values for these variables are known, the heat flowing through a wall can be calculated as follows:

$$q = \frac{\Delta TA(t)}{\Sigma R}$$

where q = heat flow (Btu)
$\Delta T = T_{interior} - T_{exterior}$ (Btu)
A = wall surface area (ft^2)
t = time (hr)
R = thermal resistance = $\dfrac{L}{k}$ $\left(\dfrac{ft^2-hr-{}^oF}{Btu}\right)$

L = thickness of a wall component (ft)
k = thermal conductivity coefficient for a given wall component (Btu/ft-hr-^{o}F)

Using the constructions shown in Figure 1 and values for the different variables as given in Table 3, calculated values for heat losses in the two kilns were also made.

Results

Measured values for heat losses through the different components for the 1 year old kiln are given in Table 4. Significantly different values were measured for similarly located points on the various wall panels. The highest measured heat loss was 0.717 Btu/hr-ft^2-^{o}F for a point on a back wall panel near the roof line.

A comparison of data points 6a and 6c clearly shows the strong influence of air flow on rate of heat loss. In this particular case the presence of a strong breeze almost doubled (0.300 to 0.585) the heat loss. The average value for heat loss excluding those values measured on panel joints was $\overline{q}$ = 0.208 Btu/hr-ft^2-$^\circ$F. Using the procedures previously discussed the calculated value for this kiln was q = 0.063 Btu/hr-ft^2-$^\circ$F. The average measured value was therefore found to be slightly more than 3 times greater than one would expect on a theoretical basis. Very similar results were also found to occur in the 6-year old kiln (Table 5). It had been expected that this kiln would exhibit higher heat losses resulting from greater moisture intrusion into the fiberglass insulation (with a concomitant loss in insulating ability) as a result of its longer time in service. This was not the case, however, as shown by its average rate of heat loss of 0.182 Btu/hr-ft^2-$^\circ$F. As with the 1-year old kiln the measured value was roughly 3 times greater than the calculated value of 0.063 Btu/hr-ft^2-$^\circ$F.

It should be noted that the rate of heat loss was not measured through the floors of the two kilns although this could be done.

Discussion

Total heat losses for the double track type of kiln shown in Figure 2 were calculated theoretically for different inside temperatures and a constant exterior or outside temperature of 80°F. The values obtained (Table 6) also permit one to see the role of heat loss through the floors. Using a within kiln temperature of 180°F the total daily heat loss is 2.6 million Btu's. Heat loss through the superstructure, i.e., walls, roof and doors, which make up 73 percent of the total surface area, is 63 percent of the total heat loss. The floor, on the other hand with only 27 percent of the total surface area gives 37 percent of the total flux loss. From this one can see that the floor rate of heat loss is greater than the walls.

At 150,000 Btu/gal of fuel oil and $0.35/gal and again using an average inside kiln temperature of 180°F, the total rate of heat loss represents a loss of $1,880 per year in energy.

Conclusions

1. Measured heat losses in two prefabricated aluminum sandwich wall construction kilns were found to be 3 to 3.5 times greater than calculated values.
2. Little difference in measured rates of heat loss were found to occur between a 1 year old and 6 year old kiln.
3. For an isolated kiln operating at 180°F inside temperature and an outdoor temperature of 80°F roughly 2.26 million Btu's are shown to be lost daily using only theoretical rates of heat loss, not the measured values.
4. Using conservative costs for fuel oil this corresponds to as much as $2,000 per year per kiln.
5. Heat losses will be greater, naturally, the higher the operating temperature of the kiln and/or the surrounding ambient temperature.

These results, and in particular the disparity between actual measured and calculated rates of energy loss, indicate that further work needs to be done. The influence of type of kiln schedule, yearly weather patterns, amount of incident radiant energy, and varying types of fuels and their costs need to be taken into account in order to determine the optimum economic tradeoff points between costs of added insulation and redesign versus potential energy savings.

Literature Cited

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TABLE 1. Operating characteristics of the
           thermal flux meter.

Full scale output	10^5 Btu/hr ft^2
Accuracy	1%
Operating range	-425 to 550°F
Response time	1 second
Dimensions	4" X 4" X 0.055"
Output	7 Btu/hr ft^2/mv

TABLE 2. Surface areas involved in heat
           losses from a typical double track
           kiln (ft^2).

Item	Total Surface Area
Roof	3,536
Side walls	3,952
End walls excluding door	1,033
Door	407
Total surface area of Super-structure	8,928 ft^2
Floor	3,328
	Total Surface Area = 12,256 ft^2

TABLE 3. Values for the different variables
used in calculating kiln heat
loss.

1.	$\overline{h}_{c,\ exterior}$	=	0.288 Btu/ft^2 hr ^{o}F
2.	$\overline{h}_{c,\ interior}$	=	0.138 Btu/ft^2 hr ^{o}F
3.	$k_{aluminum}$	=	117 Btu/hr ft ^{o}F
4.	$k_{fiberglass}$	=	0.031 Btu/hr ft ^{o}F
5.	$k_{concrete}$	=	0.54 Btu/hr ft ^{o}F
6.	k_{gravel}	=	0.20 Btu/hr ft ^{o}F
7.	$T_{interior}$	=	measured with copper constantan thermocouple
8.	$T_{exterior}$	=	measured with copper constantan thermocouple

Values 1 and 2 from Hildebrand (1970), 3
through 6 from Kreith (1966).

