

← The Appalachian → Solar Lumber Kiln

Dennis Scanlin

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Above: Students from Appalachian State University with the Solar lumber kiln.

The drying of lumber is essential before it can reliably be used indoors. Drying consumes an enormous amount of energy. Each year (in the United States) lumber drying consumes 10 trillion BTUs, the equivalent of 1.7 million barrels of oil (*Fine Woodworking*, 1986). Two-thirds of all the energy used in producing lumber is for drying, adding 40 to 75% to lumber's value. Green 4 by 4 FAS cherry currently costs \$1.27 per bd. ft. and kiln dried is \$2.20, a 73% increase. Edwin Culbreth, the former owner of General Hardwood Products in Deep Gap, North Carolina, for whom the 3000 bd. ft. capacity kiln described in this article was constructed, spent as much as \$0.08 per bd. ft. drying lumber in a dehumidification kiln. The initial cost of a kiln is also significant. An all electric 2,000 bd. ft. kiln with a small electric boiler can cost over \$30,000.

Solar Drying

Lumber drying can be successfully accomplished with solar energy. The temperatures desired for lumber drying are between 100 and 180° F (the same as for food drying) and these can be obtained with a low temperature solar thermal collector. A solar kiln can operate all year long and during good solar periods can dry lumber in virtually the same amount of time as could a fossil fuel powered kiln. The quality of solar dried lumber is also as good or better than lumber dried in conventional kilns. Solar kilns can be constructed for much less than the cost of conventional kilns. The kiln

described in this article was designed and constructed by students and faculty at Appalachian State University in the Department of Technology's Appropriate Technology Program. It has been in continual operation for 6 years. The inspiration for the design came from the "Oxford Kiln," a lightweight, portable, inexpensive, but not very durable kiln designed at Oxford University in England (*Fine Woodworking*, 1986). The 3,000 bd. ft., PV controlled, solar kiln described in this article was constructed for \$3800. I have also constructed a smaller 600 to 1000 bd. ft. kiln in West Virginia for about \$1000.

Wood Drying

Wood absorbs water, and swells and shrinks with changes in moisture content. This characteristic can make wood difficult to predictably use. The goal of wood drying is to remove moisture until it reaches the level present in the environment where the wood will ultimately be used. This keeps the swelling and shrinking to a minimum. Wood will release or absorb moisture until it is in equilibrium with the surrounding air. This state is called the equilibrium moisture content (EMC). If the wood will be used outside, then wood could be stacked outside and will eventually reach equilibrium with the environment. No kiln is necessary. The speed of drying will be affected by the thickness and density of the wood and the relative humidity of the surrounding air. Thin, low density wood placed in a low humidity environment will dry most quickly. If the lumber is for furniture to be used in a lower humidity environment inside a house, then the wood should be dried until it has the same moisture content (MC) of that environment. Usually 6 to 8%. This involves removing water from inside the cell walls (bound water), as well as the "free" water in between the cells.

The bound water is more difficult to remove. It could be removed by stacking the lumber inside the space where it will eventually be used. However this could take a year or more and most of us are not interested in living with stacks of lumber. Indoor drying can also proceed too quickly, because of the low humidity indoors, and cause surface checking. More commonly, lumber for furniture is dried in a kiln. The wood is exposed to 100° to 180° F air until it reaches the moisture content comparable to the relative humidity of the end use environment. In general the higher the temperature and air flow and the lower the humidity, the faster the drying. The goal is to speed up the drying process but keep it

Above: Installing exhaust vents.



Above: Installing the dark aluminum screen used for solar absorption.

slow enough by controlling the humidity and temperature to prevent uneven shrinkage and the resulting defects. Most conventional kilns operate with air velocities of between 200 and 500 CFM through the lumber pile. The humidity is normally kept high during the early phases of drying and lowered as the drying proceeds.

