

DESIGN FOR LUMBER DRY KILN USING SOLAR/WOOD

ENERGY IN TROPICAL LATITUDES

J. L. Tschernitz and W. T. Simpson  
Forest Products Laboratory  
Madison, WI 53705-2398

Key Words and Phrases: Solar/wood energy, lumber drying, drying kiln, tropical use.

ABSTRACT

Developing countries with a timber resource that can be manufactured into finished products either for local use or export often lack the capital to build high-cost dry kilns. Many of these countries are in the tropics where solar-radiation and ambient temperatures are high. The low-cost solar/wood energy lumber dry kiln described in this report was designed and tested for such countries where solar dry kilns can be built and operated at low cost.

The design is for a 14-m<sup>3</sup> (6,000-fbm) capacity kiln having an insulated drying compartment, an external horizontal solar collector, and a furnace room containing a wood burner. Capacities larger or smaller than 6,000 fbm are also possible. This design allows collector and wood burner sizing to match the energy demands of the dryer. The design also incorporates low-cost controls that allow unattended drying when operated as a solar-only dryer. Manual firing is necessary when the wood-burning system is supplying the energy.

---

The Laboratory is maintained in cooperation with the University of Wisconsin.

In December 1984 a kiln of this design was built in Sri Lanka at a factory that manufactures furniture and laminated beams from rubber and coconut wood.

### INTRODUCTION

In 1975 the Forest Products Laboratory (FPL) began designing and testing low-cost solar dry kilns for small- to medium-sized production facilities in tropical developing countries. Of several kiln designs proposed, one was selected from which three small-capacity prototypes were built and tested for operation and durability. This design was ultimately optimized so that a commercial-size kiln design could be proposed, a detailed description of which is contained in this report.

In 1975 the U.S. Agency for International Development (USAID) asked FPL to prepare a report on possible use of solar energy to improve the drying practices of small- and medium-scale producers in developing countries, and if feasible, to propose a kiln design (Tschernitz and Simpson 1977). A prototype, 2.4 m<sup>3</sup> (1,000 fbm), was built at Madison, Wis., in 1977 (Simpson and Tschernitz 1984, Tschernitz and Simpson 1979) and tested summers to date. In 1981 another 1,000-fbm prototype funded by USAID, SRI LANKA, was built at a furniture factory in Sri Lanka (Simpson and Tschernitz 1982). In 1982 another solar kiln of the same design funded by the United Nations Food and Agriculture Organization (UNFAO) was installed at the Forest Research Institute at Yezin, Burma. In 1984 a larger dryer was constructed at the same factory (local funding), Borwood, Ltd., of Colombo, Sri Lanka.

The scaled-up design described in this report and the existing prototype will provide the full kiln-drying needs of this furniture factory located near Horana in the southwestern quarter of Sri Lanka, 7°N latitude. While the size chosen matches the factory's needs, the design can be built in smaller or larger versions.

A schematic diagram of the prototype kiln is shown in Figure 3. The caption is keyed to labeled kiln components in enough detail to illustrate the general operation of the kiln.

