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A New Design Solar Wood Dryer

Shailendra Kumar[1]* and Kishan Kumar V.S.[2]

[1]Forest Products Division, Forest Research Institute, Dehradun
[2]Forest Products Division, Forest Research Institute, Dehradun-248006
E-mail: [1]kumarsro@icfre.org

Abstract—*A double glass glazed semi green house type solar kiln with optimized double inclined south facing roof was constructed at Dehradun(India) location . The galvanised iron (GI) flat plate collectors of the roof were finned with aluminium sheet. Eastern and western walls were also covered with GI flat plate collectors. In the month of November, inclination of southern collector (42°C) performed better than that of northern roof collector (18°C). East-west wall collectors contribute significantly in raising kiln temperature. The contribution of western wall collector was visibly significant. In the stagnant air conditions, maximum temperature of the collector was 112°C and that of kiln was 84°C when tested in the first week of November. The western collector maximum was observed 91°C around 16:00 hrs. The kiln temperatures are influenced by south facing roof thermal collectors in majority of the time. Fins under roof collectors help in faster heat removal. Maximum kiln temperature 98°C and 70°C in April and January indicates the kiln design to be efficient for drying operations. Thus, the new design solar kiln may prove a cheaper, environ-friendly option to the wood based industries in India.*

1. INTRODUCTION

Wood based handicrafts industries play a vital role in rural employment generation and economy. The Solid wood, Plywood and Allied Products industries are one of the key sectors having immense potential to contribute towards the national growth and development as India is one of the major wood-users in the Asia pacific region. Wood drying is an indispensible operation for manufacturing of quality wood products. Timber drying is the most energy intensive process amongst all wood processing operations and consumes about 70 % of the total energy [1, 8]. Therefore, any changes made in drying practices to reduce energy requirement and the drying costs would have a significant impact on cost of production as a whole. For commercial timber drying, conventional steam heated kilns are being used by various wood based industries. Solar wood drying provides not only a cheaper alternative but also an environ-friendly technology. India is exposed to a rich amount of solar energy, which can be quantified to above 5 thousands trillion KWH per year. In other words, available solar energy does significantly exceed India's total annual energy requirements [2]

A solar drying kiln consists mainly of three components: transparent glazing, absorber plate/ collector and propeller fans for ventilation. Wood is reported to be dried satisfactorily using the solar kiln all across the world. The thermal performance of the solar kiln depends on many factors such as solar flux, ambient temperature, relative humidity of air, airflow rate, geometric configuration of the solar collector, material of construction etc [3]. As the incident solar rays deviate from normal to the surface, the energy striking the plane of collector is reduced. Cosine loss factor is cosθ, where θ is angle between the perpendicular to the collector surface and the direction of sun rays (cos 0°=1 and cos 90°=0).

Geometric configuration of the solar collectors affects the solar flux received by the kiln, hence, thermal performance is also affected. The kilns vary from very simple designs i.e. green house type to external collector based automated dryers with an integrated thermal energy storage system. More than 40 designs of research kiln using solar energy have been tested on in addition to a considerable variety of the commercially run kilns [4]. In the early stages of the development of solar kilns in India, a number of different designs of solar heated system were tested [5]. A glass house type of solar kiln provided with forced air circulation of 3.5 cubic meter capacity was also designed [6].

The present study was carried out at Dehradun (Uttarakhand, India). The geographical coordinates of the place are 30.3165° N, 78.0322° E. The study involves construction of a double inclination roof, south facing semi-green house type solar kiln and the performance of the kiln was tested under various conditions.

2. MATERIALS AND METHODS

2.1 Optimum tilt angle of solar collector

For single and fixed tilted collectors, Morse and Czarnecki [9] have recommended on optimum tilt throughout the year for maximum annual flux using as:

$$\beta_{opt} = 0.9\ Ø$$

Where, Ø is latitude

In order to increase the solar flux incident on the kiln and increase intake of solar heat to the kiln, the main roof collectors of the kiln were made at two angles using equations suggested by Kern and Harris [10]:

$$\beta_{opt} = tan^{-1}\left[\left\{\sum_{i=1}^{12} \mp \bar{H}_{bi}\, tan|\emptyset - \delta|\right\} \Big/ \left\{\sum_{i=1}^{12} \bar{H}_{bi}\right\}\right]$$

..... ……equation (1)

Where,

β_{opt} = optimum tilt

$\bar{H}_{bi}$ = Monthly average beam radiation (kWh/m^2-day)

δ = declination

$\emptyset$ = latitude

The two tilts were calculated for winter season (Sept to Mar) and summer season (Mar to Sept). Side walls of the kiln were left vertical facing east and west.

