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UNDERSTANDING SOLAR FOOD DRYERS

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PREFACE

This paper is one of a series published by Volunteers in Technical Assistance to provide an introduction to specific state-of-the-art technologies of interest to people in developing countries. The papers are intended to be used as guidelines to help people choose technologies that are suitable to their situations. They are not intended to provide construction or implementation details. People are urged to contact VITA or a similar organization for further information and technical assistance if they find that a particular technology seems to meet their needs.

The papers in the series were written, reviewed, and illustrated almost entirely by VITA Volunteer technical experts on a purely voluntary basis. Some 500 volunteers were involved in the production of the first 100 titles issued, contributing approximately 5,000 hours of their time. VITA staff included Leslie Gottschalk and Maria Giannuzzi as editors, Julie Berman handling typesetting and layout, and Margaret Crouch as project manager.

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UNDERSTANDING SOLAR FOOD DRYERS

By VITA Volunteer Roger G. Gregoire, P.E.

I. INTRODUCTION

Dehydration, or drying, is a simple, low-cost way to preserve food that might otherwise spoil. Drying removes water and thus prevents fermentation or the growth of molds. It also slows the chemical changes that take place naturally in foods, as when fruit ripens. Surplus grain, vegetables, and fruit preserved by drying can be stored for future use.

People have been drying food for thousands of years by placing the food on mats in the sun. This simple method, however, allows the food to be contaminated by dust, airborne molds and fungi, insects, rodents, and other animals. Furthermore, open air drying is often not possible in humid climates.

Solar food dryers represent a major improvement upon this ancient method of dehydrating foods. Although solar dryers involve an initial expense, they produce better looking, better tasting, and more nutritious foods, enhancing both their food value and their marketability. They also are faster, safer, and more efficient than traditional sun drying techniques. An enclosed cabinet-style solar dryer can produce high quality, dried foodstuffs in humid climates as well as arid climates. It can also reduce the problem of contamination. Drying is completed more quickly, so there is less chance of spoilage. Fruits maintain a higher vitamin C content. Because many solar dryers have no additional fuel cost, this method of preserving food also conserves non-renewable sources of energy.

In recent years, attempts have been made to develop solar dryers that can be used in agricultural activities in developing countries. Many of the dryers used for dehydrating foods are relatively low-cost compared to systems used in developed countries.

This paper describes some of these dryers and discusses the factors that must be considered in determining what kind of dryer is best suited for a particular application.

THE DRYING PROCESS

Drying products makes them more stable and in the case of foods, a llows them to be stored safely for long periods of time. Safe storage requires protection from the growth of molds and other fungi, the most difficult of the spoilage mechanisms to detect and control. The types of loss generally caused by fungi are:

* Reduction in the germination rate of seed.

* Discoloration, which reduces value of foods for many purposes.

* Development of mustiness or other undesirable odors or flavors.

* Chemical changes that render food undesirable or unfit for processing.

* Production of toxic products, known as mycotoxins, some of which can be harmful if consumed.

* Total spoilage and heating, which sometimes may continue to the point of spontaneous combustion.

Drying Grains

At harvest, most grains contain more moisture than is safe for prolonged storage, because many fungi grow rapidly in warm, moist conditions. Thus, any grain stored for future use must be dried shortly after harvest to prevent the growth of destructive fungi. In general, grains will not be completely dried since they are hygroscopic--that is, they absorb moisture from the air. The higher the relative humidity of the surrounding air, the higher the moisture content of the grain. Table 1 lists the moisture content of various grains as a function of the relative humidity of the surrounding air. At the same time, there is a minimum level of relative humidity, below which the harmful fungi will not thrive. Table 2 shows these minimum relative humidity levels for common storage fungi. Proper drying lowers the moisture content of grains below the minimum needed for the growth- of fungi.

Table 1. Moisture Contents of Various Grains and Seeds in Equilibrium with Different Relative Humidities at 25 to 30 [degrees] Centigrade

Wheat, Rice Sunflower
Humidity Corn, Sorghum (Percent) Soybeans (Percent)
(Percent) (Percent) Rough Polished (Percent) Seeds Meats

65 12.5 to 13.5 12.5 14.0 11.5 8.5 5.0

70 13.5 to 14.5 13.5 15.0 12.5 9.5 6.0

75	14.5 to 15.5	14.5	15.5	13.5	10.5	7.0
80	15.5 to 16.5	15.0	16.5	16.0	11.5	8.0
85	18.0 to 18.5	16.5	17.5	18.0	13.5	9.0

Source: ASHRAE Handbook and Product Director: 1977 Fundamentals (New York: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1980), p. 10.2.

Table 2. Minimum Relative Humidity for the Growth of Common Storage Fungi at Their Optimum Temperature for Growth (26 to 30 [degrees] Centigrade)

Type of Fungus	Minimum Relative Humidity (Percent)
Aspergillus halophilicus	68
A. restrictus, Sporendonema	70
A. glaucus	73
A. candidus, A.ochraceus	80
A. flavus	85
Penicillium, depending on species	80 to 90

Source: ASHRAE Handbook and Product Directory: 1977 Fundamentals (New York: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1980), p. 10.2.

Solar dryers use the energy of the sun to heat the air that flows over the food in the dryer. As air is heated, its relative humidity decreases and it is able to hold more moisture. Warm, dry air flowing through the dryer carries away the moisture that evaporates from the surfaces of the food.

As drying proceeds, the actual amount of moisture evaporated per unit of time decreases. In the first phase of drying, the moisture in the exterior surfaces of the food is evaporated. Then, once the outer layer is dried, moisture from the innermost portion of the material must travel to the surface in the second phase of drying. Figure 1 shows the representative change in

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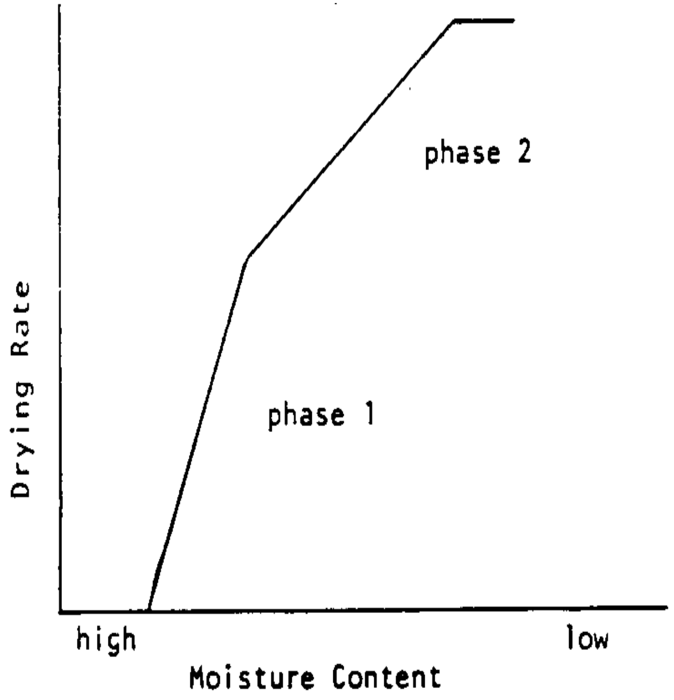