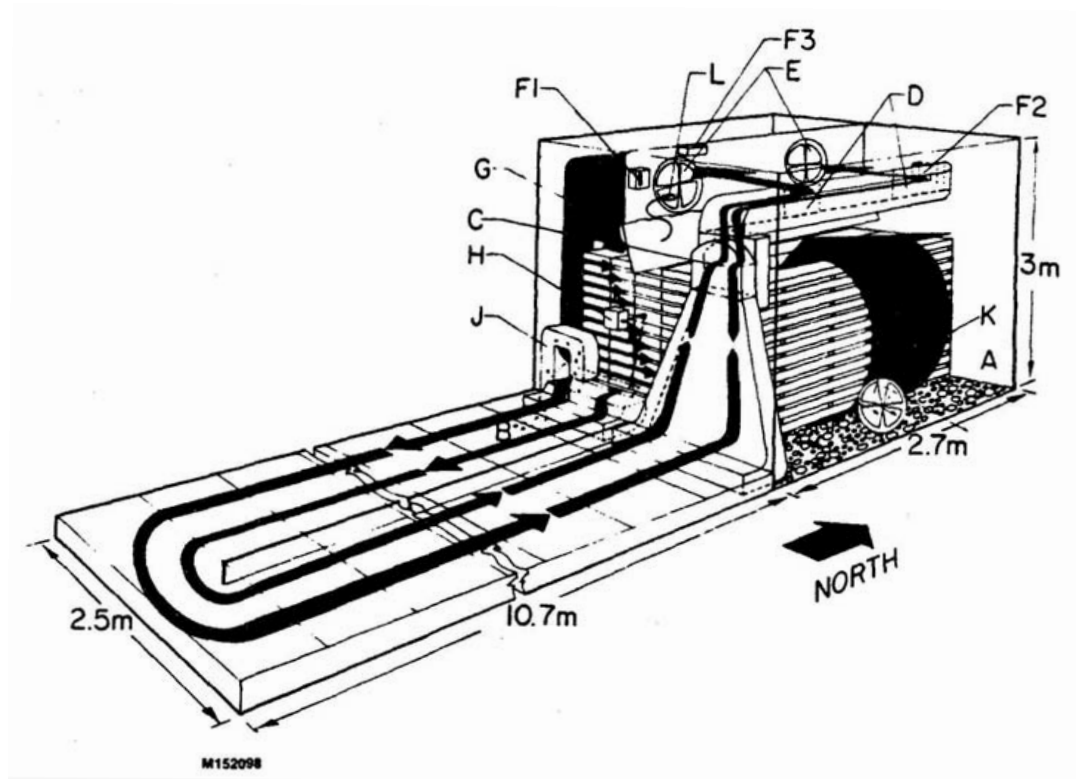


FIGURE 1.--Schematic of solar dry kiln: (A) Drying chamber; (B) solar collector; (C) blower to induce air flow through the collector; (D) hot air discharge to internal fans; (E) internal fans; (F1) humidistat for ventilator; (F2) humidistat for upper limit control; (F3) humidistat for humidifier; (G) disk humidifier; (H) damper motor for dryer-collector interchange or isolation; (J) fresh air intake; (K) power exhaust; (L) thermostat. (M152098)

#### DESCRIPTION OF THE DRYER

##### General Principles of Operation

A schematic of the proposed dryer design is shown in Figure 2. It differs from the prototype in several ways: (1) the capacity is increased from 2.4 m<sup>3</sup> (1,000 fbm) to approximately 14 m<sup>3</sup> (6,000 fbm) of 25-mm- (1-in.-) thick lumber with 19-mm (3/4-in.) stickers; (2) four collectors, instead of one, are located side-by-side

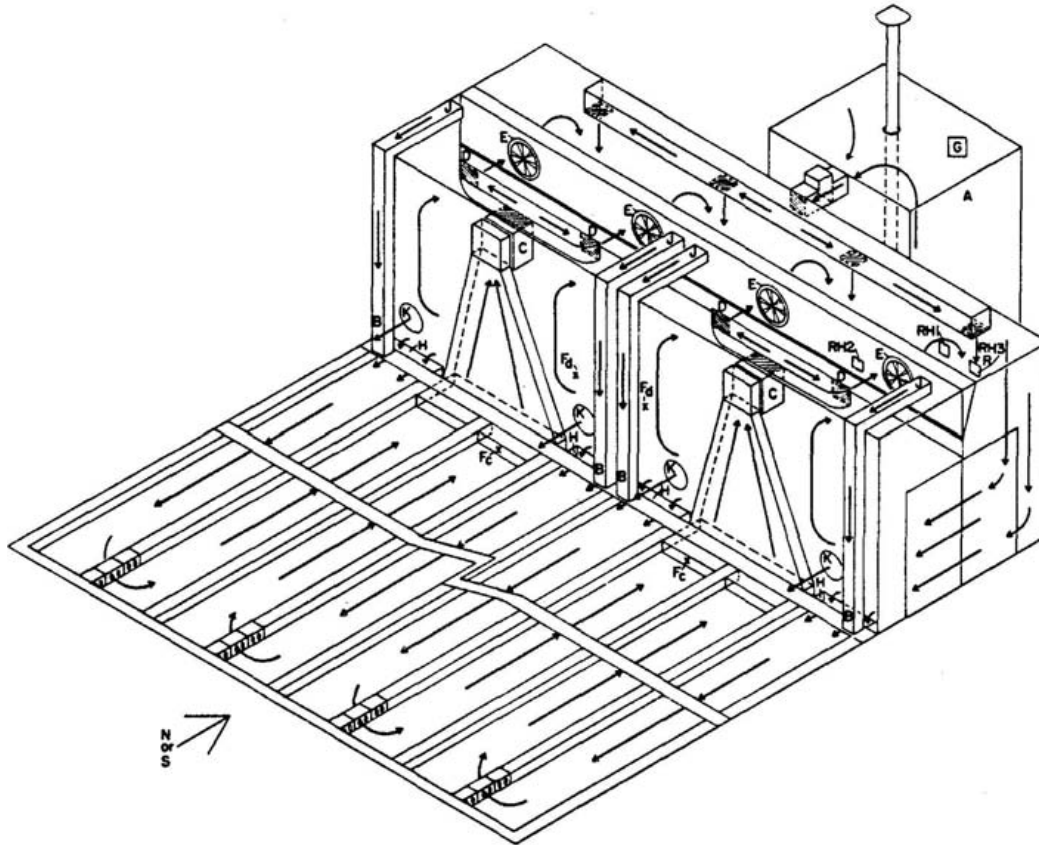


FIGURE 2.--Schematic diagram of solar/wood residue dry kiln: (A) Furnace room; (B) intake air enters collector; (C) solar blower; (D) manifold ducts for solar-heated air; (E) internal fans; (F<sub>c</sub>) differential temperature sensor-collector; (F<sub>d</sub>) differential temperature sensor-dryer; (G) humidifier; (H) return air duct from dryer to collector (dampered); (J) entry point of intake air; (K) exhaust vents; (RH1) humidistat (for exhaust vents K); (RH<sub>2</sub>) humidistat (for shutting off kiln at high humidity); (RH3) humidistat (for humidifier G). (ML845651)

delivering air into one large drying chamber; and (3) a wood residue burner has been added to allow drying 24 hours per day independent of solar insolation levels.

