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CHIMNEY SOLAR DRYER MANUAL

IMPROVED SOLAR DRYER FOR FRUITS AND VEGETABLES, DESIGNED BY UC DAVIS

JANUARY 2018

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CHIMNEY SOLAR DRYER MANUAL

JAN. 17, 2018

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The Horticulture Innovation Lab is led by the University of California, Davis, and funded by USAID, as part of the U.S. government's global hunger and food security initiative called Feed the Future.

COVER PHOTO:
UC Davis student Lauren Howe, left, works with Angelos Deltsidis, international postharvest specialist for the Horticulture Innovation Lab, to roll a clear plastic cover over trays of sliced fruits and vegetables in the chimney solar dryer. Designed by UC Davis researchers working with the Horticulture Innovation Lab, the chimney solar dryer is built with low-cost materials and combines heat collection with constant airflow for efficient drying.

Except where otherwise noted: Photos by Brenda Dawson/UC Davis

Illustrations by James Thompson/UC Davis

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INTRODUCTION

The UC Davis chimney solar dryer was designed to provide efficient drying even in hazy or partially cloudy conditions. Constructing the dryer is simple, and it can be built from low-cost materials found locally in markets and shops around the world. The objective of this manual is to provide the knowledge needed to build and use the chimney solar dryer, along with the basic value and process of using the sun to dry fruits, vegetables and other foods. This manual will be useful for growers, farmer cooperatives, trainers, development implementers, researchers, and others.

There are two key and unique characteristics of the chimney solar dryer:

1. The chimney ensures continuous airflow around the product, thus increasing the speed of drying compared to other designs.
2. The dryer's large heat-collection area ensures high temperatures and rapid moisture removal.

Built with widely available materials, the chimney solar dryer combines a table for drying fruits and vegetables with a chimney.

BACKGROUND

Fruits and vegetables are highly profitable commodities for both small-scale and large-scale farmers. Unfortunately, fresh produce is very perishable and postharvest losses can be quite high, especially in developing countries. The FAO (2011) estimates that roughly one-third of edible products are lost between the growing site and the consumer. In the developing world, the majority of these losses occur soon after harvest.

Many fruits and vegetables have production peaks when, for reasons such as season, weather, or planting time, high volumes of produce are harvested in a short period. During these peaks, product quality is often high, but prices are typically low because there is too much product available (See illustration). Shortly after the harvest, after the glut of produce has been sold, prices rise.

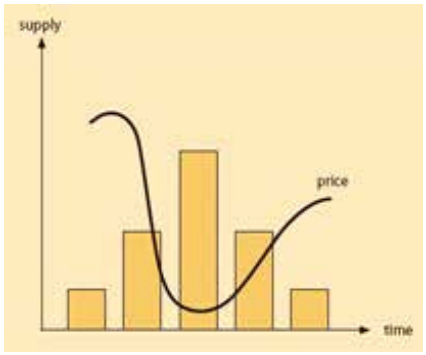

Illustration: Prices typically fall during peak supply periods and rise when supply is low.

Farmers can take advantage of the higher prices by storing some of their harvest. The primary tool for storing fresh fruits and vegetables is refrigerated cold rooms, which can extend shelf life by several weeks for some crops and up to a year for others. Where cold storage is not available or economically justified, good quality excess product frequently goes to waste. Freezing and canning are common strategies for processing peak production and adding value, but may require expensive facilities, often not available to small-scale farmers.

An alternative for many crops is drying. In certain cultures, dried fruits and vegetables are a staple part of the diet, providing important nutrients in the lean season. In addition to extending the marketing season, drying reduces the volume and weight of products resulting in lower transportation and storage costs.