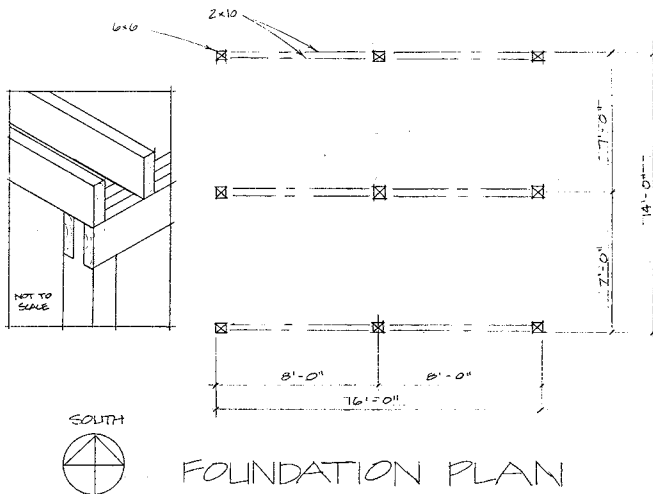
Components of a Solar Kiln

A solar kiln is basically a low temperature solar thermal collector, usually an air heating collector, connected to an insulated and tightly constructed building. A stickered lumber pile is placed inside. A solar kiln has the same basic components as most solar thermal technologies: south facing glazing to admit solar energy; an absorbing material, often metal, to absorb solar energy and convert it to heat; insulation and tight construction to reduce unwanted heat loss; an air intake, flow path and exhaust area; and an area for lumber pile. A reflector could be added to increase performance.

Glazing Options

Glazing is the material that allows solar energy to enter the solar collector. It can be glass or plastic. An ideal glazing would have a high solar transmittance, over 90% and a low terrestrial infra-red (IR) or heat transmittance. It would let a lot of solar energy in but not much heat radiate out. Glass is an ideal material having as high as 91% solar transmittance and as low as 1% IR transmittance. But it is heavy, breakable, and is not normally available in long lengths. Sun-Lite HP plastic or Kalwall is also a good material with properties similar to glass (86% and 4% transmittances), with the added advantage of coming in rolls which can be cut any length desired (manufacturer recommends no longer than 16 feet). This eliminates horizontal seams

Solar Kiln

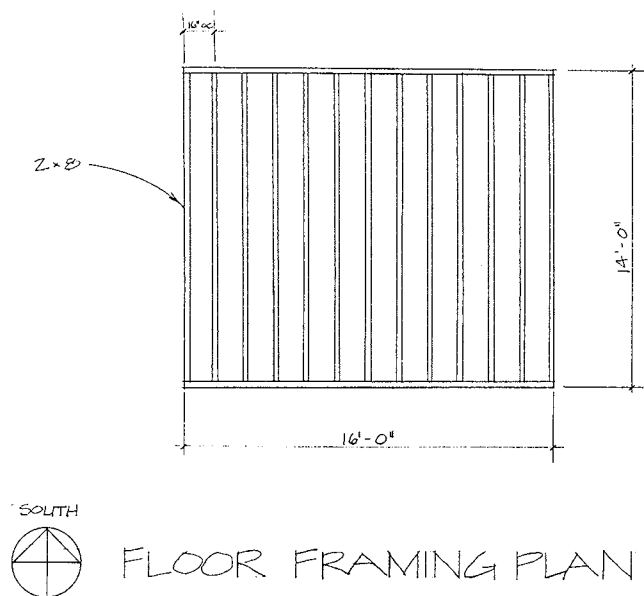


which can be problematic. It is also light weight and non-breakable. If properly maintained it can last a long time, maybe 25 years. Maintenance involves coating every 10 years with "Kalwall weatherable surface," a 2 part resin. The Sun-Lite HP glazing for the solar kiln described here is 0.040 inches thick by 49 1/2 inches wide. The cost is \$1.85 per sq. ft.

Thinner plastic glazing can also be used. Many have very high solar transmittances over 95%, but also have high IR transmittances, over 50%. They are not as durable as glass or Sun-Lite. But some resist UV degradation and can be good



Above: Laying out foundation and floor.



options for a second inner glazing. There are a variety of products on the market. The kiln depicted has an inner, second layer of glazing separated from the Sun-Lite by a 3/4 inch air space. The inner glazing is Teflon FEP film. Wengert and Oliveira (1987) have indicated that collector performance can be improved by 35% or so when a second layer is used.

Other Glazing Issues

Other glazing decisions include: what angle should the glazing be above a horizontal plane or the ground (altitude) and what direction should the glazing face (azimuth)? Assuming the kiln would be used all year round, the glazing angle should be the same as one's latitude. This would provide the greatest number of BTUs over a year. Latitude plus 10 to 15° would result in slightly better performance during the shorter days of

winter while still providing good summer performance and more usable interior space. This is the strategy we pursued. The Appalachian kiln is located at 36° N LAT and has a glazing angle of 45°.