Air circulates through three intersecting loops, one through the wood package (Fig. 2), the other through the collectors and/or residue burner. The wood package receives twice the flow volume of the collectors, which are two independent pairs of two parallel collectors. Airflow in each half of a collector pair is counter to the flow in the other half so that only one duct (C-Fig. 2) is necessary to carry air from the paired collectors to the manifold (D-Fig. 2). The four exhausters (K-Fig. 2) remove air (containing evaporated water) from the kiln at the leaving-side (high humidity) of the wood package. The makeup air from outside enters the system at four points (J-Fig. 2) through the collectors (B-Fig. 2). This is done for three reasons: (1) the cooler ambient air lowers the temperature in the collector, and thus heat losses are decreased; (2) after the solar energy input no longer maintains the collector above dryer temperatures (solar blower off), the stored energy (collector above ambient temperature) can be used to preheat the incoming air; (3) the ambient air with its lower humidity can purge the collector of high-humidity dryer air and thereby prevent or reduce condensation within the collector, particularly at night, which will increase its efficiency (energy is required to re-evaporate water at the beginning of the next diurnal cycle).

Heated air from the collectors is pulled into the dryer by two blowers (C-Fig. 2) and discharged (D-Fig. 2) directly into four overhead fans (E-Fig. 2) that circulate air through the stacked lumber.

Automatic control of the solar dryer is desirable, at the least possible cost, in order to accommodate (1) the intermittent delivery of solar energy to the collector; (2) variable relative humidities (RH) within the drying chamber, which will depend upon the ambient humidity and temperature in the chamber; and (3) the variable rate of drying of the wood. Without such controls, almost

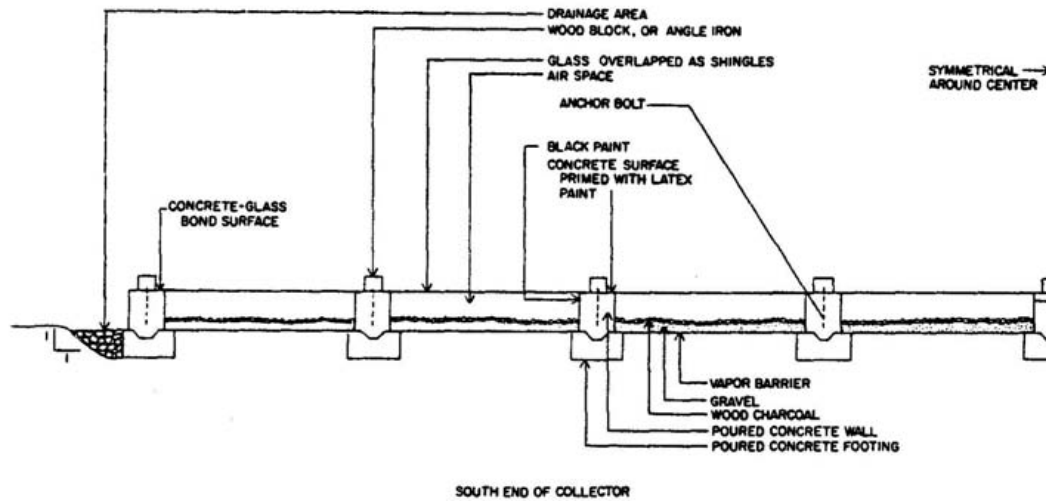
continuous manual observation would be needed to approach the wood quality and efficiency of drying attainable with automatic control. Controls include (1) two differential thermal comparators ( $F_c, F_d$ -Fig. 2) to sense the difference between dryer and collector temperatures and turn the solar blowers (C-Fig. 2) on and off accordingly; (2) a humidistat (RH1-Fig. 2) to allow automatic power venting as needed because controlled venting increases thermal efficiency and also permits scheduling high RH's early in drying and low RH's later on; (3) a second humidistat (RH2-Fig. 2) to establish a maximum RH above which the dryer will shut down. This might happen during long periods of low solar input and high humidities, i.e. rainy periods, and is particularly important when the wood is below 20 percent moisture content; and (4) a third humidistat (RH3-Fig. 2) has two functions: (a) control the humidifier (G-Fig. 2) for conditioning at the end of the drying run, and (b) raise the RH in the drying chamber in order to prevent or reduce degrade in refractory woods at intermediate moisture contents.

A low-cost combustion system fueled by wood residue has been incorporated in the solar dryer design. A simple burner is located in a furnace chamber on the opposite side of the drying compartment from the solar collector (A-Fig. 2). The furnace can operate either simultaneously or separately from the solar collector.

#### Construction Details of the Dryer

Solar collector (Fig. 3) .--The collector is external to the drying compartment so that collector area and orientation are not limited by the geometry of the dryer. The collector is horizontal (except for a  $1/2^\circ$  north-south drainage tilt) and is built into the ground for ease and low cost of construction. The horizontal orientation is particularly effective near the equator.

Figure 3 shows a cross section of one of the two pairs of collectors. A foundation of concrete blocks or poured concrete forms the perimeter of the collector. A 0.3-m- (12-in.-) deep



ML85 5525

FIGURE 3.--Section view of solar collector. (ML845525)

excavation is filled with gravel to approximately 0.15 m (6 in.) of the top of the block or concrete foundation. A layer of charcoal, average size 1.3-2.5 cm (0.5-1 in.), about 5.1-7.6 cm (2-3 in.) deep, covers the gravel. Charcoal is an inexpensive solar energy-absorbing surface and heat-transfer medium and a good insulator that reduces heat loss to the ground. The charcoal was made on-site from rubberwood in covered ground pit burners. The interior surfaces of the foundation are painted flat black. The collector cover spans the 1.3 m between sides of the foundation.