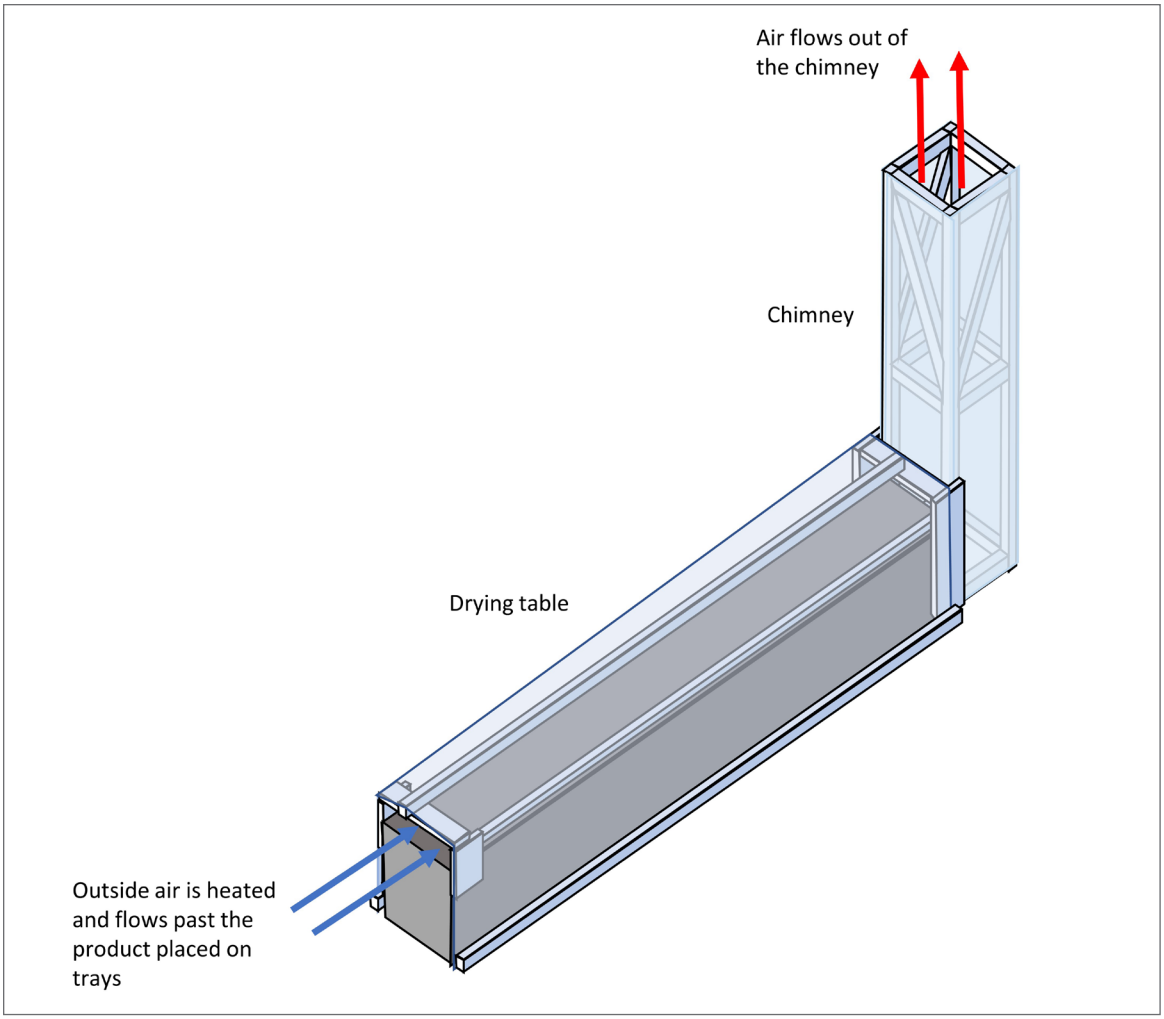

Figure 1. Chimney solar dryer showing key operational features

WHAT IS A CHIMNEY SOLAR DRYER?

The chimney solar dryer is a solar dryer designed by UC Davis researchers with the Horticulture Innovation Lab. It is a low-cost structure that can be made from locally available materials, and that reduces drying time compared to traditional solar dryers.

HOW DOES IT WORK?

The dryer comprises a long table covered with black plastic or fabric that is connected to a chimney at one end (as shown in Fig. 1). The product is placed on mesh trays along the length of the table. A clear plastic sheet placed over the trays and table creates a tunnel that traps solar energy, heating the air and reducing its relative humidity. The dry, heated air accelerates moisture loss from the heated product, and the warm, moist air leaves the dryer through the chimney. The dryer is designed so that there is little space between the black plastic under the product trays and the clear plastic covering them. This forces the air to flow through a small cross-sectional area and generates high air speeds past the product, thereby speeding drying. It is important not to block the opening at the end of the tunnel. If insects or other pests become an issue, you may want to add a screen, but only do this if necessary as it may slow airflow.

ADVANTAGES OF THE CHIMNEY SOLAR DRYER

- Drying is fast and safe
- Easy to build
- Relatively high capacity (approx. 6 kg of fresh product)
- The design can be modified to suit needs of the product and the user

The chimney solar dryer dries fresh produce about twice as fast as a traditional cabinet dryer. The trays can be used indefinitely, and only the clear plastic requires periodic replacement when damaged beyond repair. The design is flexible enough to accommodate a variety of products, from whole apricots, to smaller items such as sliced tomatoes or mangoes. The drying trays can be built in varying sizes depending on the product to be dried, as long as the drying table width accommodates the tray size. This type of solar dryer keeps produce off the ground and uses plastic which protects the product from rain and pests. Fast drying reduces product discoloration and improves flavor and overall visual quality. Adding value through improved solar drying is a proven way to extend the marketing period, diversify and increase income, and enter new markets.

BUILDING THE CHIMNEY SOLAR DRYER AROUND THE WORLD

Researchers with the Horticulture Innovation Lab have already built and used chimney solar dryers with farmers in the United States, Ghana, Guinea, Kenya, Tanzania, Bangladesh, Thailand, Guatemala and Honduras. The size and materials for this low-cost structure can be modified based on local conditions and availability. More chimney solar dryers using this concept and design have been built in other countries, with directions and advice from Horticulture Innovation Lab team members. We hope this manual helps make this efficient solar dryer design more widely available to more users.