2.2 Construction of a prototype south facing double inclination solar kiln

A double glass glazing semi-green house type prototype of solar timber dryer was constructed as shown in fig.1. The structural members of the kiln were made of sal wood as shown in fig.1. 5 mm thick, double layered transparent glass was used as glazing material keeping 38mm air gap between the two glass layers. The roof/ sourthern wall of the kiln were south facing, inclined at two angles using equation 1(fig. 1). Galvanized Iron (GI) sheet was used as absorber plate which ran parallel to the roofs.

Fig. 1: South facing dual inclined double glass glazing

For efficient heat removal, the lower surface of the flat plate roof collector was jointed with aluminum fins. Total 32 numbers of 6 cm wide fins ran parallel to each other in north-south direction on lower side of both inclined roof collectors by maintaining a spacing of 6 cm between them. The eastern and western walls of the kiln too were provided with blackened G.I. sheet flat plate collectors, placed 6 cm away from walls, to trap solar energy in early morning and late evening.

The floor of the kiln was made by stuffing 10 cm thick glass wool layer under 12 mm plywood. The northern wall was also stuffed with glass-wool in the 10 cm gap between two 12 mm plywood panels. Three propeller fans (0.5 HP) were mounted on a fan partisan placed 90 cm away from northern wall. Two windows were made on eastern and western walls of the kiln for venting and temperature control. One door was given on eastern wall of the kiln for loading and unloading of wood.

2.3 Kiln Performance Tests

In order to assess the kiln performance, following tests were done in various conditions in various months of the year.

2.3.1 Temperatures of GI flat-plate collector, aluminum fins, kiln temperature and ambient under stagnant air conditions

Temperature sensors were placed on northern GI flat plate absorber, aluminum fin beside it, east and west wall GI absorber, kiln temperature and ambient temperature. The vents and door of the kiln were closed leaving fan switched off. Temperatures of these points were recorded at intervals of 1 minute from 09:00:00 hrs to 17:00:00 hrs. In another experiment, the temperature of northern and southern roof absorbers, fins were recorded in above conditions.

2.3.2 Temperatures of various points in the kiln and ambient under flowing air conditions and vents, door opened partially to maintain a constant temperature of 60°C

The experiments in this section consisted of maintaining kiln temperature at 60°C by adjusting windows and recording the temperature at various points already described. Fans were run during the experiments.

2.3.3 Temperatures of various points in the kiln and ambient under flowing air conditions and vents, door opened fully

The next experiment was done leaving all door and windows opened, fan running, then recording the temperature at various points.

2.3.4 Temperatures of various points in the fully closed kiln and ambient under flowing air conditions

In this set of experiments, the experiment was repeated as described in section 2.3.1., but fan was switched on this time. The temperatures were recorded at various points in kiln as explained in previous section.

2.3.5 Empty run performance test of the solar kiln in summer and winter

Kiln was run in an empty condition i.e. without placing wood. The objective of this experiment was to assess the performance of the kiln without load i.e. wood drying. During the empty runs, all fans were run and the doors and window were closed. Kiln and ambient temperatures were recorded from 09:00 hrs to 17:00 hrs. The empty runs were repeated for consecutive five days each in clear weather during the last week of April, 2014 and first-second week of Jan 2015.

3. RESULTS AND DISCUSSION

Kiln performance tests

3.1 Stagnant air conditions i.e. without running the fans

Fig.2 shows the temperature of kiln absorber plates of eastern, western walls and northern roof absorber and its fin temperature in stagnant air condition i.e. fan not running.

