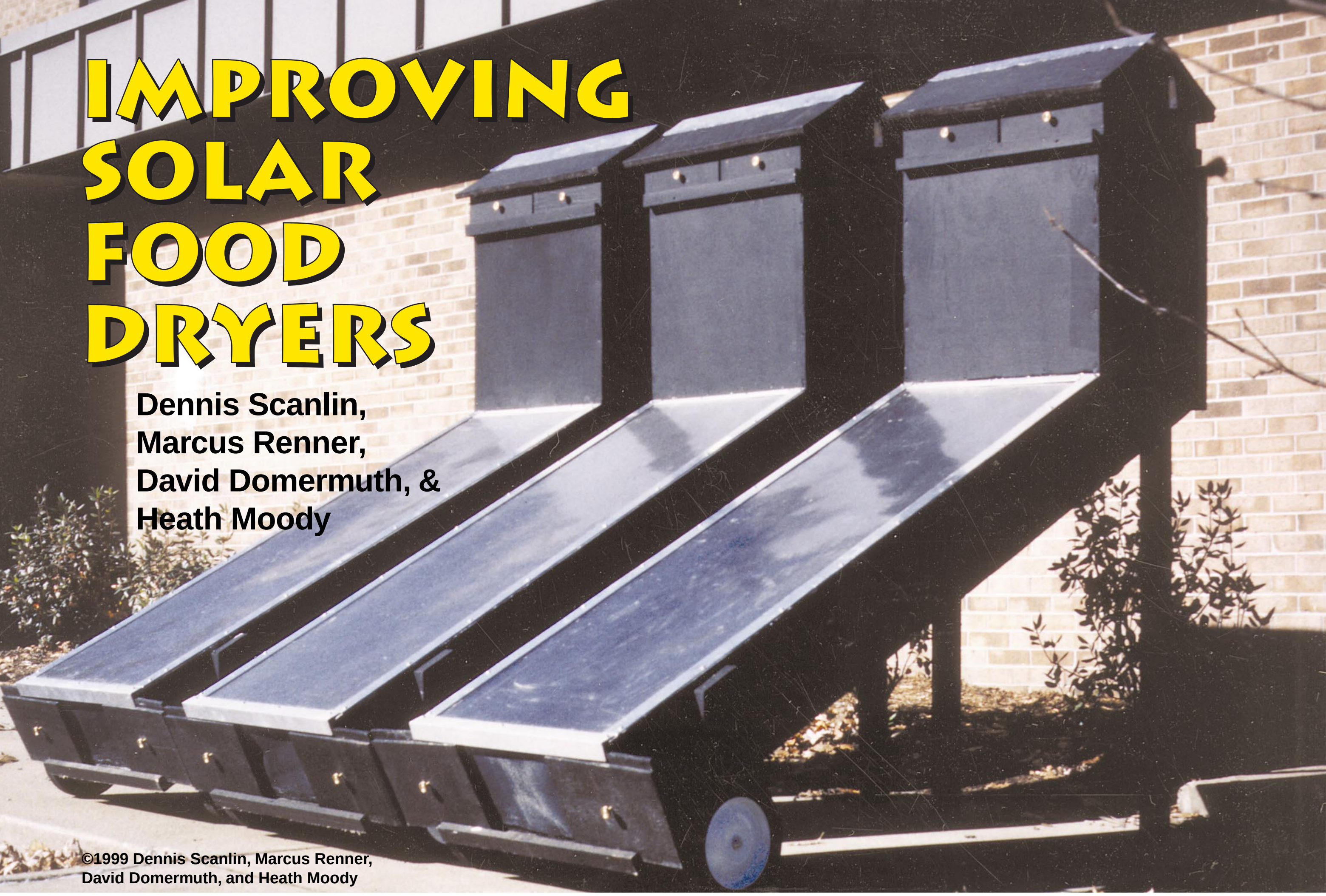
# IMPROVING SOLAR FOOD DRYERS

Dennis Scanlin,
Marcus Renner,
David Domermuth, &
Heath Moody





Above, Photo 1: Three identical solar food dryers for testing against a control.

**This article describes a series of experiments conducted over the last year and a half with three solar food dryers. The food dryers were constructed at Appalachian State University (ASU) using plans published in *HP57*. The goal of this research program was to improve the design and to determine the most effective ways to use the dryer.**