Experience with the prototype indicates that common window glass will be the most cost effective collector cover, particularly in areas without access to rigid plastic cover material. The sections of glass making up the cover (91 cm x 117 cm x 0.5 cm) are installed to overlap no more than 1.3 cm (0.5 in.). Butyl tape and silicone sealants are used to seal the glass directly to the block or concrete foundation and overlap. One feature of this construction method is avoidance of the expense of metal or wood framing for the glass and certain decay of the untreated wood.

Sections of broken glass are replaceable simply by cutting the sealant around the edges.

The collector is 15 m (50 ft) long, and each leg is approximately 1.2 m (4 ft) wide. Because of overlap at the edges, the effective collector area is approximately 139 m<sup>2</sup> (1,500 ft<sup>2</sup>). The ratio of lumber capacity to collector area is 0.1 m<sup>3</sup>/m<sup>2</sup> (4 fbm/ft<sup>2</sup>). In each of the four collectors air is drawn from the drying compartment and/or fresh air intakes (J-Fig. 2), travels the length of the collector, crosses the 1.3-m-long gap at the end, and back into the drying compartment through the ducts shown in Figure 2. The collector is under negative pressure so that any leakage is into the system.

**Drying compartment.**--The inside dimensions of the drying compartment are approximately 3 by 10.4 by 3.3 m (10 by 34 by 11 ft high). The kiln is track loaded, designed for a 1.5-m- (5-ft-) wide load of lumber. The walls are of 30- by 30- by 60-cm (12- by 12- by 24-in.) concrete block, hollow, and filled with loose insulation. The ceiling of the drying compartment consists of 50- by 100-mm (2- by 4-in.) boards on edge, treated or decay resistant species. This provides good insulation and a solid ceiling for attachment of fans and other kiln components. Above the ceiling is a built-up roof with sealed surfaces and space for insulation. Above that an open-pitched shed-type roof of corrugated metal painted black serves the dual role of providing for water runoff and as a preheater for makeup air entering the solar collector (Fig. 2).

**Wood residue burner.**--Wood residue is burned in a simple, low-cost burner housed in a furnace chamber on the side of the drying compartment opposite the solar collector. The burner consists of two 208-liter (55-gal) steel drums mounted on a framework. One drum is the combustion chamber. The other, along with the chimney, serve as additional heat transfer surfaces. The burner operates at 65 percent efficiency and can produce up to 23 kW (80,000 Btu/hr) (Anonymous 1981). A blower discharges kiln air into the furnace chamber, and forces heated air from the furnace room back

through a duct into the drying compartment. When humidity control is necessary, a humidistat- (RH3-Fig. 2) activated water spray can release water into the furnace chamber for humidification of the air going into the drying compartment. A manifold within the drying compartment distributes heated air into the internal circulating air. Details of construction are available from FPL.

#### CALCULATED ENERGY SUPPLY AND DEMAND

Energy supply and demand estimates can be made on an annual basis for the 14-m<sup>3</sup> kiln for drying 25-mm- (1-in.-) thick rubberwood in Sri Lanka, as summarized in Tables 1 and 2. Table 1 summarizes a 7-day drying schedule, and Table 2 contrasts a slower 10-day schedule where proportionately more solar than wood energy can be used. There are also many other possible similar schedules. In each schedule there are three sources of energy supply: solar (based on 139 m<sup>2</sup> (1,500 ft<sup>2</sup>) of collector operating at 50 pct efficiency), wood residue (one burner rated at 23 Kw), and electrical energy from the fan and blower motors. Assuming that the normal mode of operation will make maximum use of solar energy for a given schedule and supplement with wood residue to supply the rest, the 7-day schedule will use 41 percent solar, 46 percent wood residue, and 13 percent electric; the 10-day schedule will use 62 percent solar, 18 percent wood residue, and 20 percent electric. Thus, if one is willing to increase drying time, use of wood residue can be reduced. If one needs to minimize drying time, then proportionally more wood residue energy can be used. Electric energy might be reduced by not operating two of the four fans late in drying when air circulation requirements are reduced.

#### CONTROL AND OPERATION OF THE KILN

The kiln is designed to operate automatically except for the burner that must be charged manually. A range of operating variables can be changed by manipulating set points. This provides a means to control drying according to a schedule.

TABLE I Energy supply and demand estimates (average annual basis) for solar/wood energy dry kiln for operation in southwestern Sri Lanka, drying 14 m<sup>3</sup> of 25-mm-thick rubberwood from 60 to 13 percent using a 7-day (168-h) schedule

Schedule 1 <sup>1</sup>	Energy at times of			
	<sup>2</sup> 168 h (pct)	24 h	<sup>3</sup> 12 h	<sup>4</sup> 1 h
	- - - - - Joule x 10 <sup>3</sup> - - - - -			
Supply				
Solar (43-m <sup>3</sup> (1,500-ft <sup>2</sup> ) collector at 50 pct efficiency)	6.42 (41)	0.92	0.92	0.26
Wood residue burner	<sup>5</sup> 14.18 (46)	2.03	1.01	0.084
Electric (fan/blower motor)	2.10 (13)	0.30	0.15	0.013
Total	22.70	3.25	2.08	0.36
Demand				
Maximum	--	3.39	1.69	0.14
Average for 168 hours	15.84 (100)	2.26	1.13	0.093

<sup>1</sup>Moisture content (dry basis, pct), temperature (°C), relative humidity (pct)

60-50	43	80
50-30	49	50
30-15	54	30
15-13	60	30

<sup>2</sup>Total drying time to 13 pct moisture content.

