



Investigation of The Effect of Building Material Selection and Design Style on Kiln Thermal Properties in Solar Kilns

Kemal ÜÇÜNCÜ Aytaç AYDIN*

Karadeniz Technical University, Department of Forest Industry Engineering Kanuni Campus, Trabzon/Türkiye

Geliş/Received: 29.11.2020

Kabul/Accepted: 03.12.2020

How to cite: Üçüncü, K. & Aydın, A. (2020). Investigation of The Effect of Building Material Selection and Design Style on Kiln Thermal Properties in Solar Kilns. *J. Anatolian Env. and Anim. Sciences*, 5(5), 793-797.

Atf yapmak için: Üçüncü, K. & Aydın, A. (2020). Güneş Fırınlarında Yapı Malzemesi Seçimi ve Tasarım Stilinin Fırın Isıl Özelliklerine Etkisinin İncelenmesi. *Anadolu Çev. ve Hay. Dergisi*, 5(5), 793-797.

 <https://orcid.org/0000-0002-6294-6112>
 <https://orcid.org/0000-0001-7460-9618>

***Corresponding author's:**

Aytaç AYDIN

Karadeniz Technical University, Department of Industrial Engineering Kanuni Campus, Trabzon, Turkey.

✉: aytac@ktu.edu.tr

Mobile telephone: +90 (505) 231 91 78

Telephone : +90 (462) 377 15 13

Fax : +90 (462) 325 74 99

Abstract: The negative effects of intensive energy consumption in timber drying on costs and environmental pollution have strengthened the tendency to utilize solar energy in recent years. Although drying of timber in flat collector solar furnaces takes more time than conventional drying, energy costs are low and there are no negative environmental effects. In this study, the selection of building materials and design type to be used in the design of solar furnaces was evaluated in terms of thermal properties. Materials with different thermal capacities create different thermal properties in different designs. Therefore, it is possible to control the course of the temperature distribution in the solar timber drying oven throughout the day with the choice of different building materials and design forms.

Keywords: Building material, drying, solar kiln, thermal properties.

Güneş Fırınlarında Yapı Malzemesi Seçimi ve Tasarım Stilinin Fırın Isıl Özelliklerine Etkisinin İncelenmesi

***Sorumlu yazarın:**

Aytaç AYDIN

Karadeniz Teknik Üniversitesi Orman Fakültesi Orman Endüstri Mühendisliği Bölümü, Kanuni Kampüsü Trabzon, Türkiye

✉: aytac@ktu.edu.tr

Cep telefonu : +90 (505) 231 91 78

Telefon : +90 (462) 377 15 13

Faks : +90 (462) 325 74 99

Öz: Kereste kurutmada yoğun enerji tüketiminin maliyetlere ve çevre kirliliğine olumsuz etkileri son yıllarda güneş enerjisinden yararlanma eğilimini güçlendirmiştir. Düz toplayıcı güneş fırınlarında kerestenin kurutulması klasik kurutmaya oranla fazla zaman almasına rağmen enerji maliyetleri düşük ve olumsuz çevresel etkileri yoktur. Bu çalışmada güneş fırınlarının tasarımında kullanılacak yapı malzemelerinin ve tasarım şeklinin seçimi ısıl özellikler bakımından değerlendirilmiştir. Farklı ısıl kapasiteye sahip malzemeler farklı tasarım şeklinde farklı ısıl özellik oluşturmaktadır. Dolayısıyla, farklı yapı malzemesi ve tasarım şekli seçimi ile güneş enerjili kereste kurutma fırınında gün boyu sıcaklık dağılımının gidişinin kontrolü mümkün olabilmektedir.

Anahtar kelimeler: Güneş fırınları, kurutma, ısıl özellikler, yapı malzemesi.