**Figure 1: Cutaway View of the Appalachian Solar Food Dryer**

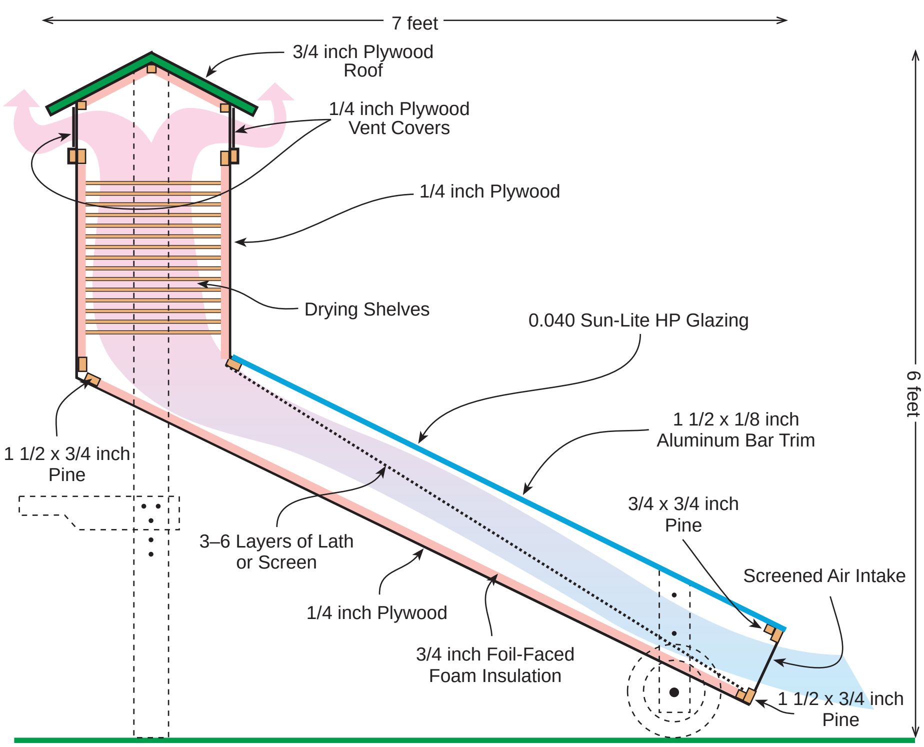
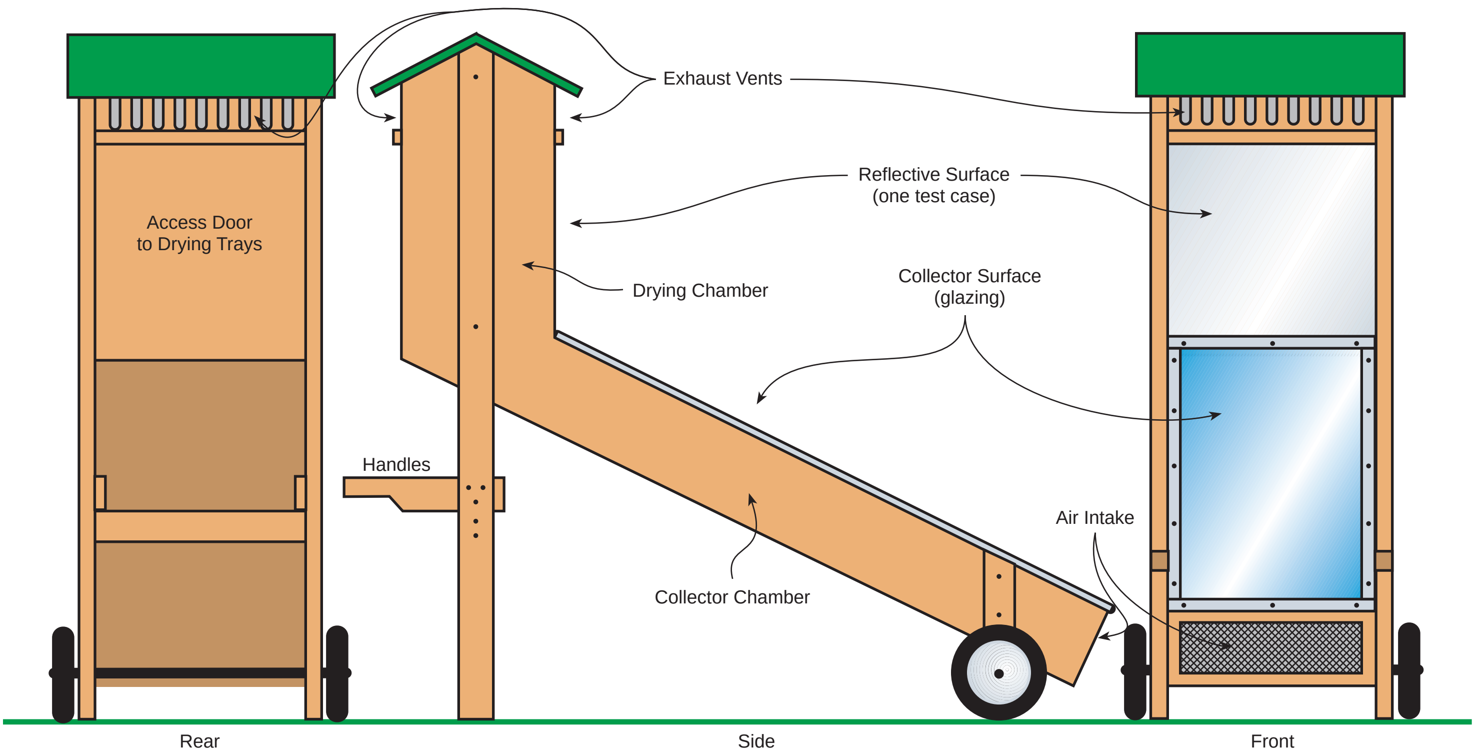


**Figure 2: Multiple Views of the Appalachian Solar Food Dryer**

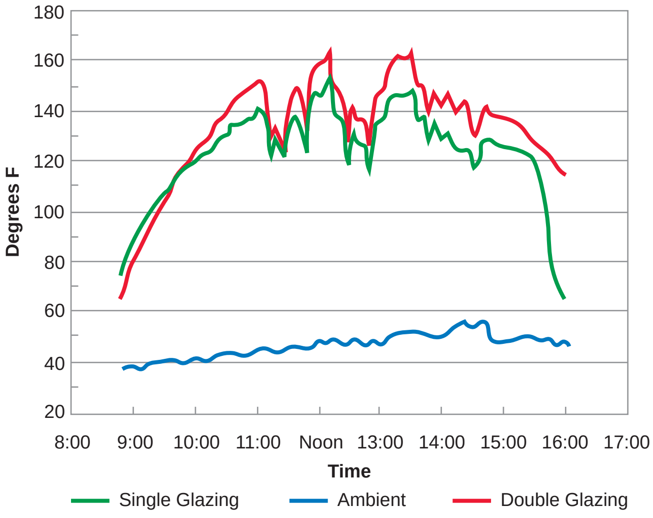



These solar food dryers are basically wooden boxes with vents at the top and bottom. Food is placed on screened frames which slide into the boxes. A properly sized solar air heater with south-facing plastic glazing and a black metal absorber is connected to the bottom of the boxes. Air enters the bottom of the solar air heater and is heated by the black metal absorber. The warm air rises up past the food and out through the vents at the top (see Figure 1). While operating, these dryers produce temperatures of 130–180° F (54–82° C), which is a desirable range for most food drying and for pasteurization. With these dryers, it's possible to dry food in one day, even when it is partly cloudy, hazy, and very humid. Inside, there are thirteen shelves that will hold 35 to 40 medium sized apples or peaches cut into thin slices.

The design changes we describe in this article have improved the performance, durability, and portability of the dryer, and reduced construction costs. This work could also help in designing and constructing solar air heaters used for other purposes, such as home heating or lumber drying. Most of our experiments were conducted with empty dryers using temperature as the measure of performance, though some of our experiments also involved the drying of peaches and apples. We have dried almost 100 pounds (45 kg) of fruit in these dryers during the past year. Graduate students in the ASU Technology Department constructed the dryers, and students taking a Solar

Above, Photo 2: Setting up the solar simulator.

**Graph 1: Single vs. Double Glazing**




Energy Technology course modified them for individual experiments.

### Methodology

We began by constructing three identical food dryers. Having three dryers allowed us to test two hypotheses at one time. For example, to examine three versus six layers of absorber mesh and single versus double glazing, Dryer One might have three layers of black aluminum window screening as an absorber with single glazing; Dryer Two, six layers of the same absorber screen with single glazing; and Dryer Three, six layers of the same absorber screen with two layers of glazing. Once we set up an experiment, we collect data. This lasts from several days to a couple of weeks until we are confident that the data is reliable. Then we try something different.