The azimuth angle for the kiln's collector should be due south for best performance in northern latitudes, although slight variations won't significantly affect the performance. Make sure the sun can strike the collector all day long or at least from 9 to 3 solar time.

A final consideration is what size the glazing needs to be. Wengert and Oliveira (1987) recommend 1 sq. ft. of glazing for each 10 bd. ft. of dryer capacity. All successful designs surveyed have this much or more glazing. The Appalachian kiln has a 3,000 bd. ft. capacity (1,000 cubic feet) and 320 sq. ft. of glazing, a little more than 1 sq. ft. per 10 bd. ft. (0.32 sq. ft. per

cubic ft.). This ratio performs well, although two recently published kiln designs have higher ratios of around 1 to 3 sq. ft. per cubic foot and are capable of producing higher temperatures and faster drying (Kashihara, 1989; Kavvouras, M. and Skarvellis, M.A., 1996). They also cost considerably more to build.

Absorbers

A good absorber will be a dark color, thin, and have good conductivity. Most absorbers are made of black metal. Copper and aluminum are often used because of their excellent conductivity. The Appalachian dryer uses 6 layers of dark gray aluminum window screening. 5 to 7 layers has been suggested in articles and books on solar air heating. We have not explored the difference in performance with different numbers of layers. Others have used metal or wire lathe painted black instead of window screening. When we compared the lathe to the screening in small test collectors we found no significant difference in performance. The screening cost less, \$0.22 vs. \$0.28 per sq. ft., and did not have to be painted. The screen is diagonally positioned in the air flow channel. This through-pass mesh type absorber has been proven to be a superior configuration in our tests. Other published reports have come to the same conclusion. The air must pass through the warm metal mesh, resulting in good heat transfer.



Above: Bracing the north wall.

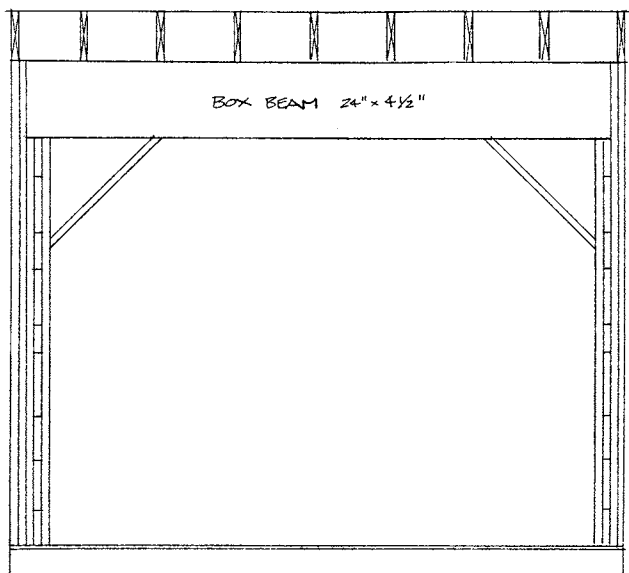
Insulation and Tight Construction

The floor of the dryer is insulated with 8 inch unfaced fiberglass insulation (R25). The east, west, and north walls are insulated between the studs with 3 1/2 inch faced fiberglass insulation (R11) and are sheathed with 1/2 inch Tuff-R polyisocyanurate insulation board (R3.5). The exterior surface is 3/8 inch T111 sheeting and the interior was sheathed with 3/8 inch plywood. A layer of polyethylene was caulked and stapled to the interior surface of the studs before the 1/2 inch plywood was installed. Caulking and weather stripping made the structure as tight as possible.

Air Intake, Flow Path, and Exhaust

The air flow path through the collector was created using the south facing framing members. They are 2 by 12's on 24 inch centers. On the bottom of the 2 by 12's, 1/2 inch plywood was glued and screwed in place. Then 3/4 inch by 3/4 inch absorber mesh support strips were positioned diagonally up the air flow channel on the faces of the 2 by 12's and screwed in place. The inside of the air flow channel (the 2 by 12's, absorber mesh support strips, and the top or south side of the plywood) was painted a dark brown (black was not available at the time). Then the 6 layers of dark gray aluminum screening were stapled in place and the glazing layers fastened to the top, south facing surface.