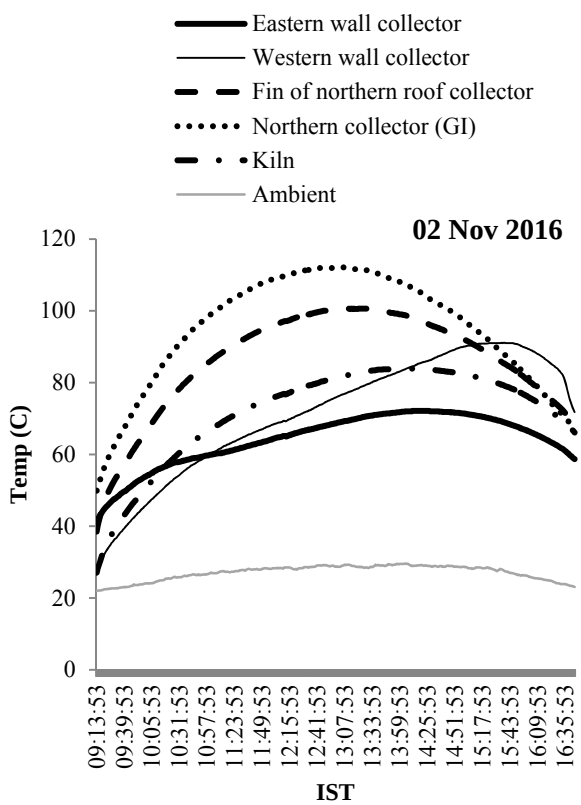

Fig.2: Temperature of absorber plates of the kiln without running fan

Fig. 2 shows that the maximum temperature of the northern roof absorber plate was reached 112°C around 13:00:00 hrs IST. The temperature of fins also went up as the temperature of flat plate (GI) went up and maintained a gap of 10°C below flat plate until after 15:30:00 hrs in evening; this indicates the efficacy of the fins in removal of heat from collectors to kiln air. It can be seen that kiln temperature was lower than eastern wall up to 10:15 hrs; thereafter, the temperature of eastern wall went lower than kiln temperature. The slow rise in kiln temperature and eastern wall may be due to absorption of heat energy by kiln components i.e. walls, floor etc in the form of specific heat.

Temperature of western collector went above kiln temperature at 14:00:00 hrs. Most of the time the roof collector was higher and much above the side wall absorbers, but, at 15:20:00 hrs, the temperature of western wall absorber plate surpasses roof absorber (91°C) and remained above it till evening. Fig. 2 shows that the roof collector temperature was maximum 112°C at 13:00 hrs but the kiln maximum temperature of 84°C was reached at 14:20 hrs, when the western wall temperature was on rise. This clearly indicates that the eastern-western walls of the kiln contribute significantly in maintaining higher kiln temperature in early morning and late evening. During the experiment, ambient temperature stayed around 22°C. Fig 2 also shows that eastern and western wall absorbers are helpful only for early and late hours. For majority of the time, the heat to kiln is supplied by the roof absorbers.

Fig 3 shows temperature of top and southern flat plate absorbers and their fins. It indicates that northern absorber plate showing little higher temperature than southern plate. Since, the air inside kiln is stagnant i.e. not under forced convection. However, the air of the kiln is under natural convection which results in thermal stratification i.e. upper strata of air at higher temperature and lower at lower temperature.

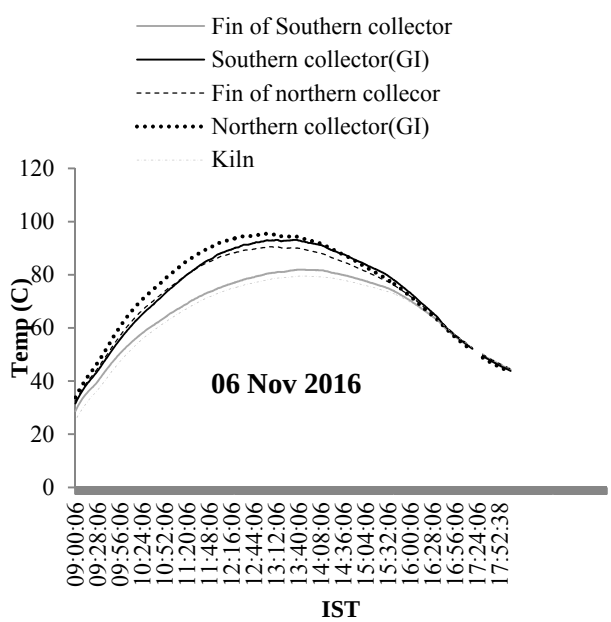

Fig. 3: Northern and southern roof absorber plate temperatures under stagnant air