Using three food dryers also allows us to offer more students hands-on experiences with solar air heaters. Each semester, students take apart the dryers' solar collectors and rebuild them using different materials or strategies. This classwork was supplemented with experiments set up and completed by several graduate students.

### Equipment for Data Collection

We have two systems for measuring temperature. The first system uses inexpensive indoor/outdoor digital thermometers. One temperature sensor is placed inside the dryer and the other one outside. Different locations are used for the sensor inside the dryer. If food is being dried, we normally place it under the bottom tray of food and out of direct sunlight. This temperature data is recorded on a data collection form every half hour or whenever possible.

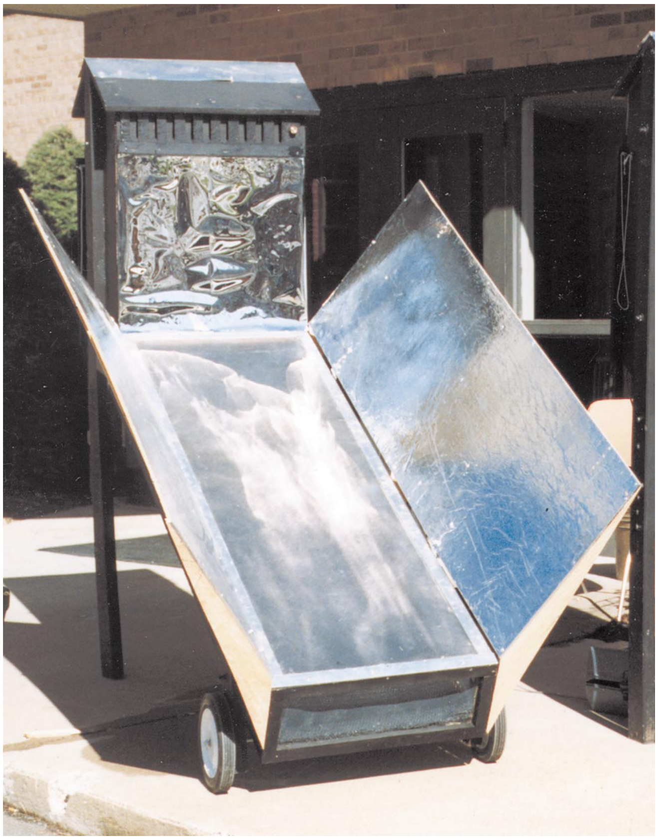
The other system uses a $600 data logger from Pace Scientific to record temperature data. It is capable of measuring temperature, relative humidity, AC current, voltage, light, and pressure. The logger does not have a display, but it's possible to download the data to a computer. The software that comes with the logger allows us to see and graph the data. The data can also be exported to a spreadsheet for statistical analysis.

We measure air flows with a Kurz 490 series mini-anemometer. We weigh the food before placing it in the dryer, sometimes during the test, and at the end of each day. We use an Ohaus portable electronic scale, purchased from Thomas Scientific for $111. We measure humidity with a Micronta hygrometer purchased from Radio Shack for about $20.

### Solar Simulator

In addition to outdoor testing with the actual food dryers, we use a solar simulator (see Photo 2) built by David Domermuth, a faculty member in the Technology Department at ASU. With the simulator, we can do more rapid testing and replicate the tests performed on the dryers, even on cloudy days. The simulator also lets us control variables such as ambient temperature, humidity, and wind effects. The unit can be altered quickly because the glazing is not bolted on. The simulator was constructed for $108. It was built in the

Below, Photo 3: This dryer has both a vertical wall reflector and side reflectors.



same way as the food dryer, but without the food drying box at the top.

The simulator uses three 500 watt halogen work lights to simulate the sun. The inlet and outlet temperatures are measured with digital thermometers. The temperature probes are shaded to give a true reading of the air temperature. We conducted the simulator tests inside a university building with an indoor temperature of 62–64° F (17–18° C). As we changed variables, we noticed significant differences in outlet air temperatures. The simulator did produce temperatures comparable to those produced by the food dryers out in the sun. However, we did not always achieve positive correlations with our food dryers' outdoor performance. We may need to use different kinds of lights or alter our procedures somewhat.

**Experiments**

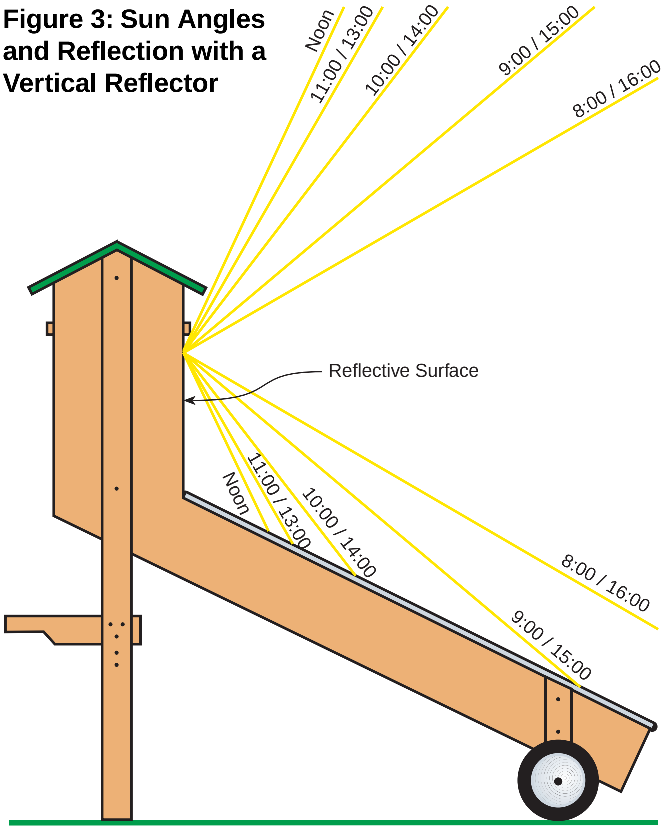
We have done at least twenty different tests over the last year and a half. All were done outside with the actual food dryers and some were also repeated with the solar simulator. The dryers were set up outside the Technology Department's building on the ASU campus in Boone, North Carolina. We collected some additional information at one of the authors' homes. Every test was repeated to make sure we were getting consistent performance. We tried to run the tests on sunny to mostly sunny days, but the weather did not always cooperate. The dips in many of the charts were caused by passing clouds.