TABLE 4. Representative measured heat losses from 1-year old
aluminum prefabricated kiln.

Location of Measurement	Heat Loss BTU/Hr-Ft^2-$^\circ$F
1. a. North wall, 5' off floor, middle of panel	0.066
b. Same as above, next to joint	0.415
c. Same as above, on joint	0.717
2. Back wall, 6' off floor, middle of panel	0.112
3. Back wall, near roof line	0.053
Back wall, near roof line, 200 fpm breeze	0.113
4. Roof, north face, middle of panel	0.303
5. Roof, north face, middle of panel	0.234
6. a. Roof, north face, middle of panel, no breeze	0.300
b. Roof, north face, middle of panel, slight breeze	0.388
c. Roof, north face, middle of panel, strong breeze (300 fpm)	0.585
Average of all panel measurements (excluding joints) $\overline{q}$ =	0.208

TABLE 5. Representative heat losses from 6-year old aluminum prefabricated kiln.

Location of Measurement	Heat Loss BTU/Hr-Ft^2-^{o}F
1. East wall, 6.5' off floor, middle of panel	0.059
2. a. Door, north face, 6.5' off floor	0.109
b. Door, north face, 6.5' off floor, slight breeze	0.218
3. a. Door, north face, 6.5' off floor	0.103
b. Door, north face, 6.5' off floor, strong breeze	0.422
Average of all panel measurements (excluding joints) $\bar{q}$ =	0.182

TABLE 6. Theoretical daily heat losses for prefabricated kilns operating at different temperatures and constant outside temperature of 80°F.

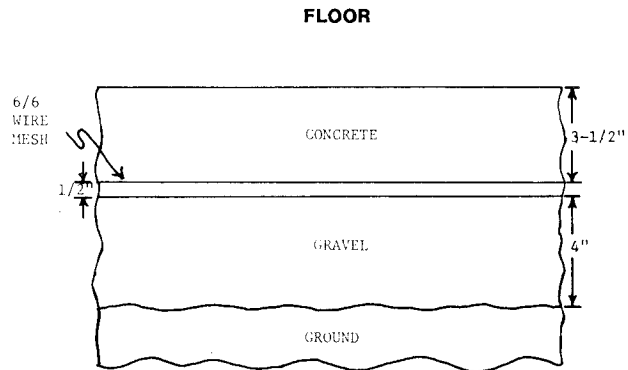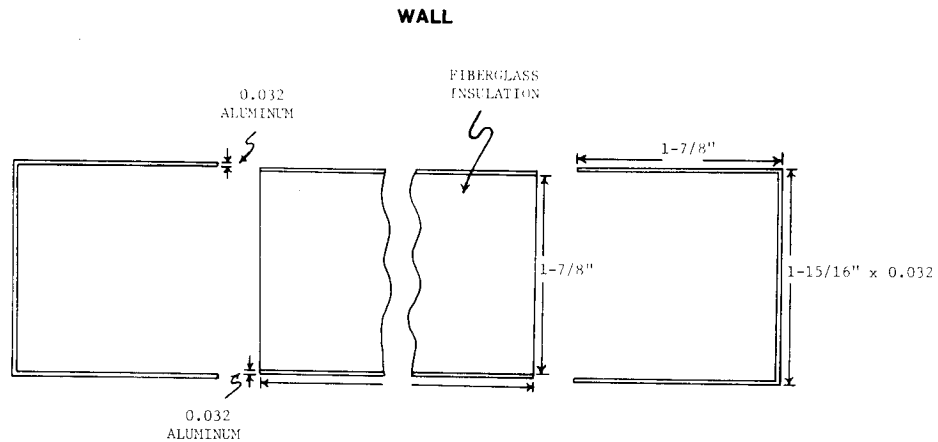| Part of Kiln	Heat Loss for Average Operating Temp. of:		
	220°F	180°F	140°F
Superstructure	1.991×10^6	1.422×10^6	0.953×10^6
Floor	1.176×10^6	0.840×10^6	0.504×10^6
Total	3.167×10^6	2.262×10^6	1.357×10^6