Since, northern flat plate was placed over upper strata, it might have resulted that lower and higher temperature air remained stacked around upper absorber, resulting in lower heat extraction. Whereas, lower southern absorber was tilted at an angle of 42°, favoring higher natural convection. As the air got heated around it, the air moved to top layers in kiln where the northern absorber was placed. Thus, the roof northern absorber showed little higher temperature than that of southern. Very high temperature of the collectors may result into high radiation heat losses from the kiln. Hence, very high collector temperature in the kilns is not advisable.

3.2 Fan running under condition of windows/ door adjusted to maintain kiln temperature 60°C: Temperature of the collectors and glazings

Fig. 4 presents relative temperature of kiln components when the kiln temperature was maintained at 60°C by adjusting/ opening of vents and door.

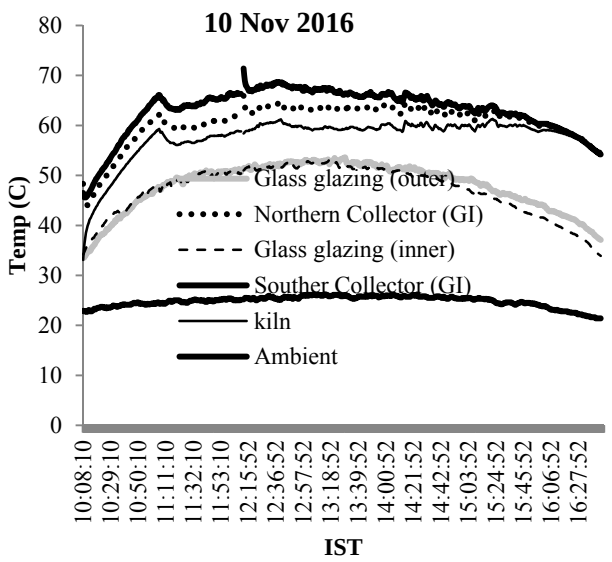

Fig. 4: Kiln components temperatures when kiln temperature was maintained at 60°C

In fig.4, it may be seen that the inner and outer glass layer temperature are almost similar, this indicates higher loss of heat from the kiln. This may be due to the poor sealing of air between the glass layers, which may have resulted into leakages of hot air from the kiln to the space between two glass layers.

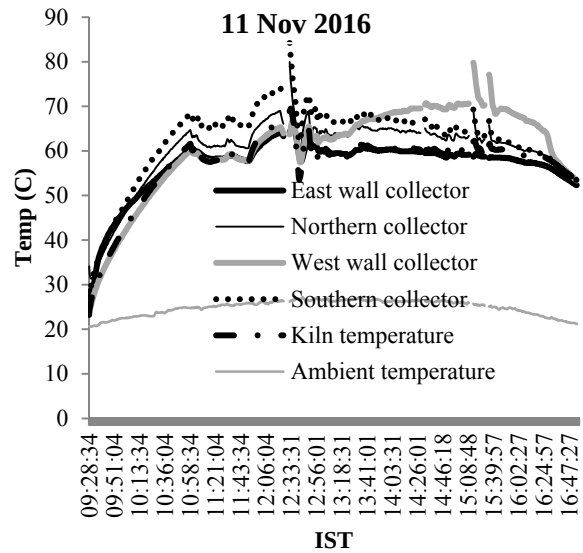

Fig. 5: Kiln components temperatures when kiln temperature was maintained at 60°C

It can be seen from fig. 5 that the southern absorber maintained higher temperature than northern counterpart indicating the usefulness of double inclination. Eastern absorber could maintain higher than kiln temperature only up to 10:30:00 hrs. At 14:00:00 hrs (approximately), temperature of western absorber was the highest and maintained until 16:00:00 hrs. Thereafter, temperature of kiln, all absorbers and fins attained single almost uniform temperature.