The Horticulture Innovation Lab team has built chimney solar dryers in several countries, including Bangladesh (top photo) and Tanzania (above). Materials and dimensions can be adjusted based on location. (Horticulture Innovation Lab photos by Britta Hansen and Angelos Deltsidis)

HOW TO USE THIS MANUAL

This manual has been divided into two main sections:

1. How to build the chimney solar dryer
2. Drying fruits and vegetables with the chimney solar dryer

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SECTION 1

HOW TO BUILD A CHIMNEY SOLAR DRYER

Steps to build a chimney solar dryer using low-cost, easily available materials

FOUR MAIN COMPONENTS OF THE CHIMNEY SOLAR DRYER

The dryer design has four elements:

1. A drying table covered with black plastic or fabric.
2. A chimney covered with clear plastic with an opening at the drying table.
3. Mesh-covered drying trays to hold the produce.
4. Clear polyethylene film that covers the trays and the drying table and is sealed to the chimney.

Four main components to the chimney solar dryer, clockwise from top left: a drying table, a chimney, mesh trays, and clear film to cover the drying table.

INSTRUCTIONS

The dryer dimensions can be changed to meet various capacity needs. The chimney and the table should be the same width. The height of the chimney, as measured from the top of the table, should be half the length of the table. Note that significantly increasing the length of the table and thus the height of the chimney may be cumbersome, as the structure might tip over.

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MATERIALS NEEDED TO BUILD THE CHIMNEY SOLAR DRYER

Item description	Label in figures	Number of pieces	Size (W x H x L)	Running length (m)
Combined wood for dryer table and chimney frames				(total: 56.09 m)
Wood for table frame and chimney frame	A	23	3 cm x 3 cm x 54 cm	12.42 m
	B	4	3 cm x 3 cm x 2.8 m	11.20 m
	C	4	3 cm x 3 cm x 4 m	16.00 m
	D	8	3 cm x 3 cm x 74 cm	5.92 m
Diagonal stabilization boards for drying table and chimney	E	3	3 cm x 3 cm x 95 cm	2.85 m
	F	2	3 cm x 3 cm x 1.6 m	3.20 m
	G	3	3 cm x 3 cm x 1.5 m	4.50 m
Combined wood for trays				(total: 24 m)
Wood for 10 trays	H	40	2 cm x 4 cm x 60 cm	24.00 m
Combined wood or bamboo poles				(total: 12 m)
Wood or bamboo poles	I	3	Minimum length 4 m	12.00 m
Additional wood for support and attachment				(total: 11.6 m)
Table attachment to the chimney	J	2	2 cm x 15 cm x 90 cm	1.80 m
Pole support	K	2	2 cm x 15 cm x 30 cm	0.60 m
Pole support shelf	L	2	3 cm x 3 cm x 60 cm	1.20 m
Wood strips	M	2	2 cm x 4 cm x 4 m	8.00 m
Clear polyethylene - Greenhouse grade polyethylene plastic, thickness 0.10 – 0.15 mm, do not use milky colored PE or PVC plastic.				
Clear plastic for chimney cover		1	2.2 m x 3 m	
Clear plastic for dryer table cover		1	4 m x 3 m	
Black plastic or fabric - Thicker is better.				
Black plastic or fabric to cover dryer table (thicker is better)		1	6 m x 2.7 m	
Food grade plastic/metal mesh				(total: 6 m)
Mesh for 10 trays		10	60 cm x 60 cm	6.00 m

Note: The table lists materials, dimensions, and number of pieces needed to build a dryer with a 4-meter long table and 2.8-meter high chimney.

In this manual, all instructions are for a 4-meter long table and 2.8-meter high chimney. This design uses 60 cm x 60 cm trays, because the table frame is 60 cm wide, and you can fit 5 trays (or 10 trays in stacks of 2) on a 4-m long table. The chimney is always 60 cm deep and the same width as the drying table.

MATERIALS

Materials needed to build the dryer include wood, clear polyethylene plastic, black plastic or fabric, and food-grade mesh. Quantities may vary depending of the size of your chimney solar dryer. Materials above are calculated based on actual dimensions. It is suggested to buy 10 percent extra material to account for minor errors or other unforeseen issues.

SITE SELECTION

A full-sized dryer, using the design in this manual will be 4 m long. You will need enough flat area with good sun exposure to