**Single vs. Double Glazing**

The original design published in *HP57* used two layers of glazing separated by a 3/4 inch (19 mm) air gap. We used 24 inch (0.6 m) wide, 0.040 inch (1 mm) Sun-Lite HP fiberglass-reinforced polyester plastic for the outer layer. For the inner layer, we used either another piece of Sun-Lite, or Teflon glazing from Dupont. Sun-Lite glazing is available from the Solar Components Corporation for about $2.40 per square foot ($25.83 per $m^2$). These two layers cost over $50, or about one-third of the total dryer cost. We wanted to see if the second layer helped the performance significantly and justified the added expense.

We set up two dryers with six layers of steel lath painted flat black. One had single glazing and the other had two layers of glazing. The outer glazing was Sun-Lite HP on both dryers. The dryer with double glazing used Teflon as the inner glazing. The two dryers were identical except for the number of glazing layers. The tests were run on nine different days between February 17 and March 26, 1998. We opened the bottom vent covers completely and the top vent covers to two inches (51 mm). The ambient temperatures were cool and no food was being dried.

**Figure 3: Sun Angles and Reflection with a Vertical Reflector**



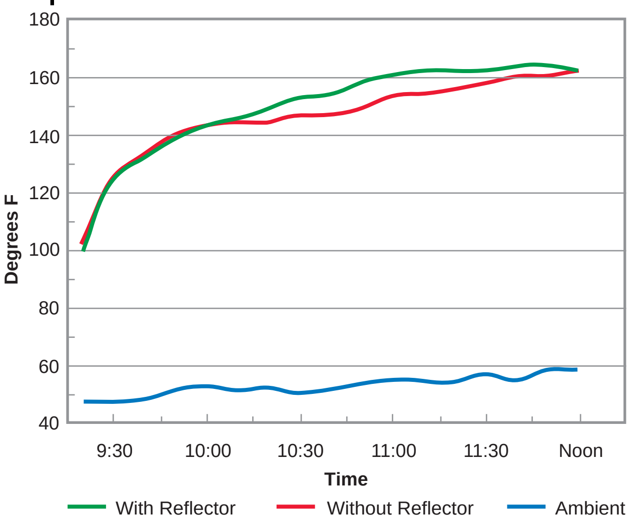

As Graph 1 shows, the double glazing did result in higher dryer temperatures. This was on a sunny day with clear blue skies and white puffy clouds, low humidity (30%), and light winds. The temperatures throughout most of the day were slightly higher with double glazing. However, the single glazed dryer works well and routinely reached temperatures of 130–180° F (54–82° C). When this test was replicated with the solar simulator, the double glazing also produced slightly higher temperatures.

Our conclusion is that double glazing is not necessary for effective drying. It does reduce some heat loss and increases the dryer's temperature slightly, but it increases the cost of the dryer significantly. Another problem is that some condensation forms between the two layers of glazing, despite attempts to reduce it by caulking the glazing in place. The condensation detracts from the dryer's appearance and may cause maintenance problems with the wood that separates the two layers of glazing.

**Reflectors**

One possible way to improve the performance of these dryers is to use reflectors. We tried several strategies: making the vertical south wall of the dryer box a reflective surface, hinging a single reflector at the bottom of the dryer, and adding reflectors on each side of the collector.

**Graph 2: Vertical Wall Reflector vs. No Reflector**




Look at the temperatures recorded on Graph 2. A slight increase in dryer temperature was recorded in the dryer having the south-facing reflective wall. The reflected light covers the collector most completely at mid-morning and afternoon. As the sun gets higher, the light is reflected onto a smaller area of the collector.

### Single Reflector

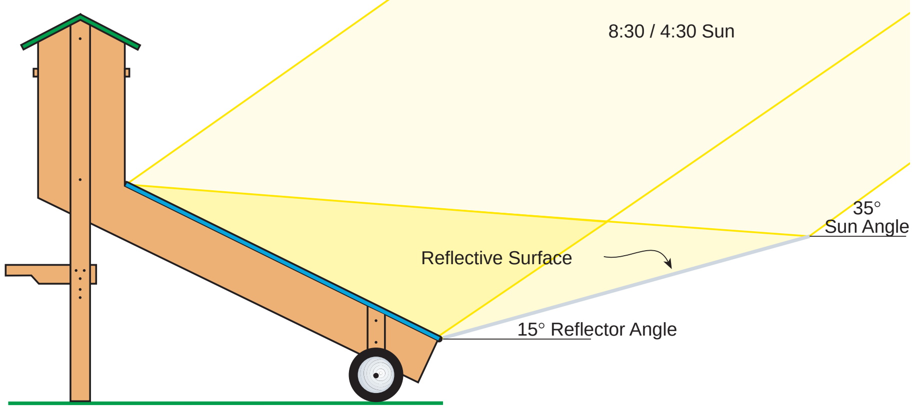
A single reflector was hinged to the bottom of the collector (see Photo 4). This reflector was supported with a string and stick arrangement, similar to one used by Solar Cookers International. With all reflector systems, the dryer has to be moved several times throughout the day if performance is to be maximized. This allows it to track the azimuth angle of the sun. The altitude angle of the reflector also needs to be adjusted during the day from about 15° above horizontal in the morning and evening to 45° above horizontal around noon (see Figures 4 and 5). The reflector added 10–20° F (2.4–4.8° C) to the temperature of the dryer and removed slightly more moisture from the food than a dryer without a reflector.

### Vertical Wall Reflector

We realized that the vertical south wall of the dryer box could be painted a light color or coated with aluminum foil, a mirror, or reflective Mylar (see Photo 3). A vertical south-facing wall reflector would reflect some additional energy into the dryer's collector, protect the wood from cracking, and prevent deterioration from UV radiation. Considering the fact that the angle of reflection equals the angle of incidence, we were able to model the performance of this reflector, using a protractor and a chart of sun altitude angles (see Figure 3). If the dryer is moved several times throughout the day to track the sun's azimuth angle, then the reflector concentrates some additional solar energy onto the dryer's collector during most of the day.

Above, Photo 4: Setting the front reflector angle.