3.3 Under condition of all windows/ door opened and forced ventilation

Fig.6 shows the temperature profiles of absorbers, fins, kiln air etc, when fans were switched on after opening all possible ventilation channels i.e. door, windows etc.

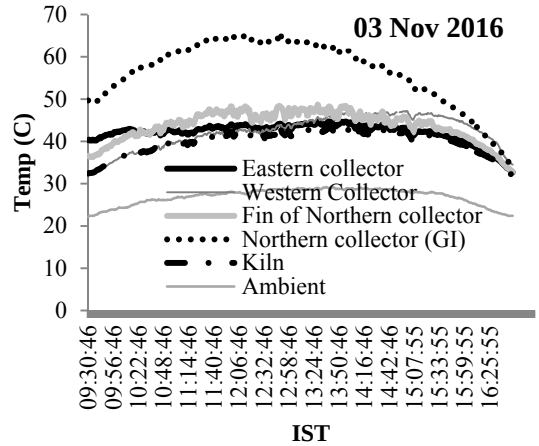

Fig. 6: Kiln components temperatures when all doors and windows were in opened condition

Fig.6 shows that GI absorbers maintained 64°C temperature even in conditions of all the vents in open conditions. It can be seen that fins and kiln air had very small difference with temperatures of fins. Temperature of east and west absorbers too were around kiln temperature. The temperature of northern collector remained maximum at 64°C indicate that fins helped efficiently in removing heat from the absorbers.

Thus, it may be concluded that mainly roof absorbers are more effective and responsible for maintaining kiln temperature than east-west absorbers. The kiln temperature was around 18°C higher than ambient temperature in fully ventilated condition.

3.4 Under closed kiln air and forced ventilation conditions

Fig.4 shows that in the flowing air conditions, the maximum temperature attained by GI absorber of southern roof is 86°C at around 14:00:00 hrs. However, the rise in kiln temperature was steeper in flowing air condition due to better and faster heat removal from collectors.

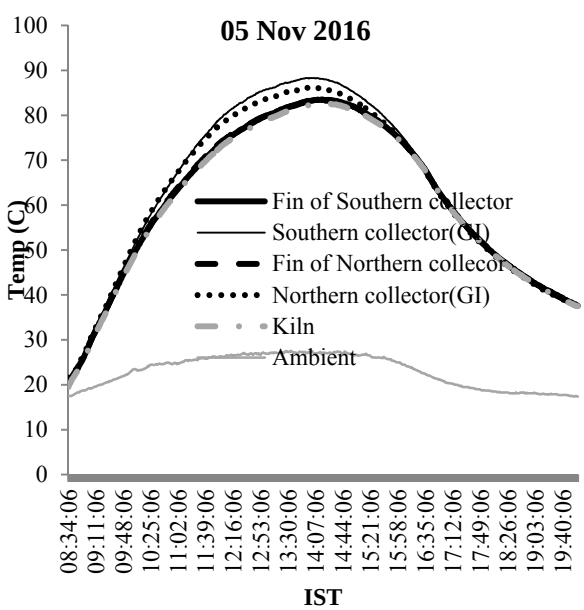

Fig. 4: Temperatures flowing air conditions

Out of two roof absorbers, the temperature of southern absorber was higher than northern roof in contrast to stagnant air conditions. Kiln air and fin temperatures showed almost same temperature, which indicates the efficacy of aluminum fins in heat removal.

Empty Run Test in different seasons of the year

Empty run tests performance of the kiln is presented in this section.

4.9.1. Summer

Fig.5 present empty performance test of the kiln in months of April 2014 and Jan 2015.