INTRODUCTION

Natural and technical drying methods are generally used in drying timber. Although energy is not consumed in natural drying, the drying period is long and timber cannot be dried to the desired result humidity for interiors. Although the timber can be dried to the desired result humidity level in technical drying, drying costs are

high. 60-70% of the energy in the timber industry is spent during the drying phase. The energy consumed depending on the tree type and timber thickness varies between 600-1000 kWh per 1 m³ of timber (Comstock, 1978).

In recent years, drying timber with solar energy has been studied as an alternative drying method in order

to reduce energy costs in drying. For this purpose, various types of solar-powered timber drying furnaces are designed and drying trials are carried out. In most of these studies, it has been concluded that solar furnaces can be used economically if the fuel prices increase and the costs of solar collectors can be reduced. In these studies, little coverage has been given to the effects of wall building materials on the temperature regime (Read et al.,1974; Gaugh, 1977; Bois, 1977; Yang,1980; Chen, 1981; Little,1984; Örs and Üçüncü,1992).

In terms of drying quality, drying temperatures suitable for the properties of the dried timber should be applied. In solar furnaces, the temperature varies according to solar energy values and shows significant differences throughout the day. During the sunbathing period, the temperature first rises and decreases again after reaching the maximum value between 12:00 - 14:00. The width of the hourly temperature change interval negatively affects the drying time and quality. In Figure 1, possible hourly variations in temperature during the day are shown for a solar furnace. The temperature of the furnace, which decreases to the lowest level at night, reaches its maximum value between 13:00 and 14:00 during the day due to the effect of solar radiation, and this temperature difference between this temperature difference negatively affects the drying.

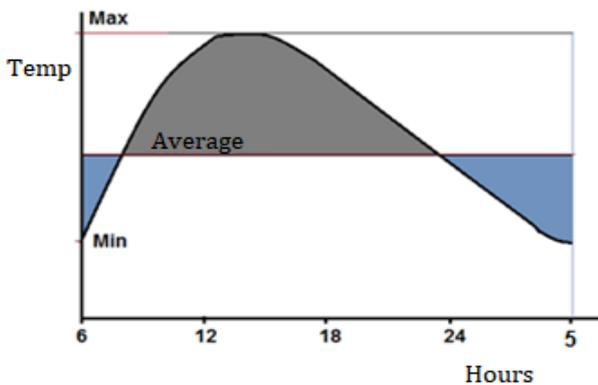


Figure 1. Hourly change graph of temperature in solar furnace.

The specific heat and heat conduction coefficients of the wall materials also have an important effect on the change of furnace temperature. Therefore, by choosing the wall building materials to be used, a more homogeneous distribution of the oven temperature can be achieved. Greenhouse type solar furnaces have been considered in this study and these furnaces can be designed up to 10 m³ capacity. In the study, the effects of the wall designs of the greenhouse type solar furnace with a lumber capacity of 10 m³ and a collector area of 60 m² on the temperature regime were examined.

MATERIALS AND METHOD

Materials: The collector area of the examined greenhouse type solar furnace is 60 m² and its timber capacity is 10 m³. 34.5 m² of the solar collector designed in the position of the roof of the oven has a 30° and 25.5 m² slope of 60° (Üçüncü,1995).

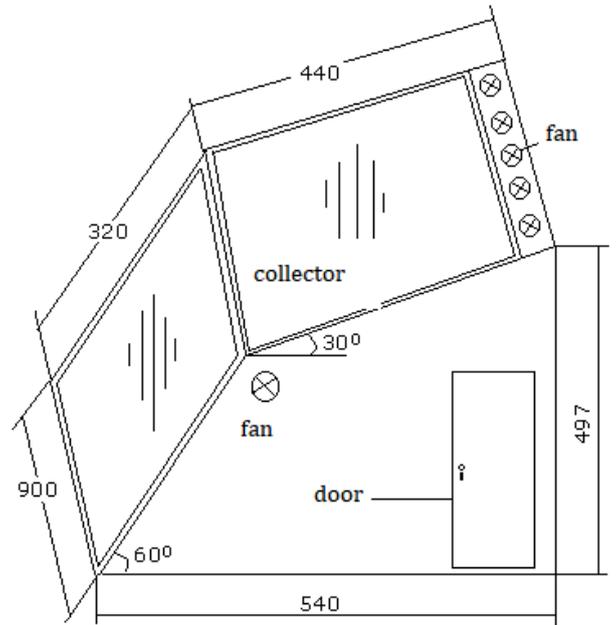


Figure 2. Solar furnace.