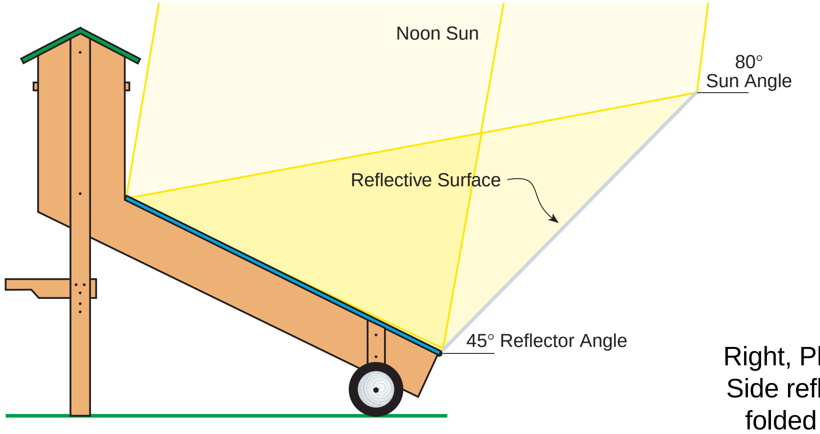
**Figure 4: Single Reflector at Low Sun Angle**




### Side Mounted Reflectors

A third strategy was to add reflectors to both sides of the collector. This captures more solar energy than the

**Figure 5: Single Reflector at High Sun Angle**

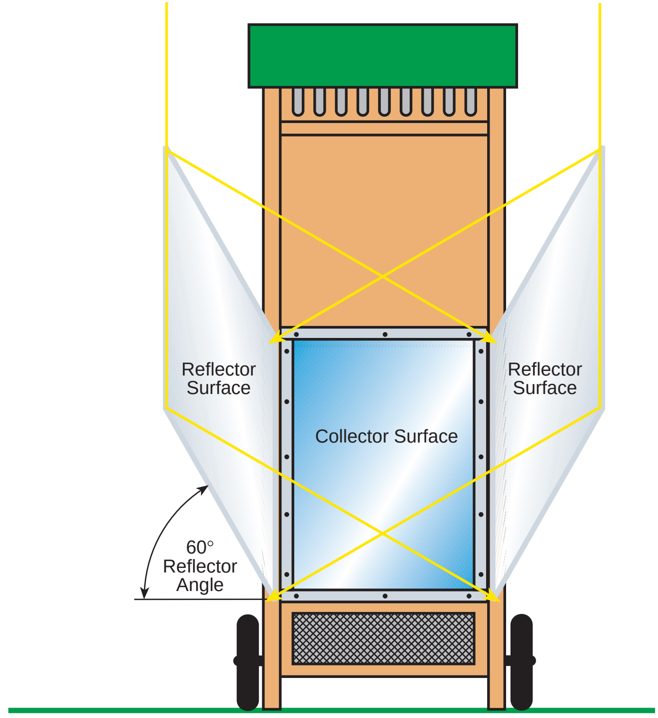



Right, Photo 5: Side reflectors folded onto glazing for transportation.

other two strategies. We determined that the ideal reflector angle would be 120° from the collector surface (see Figure 6). This assumes that the dryer is pointing toward the sun's azimuth orientation.

We performed an experiment to compare a dryer with two side reflectors and a vertical wall reflective surface with a dryer having no reflectors (see Photo 3). Both dryers were moved throughout the test period to track the sun. The reflectors were mounted with hinges and could be closed or removed when transporting the dryer (see Photo 5). Graph 3 shows the significant increase in temperatures attained by using these reflectors. The problem with this design was that if the dryer could not track the sun for one reason or another, one of the reflectors would shade the collector in the morning and the other in the afternoon.

**Figure 6: Ideal Angle for Side-Mounted Reflectors**




We concluded that the vertical wall reflector and the single reflector mounted to the bottom of the collector are the best ways to add reflectors, since tracking is not crucial in these applications. However, these dryers routinely attain temperatures of 130–180° F (54–82° C) without reflectors, which is hot enough for food drying and for pasteurization. Based on our work so far, reflectors just don't seem to be worth the trouble.

### Absorbers

All low temperature solar thermal collectors need something to absorb solar radiation and convert it to heat. The ideal absorber is made of a conductive material, such as copper or aluminum. It is usually thin, without a lot of mass, and painted a dark color, usually black. The original dryer design called for five layers of

**Graph 3: Vertical Wall & Side Reflectors vs. No Reflector**

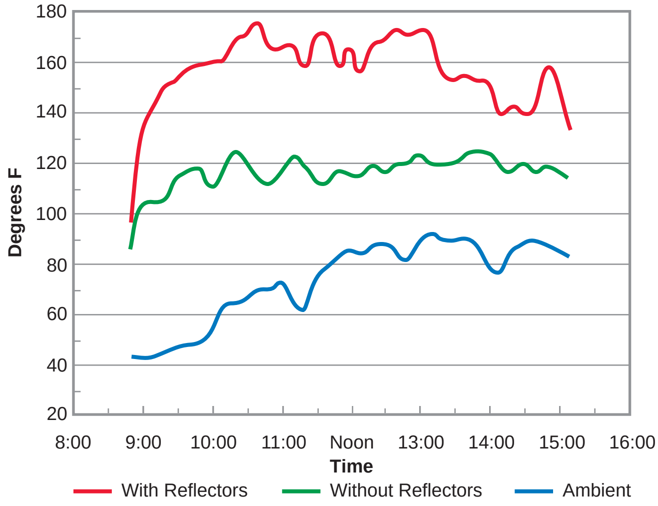
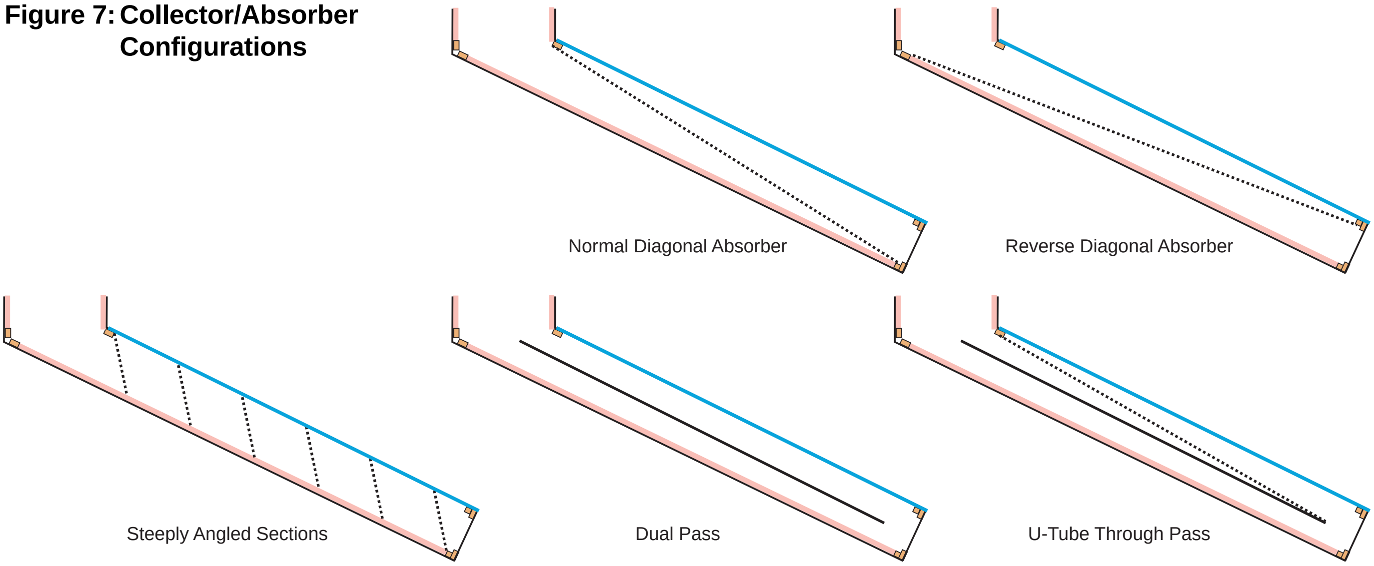