The depth of the air flow channel, determined by the 2 by 12's, was selected by computing 1/20 of the length of the collector which was approximately 20 feet or 240 inches ($1/20$ or $0.05 \times 240 = 12$ inches). The 11.25 inch depth of a 2 by 12 was as close as we could get using stock lumber.



NORTH WALL FRAMING PLAN



Above: Setting up 2 by 12 south wall rafters.

of the south facing 2 by 12's. The air is pulled down through the absorbing mesh and into the air plenum. The fans then blow the air into the lumber pile. A row of eight exhaust vents was placed below the intake vents just above the doors. Covers hinged at the top of the vents permit regulation of air intake, exhaust, temperature, and humidity inside the kiln. These can be controlled by ropes and pulleys operated from the ground. Another set of eight vents was constructed inside the kiln at the top of the north side. These can be opened when the other two sets are fully or partially closed to permit the recirculation of the kiln air for further heating. This permits greater control of temperature and humidity.

Air is drawn into the kiln by three 1000 CFM, 12 VDC, 1.1 Amp fans, powered by a single MSX-60 Solarex PV module. The fans are 16 inches in diameter, with a three wing aluminum blade. An air plenum for the fans was constructed in the bottom south corner of the drying chamber. The PV module is connected directly to the fans, which are connected in parallel. No controls, regulators, or batteries are used. When the sun is shining the fans are turning. They have done so now for 6 years with no maintenance. The fans draw air into eight 8 inch by 16 inch soffit vents placed in the top of the north wall. These vents were placed between each

Area for the Lumber

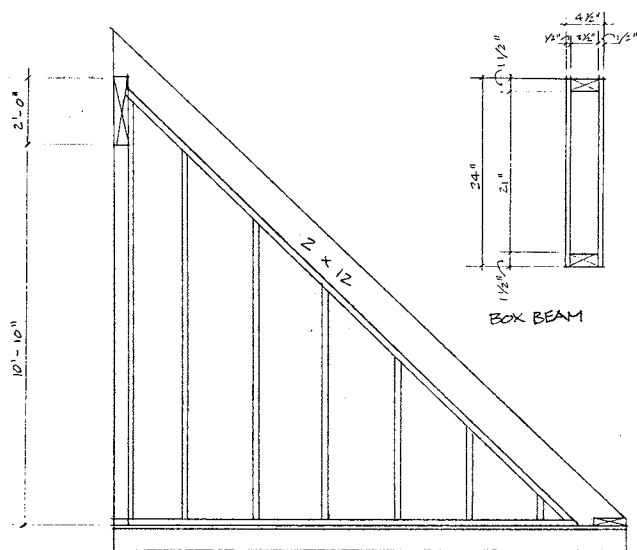
The kiln will accommodate up to 3,000 bd. ft. of lumber, up to 14 feet long. It has two large doors on the north side to facilitate loading with a fork lift. Baffles were installed inside the kiln on the east and west interior walls to force the warm air through the lumber. They are 1/4 inch plywood panels hinged to the sides and controlled with string and cleats.