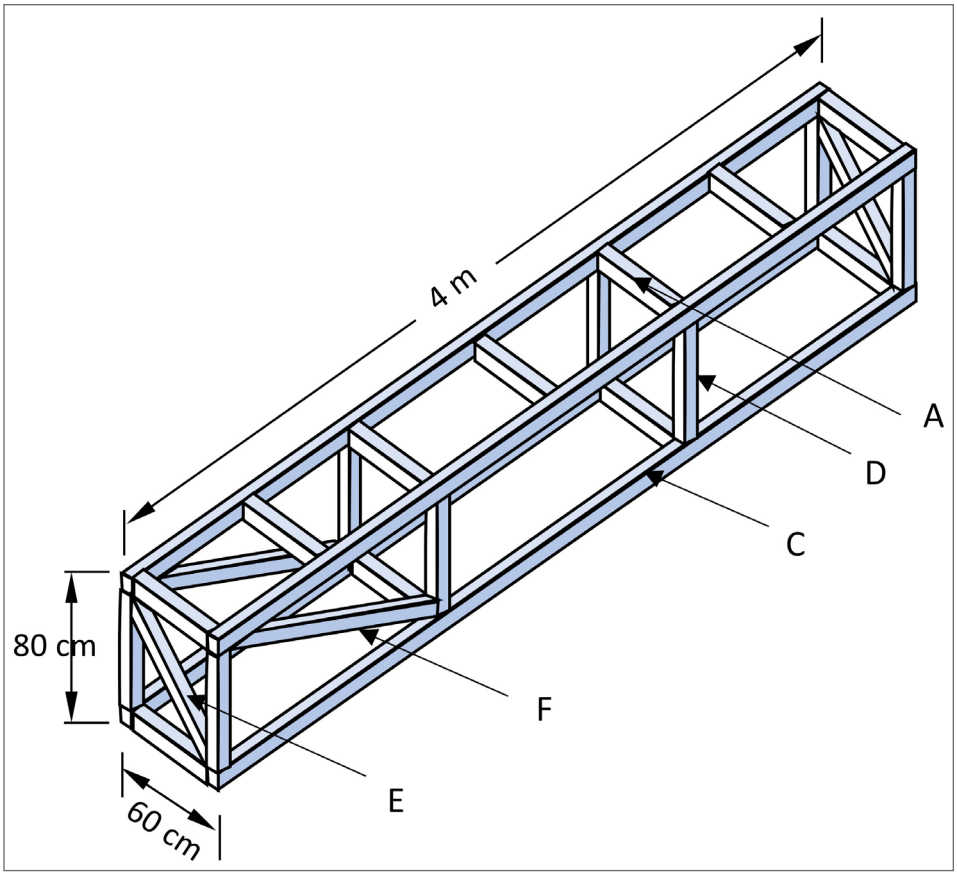

Figure 2. Wood frame for the table

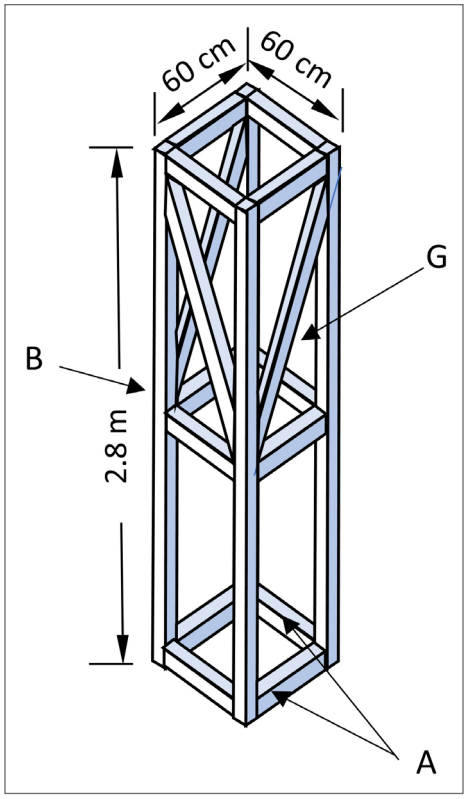

Figure 3. Wood frame for chimney

take full advantage of the dryer. The opening of the dryer should always face the equator, to maximize sun exposure. In the northern hemisphere, this means the opening of the dryer should face south, with the chimney in the north. In the southern hemisphere, the chimney would be in the south, with the opening of the dryer facing north. Select an area where trees do not shade the dryer. Make sure the ground is cleared of tall grasses, and the area is relatively free from roaming animals.

BUILD THE FRAME FOR THE TABLE

The drying table is the core of the dryer; it holds the trays and is attached to the chimney (Fig. 2). The frame can be built from scratch or you can use an existing table or other similarly shaped structure. The table height can be adjusted according to preference and should be at a comfortable height to work on the product trays. We choose to use 80 cm for the height of the table. For a 4 m dryer, the table frame will be 4 m long, 80 cm tall and 60 cm wide. Using the materials listed in the table, build a sturdy frame of wood that can support the weight of the trays filled with product. We like to use the 54 cm pieces (shown in Fig. 2 as A) as slats across the top to support the trays. Once the table frame is built, then stretch the black, non-woven fabric or plastic sheet over the top and sides of the frame and secure to the frame with staples. Attach two narrow strips of wood to the drying table on top of the black material, to hold trays above the surface.

BUILD THE CHIMNEY

The chimney is made from four planks of wood (shown in Fig. 3 as B). Make sure that the chimney is tall enough so that it rises 2 m (200 cm) above the top of the drying table (Fig. 3). For instance, if your drying table is 80 cm tall, then your chimney poles should be 2.8 m (280 cm) tall. The chimney must be as wide as the drying table and 60 cm deep. Cover the whole chimney frame in clear plastic, securing the plastic to the frame with staples, leaving the top open but covering the bottom.