In order to examine the effects of wall designs and materials on temperature regime, 4 types of walls were designed (Figure 3).

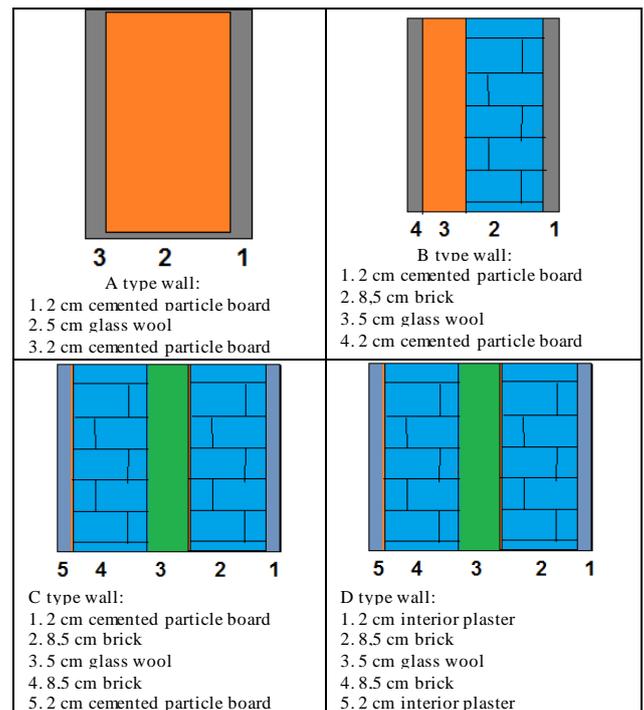


Figure 3. Wall design and building materials

Method: The furnace temperature was calculated using the thermal equilibrium equation (Dağsöz,1977).

$$Qg = Qd + Qk \tag{1}$$

Here, Qg is the useful solar radiation (W) entering the furnace, Qd is the energy stored in the furnace walls (W), Qk is the heat lost from the furnace (W).

Useful solar radiation entering the oven

$$Qg = \eta Ac Ie \tag{2}$$

Here, η is collector efficiency, Ac collector field and Ie is the instantaneous solar radiation incident on the

collector surface. Hourly solar radiation values coming to the collector surface are calculated from Trabzon's average irradiance values for many years and given in Table 1 (Kılıç and Öztürk,1983). The value of 45% was taken as a basis for collector efficiency (Üçüncü,1991).

Stored heat

$$Qd = \sum mCp (t_i - t_{i-1}) \tag{3}$$

Lost heat

$$Qk = K Ad (t_i - t_o) \tag{4}$$

Table 1. Hourly solar radiation coming to the collector surface in Trabzon and monthly average values of outdoor temperature, Ie (W/m²).