Other Construction Details

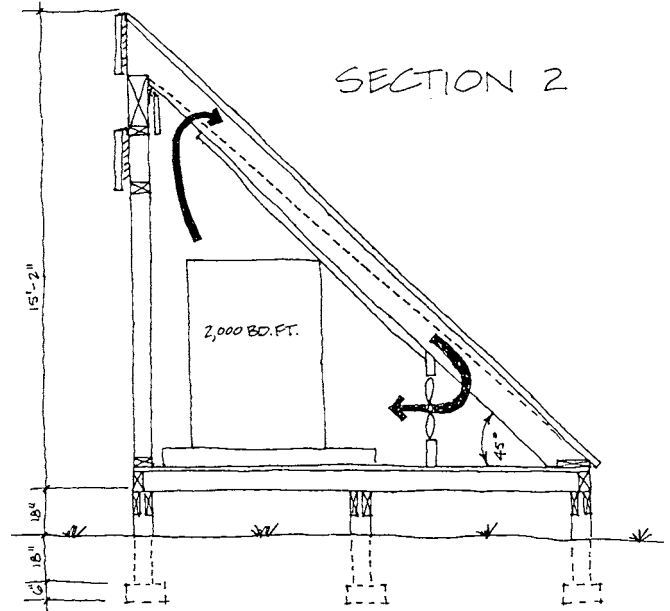
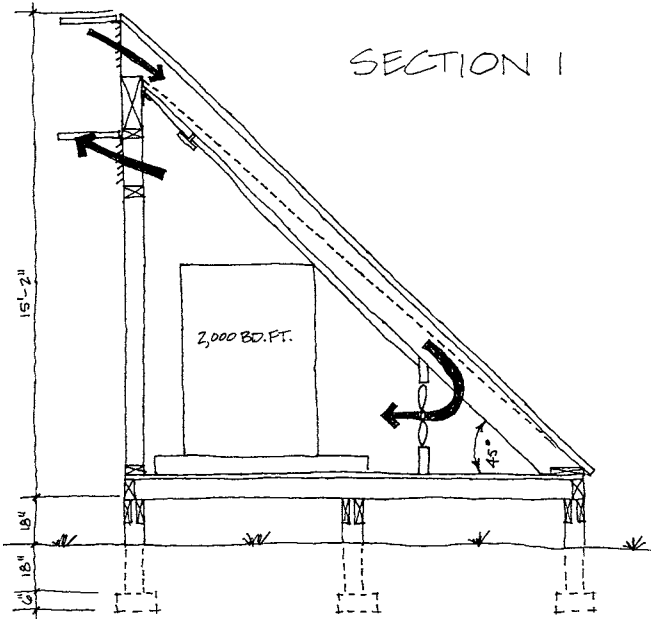
Except for the glazing, the kiln was constructed of common building materials. The kiln is 16 feet long east to west, 14 feet wide north to south, and approximately 15 feet tall. The drawings provide most of the construction details. The foundation is nine 6 by 6 locust posts positioned in three rows. Three posts are 8 feet apart in each row and the rows are 7 feet apart. Two 2 by 10's are bolted to each of the rows to form three 16 feet long girders. The floor is 2 by 8 joists, 16 inches o.c., with 1 by 8 boards nailed diagonally to the joists. A 1/4 inch plywood air barrier was fastened to the underside of the joists after the insulation was installed.

After the floor, the north wall was constructed. This required a 24 inch by 4 1/2 inch by 15 1/2 foot box beam, constructed of a 2 by 4 frame with 1/2 inch plywood glued and screwed to each side. The beam permitted the large opening for loading with a forklift. The beam and north wall were constructed, plumbed, and braced in place.

Next came the 2 by 12's for the south framing, the east and west framing, and collector construction. Insulation, vent detailing, door construction and installation, painting, and all the other details followed.



EAST/WEST FRAMING PLAN



Kiln Operation

As soon as possible after cutting the lumber, the ends should be sealed with aluminum paint, paraffin, glue, latex paint, or urethane varnish to reduce rapid drying at ends. This helps avoid cracking. The lumber should also be stacked and stickered as soon as possible after cutting. Shelter furniture grade lumber from direct sun and aim the end of the stack into the prevailing wind. This also helps avoid overly rapid drying and cracking. Build the pile about 1 foot off the ground and place stickers (1 inch by 1 inch) at the ends and every 18 to 24 inches. Cover the top of pile with scrap boards or plywood and put some rocks or cinder blocks on top. Lumber can be air dried outside to about 20%. To compute moisture content, use an electronic moisture meter or use an oven and 1 inch cubes from a board about 2 feet from the end. Weigh a cube and put it in the oven at about 220° F until it no longer loses weight. Subtract the oven dry weight from the sample's wet weight, divide by the oven dry weight, and multiply by 100.

$$\frac{W - D}{D} \times 100 = MC$$

where

W = Sample wet weight

D = Sample oven dry weight

MC = Moisture content in percent

The air dried lumber can then be kiln dried down to 6 to 8%. Green lumber can also be placed into the kiln. The normal operation of a dry kiln is to maintain low to moderate temperatures (120° F) until the wood drops to about 30% MC then increase the temperatures to 160 to 180° F in several steps. Most solar kilns do not

permit as much adjustability as in a conventional powered kiln. However, it is possible to adjust the temperature and humidity by controlling the air vent covers. The temperature will drop at night. This temperature drop allows the lumber MC and temperature to equalize. Some (Wengert and Oliveira, 1987) have suggested that this reduces cracking and bending.

In the initial phases of drying green lumber keep the inner vent cover open and the outer vent covers closed to keep the humidity high. The temperature will automatically be depressed by the mass of all the

Below: A Solarex MSX-60 powers three 1000CFM fans.