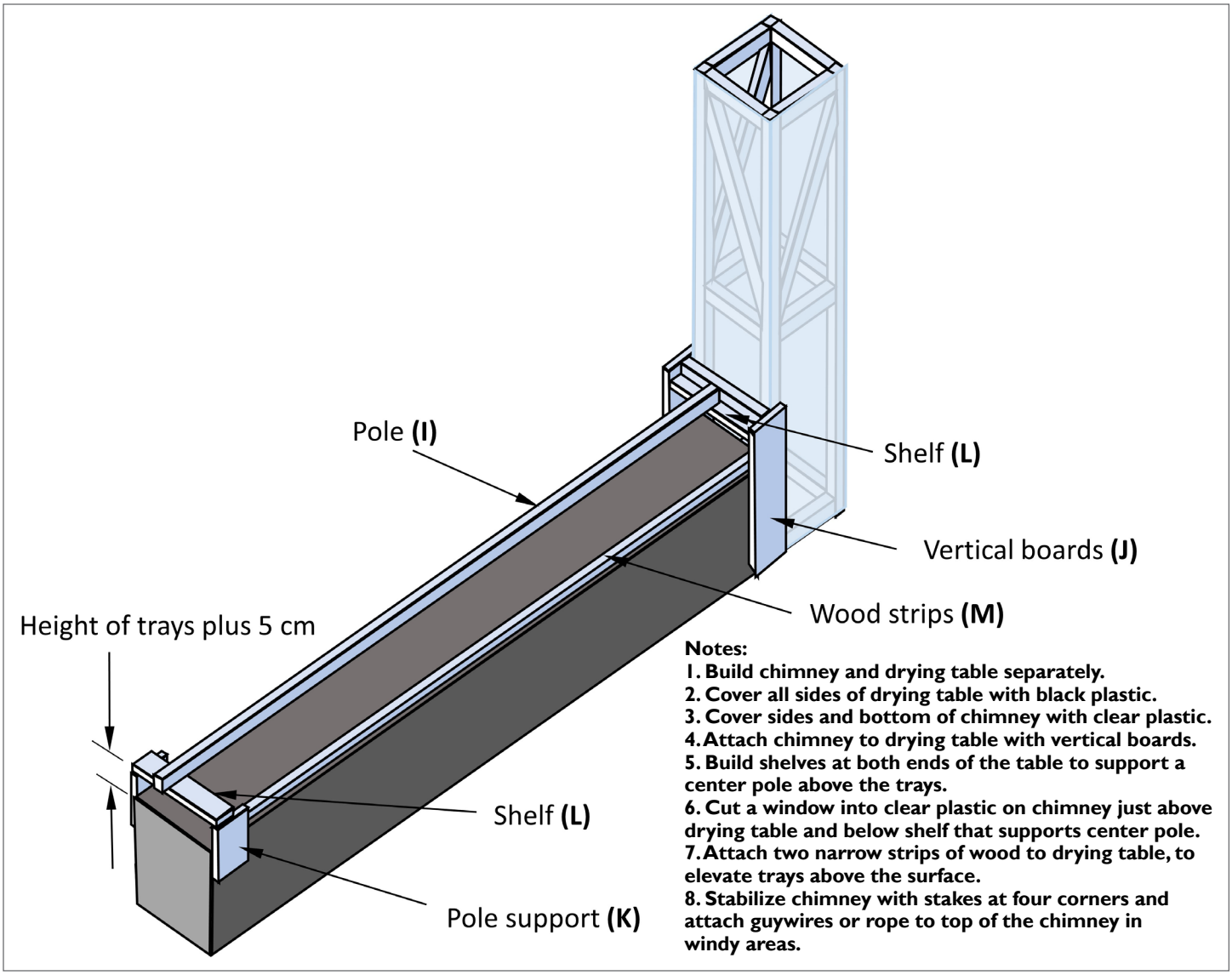

Figure 4. Sketch of the chimney attached to the drying table

PUT THE PIECES TOGETHER

Attach the table to the chimney with two vertical boards (Shown in Fig. 4 as J) and screws. Create a shelf above the table by using the two "pole support" wood pieces (Shown in Fig. 4 as K) and the two "pole support shelves" (Shown in Fig. 4 as L). This should be done on both ends of the table. The height of the space under the shelves should be equal to the height of two stacked trays plus 5 cm. Cut an opening in the chimney in the shape of a rectangle, above the drying table and below the shelves, to help create a tunnel for air to flow over the product, through this opening, and out the chimney. Place the wood pole (Shown in Fig. 4 as I) on top of the shelf and drape the clear plastic over the pole and the table. After the clear plastic has been draped over the dryer pole and trays of product, you need to secure the long ends of the plastic to the ground with a heavy pole to take slack out of the plastic on the sides of the dryer table. Attaching the plastic to a pole allows it to be rolled up and lifted off the dryer, providing easy access to the product. Tuck the clear plastic tightly between the two vertical boards and the chimney to seal. This prevents air from short-circuiting the drying table and entering the chimney.

Build a shelf above the table and the trays of product, which will support a pole over which the clear plastic will be draped.

