PN AAR 319
20

SOLAR CURING BARNS, FAST-GROWING TREES AND AGROFORESTRY OFFER A SOLUTION TO THE DEFORESTATION CAUSED BY TOBACCO PRODUCTION IN THAILAND, TANZANIA, SRI LANKA, NEPAL, PHILIPPINES AND OTHER DEVELOPING COUNTRIES.

TECHNICAL SERIES #15

COMPILED BY:
Michael D. Benge
S&T/FNR Agro-forestation
Rm. 515-D, SA-18
Agency for International Development
Washington, D.C. 20523

INFORMATION MEMORANDUM

SUBJECT: Solar Curing Barns, Fast-Growing Trees and Agroforestry Offer a Solution to the Deforestation Caused By Tobacco Production in Thailand, Tanzania, Sri Lanka, Nepal, Philippines and Other Developing Countries.

Cutting trees for fuelwood to cure tobacco is a major cause of deforestation in the tobacco growing regions of many developing countries. Most often cited are Thailand, Tanzania, Sri Lanka, Nepal and the Philippines; however, many other LDCs share this problem.

In Thailand, tobacco curing, together with rubber preparation, was estimated to have required 300,000 m^3 of fuelwood in 1970, and in Tazania nearly 1.1 million m^3 in the same year (ref. Section IV, p. 3). A recent newspaper article states that vast areas of forests have been cleared for tobacco production in Sri Lanka (ref. Section V). According to the article each family in the area of Kandy (a major tobacco growing region) is encouraged to clear at least one acre of land to plant tobacco, and an estimated 25,000 families in the area now grow tobacco. The article goes on to say that it requires 7 tons (6.35 mt) of fuelwood to cure the tobacco produced on one acre (0.4047 ha). Thus, approximately 158,760 mt or 244,246 m^3 of fuelwood are needed to cure one crop of tobacco (assuming that the specific gravity of the wood is 0.65, an average for tropical hardwoods and the moisture content is 25-30%). Therefore, 2,442 ha of forest will destroyed each year if clear cut (assuming that one ha of tropical forests contains 100 m^3 of wood), or if the forests were managed and harvested as a renewable resource, this would be equal to one year's growth of wood from 48,849 ha (assuming an average annual regrowth rate of 7.5 m^3).

Crop substitution is not the answer, since tobacco production provides the farmer with a good cash income. The use of more traditional fuels, such as oil, gas and electricity, most often is not feasible, since alternative fuels usually cost more than fuelwood and may not be available, and farmers cannot afford the equipment needed for conversion.

However, solar heat for tobacco curing, the planting of fast-growing trees and agroforestry show great promise as solutions to this seemingly insoluble problem.

Solar Curing Barns

Dr. B.K. Huang and associates at North Carolina State University have developed a solar tobacco barn that reduces fuel costs of curing tobacco in the U.S. by 41% (ref. Section I). In tropical countries, the savings could be much higher, since more solar energy is available.

The cost of building a solar tobacco barn can be substantially higher than traditional types of wood-fueled barns made from local materials. However, the higher initial cost can be offset if it is shared among several farmers (by forming cooperatives or farmer associations). This burden also can be eased by long-term, low-interest loans or through government or donor-assisted projects.

The farmers would greatly benefit by using solar tobacco curing barns, since fuel costs would be reduced and labor requirements would be less (wood-fueled flues have to be tended 24 hours a day during the curing period). Often, a better quality of tobacco can be produced, which would command a higher price. By forming cooperatives and associations, the farmers would have greater bargaining power when selling their tobacco, which should enable them to obtain a higher price (individual tobacco growers are at the mercy of large buyers and monopolies that dominate this sector). Furthermore, farmers would be in a better position to receive credit and extension services for crop improvement.

In the long run, the government could benefit from farmers' converting to solar tobacco curing barns. Tobacco production on the same unit of land will increase (through credit and extension), and the quality of the tobacco should be improved. Both will result in increased profits for the farmer and increased revenues for the government. Once fuelwood becomes critically scarce, farmers are forced to convert to oil, increasing the demand for imported oil--imports the LDC governments cannot afford. If solar heat is used, however, local deforestation problems would decrease, as would environmental degradation and deterioration of the natural resource base.

Fast-Growing Trees

In the Philippines, I had the opportunity to initiate an innovative program with farmers in the major tobacco growing region of Illocos Norte, Illocos Sur and Abra Provinces through an association of rural banks in these provinces and the Philippine Virginia Tobacco Administration, assisted by U.S. Peace Corps. There deforestation was rampant, caused by felling of trees for fuelwood for tobacco curing. The members of the association of rural banks agreed to require that borrowers, to qualify for a loan to grow tobacco, plant a quantity of fast-growing trees (*Leucaena leucocephala*). The seedlings were grown in regional nurseries by the Tobacco Administration, which furnished them to the farmers, through the rural banks, free of charge. The credit extension agents at the banks ensured that the farmers grew the trees. It was felt that once the farmers saw the rapid growth of the trees, they would realize the value of growing their own fuelwood. Also, since the trees were prolific seeders, other farmers in the area would obtain seed and follow suit.

This program succeeded and led to World Bank loan financing, through the Development Bank of the Philippines (one component of a U.S. $4.4 million loan), of a much larger project to continue this pilot effort of reducing deforestation through increasing local fuelwood supplies (ref. Section II, pp. 29-31).

Agroforestry

Establishing agroforestry systems in which tobacco and trees are planted together is another effective means of reducing problems stemming from deforestation for tobacco production. The adoption of "modern" agricultural practices, in which clean row farming is practiced, has led to the elimination of trees from traditional farming systems. Many crops that do not require full sunlight for optimum yield are unnecessarily being grown in open fields, when in fact, they produce as well under partial shade.