<sup>3</sup>Daylight hours.

<sup>4</sup>Maximum hourly rate at solar noon.

<sup>5</sup>If the full 6.42 x 10<sup>3</sup> Joule of net available solar energy is utilized, then the net wood residue is 7.31 x 10<sup>3</sup> Joule.

TABLE 2 Energy supply and demand estimates (average annual basis) for solar/wood energy dry kiln for operation in southwestern Sri Lanka, drying 14 m<sup>3</sup> of 25-mm-thick rubberwood from 60 to 12 percent using a 10-day (240-h) schedule

Schedule 1 <sup>1</sup>	Energy at times of			
	<sup>2</sup> 168 h (pct)	24 h	<sup>3</sup> 12 h	<sup>4</sup> 1 h
- - - - - Joule x 10 <sup>3</sup> - - - - -				
<b>Supply</b>				
Solar (43-m <sup>3</sup> (1,500-ft <sup>2</sup> ) collector at 50 pct efficiency)	9.18 (62)	0.92	0.92	0.26
Wood residue burner	<sup>5</sup> 20.26 (18)	2.03	1.01	0.084
Electric (fan/blower motor)	3.00 (20)	0.30	0.15	0.013
Total	32.44	3.25	2.08	0.36
<b>Demand</b>				
Maximum	--			
Average for 240 hours	14.84 (100)	1.49	0.74	0.061

<sup>1</sup>Moisture content (dry basis, pct), temperature (°C), relative humidity (pct)

60-50	38	80
50-30	43	50
30-15	46	30
15-12	49	40

<sup>2</sup>Total drying time to 12 pct moisture content.

<sup>3</sup>Daylight hours.

<sup>4</sup>Maximum hourly rate at solar noon.

<sup>5</sup>If the full 9.18 x 10<sup>3</sup> Joule of net available solar energy is utilized, then the net wood residue is 2.67 x 10<sup>3</sup> Joule.

### Solar-Only Operation

#### Daily Control Sequence

A description of events in a typical 24-hour control sequence will illustrate how the dryer operates.

0000-0800 hours.--The timer (Fig. 4) has opened the control relay, and the kiln is turned off.

0800 hours.--The timer closes the control relay (R1-Fig. 4) if the RH in the dryer is below the RH2 set point (the upper limit of RH set by RH2 in Fig. 2). The internal fans are on. The power vents (K-Fig. 2) are on if the RH in the dryer is above RH1 set point.

0800-2200 hours.--The solar blowers (C-Fig. 2, Fig. 4) start when the temperature in the collector ( $F_c$ -Fig. 2) is above the temperature in the drying chamber ( $F_d$ -Fig. 2) (Deko Lab control-Fig. 4). Simultaneous with the solar blower operation, the dampers (H-Fig. 2, Fig. 4) open. When the solar blowers are off, dampering prevents the loss of energy through induced circulation, by fan head, of warm air from the drying chamber through the cool collector. The electrical input to the solar blowers is in front of the control relay (R1-Fig. 4) so that the solar blowers (C-Fig. 2, Fig. 4) can be activated if they have been shut off by high RH (RH2-Fig. 2, Fig. 4). This is important because when sufficient solar energy becomes available to heat the air in the collector, it lowers the RH of the air entering the drying chamber. When the RH falls below the set point (RH2) the dryer turns on automatically.

The differential temperature controls activate the solar blowers intermittently throughout the drying day (0800 and 2200, or other intervals as set by the timer). When the solar blowers are OFF, the fans and exhaust blowers will continue to operate. Drying can proceed without solar heat input into the collector because of energy storage in the wood/dryer system, the drying capacity of the ambient air, and the stored energy in the collectors. This stored energy can be recovered by preheating, i.e., scavenging of the collector with the vent air entry induced by the exhaust blowers.