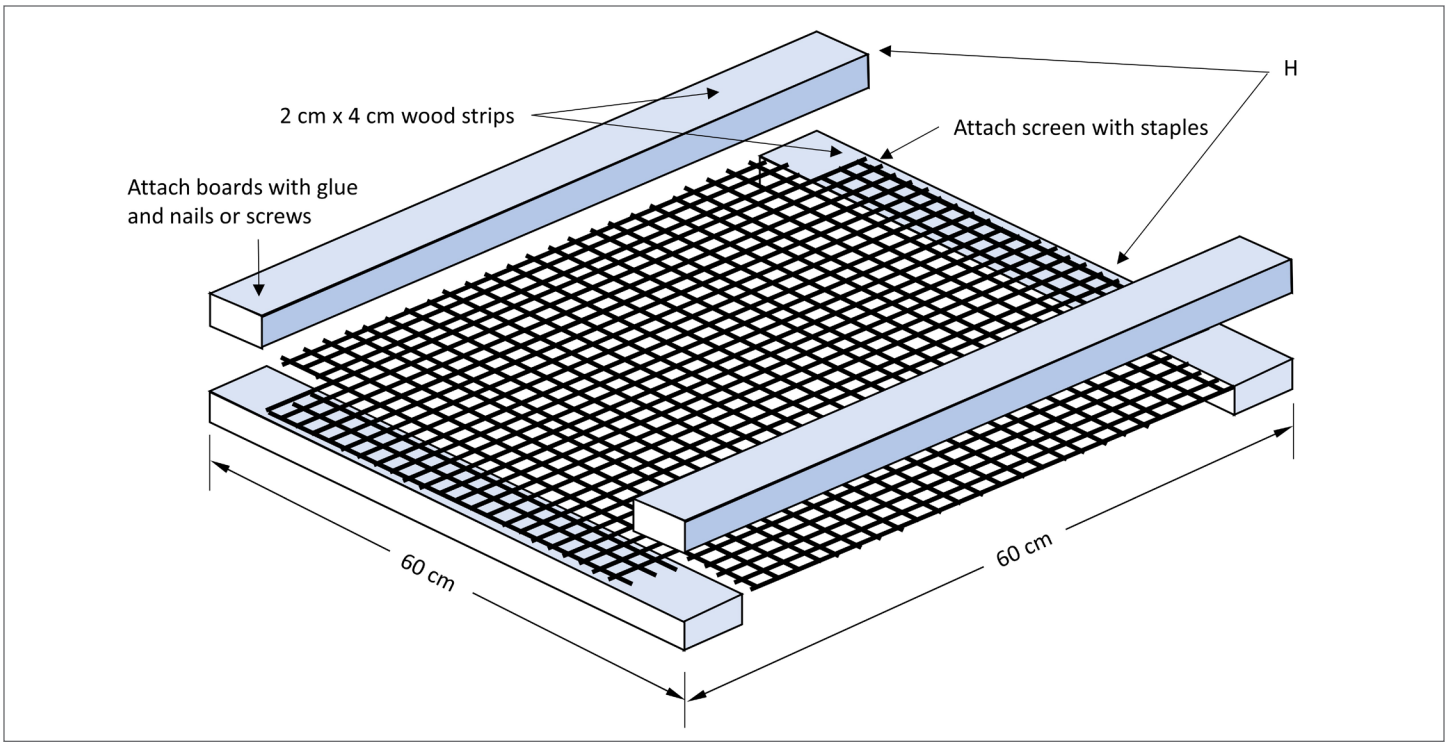

Figure 5. Expanded view of a drying tray

BUILD THE TRAYS

Use the 60 cm long wood strips to make the trays (Shown in Fig. 5 as H). Each tray will use 4 pieces (60 cm each side), one on each side. By joining the wood stacked as shown in Fig. 5, you will use less wood and still get good airflow. Pre-cut the mesh and staple it to two strips opposite each other, pull them apart, tightening the mesh, and secure the other two strips of wood, assuring the corners are at right angles and the overall tray is square. Staple along each edge to secure the mesh to the wood. Trim the edges of the mesh if needed so that edges are smooth and will not rip the plastic during use.

Photos, clockwise from top left: Pre-cut the mesh, including the corners. Join the wooden edges of the tray with a nail. Staple the mesh to the wood sides of the tray. Trim any sharp edges of the mesh to prevent ripping the dryer's plastic during use.

BEFORE YOU COVER THE DRYER WITH PLASTIC

Make sure that the desired number of trays fits on the frame; trays can be stacked one or two high. If the trays are stacked, make sure that the product on the bottom tray does not touch the tray above. Position the 4 m wood or bamboo pole just



Photos from left: Build a shelf at each end of the drying table. Cut a rectangular window into the chimney plastic and attach edge of the plastic to the shelf. Place bamboo or wood pole across the top of the shelf, which will hold plastic above trays when in use.

above the top tray, to hold the plastic above the product (Fig. 6). Then drape the clear plastic film over the drying table.