Months	Hours																				Total	Temperature (°C)				
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1			2	3	4	5
January	0	8	112	232	310	344	344	310	232	112	8	0	0	0	0	0	0	0	0	0	0	0	0	0	2012	7,4
February	0	58	191	315	397	436	436	397	315	191	58	0	0	0	0	0	0	0	0	0	0	0	0	0	2794	7,3
March	21	116	234	336	407	437	437	407	336	234	116	21	0	0	0	0	0	0	0	0	0	0	0	0	3102	8,3
April	69	177	298	400	463	493	493	463	400	298	177	69	0	0	0	0	0	0	0	0	0	0	0	0	3800	11,4
May	102	216	334	424	487	517	517	487	424	334	216	102	0	0	0	0	0	0	0	0	0	0	0	0	4160	15,8
June	119	242	335	447	506	539	539	506	447	335	242	119	0	0	0	0	0	0	0	0	0	0	0	0	4376	20,0
July	100	213	320	401	457	482	482	457	401	320	213	100	0	0	0	0	0	0	0	0	0	0	0	0	3946	22,6
August	77	179	287	370	430	454	454	430	370	287	179	77	0	0	0	0	0	0	0	0	0	0	0	0	3594	23,1
September	36	135	249	345	406	441	441	406	345	249	135	36	0	0	0	0	0	0	0	0	0	0	0	0	3224	20,0
October	0	79	212	324	401	436	436	401	324	212	79	0	0	0	0	0	0	0	0	0	0	0	0	0	2904	16,5
November	0	19	151	273	362	396	396	362	273	151	19	0	0	0	0	0	0	0	0	0	0	0	0	0	2402	13,2
December	0	3	90	211	288	322	322	288	211	90	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1828	9,7
Average	52	138	251	353	421	452	452	421	353	251	138	52	0	0	0	0	0	0	0	0	0	0	0	0	3334	16,1

Here, m wall mass (kg), specific heat of Cp wall material (Wh / kg °C), $\sum mCp$ sum of thermal capacities of furnace walls (WH/°C), furnace temperature at ti i (°C), ti-1 initial furnace temperature (°C), to outdoor temperature (°C), K is the total heat transfer coefficient of the furnace (W/m² °C), Ad is the furnace wall area (m²). Based on the equations given, the following equation is obtained for the oven temperature.

$$t_i = \frac{\eta Ac Ie + \sum mCp t_{i-1} + KAd t_o}{\sum mCp + KAd} \tag{5}$$

In the calculation of the total heat transfer coefficient, the heat transfer coefficient of the wall and the heat losses resulting from air renewal are taken into account. The furnace volume is approximately 150 m³ and the rate of air regeneration in the furnace has been taken as 4, considering the required moist air requirement for drying. Equations and equation coefficients regarding the possible temperatures that will occur in the furnace according to the designed walls are given below.

For wall type A:

$$t_i = 0,0250 Ie + 0,7868 t_{i-1} + 0,2132 t_o \tag{6}$$

For wall type B:

$$t_i = 0,0175 Ie + 0,8366 t_{i-1} + 0,1634 t_o \tag{7}$$

For type C wall:

$$t_i = 0,0118 Ie + 0,9026 t_{i-1} + 0,0974 t_o \tag{8}$$

For wall type D:

$$t_i = 0,0153 Ie + 0,8740 t_{i-1} + 0,1260 t_o \tag{9}$$

FINDINGS

The temperature in solar furnaces varies significantly throughout the day due to reasons such as the constant change of solar energy during the day, the variation in terms of the seasons, and none at night. With these features, drying in solar ovens can be considered within the concept of batch drying. Although intermittent drying does not have a direct harmful effect on drying quality, the continuous and sudden change in temperature may affect the drying quality as well as increase the drying time. Wall materials also have a significant effect on the furnace temperature in solar furnaces. In order to examine the effect of wall materials on temperature, the annual average hourly temperature distribution, standard deviation, maximum, minimum and change interval values for four types of furnace walls designed in Trabzon climatic conditions are given in Table 2.

Table 2. Furnace temperature values according to wall types .

Wall type	Hours																									t1	S1	MAX	MIN	CI
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5						
A	16	18	24	30	37	43	48	51	52	50	45	40	35	30	27	24	22	21	19	18	18	17	16	16	30	13	52	16	36	
B	15	17	21	26	31	36	40	43	45	44	41	38	34	31	28	26	24	22	21	20	19	18	18	17	28	11	45	15	29	
C	15	16	19	23	27	31	34	37	39	39	38	37	35	33	31	29	28	27	25	24	23	23	22	21	28	9	39	15	24	
D	15	17	20	25	30	35	39	42	44	44	42	39	36	33	31	29	27	26	24	23	22	21	20	20	29	11	45	15	29	

In Table 3, the monthly average furnace temperature and standard deviation values for four types of furnace walls. Here, t1 and S1 are solar furnace temperature (°C) and standard deviation with wall type A,

t2 and S2 solar furnace temperature and standard deviation with wall type B, t3 and S3 solar furnace temperature and standard deviation with wall type C, t4 and S4 D-type wall furnace temperature and standard deviation.