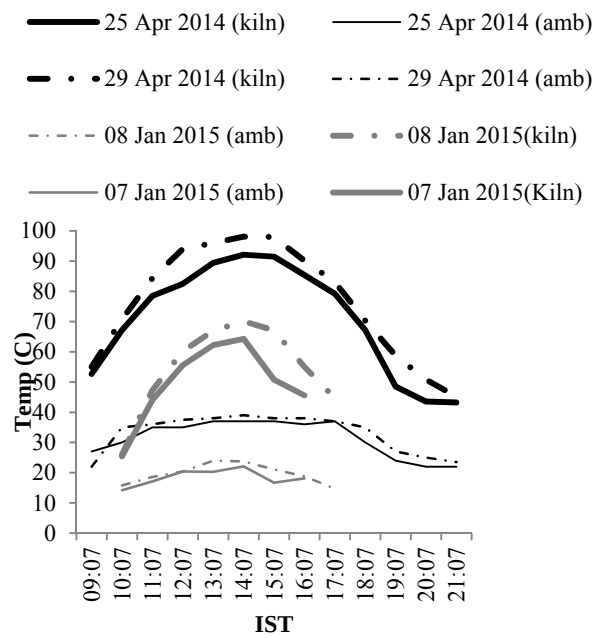

Fig. 5: Kiln and ambient temperatures during empty kiln run test in April

For the month of April, It may be seen that kiln temperature is as high as 98.1°C in April when ambient temperature was 37°C. At 17:07 hrs, temperature was as high as 83.1°C. At 21:07 hrs, the kiln temperature attained level of 45.2 °C. During the month of January, maximum kiln temperature reached 70°C, when the ambient temperature was 22°C. Empty kiln temperature could reach maximum of 63 to 70°C around 14:00 hrs when ambient temperature was around 22-23°C °C. Temperature of 45°C was observed around 17:00 hrs. Thus, in April and January, the maximum kiln temperatures were 61°C and 48°C above the ambient temperature. The main reason behind this difference may be attributed to the available lower solar irradiance in winters.

Fig. 6 presents the solar energy falling on horizontal surface during the experiments in April and January (www.imdaws.com).

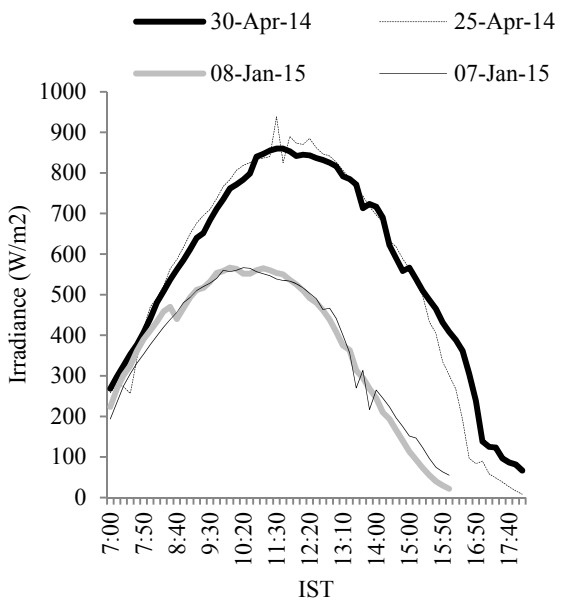

Fig. 6: Solar irradiance during the experiments

It may be seen from figure 6 that the magnitude of solar flux falling on horizontal surfaces in the month of April was very high (600 W/m^2) in the morning (09:00 hrs), while it was only 493.3 W/m^2 at 09:00 in the month of January. The maximum intensity in the month of April recorded was 890 W/m^2 at 11:50 hrs, while in the month of January, maximum intensity recorded was 565 W/m^2 at 10:30 hrs. Thus, 57% increase in maximum solar intensity in April, resulted approximately 40% increase in kiln temperature as compared with January due to the new design of the kiln.

4. CONCLUSION

The dual inclined thermal collectors in the solar kiln performed effectively. In the month of November, inclination of the southern collector (42°C) performed better than that of the northern (top) roof collector (18°C). East-west wall collectors contribute significantly in raising kiln temperature during morning and evening. The contribution of western wall collector was visibly significant. In the stagnant air conditions, maximum temperature of the roof collector was 112°C and that of kiln was 84°C when tested in the first week of November. The western collector maximum was observed to be 91°C around 16:00 hrs. The kiln temperatures are influenced by south facing roof thermal collectors consistently. Fins under roof collectors help in faster heat removal. Maximum kiln temperature of 98°C and minimum 70°C in April and January indicate the kiln design to be efficient for drying operations in both summer and winter seasons.

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