Figure 1. Drying Rate Versus Moisture Content

evaporation rate for hygroscopic materials (including most foodstuffs) commonly dried. During the second phase of the drying process, overheating may occur because of the lessened cooling effect resulting from the slower rate of moisture evaporation. If the temperature is too high, the food will "case harden" or form a hard shell that traps moisture inside. This can cause deterioration of the food. To prevent overheating during this portion of the drying cycle, increased airflows or less heat collection may be desirable.

III. DESIGN VARIATIONS

SOLAR DRYER TYPES

Solar dryers fall into two broad categories: active and passive. Passive dryers can be further divided into direct and indirect models. A direct (passive) dryer is one in which the food is directly exposed to the sun's rays. In an indirect dryer, the sun's rays do not strike the food to be dried. A small solar dryer can dry up to 300 pounds of food per month; a large dryer can dry up to 6,000 pounds a month; and a very large system can dry as much as 10,000 or more pounds a month. (Figures are based on harvests in temperate climates.)

Figure 2 shows the breakdown, by type, of solar food dryers.

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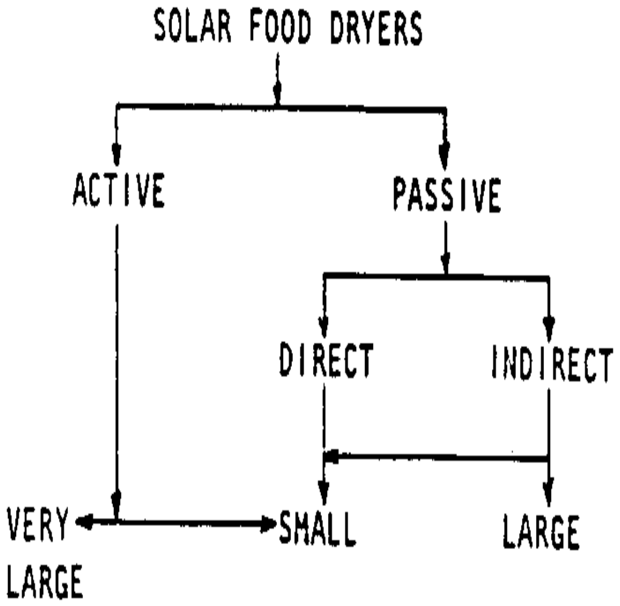

Figure 2. Breakdown of Solar Food Dryers

Passive dryers use only the natural movement of heated air. They can be constructed easily with inexpensive, locally available materials. Direct passive dryers are best used for drying small batches of foodstuffs. Indirect dryers vary in size from small home dryers to large-scale commercial units.

Active Dryers

Active dryers require an external means, like fans or pumps, for moving the solar energy in the form of heated air from the collector area to the drying beds. These dryers can be built in almost any size, from very small to very large, but the larger systems are the most economical.

Figure 3 is a schematic drawing showing the major components of

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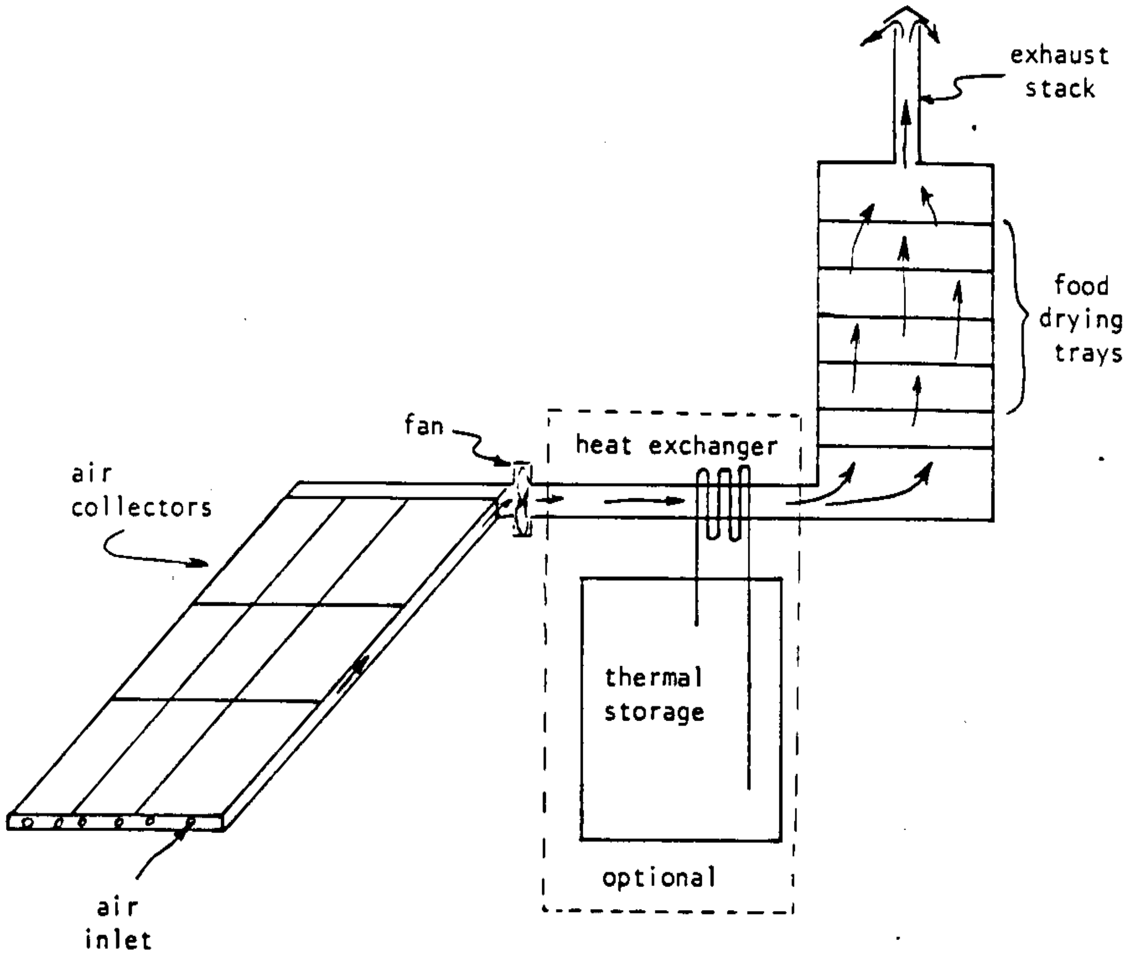