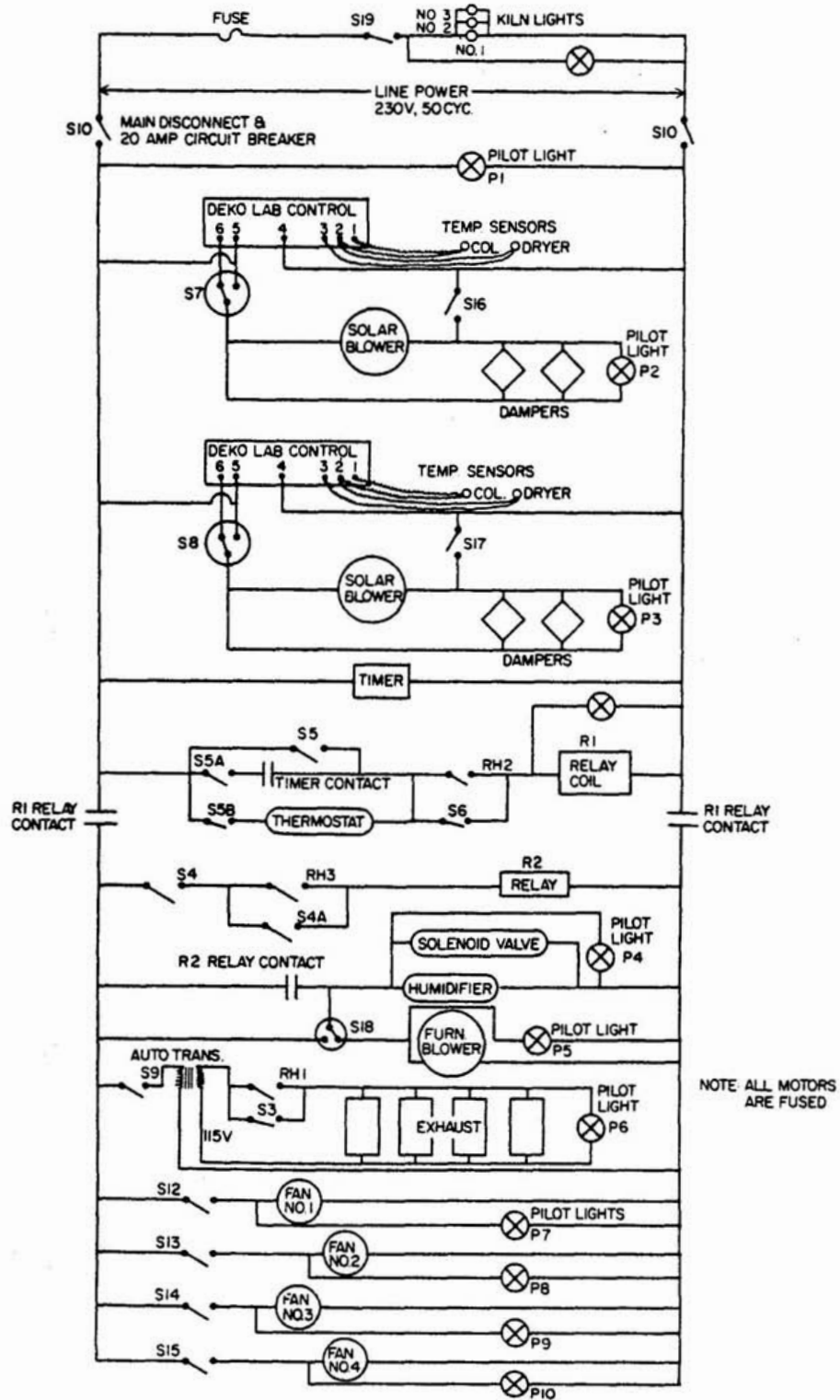


FIGURE 4.--Wiring diagram of control system. (ML845650)

TABLE 3 Control panel operational modes (refer to Fig. 4)

Switch	Automatic mode	Manual mode
S5B	Closed <sup>1</sup>	Open <sup>2</sup>
S7, S8	Position 6	Position 5
S12, S13, S14, S15	Closed	Closed
S16, S17	Closed	Closed
S5	Open	Closed
S5A	Closed	Open
S6	Open	Closed
S4	Closed or open	Closed
S4A	Open	Closed or open
S9	Closed	Closed or open
S3	Open	Closed
S18	Position 2	Position 1 or 2

<sup>1</sup>Closed--power ON.

<sup>2</sup>Open--power OFF.

If the RH falls below set point RH1 (some time between 0800 and 2200, or other time as set by the timer), the humidifier (G-Fig. 2, Fig. 4) is activated by its own humidistat (RH3) to increase the RH.

2200-2400 hours.--The dryer will normally stop operation. Since the dampers (H-Fig. 2, Fig. 4) are closed (solar blowers have been off) the drying chamber will be isolated from the collectors and overnight heat loss is minimized. A thermostat is located in parallel with the timer/relay circuit (Fig. 4). If at 2200 hours (or other time set by the timer) the temperature in the

chamber is greater than 32°C (90°F), or other variable setting, the drying will continue until the temperature drops below 32°C (90°F) or the humidity rises above set point RH2. The cycle will be repeated again at 0800 hours the next day.

#### Operating Controls

Timer.--ON and OFF interval within any 24-hour-days, variable. The timer can also be bypassed manually (switch S5-Fig. 4).

Differential temperature switch--Deko Lab.--With bypass (S7, S8-Fig. 4).

Relative humidity control.--All set point selection is manual within the dryer. RH is closed above set point and controls the exhaust blower. Customarily, the set point will be high initially and low in the final stages of drying, particularly for refractory woods.

RH2 is similar to RH1, except the switch is open (OFF) above set point. The switch controls the power relay. This control is used to maintain humidities below a certain maximum level.

RH3 operates the humidifier (solenoid-spray nozzles) and is similar to RH1, except the switch is open (OFF) above set point. The drying chamber can be controlled to maintain the humidity above a minimum level by means of this humidifier. If drying stresses are present at the end of the drying run, the humidifier can be used to accomplish a conditioning stress relief period.

Air circulation.--Four single-speed fans are controlled by the timer, RH2, thermostat, and manual switches (S12-15-Fig. 4). The fans can be operated together or separately, and in the later stages of drying when air circulation requirements decrease, it will be economical to switch two of the four fans off for reduced energy consumption.

Furnace blower.--RH3 or manual switch (S18-Fig. 4).