WALL

FLOOR

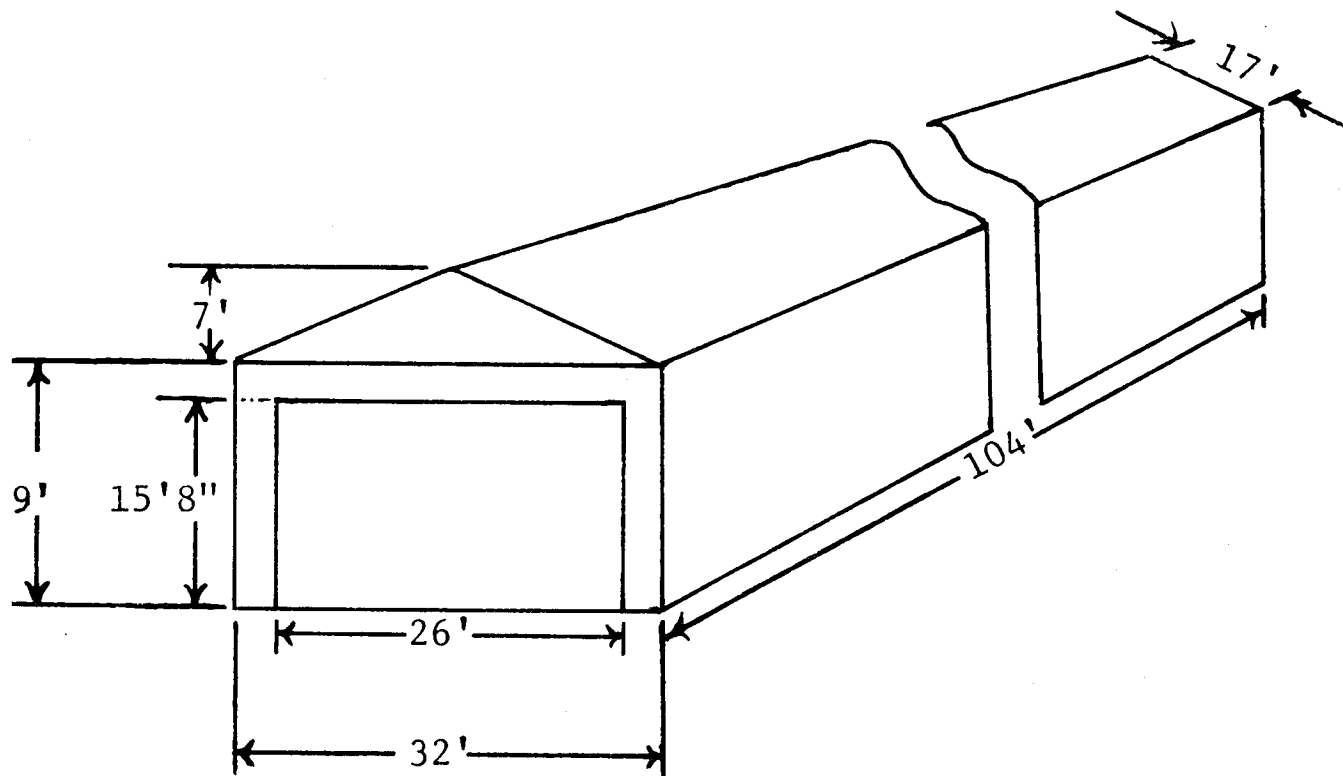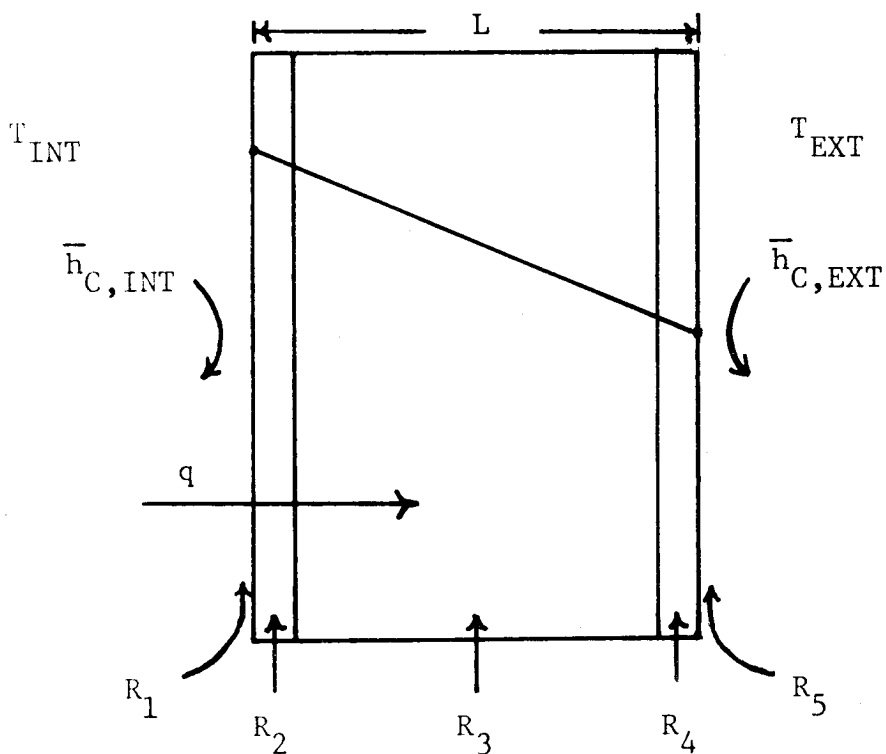Figure 1. Panel and floor construction for the prefabricated kilns studied.

Figure 2. Dimensions of 104 foot double track kiln.

$$q(BTU) = \frac{kA\Delta T(t)}{L} \quad \text{or} \quad q = \frac{\Delta TA(t)}{\Sigma R}$$

Figure 3.   Conductive heat transfer through a composite structure.