Figure 3. Major Components of an Active Dryer

an active solar food dryer. Either air or liquid collectors can be used to collect the sun's energy. The collectors should face due south if you are in the northern hemisphere or due north if you are in the southern hemisphere. At or near the equator, they should also be adjusted east or west in the morning and afternoon,

respectively. The collectors should be positioned at an appropriate angle to optimize solar energy collection for the planned months of operation of the dryer. The collectors can be adjacent to or somewhat remote from the solar dryer. However, since it is more difficult to move air long distances, it is best to position the collectors as near the dryer as possible.

The solar energy collected can be delivered as heat immediately to the dryer air stream, or it can be stored for later use. Storage systems are bulky and costly but are helpful in areas where the percentage of sunshine is low and a guaranteed energy source is required; or in carrying out round-the-clock drying.

In an active dryer, the solar-heated air flows through the solar drying chamber in such a manner as to contact as much surface area of the food as possible. The larger the ratio of food surface area to volume, the quicker will be the evaporation of moisture from the food. Thinly sliced foods are placed on drying racks or on trays made of a screen or other material that allows drying air to flow to all sides of the food. For grain products, pipes with many holes are placed at the bottom of the drying bin with grain piled on top. The heated air flows through the pipes and is released upward to flow through the grain--carrying away moisture as it flows.

Passive Dryers

Passive solar food dryers use natural means--radiation and convection--to heat and move the air. The category of passive

dryers can be subdivided into direct and indirect types.

Direct Dryers. In a direct dryer, food is exposed directly to the sun's rays. This type of dryer typically consists of a drying chamber that is covered by transparent cover made of glass or plastic. The drying chamber is a shallow, insulated box with holes in it to allow air to enter and leave the box. The food is placed on a perforated tray that allows the air to flow through it and the food. Figure 4 shows a drawing of a simple direct

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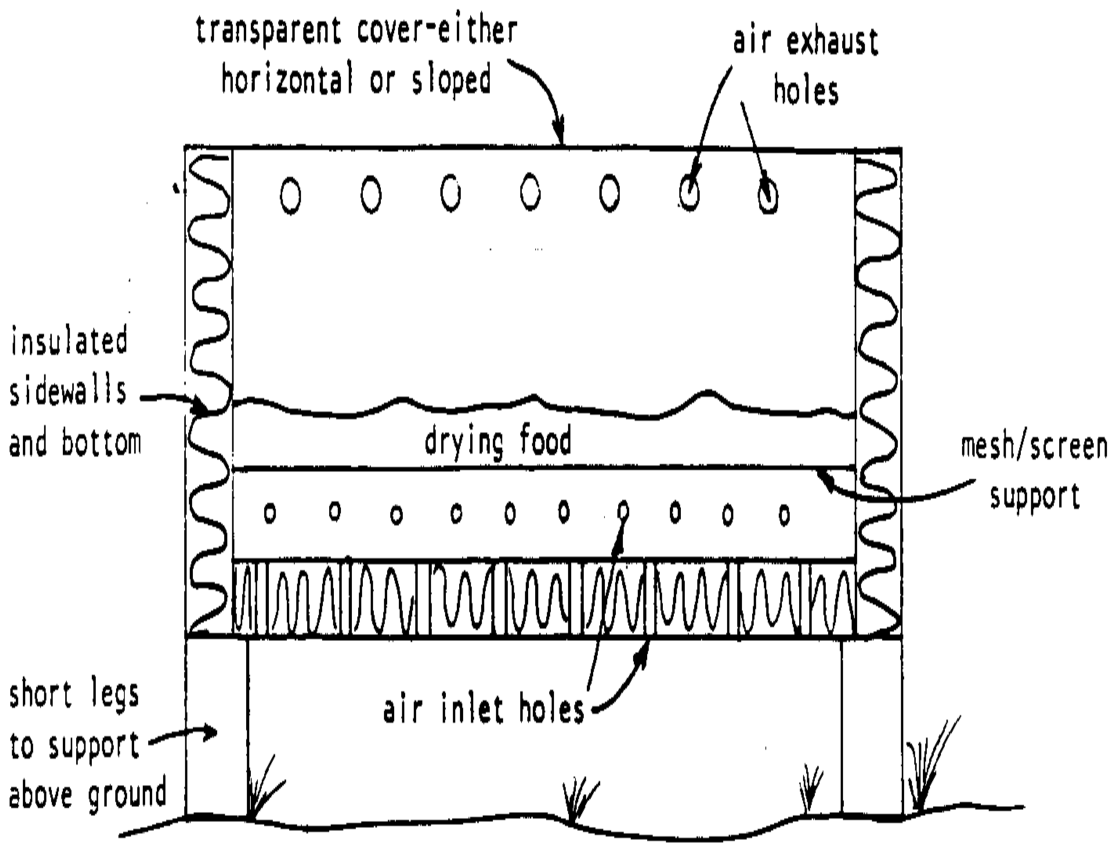

Figure 4. Direct Dryer

dryer. Solar radiation passes through the transparent cover and is converted to low-grade heat when it strikes an opaque wall. This low-grade heat is then trapped inside the box in what is known as the "greenhouse effect." Simply stated, the short wavelength solar radiation can penetrate the transparent cover. Once converted to low-grade heat, the energy radiates on a long wavelength that cannot pass back through the cover. Figure 5 shows the greenhouse effect in a simplified schematic drawing.