**Figure 7: Collector/Absorber Configurations**

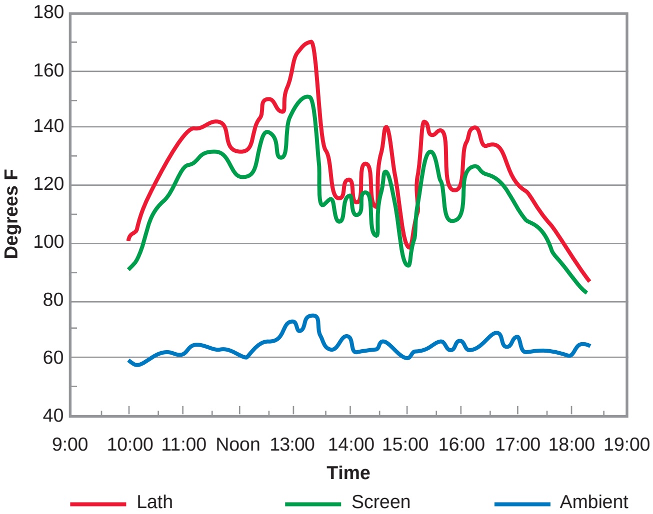



black aluminum window screening, which had proven to work well in other air heating collectors we had constructed. Other designs call for metal lath, metal plates such as black metal roofing, or aluminum or copper flashing. We decided to try some different materials and approaches to see if we could come up with a better absorber.

### Plate vs. Screen

First, we compared five layers of black aluminum window screen placed diagonally in the air flow channel to one piece of black corrugated steel roofing placed in the middle of the channel (see Figure 7). We found that the mesh produced temperatures about 7° F (3.9° C) higher than the roofing in full sun. Other experiments have shown that mesh type absorbers are superior to plate type absorbers. These differences might be reduced if we used a copper or aluminum plate instead of the steel roofing.

**Graph 4: Lath vs. Screen Absorber**




### Lath vs. Screen

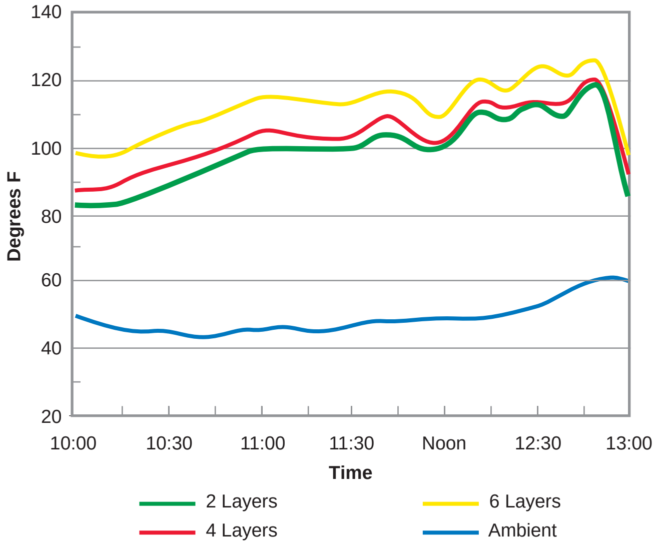
Next, we compared three layers of pre-painted black aluminum window screening to three layers of galvanized steel lath painted flat black. We found that the lath produced temperatures as much as 15° F (3.6° C) higher than the screen in our outdoor solar food dryer tests. We got the same results when we compared six layers of screen to six layers of lath (see Graph 4). While we found that the lath produced slightly higher temperatures, it was harder to work with, needed to be painted, and cost slightly more than the screen.

When these tests were replicated with the solar simulator, we had slightly better results with the screen than with the lath in both the three and six layer tests. We were disappointed by the lack of positive correlation between our outdoor tests with the actual food dryers and our indoor tests with the solar simulator. But there are many variables to control and quite a few people involved in setting things up and collecting data, so our control was not as tight as we would have liked. Despite these problems, we are confident in concluding that there is not a great deal of difference in performance between lath and screen—both work effectively.

### Layers of Absorber Mesh

We then compared three layers of lath to six layers of lath, and three layers of screen to six layers of screen. Obviously the more screen used, the greater the expense. The literature on solar air heaters recommends between five and seven layers. We arbitrarily picked three and six layers. In our outdoor tests, we found that six layers of screen produced temperatures 5–10° F (1.2–2.4° C) higher than three layers. Likewise, when we repeated these experiments outdoors with lath, we found that six layers outperformed both two and four layers (see Graph 5).

**Graph 5: Two vs. Four vs. Six Layers of Absorber**

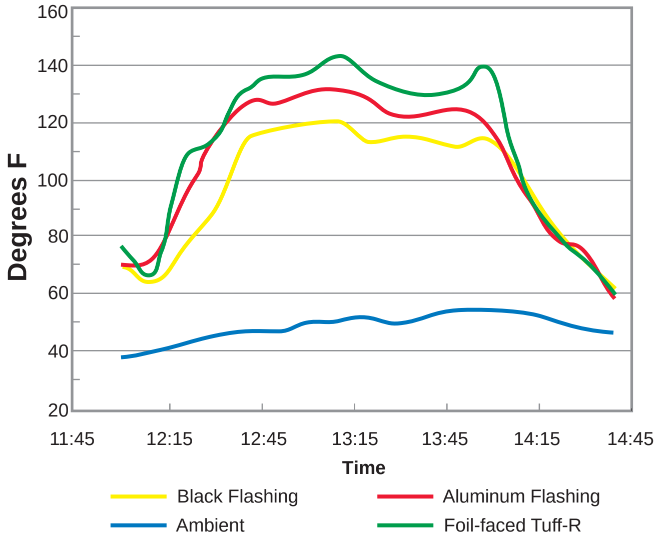



Tests performed in the solar simulator showed very little difference between three and six layers. We used the simulator to test one and two layers and no absorber. With no absorber, the temperature decline was over 60° F (33° C), dropping from 153 to 89° F (67 to 32° C) . The temperatures for one, two, three, and six layers of lath after one half-hour were 145, 155, 159, and 160° F (63, 68, 70, and 71° C). Based on our work, we feel that two or three layers of screen or lath are adequate for effective performance, but adding a few more layers will produce slightly higher temperatures.