Table 3. Monthly average temperature and standard deviation values of furnace types .

Months	A		B		C		D	
	t1	S1	t1	S1	t1	S1	t1	S1
January	17,1	9,2	16,0	6,9	16,0	5,2	16,8	6,5
February	20,8	12,1	19,3	9,2	19,2	6,9	20,3	8,5
March	23,2	12,7	21,6	9,6	21,5	7,2	22,7	9,0
April	29,7	14,8	27,7	11,2	27,6	8,4	29,1	10,5
May	35,8	15,7	33,6	12,0	33,5	9,0	35,2	11,2
June	41,1	16,4	38,7	12,5	38,6	9,3	40,4	11,6
July	41,6	14,8	39,5	11,3	39,4	8,4	41,1	10,5
August	40,4	13,8	38,5	10,5	38,4	7,8	40,0	9,8
September	35,5	12,9	33,8	9,8	33,7	7,3	35,1	9,2
October	30,5	12,4	28,9	9,4	28,9	7,0	30,1	8,8
November	24,8	10,8	23,5	8,2	23,5	6,1	24,5	7,6
December	18,5	8,5	17,5	6,4	17,5	4,8	18,3	6,0
Average	29,9	12,8	28,2	9,7	28,2	7,3	29,5	9,1

Average oven temperature has the highest value in A type oven and the lowest in C type oven. In A type oven, the highest value of the average oven temperature during the day (24 hours) occurred in July with 41.6 °C, and the lowest value occurred in January with 17.1 °C. The same values in B, C and D type furnaces, respectively; 39.5; 39.4; 40.1 °C and 16.0; 16.0; It became 16.8 °C. Standard deviation also increases in high temperature average values. The largest standard deviation was observed in A type furnace with 12.8 °C, the smallest standard deviation was observed in C type furnace with 7.3

°C. In Figure 4, the temperature changes of solar furnaces with wall types A, B, C and D are shown by months depending on time. In Figure 5, hourly temperature distribution for wall types is shown. In solar furnaces, the maximum temperature for any type of wall material is generally reached between 14:00 and 15:00 hours. In the solar oven for all wall types, the temperature of the oven does not fall to the ambient temperature the next day, when the solar radiation starts. In the furnace with a wall with a high thermal capacity, the difference between the final temperature and the ambient temperature is greater.

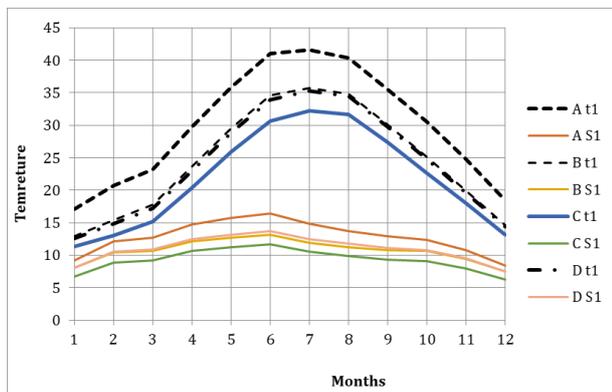


Figure 4. Monthly average temperatures.