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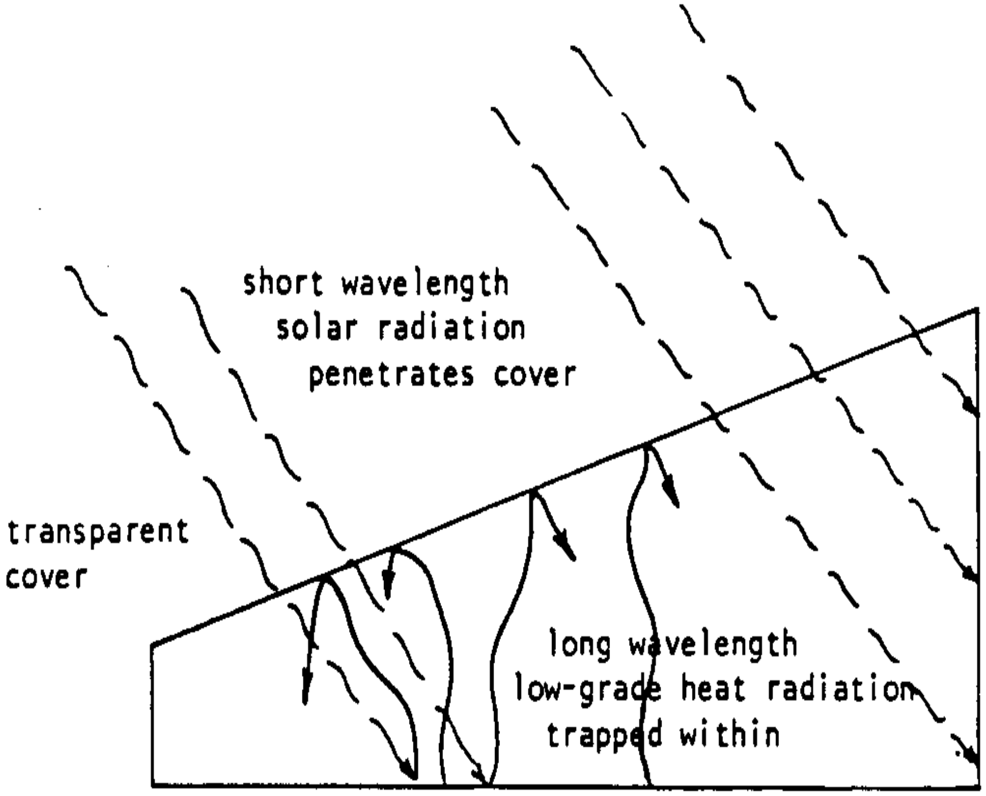

Figure 5. Greenhouse Effect

Figures 6 and 7 show examples of simple, direct dryers that can

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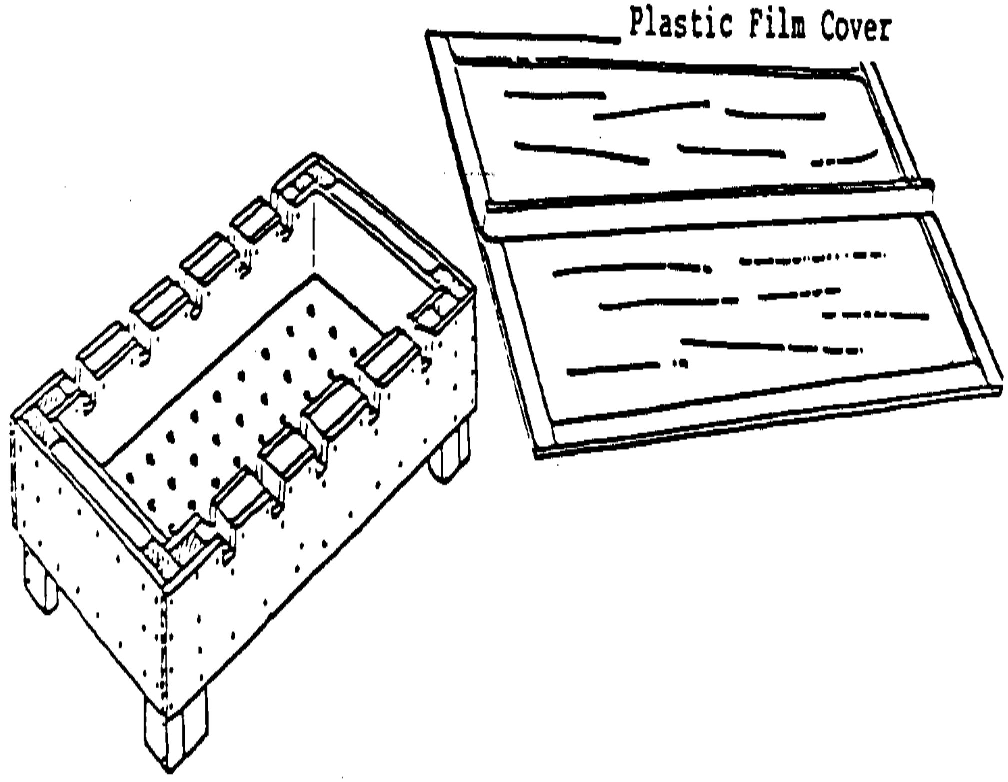

Figure 6. VITA Solar Crop Dryer

be used to dry small quantities of a wide variety of foods. The drying chamber can be constructed of almost any material-- wood, concrete, sheet metal, etc. The dryer should be 2 meters (6.5 feet) long by 1 meter (3.2 feet) wide and 23 to 30 centimeters (9 to 12 inches) deep. The bottom and sides of the dryer should be insulated, with 5 centimeters (2 inches) recommended. Blackening the inside of the box will improve the dryer efficiency, but be sure to use a non-toxic material and avoid lead-based paints. Wood blackened by fire may be a safe and inexpensive material to use.

The tray that holds the food must permit air to enter from below and pass through to the food. A wire or plastic mesh or screen will do nicely. Use the coarsest possible mesh that will support the food without letting it fall through the holes. The larger the holes in the mesh, the easier the air will circulate through to the food. Air holes below the tray or mesh will bring in outside air, which will carry away the moisture evaporated from the food. As the air heats up in the dryer, its volume will increase, so either more or larger holes will be required at the top of the box to maintain maximum air flow.