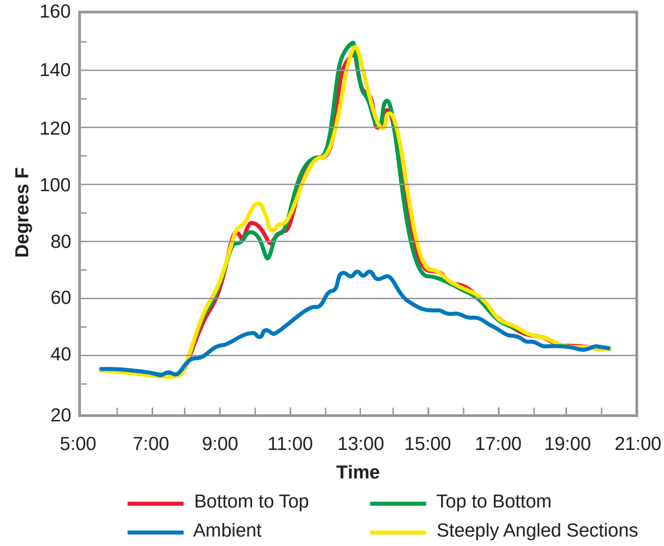
### Reflective Is Effective

When constructing a solar air heater, you must decide what to do with the bottom of the air flow channel, below the absorbing material. In the next part of our research, we placed aluminum flashing in the bottom of the air flow channels of two of the three dryers, on top

**Graph 6: Collector Bottom Material Comparison**




**Graph 7: Absorber Installation Comparison**




of the 3/4 inch (19 mm) foil-faced insulation (Celotex Tuff-R, polyisocyanurate). The flashing in one of the dryers was painted flat black. The third dryer was left with just the reflective insulation board on the bottom of the air flow channel. This test was done with both the actual dryers and the solar simulator. In both cases, the highest temperatures were attained with the reflective foil-faced insulation. The differences were substantial, with the reflective insulation showing readings as much as 25° F (14° C) higher than the dryer with the black aluminum flashing (see Graph 6).

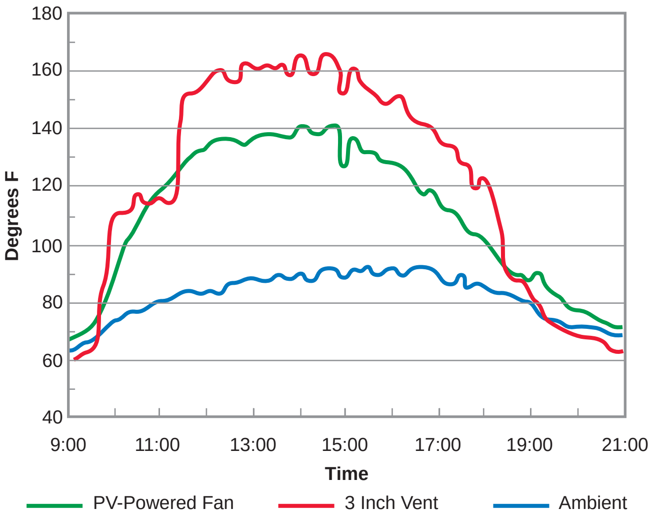
### Mesh Installation

The original design called for the mesh to be inserted into the collector diagonally from the bottom of the air flow channel to the top (see Figure 7). This seemed the best from a construction point of view. In this test, three configurations were compared: from bottom to top as originally designed, from top to bottom, and a series of more steeply angled pieces of mesh stretching from the top to the bottom of the air flow channel. The differences in temperatures attained were very small (see Graph 7), and we concluded that there was not much difference in performance.

### U-Tube vs. Single Pass

Another characteristic of the original design is the U-tube air flow channel. In addition to the air flow channel right below the glazing, there is a second air flow channel right below the first one, separated by a piece of insulation board (see Figure 7). We compared a dryer with this U-tube design to a dryer with just a straight shot single channel and found no significance difference in temperatures. We removed the insulation board from our dryers and have completed all the experiments detailed in this article without the U-tube setup.

**Graph 8: PV Exhaust Fan vs. Vent**

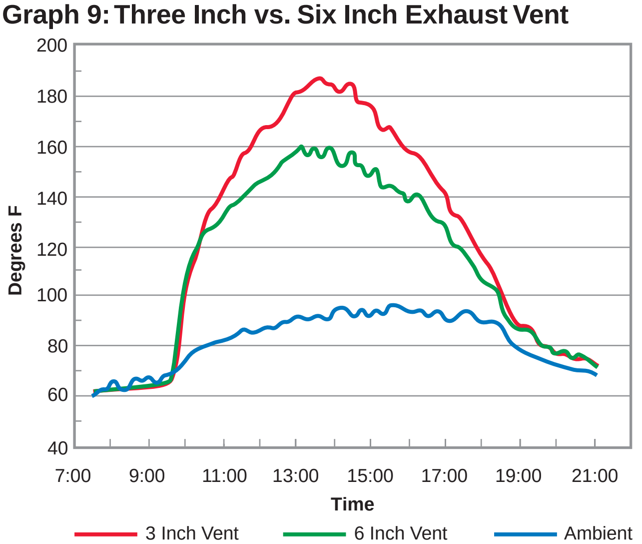



### Active vs. Passive

We experimented with several small, PV-powered fans to see if they would generate higher air flows and possibly accelerate food dehydration. We tried three different sizes: 0.08, 0.15, and 0.46 amps. We placed the fans in the exhaust area of the dryer. Of the three, the 0.15 amp fan seemed to work the best. It increased the air flow from about 25 to 50 feet per minute (8 to 15 meters per minute), but decreased temperatures significantly (see Graph 8). The larger fan did not fit in the exhaust vent opening, and the smallest fan did not significantly increase the air flow.

Even with the fans in use, the drying performance did not improve. In every trial, the passive dryer either matched or outperformed the active dryer. Each morning during a five-day experiment, we placed exactly the same weight of fruit in each dryer. We used one to three pounds (0.4 to 1.4 kg) of apple or peach slices. Each afternoon between 2:30 and 5 PM, we removed and weighed the fruit. On all five days, the fruit dried in the passive dryer weighed either the same or less than the fruit dried in the active dryer.