Solar Kiln



Above: Setting up vent control lines.

experimented with one on this kiln, but a reflector added to solar food dryers has increased temperatures by about 20° F and reduced drying time.

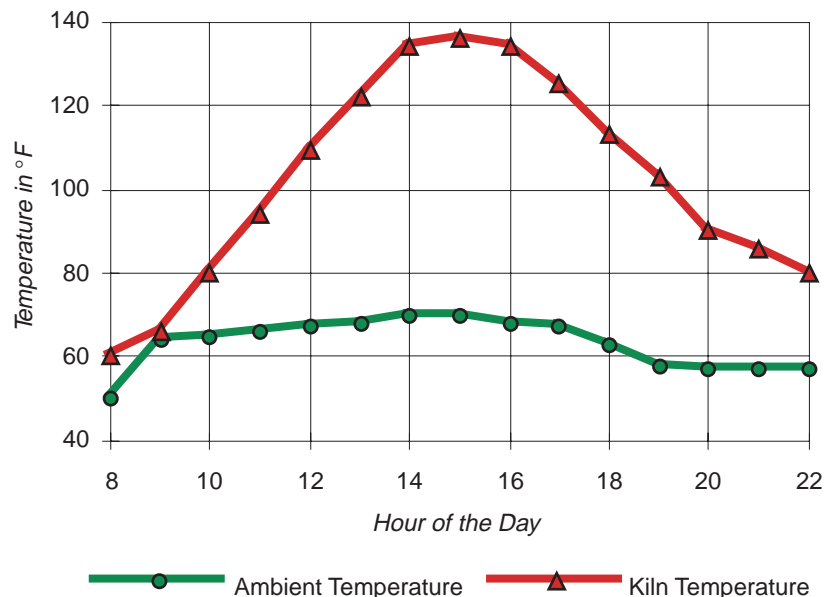
After drying to below 6 to 8% remove lumber from kiln if you have a dry place to store it. Lumber will reabsorb moisture after being dried if left in an environment having a higher moisture content. Stack the lumber tightly without stickers.

Kiln Performance

The kiln has been in continual use for 6 years and has successfully dried many loads of lumber down to 6 to 8% MC. The maximum temperature observed in this kiln is about 150° F. The graph shows the kiln's typical performance on a sunny day in September midway through a drying cycle. It dries more quickly in the spring, summer, and fall than in winter. The first load of lumber placed in the kiln was about 2150 bd. ft. of 4 by 4 basswood. It was put in on December 13 and was down to 38% by December 28, 28% by January 12, 15% by February 5, and 7% by March 13. There were a lot of cold, cloudy days throughout the period. During most of the year, air dried lumber with a moisture content of about 25% placed in the kiln takes 2 to 4 weeks to reach 6 to 8% MC. During one summer, 4 by 4 cherry dried from 39% to 15% in 2 weeks. After 4 more weeks the wood had an average MC of 8%. Ash, oak, cherry, poplar, and cedar have all been successfully dried. The largest load dried at one time was 3,880 bd. ft.

moisture. Some moist air will still escape and after the moisture content drops to around 30% or the temperature rises over 130° F, the outer vent covers should be opened a little and the inner vent cover closed. Adjust the exterior vent covers to regulate the temperature. They normally won't need to be opened very much. Gradually close them to increase the temperature as much as possible at the end of the drying cycle for maximum drying. Keep taking MC measurements and closing vent covers until wood gets down to about 6% MC. The operators of the Appalachian kiln found that it dried well by keeping the interior vent covers open and the exterior vent covers almost closed. A reflector would probably improve the kiln's performance but add to the cost and complexity. We have not

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Solar Kiln Costs

Basic framing, sheathing and foundation	\$1,800
Insulation	\$279
Absorber mesh	\$480
Glazing (FRP)	\$635
Air distribution system (PV module, 3 fans)	\$665
<i>Total</i>	\$3,859

Access

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Fans and module: Alternative Energy Engineering, PO
Box 339, Redway, CA 95560
800-707-6609.

Sun-Lite HP: Solar Components Corporation, 121
Valley Street, Manchester, NH 03103 • 603-668-8186.

Teflon FEP film: DuPont Company, Electronics
Department, High Performance Films Division,
Wilmington DE 19898 • 800-441-9494.

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