Finally, tests of the hot box dryer shown in Figure 7 have determined

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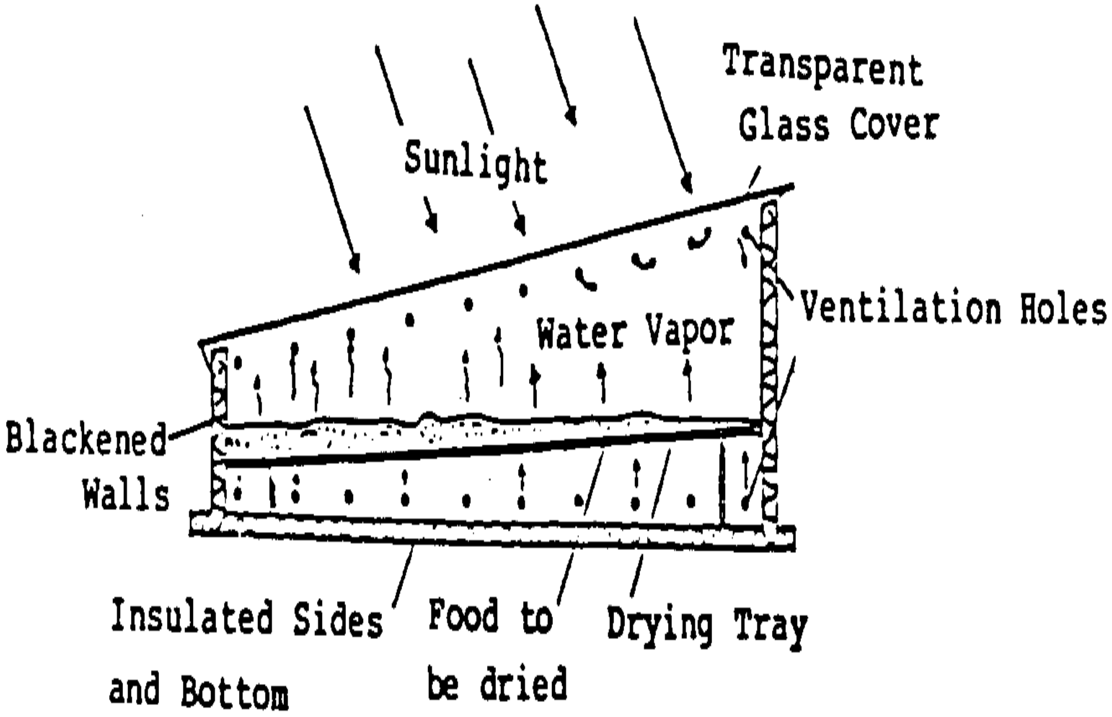

Figure 7. Brace Research Institute's Hot Box Dryer

that the temperature within the dryer can be as much as
40 [degrees] Centigrade (104 [degrees] Fahrenheit) higher than the outside ambient
(surrounding) temperature.

Indirect Dryers. An indirect dryer is one in which the sun's rays do not strike the food to be dried. In this system, drying is achieved indirectly by using an air collector that channels hot air into a separate drying chamber. Within the chamber, the food is placed on mesh trays that are stacked vertically so that the air flows through each one. Figure 8 shows an indirect passive

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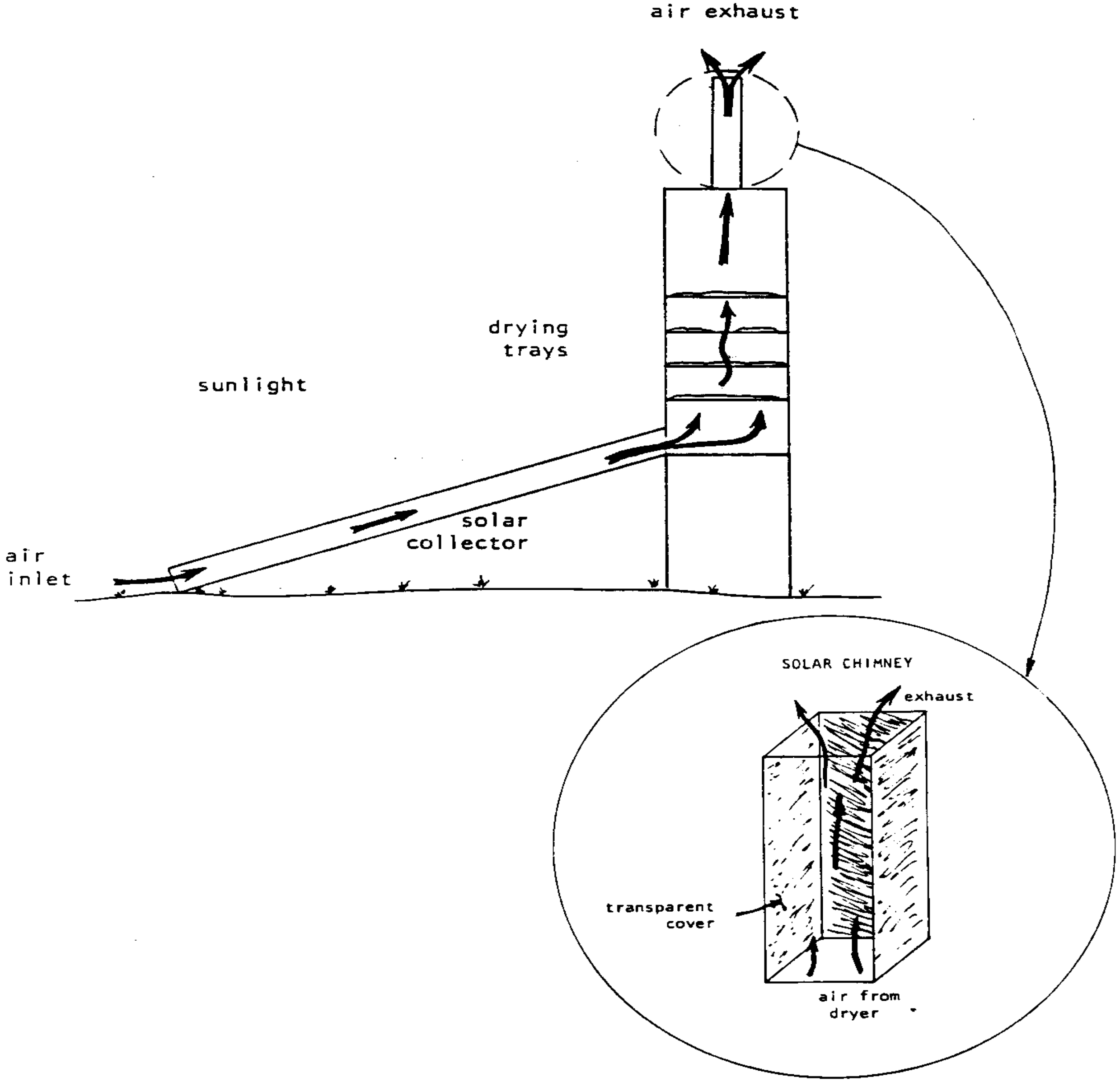

Figure 8. Indirect Dryer

dryer. The solar collector can be of any size and should be tilted toward the sun to optimize collection. By increasing the collector size, more heat energy can be added to the air to improve overall efficiency. Larger collector areas are helpful in places with little solar energy, cool or cold climates, and humid regions. Section V of this paper indicates climatic conditions where larger collector areas might be more effective.