**Graph 9: Three Inch vs. Six Inch Exhaust Vent**




### Vent Opening

The dryers have vent covers at the top which can be adjusted to regulate the air flow and temperature. The smaller the opening, the higher the temperatures attained. We wanted to know how much the vents should be opened for maximum drying effectiveness. We tried a variety of venting combinations while drying fruit. For most of our experiments, we filled five to seven of the thirteen shelves with 1/8 inch (3 mm) fruit slices. We cut up, weighed, and placed an identical quantity and quality of fruit in each of two dryers in the morning. Sometime between 2 and 6 PM, we removed the fruit from the dryers and weighed it again. We compared openings of different measurements: a one inch (25 mm) to a seven inch (178 mm), a 3/4 inch (19 mm) to a five inch (127 mm), a three inch (76 mm) to a six inch (152 mm), a three inch (76 mm) to a nine inch (229 mm), and a three inch (76 mm) to a five inch (127 mm). During these experiments, the bottom vents were completely open.

We found that higher temperatures were attained with smaller vent openings, but that drying effectiveness was not always maximized. The best performance was observed when the vents were opened between three and six inches (76 and 152 mm), and temperatures peaked at 135–180 °F (54–82° C) (see Graph 9). With the one inch (25 mm) and smaller openings and the seven inch (178 mm) and larger openings, less water was removed from the fruit. There was no difference in the water removed when we compared three inches to five inches (76 mm to 127 mm) and three inches to six inches (76 mm to 152 mm).

Based on this work, we would recommend opening the leeward exhaust vent cover between three and six inches (76 and 152 mm), or between ten and twenty square inches (65 and 129 $cm^2$) of total exhaust area. The exact size of the opening depends on the weather conditions. With the vents opened between three and six inches (76 and 152 mm), we have been able to remove as much as sixty ounces (1.75 *l*) of water in a single day from a full load of fruit and completely dry about three and one-half pounds (1.5 kg) of apple slices to 12–15% of the fruit's wet weight.

### Construction Improvements

As we experimented with the dryers, we came up with some design improvements to simplify the construction, reduce the cost, and increase the durability or portability of the unit. To simplify the construction and eliminate warping problems caused by wet weather, we decided to eliminate the intake vent covers during our experiments. The vent covers at the top, if closed at night, would prevent or reduce reverse thermosiphoning and rehydration of food left in the dryer.

The redesigned air intake now has aluminum screen secured to the plywood side pieces with wooden trim. We also redesigned the top exhaust vent cover to eliminate the warping problem caused by leaving the vent covers opened during wet weather. The new exhaust vent cover works very well (see Photo 6). It spreads the exhaust air across the dryer's width rather than concentrating it in the center. This should improve convective flows and performance. However, the vent cover makes it more difficult to calculate the exhaust area, and as a result, we mainly used the old design for our research this past year.

We added wheels and handles to the unit, as it is heavy and difficult to move around. It's now easier to maneuver, although it is still difficult to transport in a small pickup truck. We purchased ten-inch (254 mm) lawnmower-style wheels for $6 each. The axle cost $2. With the wheels on the small legs at the bottom of the collector, one person can move the dryer.

The original design specified thin plywood for the roof of the dryer. We replaced that with 3/4 inch (19 mm) plywood and covered the peak of the roof with aluminum flashing. We also used 1/2 inch (38 mm) wide by 1/8 inch (3 mm) thick aluminum bar stock and stainless steel screws to attach the glazing to the dryer's collector. Each collector used fourteen feet, eight inches (4.5 m) of aluminum bar at a cost of $23. The 1/4 inch (6 mm) plywood strips used in the original design were adequate and less expensive, but would have required more maintenance.

**Conclusions and Recommendations**

The dryer described in *HP57* has worked well in our tests. It produces temperatures of 130–180° F (54–82° C), and can dry up to 15 apples or peaches—about 3 1/2 pounds (1.6 kg) of 1/8 inch (3 mm) thick slices—in one sunny to partly sunny day. The best performance in our outdoor tests was attained with six layers of expanded steel lath painted black, although aluminum screen works almost as well and is easier to work with. We also found that two or three layers of screen or lath would produce temperatures almost as high as six layers. The surface behind the absorber mesh should be reflective, and for best performance the exhaust vent covers should be opened three to six inches (76–152 mm). The cost of the dryer and the time to construct it can be reduced by eliminating the U-tube air flow channel divider, the second or inner layer of glazing, and the intake vent covers, and by reducing the number of layers of screen or lath to two or three.

Above, Photo 6: The new vent design.

We made the unit more portable by adding wheels and handles, and improved the durability by fastening the legs with nuts and bolts, using aluminum bar to hold the glazing in place, and using 3/4 inch (19 mm) plywood for the roof. We would also like to take the insulation board out of a dryer to see if it significantly impacts the performance. This would further decrease the cost of the dryer. Soon, we hope to compare this design to direct solar dryers, which a *Home Power* reader has recently suggested can outperform our design. Thus far, we have avoided direct dryers because of concerns about vitamin loss in foods exposed to direct solar radiation.

We have tried to carefully explore all of the significant variables affecting this dryer's performance. We have been able to increase drying effectiveness with higher temperatures of approximately 30° F (16.6° C), while decreasing the cost by about $30. We have demonstrated the best vent opening for drying effectiveness, and seen the impact that variables such as double glazing, fans, reflectors, and absorber type have on performance. We have also developed and demonstrated a low cost solar simulator that can be used to test solar thermal collectors indoors.

**Access**

Authors: Dennis Scanlin, Marcus Renner, David Domermuth, and Heath Moody, Department of Technology, Appalachian State University, Boone, NC 28608 • 704-262-3111 • scanlindm@appstate.edu

Solar Cookers International (SCI), 1919 21st Street, Sacramento, CA 95814 • 916-455-4499 Fax: 916-455-4498 • sci@igc.org

Sun-Lite HP glazing was purchased from Solar Components Corporation, 121 Valley Street, Manchester, NH 03103-6211 • 603-668-8186 Fax: 603-668-1783 • solar2@ix.netcom.com www.solar-components.com

Scales, anemometers, and other data collection equipment were purchased from Thomas Scientific, PO Box 99, Swedesboro, NJ 08085 • 800-345-2100 609-467-2000 • Fax: 800-345-5232 value@thomassci.com • www.thomassci.com

Data logger was purchased from Pace Scientific, Inc., 6407 Idlewild Rd., Suite 2.214, Charlotte, NC 28212 704-568-3691 • Fax: 704-568-0278 sales@pace-sci.com • www.pace-sci.com