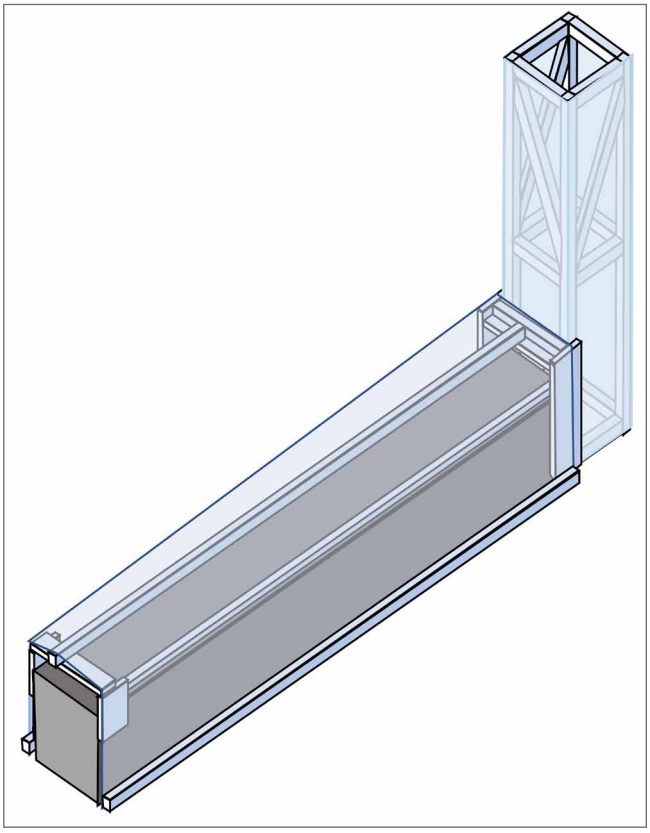

Figure 6. Clear plastic wrapped around the table

COMMON PROBLEMS IN BUILDING THE CHIMNEY SOLAR DRYER

LIMITED AIRFLOW ACROSS THE DRYING TRAYS

Ensure the clear plastic is sealed tightly to the wood shelf above the opening to the chimney and sealed tightly to the drying table near the chimney. There are two simple option to check airflow in the dryer:

- Look at the shadow of the top of the chimney, cast by the sun on the ground. When air is flowing, you will see a shimmer just above the chimney shadow.
- Another option is to hang small strips of tissue paper (0.5 x 7.5 cm) from the pole in the middle of the drying table. When air is flowing, these strips will move with the flowing air.

The height of the pole above the trays should not be more than 5 cm, or it will reduce the air speed in the tunnel.

TRAYS ORIENTED INCORRECTLY ON THE DRYING TABLE

The airflow above and below the tray is imperative; orient the trays accordingly so that edges do not block airflow. If the products on the lower tray are touching the tray above, they will block airflow through the products and products will take longer to dry. Overloading the trays with fruits and vegetable can also slow the rate of drying.

BLOCKAGE AT THE FRONT OF THE DRYING TABLE

Ensure that the clear plastic is open at the front of the dryer so that air can flow into the dryer. An open mesh screen can be used to cover the air inlet to keep animals out, if needed. Insects are usually not a problem, as they are not attracted to the fruit during drying due to the airflow.

REMOVE THE SHARP EDGES

Make sure to remove all sharp edges on the pole support, trays and shelves before putting the clear plastic over the drying table.

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SECTION 2

DRYING FRUITS AND VEGETABLES WITH THE CHIMNEY SOLAR DRYER

Once the chimney solar dryer has been built, you are ready to use it to dry your products

TEST THE DRYER

We recommend giving the dryer a test run to make sure all the pieces fit well together, that there are no air leaks or gaps in the plastic, and to measure the temperature (if possible) at different locations within the dryer table. If the dryer is working well, strips of tissue paper hanging from the center pole under the clear plastic will flutter, the plastic over the table will be concave (due to suction from the chimney), and you will see shimmering at the top of the chimney's shadow.

Load fruits and vegetables onto trays to dry. Peeling and removing pits (such as with mangos, above right) and slicing thinly (tomatoes, above left) will shorten time needed to dry.

PREPARE PRODUCT FOR DRYING:

Produce should be clean and undamaged. Bulky products dry faster if they are cut into pieces prior to drying. It is best to begin the drying process in the morning to give the maximum drying time before sunset.

PRODUCT SIZE

Thin items like herbs and leafy greens may dry in a few hours, while large products like whole apricots or whole bananas will require several days to dry. You can decrease drying time by removing pits, peeling the product, and/or cutting it into thin (6 mm) slices.

Product will shrink as it loses moisture, so it can overlap slightly when loaded onto the trays.

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A chimney solar dryer ready for drying fruits and vegetables. Leave the first tray space (left side of photo) empty as a "preheat area."

LOAD THE TRAYS

Load the trays with whole or sliced products (fruits and vegetables). The pieces can overlap slightly because they will shrink as they lose moisture. Make sure the tray is not too heavy to lift.

DRYING PRODUCT IN THE CHIMNEY SOLAR DRYER

PREHEAT AREA

The first tray space (farthest away from the chimney) should be left empty (see photo). Leaving the first tray space empty allows the air to heat before it contacts the product.