#### SUPPLEMENTAL WOOD FUEL OPERATION

A simple wood waste fuel combustion system has been incorporated into the solar drying system. It consists of two 208-liter

(55-gal) steel drums, mounted on a framework, as the combustion chamber and heat transfer surfaces. The purpose of this adjunct system is to increase the drying throughput of the kiln by operating (1) at night, (2) on cloudy days, and (3) during rainy periods. The auxiliary furnace can operate simultaneously with the solar collector in the following way. The solar blower is only activated when the collector is warmer than the kiln chamber. Thus, if the furnace has heated the drying chamber higher than the discharge temperature of the collector, the solar blower will stop and the dampers will close. Two events then follow: (1) When the RH1 control calls for venting, fresh air is drawn through the collector to be preheated, thereby recovering any solar energy accumulating in the collector when the blower is off, even though the collector is now at a lower temperature than the dryer. (2) At low vent rates the collector temperature may again rise above the kiln "control" temperature, and the solar blower will start. The energy input from the furnace will be varied manually from the maximum to lower levels by damper control of combustion air to the drum and with the amount and quality of fuel charged to the furnace. Observation of temperature in the furnace house and/or the kiln will guide the operator in the manual firing of the combustion chamber. If for some reason the temperature in the kiln rises to levels felt injurious to the wood, a discharge vent can be opened to cool the system.

The steel drums will probably need to be replaced frequently because corrosion will perforate the drum wall. This compromise is made with the assumption that steel drums are readily available, and that even with frequent replacement the cost will be less than with a more durable but more expensive burner. If a different combustion unit is substituted, the operation of the blockhouse furnace chamber (A-Fig. 2) would still be maintained.

If it is necessary to raise the humidity at certain stages of the drying cycle (RH3 control), a pneumatic atomizer (G-Fig. 2, Fig. 4) has been installed in the furnace chamber to spray water onto the heated drums. The evaporated water is then introduced

along with the heated air into the kiln. If the furnace is not in operation when it is necessary to raise the humidity in the dryer, the atomizer is still activated by RH3. In addition, when switch S18 (Fig. 4) is in the correct position, the furnace blower will also be activated by RH3 so that the humidified air is circulated from the furnace room to the drying chamber.

Waste wood fuel should be inventoried in order to provide for air drying and thus more efficient combustion and higher heat release from the lower moisture content wood. It may be desirable to use the solar dryer itself to predry fuel between wood charges should the inventory of air-dried fuel be low.

#### CONSTRUCTION OF KILN

In August 1984 kiln control equipment (fans, blowers, motors, various sensors, etc.), and special sealants for the glass collector, were shipped from the United States to Sri Lanka. Concurrently, the staff of Borwood, Ltd., began construction of the kiln structure using local building materials. In early November, the authors arrived in Sri Lanka to help in final construction details and assure proper operation. The kiln was completed in early December. Figure 5 shows the kiln shortly before completion.

#### DRYER PERFORMANCE

Since the authors left before the dryer could be operated (November 1984), no extensive drying data are yet available. Partial energy balances have been calculated from two recent communications from Borwood, Ltd., and are reported in Table 4. The assumptions needed to complete the table are given in the footnotes. It is interesting to compare these dryer "observations" in Table 4 with the design estimates shown in Table 2. An energy study of material and energy balances for this drying system is currently being planned and will begin in the near future (September 1986).

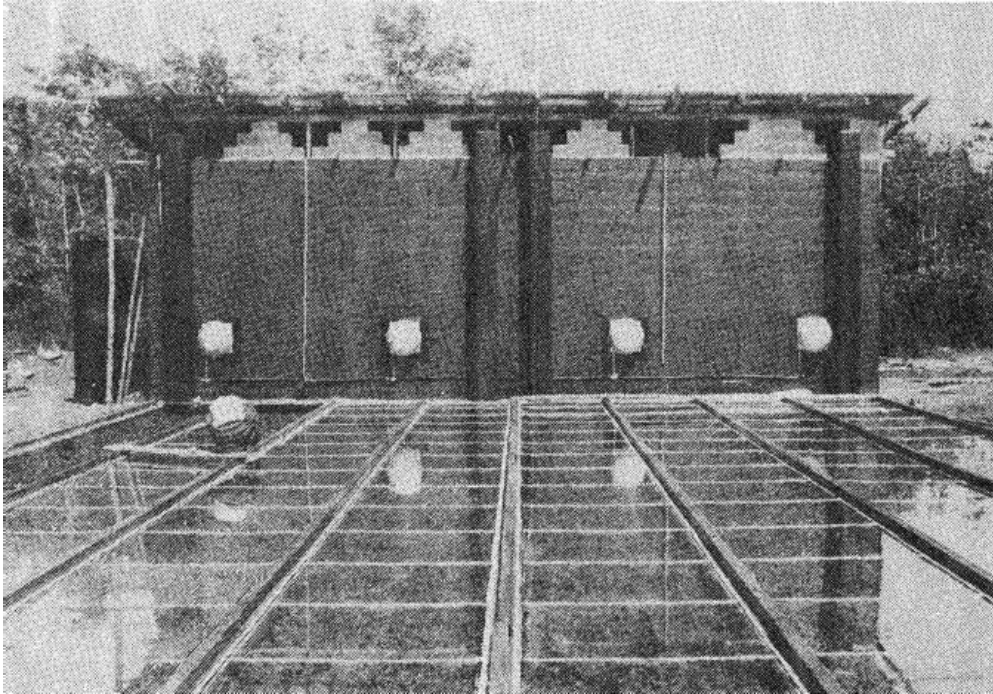


FIGURE 5.--Partially completed 14-m<sup>3</sup> (6,000-fbm) solar/wood energy dry kiln at Borwood, Ltd., near Colombo, Sri Lanka. (M840506-11)

#### SUMMARY

The FPL design for the solar/wood energy dry kiln described in this report is the culmination of a project that included design, construction, and testing of several small prototype kilns. The final design is commercial size (for small- to medium-size operations in tropical developing countries) and incorporates design improvements suggested by prototype performance.