Tilting the collectors is more effective than placing them horizontally, for two reasons. First, more solar energy can be collected when the collector surface is more nearly perpendicular to the sun's rays. Second, by tilting the collectors, the warmer, less dense air rises naturally into the drying chamber. The drying chamber should be placed on support legs, but it should not be raised so high above the ground that it becomes difficult to work with.

The base of the collector should be vented to allow the entrance of air to be heated for drying. The vents should be evenly spaced across the full width of the base of the collector to prevent localized areas within the collector from overheating. The vents should also be adjustable so that the air flow can be matched with the operating conditions and/or needs. Solar radiation, ambient air temperature, humidity level, drying chamber temperature, and moisture level of the food being dried must all be considered when regulating the flow of air.

The top of the collector should be completely open to the bottom of the drying chamber. Once inside the drying chamber, the warmed air will flow up through the stacked food trays. The drying trays must fit snugly into the chamber so that the drying air is forced through the mesh and food. Trays that do not fit properly will create gaps around the edges, causing large volumes of warm air to bypass the food, and preventing the dryer from removing moisture evaporated from the food.

As the warm air flows through several layers of food on trays, it becomes more moist. This moist air is vented out through a chimney. The chimney increases the amount of air flowing through the dryer by speeding up the flow of the exhaust air. Figure 8 shows a solar chimney with plastic film on the south-facing side. As the warm, moist air flows through the solar chimney, the additional solar energy entering the chimney warms the escaping air further. This added heat makes the air less dense and causes it to flow up through, and out of, the solar chimney at a faster rate, thereby bringing in more fresh air into the collector.

SOLAR DRYER APPLICATIONS

Solar energy is used throughout the world to dry food products too numerous to list completely. Listed below are a few representative items to show the diversity to which the sun's energy is put to use.

* grains * fruits
* meat * vegetables
* salt * fish

EQUIPMENT/MATERIALS NEEDED

The glazing materials used to cover direct dryers or as cover plates on the collector portion of indirect dryers can be any transparent or translucent material. Glass is probably the best known material, but it is costly and breaks easily.

Rigid plastic materials are equal to glass for solar transmission and can be much more durable against breakage. Fiberglass reinforced polyester, acrylics, and polycarbonates will not break easily in normal use and, depending on the material, may cost less, ranging from US$11 to US$32 per square meter (US$1 to US$3 per square foot). However, these materials tend to degrade somewhat with time, allowing less sunlight to pass through them. Their useful life is estimated to be about 10 years. Acrylics and polycarbonates may be more expensive than glass. Many of these materials are also difficult to find in developing countries and may need to be imported.

Thin plastic films are inexpensive and have good transmissivity (the ability of a material to allow sunlight to pass through it), but may degrade quickly, and are easily punctured and torn. The cheapest film, polyethylene, may cost US$.50 per square meter (US$.05 per square foot) and last less than one season--a little more than a year if it is handled carefully. Ultraviolet-stabilized polyethylene can last two to four years but will cost three to five times as much. Tedlar and teflon films have long useful lives (10 years or more), excellent transmissivity (allowing 92 percent or more of the solar energy to pass through) and cost in the range of US$4 to US$8 per square meter (US$.40 to US$.70 per square foot). These films are probably the best choice if they can be protected from puncturing.

SKILLS NEEDED TO BUILD, OPERATE, AND MAINTAIN

Building a solar food dryer requires some carpentry skills. Mastering the technique of drying comes from direct experience with drying products rather than from reading about it. Maintaining a solar food dryer requires only that an operator monitor the parts periodically for wear and tear. For example, an operator should make sure that the legs that support the drying chamber are not loose, and that vents are not blocked. Plastic glazing material should be checked to see if it turns cloudy, which will cause less sunlight to pass through it.

COST/ECONOMICS

Cost comparisons between indirect and direct dryers are presented in Table 3. Dryers 1, 2, 3, and 4 are indirect dryers, and dryers 5 and 6 are direct dryers. The table shows the cost per unit; more important, it compares the cost per drying tray and the tray area for each dryer. Table 4 gives some values of vitamin C retention for two products dried by indirect, direct, and open air drying. Overall, it appears that indirect dryers are more efficient and have higher vitamin retention than direct dryers.

Table 3. Cost Comparisons

Tray Space Cost Per Unit Cost Per Unit
Type of Dryer (Square Meter) (U.S. Dollars) (U.S. Dollars)

Indirect dryer	1.12	65.00	58.04
Indirect dryer	1.49	90.00	60.40
Indirect dryer	1.30	75.00	57.69
Indirect dryer	3.16	115.00	36.39
Indirect dryer	2.88	175.00	60.76
Indirect dryer	1.21	50.00	41.32

Source: American Solar Energy Society, Inc., Progress in Passive Solar Energy Systems (Boulder, Colorado: American Solar Energy Society, Inc., 1983), p. 682.

Table 4. Vitamin C Retention

Type of Dryer	Type of Food	Percentage of Vitamin C Retained
Indirect	Cantaloupe	70.4
Indirect	Cantaloupe	51.0
Direct	Cantaloupe	53.6

Open sun Cantaloupe 39.5

Indirect Spinach 35.9

Direct Spinach 22.4

Source: American Solar Energy Society, Inc., Progress in Passive Solar Energy Systems (Boulder, Colorado: American Solar Energy Society, Inc., 1983), p. 682.

IV. COMPARING THE ALTERNATIVES

FOSSIL-FUEL DRYERS VERSUS SOLAR DRYERS

Conventionally fueled dryers are the primary alternative to solar dryers. In conventional dryers, a fuel is burned to heat the food-drying air. In some cases, the gaseous products of combustion are mixed with the air to achieve the desired temperature. Although these drying systems are used around the world with no apparent problems, there is the possibility of a mechanical malfunction, which might allow too much gas into the drying stream. If this occurs, the food in the dryer can become contaminated.

The great advantage that conventional dryers have over solar dryers is that drying can be carried out around-the-clock for days on end, in any kind of weather. Unlike solar dryers, conventional dryers are not subject to daily and seasonal variations and other climatological factors. On the other hand, the fuels burned in conventional dryers may present other problems:

Use of wood may contribute to problems of deforestation; coal may cause pollution. Fossil fuels are becoming increasingly expensive and are not always available.

ADVANTAGES OF SOLAR DRYERS

Solar dryers have the principal advantage of using solar energy--a free, available, and limitless energy source that is also nonpolluting. Drying most foods in sunny areas should not be a problem. Most vegetables, for example, can be dried in 2-1/2 to 4 hours, at temperatures ranging from 43 to 63 [degrees] Centigrade (110 to 145 [degrees] Fahrenheit). Fruits take longer, from 4 to 6 hours, at temperatures ranging from 43 to 66 [degrees] Centigrade (110 to 150 [degrees] Fahrenheit).
At this rate, it is possible to dry two batches of food on a sunny day.