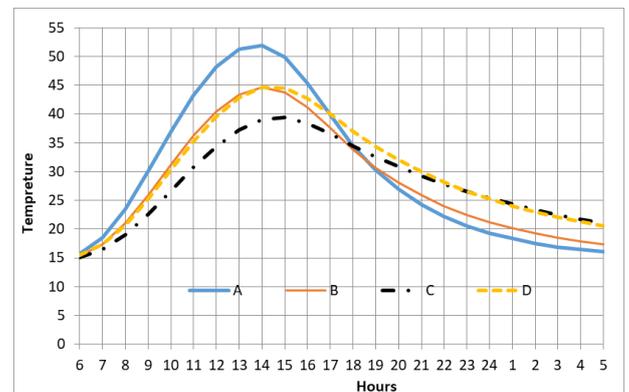


Figure 5. Hourly temperature distribution according to wall types.

DISCUSSION AND CONCLUSION

Since materials with high thermal capacity will store large amounts of heat, the furnace temperature decreases in furnaces built of these materials. However, despite the low temperatures that occur in the oven during the sunbathing period, the temperature drop is less after the sunbathing ends and at night. In furnaces built of materials with low thermal capacity, the temperature of the furnace, which is higher during the sunbathing period, is greater at night. Accordingly, although the average temperature is lower in furnaces built with materials with high thermal capacity, the variation interval and standard deviation are also small, so they may have more positive effects on the drying quality. This type of furnace has more suitable features in terms of ensuring homogeneous and high quality drying.

In solar systems where high temperatures are desired during the sunshine period, the selection of low thermal capacity building materials can be recommended. However, it would be beneficial to use materials with higher thermal capacity in solar ovens where activity is desired throughout the day. According to theoretical calculations, it is seen that more stable temperature values will be formed in solar furnaces to be built from C and D type walls.

In terms of heat loss in solar furnaces, since the heat losses caused by air renewal are more effective than the thermal conductivity of wall materials, the thermal insulation thickness of 5 cm is taken as a basis instead of the 8 cm thermal insulation thickness recommended in the literature. For the same reason, it is possible to use polyurethane or styrofoam for thermal insulation.

ACKNOWLEDGMENTS

This study was presented in ORENKO 2020 held by Karadeniz Technical University, Trabzon.

REFERENCES

- Bois, P.J. (1977).** Construction and operating, a small solar heated lumber dryer. Forest Products Utilization Technical Report. USDA, For. Service No. 7. 11pp.
- Chen, P.Y.S. (1981).** Design and tests of a 500 BF solar kiln. *Forest Prod. J.*, **31**(3), 33-38.
- Comstock, G.L. (1978).** Energy requirement for drying of wood products. *Forest Prod. J.*, **28**(3), 22-26.
- Dağsöz, A.K. (1977).** *Heat transfer*. ITU Faculty of Mechanical Engineering, İstanbul.
- Gaugh, D.K. (1977).** The design and operating a small solar timber kiln. *Fiji Timbers and Their Uses*, No: 67, Fiji, F. D., 17pp.

- Kılıç, A. & Öztürk, A. (1983).** *Solar energy*. ITU Faculty of Mechanical Engineering, İstanbul.
- Little, R.L. (1984).** Industrial use of solar heat in lumber drying: a long-term performance report. *Forest Prod. J.*, **34**(9), 22-26.
- Örs, Y. & Üçüncü, K. (1992).** Investigations on lumber drying possibilities at 41° north parallel. *TÜBİTAK Nature Magazine*, **16**, 22-37.
- Read, W. R., Choda, A. & Cooper, P. I. (1974).** A Solar timber kiln. *Solar Energy*, **15**(4), 309-316.
- Üçüncü, K. (1991).** *Investigation of drying possibilities of timber (eastern spruce) with solar energy in 41° north latitude (Trabzon)*. PhD Thesis (Unpublished), KTU Institute of Science and Technology, Trabzon.
- Üçüncü, K. (1995).** Greenhouse type solar furnace design and economic analysis for small capacity timber cutting and furniture plants in the climatic conditions of the Black Sea Region. *I. National Black Sea Forestry Congress*, 2. Volume, Proceedings, Trabzon.
- Yang, K.L. (1980).** Solar kiln performance at a high latitude, 48°N. *Forest Prod.*, **30**(3), 37-40.