The specific design is for 14-m<sup>3</sup> (6,000-fbm) capacity, although within practical limits the design is modular in 7-m<sup>3</sup> (3,000-fbm) increments. The kiln consists of three major components: (1) a glass-covered collector built horizontally into the ground; (2) a separate drying compartment; and (3) a furnace room housing a wood residue burner. The basic design philosophy was to

TABLE 4 Commercial solar/wood waste statistics: rubberwood

Run No.	Month <sup>1</sup>	Drying days	Thick-ness (mm)	Solar insulation <sup>2</sup>	Moisture content (pct)	Energy input x 10 <sup>9</sup> Joules (pct)			Dryer efficiency <sup>7</sup> (kg/kg)
						Wood waste <sup>3</sup>	Electric <sup>4</sup>	Solar <sup>5</sup>	
1	Dec.	22	38	--	80	--	4.87	Solar only	1.69
2	Dec.	13	38	--	67	--	4.75	Solar + 4 night wood fire	1.83
3	Jan.	9	38	--	64	--	3.33	do.	1.85
4	Jan.	8	38	--	73	--	3.78	Solar + 6 night wood fire + 2 day and night	1.95
5	Jan.	9	26	378	70.1	14.3	2.38	3.40 (21.6)	9.92 (63)
6	Feb.	10	26	408	72.7	12.9	2.38	3.85 (21.2)	11.92 (65.7)
7	Feb.	7	26	381	65.2	17.5	2.62	2.73 (18.6)	9.31 (63.5)
8	Feb.	11	32	372	69.7	12.3	2.28	4.27 (23.1)	11.96 (64.6)
9	Mar.	10	26	387	69.2	12.0	2.46	3.81 (20.6)	11.27 (60.9)
10	Mar.	11	26	493	73.4	9.9	3.64	4.55 (18.9)	15.81 (65.9)
11	Mar.	12	32	439	69.8	15.9	3.42	3.68 (16.4)	15.36 (68.4)
12	Apr.	14	26	296	72.8	11.7	1.87	5.29 (27.4)	12.11 (62.9)
13	Jun.	14	26	343	76.2	18.2	2.68	5.14 (23.4)	14.11 (64.3)
14	Jul.	12	26	--	80.7	14.9	2.49	3.24 (15.2)	--

<sup>1</sup>1984-85.  
<sup>2</sup>Average per run, Langley/day on-site measurement; Belfort pyranometer.  
<sup>3</sup>Assume 23 pct moisture content, as received basis; 65 pct furnace efficiency; heat value = 19,940 x 10<sup>3</sup> x (0.77) (0.65) = 9,980 x 10<sup>3</sup> Joule/kg.  
<sup>4</sup>All electric power as measured input appears as useful energy in kiln.  
<sup>5</sup>Assume 50 pct solar collector efficiency, 139-m<sup>2</sup> area.  
<sup>6</sup>Sum of 3, 4, and 5.  
<sup>7</sup>Dryer efficiency expressed as kilogram of steam requirement per kilogram of water evaporated.

provide as much automatic control as practical using low-cost industrial controls. The combination of solar and wood waste energy allows 24 hours per day drying regardless of weather.

The design was intended specifically for a furniture and laminated beam factory near Colombo, Sri Lanka. The kiln was built in December 1984, and is now operational. Initial results show that the kiln operates as expected. Drying times for 25- to 38-mm- (1- to 1.5-in.-) thick rubberwood range from 7 to 22 days, depending on how much supplemental wood energy was used and the weather.

#### ACKNOWLEDGMENT

We wish to acknowledge Hope Todd, Director of Borwood, Ltd., for his interest in this project as well as his management of the financing and construction of the solar kiln at Horana; and C. Dassanayake, Engineer at Borwood, for his effective efforts in directing the technical details of construction.

#### REFERENCES

1. Anonymous. 1981. The return of the wood stove. *Consumer Reports* 46(10).
2. Simpson, W. T., and Tschernitz, J. L. 1982. Solar dry kiln gets trial in Sri Lanka. *World Wood* 23(1):13.
3. Simpson, W. T., and Tschernitz, J. L. 1984. Solar dry kiln for tropical latitudes. *Forest Prod. J.* 34(5):25-34.
4. Tschernitz, J. L., and Simpson, W. T. 1977. Solar kilns: Feasibility of utilizing solar energy for drying lumber in developing countries. USAID FPL-AID-PASA TA (AG 02-75). U.S. Department of Agriculture, Forest Service, Washington, DC.
5. Tschernitz, J. L., and Simpson, W. T. 1979. Solar-heated, forced-air lumber dryer for tropical latitudes. *Solar Energy* 22:563-566.