A solar food dryer improves upon the traditional open-air systems in five important ways:

1. It is faster. Foods can be dried in a shorter amount of time. Solar food dryers enhance drying times in two ways. First, the translucent or transparent glazing over the collection area traps heat inside the dryer, raising the temperature of the air. Second, the capability of enlarging the solar collection area allows for the concentration of the sun's energy.

2. It is more efficient. Since foodstuffs can be dried more

quickly, less will be lost to spoilage immediately after harvest. This is especially true of produce that requires immediate drying--such as a grain with a high moisture content. In this way, a larger percentage of food will be available for human consumption. Also, less of the harvest will be lost to marauding animals, vermin, and insects since the food will be in an enclosed compartment.

3. It is safer. Since foodstuffs are dried in a controlled environment, they are, less likely to be contaminated by pests, and can be stored with less likelihood of the growth of toxic fungi.

4. It is healthier. Drying foods at optimum temperatures and in a shorter amount of time enables them to retain more of their nutritional value--especially vitamin C. An extra bonus is that foods will look and taste better, which enhances their marketability.

5. It is cheaper. Using solar energy instead of conventional fuels to dry products, or using a cheap supplementary supply of solar heat in reducing conventional fuel demand can result in a significant cost savings. Solar drying lowers the costs of drying, improves the quality of products, and reduces losses due to spoilage.

DISADVANTAGES OF SOLAR DRYERS

Solar dryers do have shortcomings. They are of little use during cloudy weather. During fair weather they can work too well, becoming so hot inside at midday as to damage the drying crop. Only with close supervision can this be prevented. As temperatures rise (determined with a thermometer or by experience), the lower vents must be opened to allow greater airflow through the dryer and to keep the temperatures down. Rice, for example, will crack at temperatures above 50 [degrees] Centigrade; seed grains can be dried at temperatures no higher than 40 to 45 [degrees] Centigrade.

V. CHOOSING THE TECHNOLOGY RIGHT FOR YOU

Four important questions must be answered before one decides to build a solar food dryer. The brief discussion following each question points out many factors that must be considered prior to the construction of a solar food dryer. The questions are:

1. What food will the dryer be used for? Also, what quantities of food will be dried?

Grains, fruits, and vegetables require different drying techniques. Figure 9 shows a flow diagram that may be

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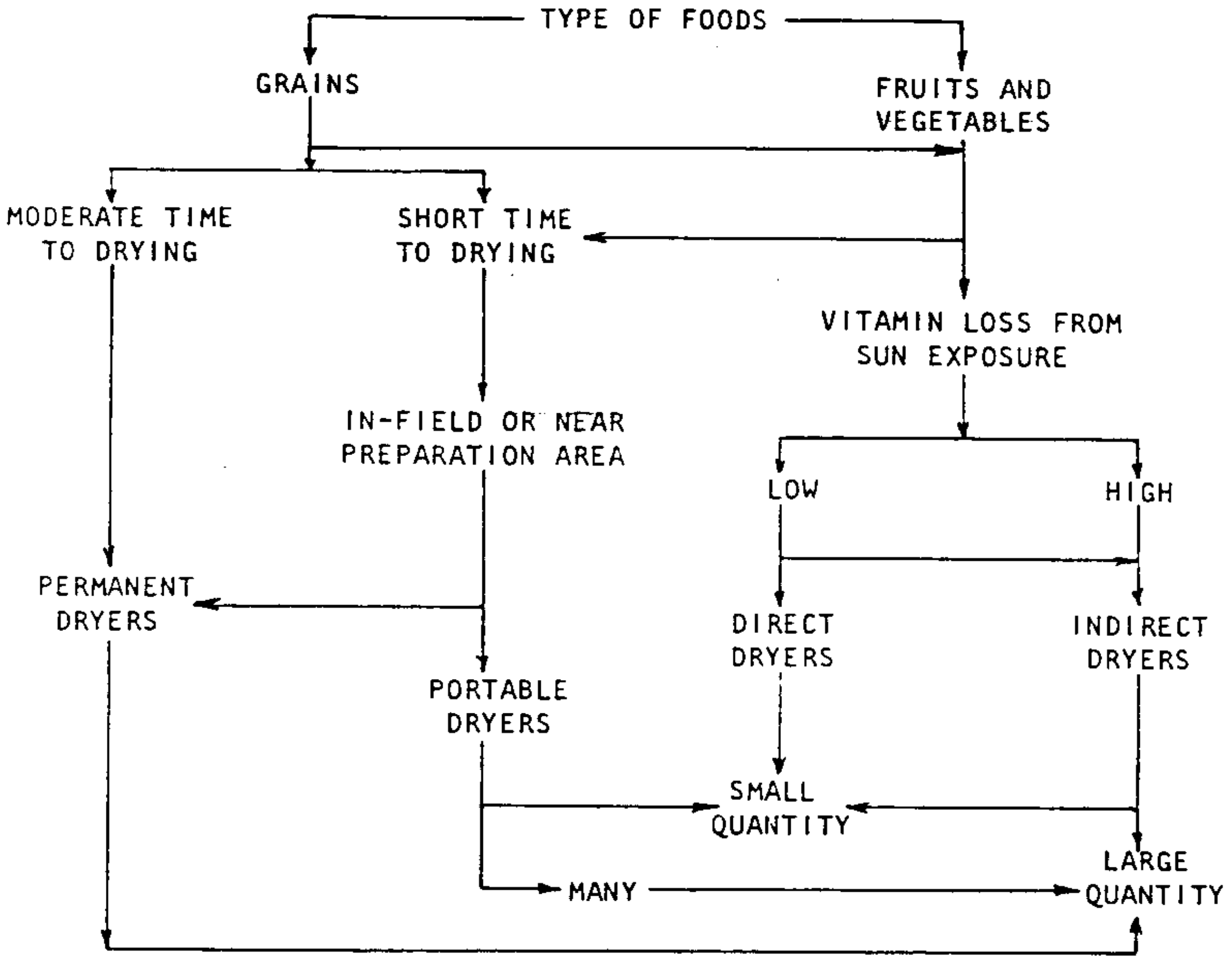

Figure 9. Flow Diagram of Factors to Consider in Selecting a Solar Food Dryer

helpful in defining the type of design. The safe storage of the harvest is of prime concern to all. As soon as fresh fruits and vegetables have been prepared (i.e., some may need to be peeled, sliced, or blanched) for the drying process, they must be dried immediately. Grains, too, have only a limited time in which they must be dried to ensure their storage. Rice in the husk, for example, will begin to germinate within 48 hours if its moisture content is about 24 percent. Crops that must be dried immediately after they are harvested may require the use of portable dryers, which can be set up in the harvest field as needed. Permanent dryers can be erected near preparation areas for fruits and vegetables or centrally located for grain crops.