ROTATE TRAYS DURING DRYING

Rotate the trays according to the thickness and water content of the product. Generally, thicker and moister products require more time and thus more rotations compared to leaves and other similar products. It is advised that you rotate the trays 2 to 3 times during the drying process. Move the trays closest to the chimney to the opening of the dryer and the trays from the opening next to the chimney. Switch the bottom tray with top tray if trays are stacked. By rotating trays and leaving an open preheat area, you will get a more uniform moisture content across all of the product in the dryer.

PLASTIC COVER AND AIRFLOW

The clear plastic that covers the trays should not touch the fresh product; this may cause burning or incomplete drying. The plastic should be as taut as possible, creating a tent over the product and trays. Make sure that there is plenty of airflow through the dryer, especially above and below the product. Remember, ambient air enters, quickly warms up and dries the product. Warm, humid air exits through the chimney.

CONDITIONS THAT AFFECT DRYER PERFORMANCE

AIR TEMPERATURE

High air temperature speeds drying. However, air temperature must not get too hot or it could damage the product. Excessively hot air results from too little airflow. Make sure the openings at the front of the drying table and the chimney are not obstructed. The clear plastic cover should not touch product.

Maximum air temperature during drying of most fruits and vegetables should be in the range of 60 – 65°C (140 – 150°F). Cabbage and onions should not be dried at temperatures above 57°C (135°F). Grains and most nuts should not be dried above 54°C (130°F) with the exception of walnuts that should not be dried above 43°C (110°F). Air temperatures above these recommendations cause quality loss, such as darker color or decreased storage life. Test products in the dryer to be sure of the conditions required for best quality. Operators should regularly monitor air temperature in the drying area. An inexpensive dial thermometer works well for this purpose.

SOLAR RADIATION

Direct radiation on the top trays will result in faster drying than product on the lower trays. More uniform drying can be achieved by rotating tray positions once or twice during the drying process. Rotating trays is also beneficial because exposure to direct solar radiation may cause bleaching of some items and this light color may or may not be desirable by consumers. Product on the top tray may be exposed to excessive heating, which usually causes quality loss. In addition to rotating trays, the top trays can be covered with a light colored fabric, which should not touch the product and be layered underneath the plastic, to partially shade sensitive products.

AIRSPEED

Faster airflow increases the rate of moisture loss from the product and speeds drying. Make sure the air entrance is not blocked or covered in any way. A few centimeters of headspace over the product is enough to provide for the free flow of air and allow for air to heat up. If the plastic covering is too high above the trays, air speed will be slowed and drying times will increase.

HUMIDITY

When the relative humidity of the ambient air is low, drying speeds are faster. Heating of the air from solar radiation further reduces its relative humidity. Even in locations with high ambient relative humidity, the dryer heats the air enough to produce the low relative humidity levels required for rapid drying.

AMOUNT OF PRODUCT ON TRAYS

Adding more product (by weight) to the trays increases the overall amount of product dried per drying cycle; however, it also increases the length of the drying cycle. Users should experiment with the product load to determine what works best under their conditions. Light tray loadings associated with drying of flowers, herbs or products weighing less than 2.5 kg/m^2 (0.5 lbs. /ft^2) will dry in less than one day. The dryer has been modified by some users to dry grapes in bunches, producing equivalent tray loadings of more than 50 kg/m^2 (10 lbs. per ft^2). In preliminary experiments, complete drying was achieved in about 5 to 7 days.

STACKED TRAYS

The dryer can be used with two or more trays stacked on top of each other. Because air temperatures are higher at the top of the drying table, the top trays will dry faster than the lower trays. Rotating trays may also reduce bleaching, an effect of direct solar radiation that may not be desirable. Bleaching may also be reduced by covering the top trays with a light shade cloth.

ADVERSE WEATHER CONDITIONS

The dryer works in cloudy to sunny conditions, and even occasional rain showers are not a problem. However, drying should not be attempted during periods of continuous rain or heavy clouds.

STORING DRIED PRODUCT

Properly dried fruits and vegetables can be stored for several months to a year. Dried products should be stored in a cool, dry and dark area. After drying, the produce should be allowed to cool and then packed into dry, airtight containers or sealed plastic bags. Do not be afraid to pack the dried product tightly together. Storing at cool temperatures increases storage life of dried products.

HOW DRY IS DRY ENOUGH?

The moisture content of fresh produce at harvest ranges from 20 to 95 percent. Crops must be sufficiently dried to be safely stored. High sugar content fruit should be dried to approximately 20 percent moisture content; this means that the fruit will still be pliable, but not sticky or tacky. Dried berries should rattle when shaken in a container. Vegetables are sufficiently dried when they are hard and brittle or tough and leathery, depending on the vegetable. Sufficiently dried beans, corn and peas are hard and can shatter. Dried leafy, thin vegetables should be brittle, and larger chunks or slices of vegetables should be leathery. At this stage, the produce should contain about 10 percent moisture.

The best method of determining safe product for storage is to measure the relative humidity of the air in the dried product storage container. Mold will not grow when relative humidity is lower than 65 percent. One inexpensive method for measuring relative humidity to use a DryCard™ indicator (more information at http://drycard.ucdavis.edu).

ADDITIONAL RESOURCES

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Resources from the ECHO Community Global Network
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