Some foods may lose much of their nutritional value, or become discolored, if dried at too high a temperature or if exposed to the direct rays of the sun. Using indirect dryers can minimize the loss of vitamins, especially vitamin C.

Finally, the quantity of food to be dried, the capacity of the dryer, the average time requried to dry one batch, and the time available in which to dry the harvest must all be considered in determining the number and size of the dryers needed.

2. What are the climatic conditions during the harvest (and drying) season?

Climatic conditions (solar radiation, rainfall, temperature, humidity, wind, etc.) should be considered in determining what kind of dryer is best suited for a particular application.

Figure 10 will help you to visualize the factors that must

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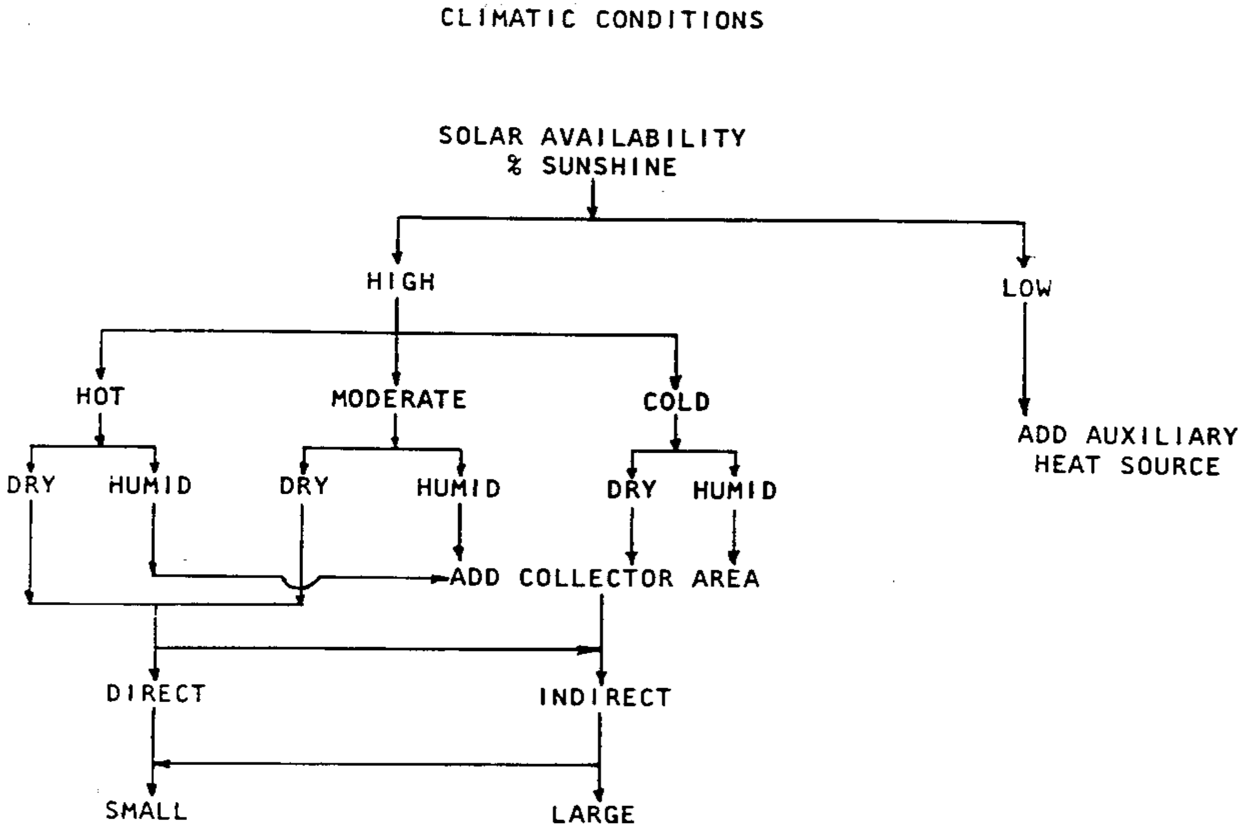

Figure 10. Flow Diagram of Climatic Conditions

be considered here. If the occurrence of sunshine is low--say, 50 percent or less--then it may be wise to add an auxiliary heat source to enable drying to continue on cloudy

days or even through the night. Dry climates with hot or moderate temperatures are well suited for solar food dryers.

Cold climates or humid climates pose the problem of making it more difficult to obtain the necessary quantity of warm, dry air to dry foods effectively before spoilage can occur. Such weather conditions may limit the use of direct dryers to preserving only small quantities of food that must be dried in a short time (one or two days). Indirect dryers have the advantage over direct dryers in that they are capable of concentrating solar energy. Enlarging the collector area and varying the airflow through the collector enable indirect dryers to achieve near optimum conditions in most climates.

3. Is the food to be stored for long periods or will it be shipped to market for quick consumption?

The answer to this question determines the dryness required of the finished product. Rice at harvest might typically contain 24 percent moisture. If it is sold quickly, say, for milling, it is fine as is. If, on the other hand, it is to be stored for any length of time, it must be dried to only 12 to 14 percent moisture content. Thus, the dryness required will determine how long and at what temperature the food must remain in the dryer. The time required for the food to remain in the dryer must be taken into account in determining the number of dryers needed to dry the entire harvest.

4. What materials are available to construct the dryer? Are the materials available locally?

Masonry may be a good construction medium for permanent dryers, where the food can be brought to the dryer. If, however, the dryers are to be transported into the fields, lightweight materials will be needed to make the units portable. The availability of materials may govern, in part, the placement of the food dryers.

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TECHNICAL ASSISTANCE ORGANIZATIONS

Brace Research Institute
McDonald Campus of McGill University
Ste. Anne de Bellavue 800
Quebec, Canada
The Institute has designed direct and indirect dryers and has plans available.

New Mexico Solar Energy Association (NMSEA)
P.O. Box 2004
Santa Fe, New Mexico 87501 USA
NMSEA publishes detailed construction plans for a solar crop dryer.

Volunteers in Technical Assistance (VITA)
1815 North Lynn Street, Suite 200
Arlington, Virginia 22209 USA
VITA's Solar Crop Dryer manual includes plans for a direct and an indirect solar dryer.

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