Similar high yields of cured tobacco were produced both under shade trees and in full sunlight when the effect of shade on yields of five crops was researched in Puerto Rico (ref. Section III). Sunlight intensity in the shaded plots was about half of that in the unshaded plots. Shading did not affect the yield or appearance of the tobacco which was graded of highest quality (CLF or XlF); however, some varieties of tobacco may be more shade tolerent than others. In this experiment, Olor was the variety of tobacco used.

Instead of clearing the land completely in the traditional practice of slash-and-burn, farmers could leave desirable trees and plant tobacco between them. The trees can then be periodically harvested for fuelwood, timber, etc., for tobacco curing, for home consumption or as a cash crop. Fast-growing trees could also be planted; they would produce a wood crop in a much shorter time. If the trees were nitrogen-fixing, soil improvement would be enhanced. However, under continious cropping, weeds, plant diseases and pests build up over time and soil structure, erosion and fertility problems are aggravated. Unless these crop lands are put into a tree fallow (by planting or regeneration) to break the cycle of these pests and to allow the soil to rejuvenate, crop yields will decline until it may no longer be economical to farm these lands.

The problems resulting from deforestation for tobacco production continue to increase; however, this problem can be minimized by the introduction of solar tobacco curing barns, the planting of fast-growing trees and agroforestry. These technologies warrant serious examination, research and testing in Thailand, Tanzania, Sri Lanka, Nepal, the Philippines, as well as in other LDCs by both development agencies and governments.

Michael D. Benge
S&T/FNR Agroforestation
Rm. 515-D, SA-18
October 31, 1983

5

TABLE OF CONTENTS

I. Huang, B.K. and C.G. Browers, Jr. (1978) Plant Production, Automatic Transplanting, and Greenhouse Solar Systems.

II. Hyman, E.L. Small Holder tree Farming in the Philippines: a comparision of two credit programmes.

III. Vicente-Chandler, J., F. Abruna and S. Silva. Effect of Shade Trees on Yields of Five Crops in the Humid Mountain Region of Puerto Rico.

IV. Arnold, J.E.M. and J. Jongma. Fuelwood and Charcoal in Developing Countries.

V. Madeley, J. Deforestation heats up tempers and temperatures.

VI. Hudson, J. A Greenhouse That Cures Tobacco.

VII. Huang, B.K. Greenhouse Bulk Curing Solar Barn.

VIII. Hammons, N. Solar curing barn cuts fuel costs, aids mechanization.

IX. Huang, B.K. and C.G. Bowers, Jr. (1977) Plant Production, Automatic Transplanting, and Greenhouse Solar Systems.

6

SECTION I

Huang, B.K. and C.G. Bowers, Jr., Plant Production, Automatic Transplanting, and Greenhouse Solar Systems. 1978

7

GREENHOUSE BULK CURING SOLAR BARN

B.K. Huang, Professor
Department of Biological and Agricultural Engineering
North Carolina State University, Raleigh, N.C. 27607

BIOLOGICAL AND AGRICULTURAL ENGINEERING

State 2504: System Approach to Tobacco Mechanization

PLANT PRODUCTION, AUTOMATIC TRANSPLANTING, AND GREENHOUSE SOLAR CURING SYSTEMS

B.K. Huang (Project Leader) and C.G. Bowers, Jr.

ABSTRACT

Continuing efforts were made to accomplish the systems engineering of total tobacco cultural operations from plant-bed preparation, automated seeding, seedling production, and automatic transplanting to harvesting and solar energy bulk curing. Special emphasis was placed on utilizing the solar barn as a year-round crop production system for curing tobacco with solar energy, producing horticultural crops, and growing tobacco transplants for fully automatic transplanting.

The production of tobacco transplants was enhanced by the controlled environment of the solar barn greenhouse system. Significant improvements were made in growing tobacco transplants using seedling growing and handling trays in multiple tiers. Excellent germination rates of 95-97 percent and uniform growth in early stages of transplant growth were achieved in all three tiers of seedling production.

Four full scale tobacco cures with solar energy demonstrated quality tobacco curing with a 41 percent fuel saving for this system as compared to a conventional bulk curing barn. The average fuel consumption for the four solar-barn cures was 0.0685 gallons LP gas per pound of cured and ordered tobacco.

At the end of the tobacco curing season the solar barn was converted to a greenhouse to grow a crop of tomatoes and cucumbers. In order to facilitate the conversion of the structure from the curing mode to the greenhouse mode or vice versa, hydroponic plant production systems were investigated for ease of installation of plant production system and for efficient production within the solar barn structure.

I. SUMMARY OF RESEARCH

A. Tobacco Seedling Production in Greenhouse Bulk Curing Solar Barn

Automation of plant-bed and transplanting operations is currently the major bottleneck in tobacco mechanization. The changing labor situation demands help for the tobacco farmer in mechanization of plant-bed and transplanting operations. In March 1977, the solar barn was set up for tobacco transplant production. Tobacco transplants were grown on the layers using perforated sheet metal covered frames spaced approximately 984 cm apart. An automated misting system was installed on each layer using propagation nozzles at 100 psi to provide fine misting for approximately 15 seconds per 30 minutes during daylight hours. Artificial lighting was added for each layer to provide approximately 1000 foot candles at center of each layer. Temperatures in the greenhouse were maintained between 22°C minimum and 29°C maximum during the day and 18°C minimum at night. Thermostats controlled a greenhouse LP gas heater and two vent fans to maintain these temperatures.

The tobacco seedling, growing and handling trays were seeded March 10-11, 1977 using the automated precision seeder shown in Fig. 1. The soil used for the germination and growing medium was Hecco Number 1 soil - a spaghaum peat moss mixture. This mixture was almost saturated prior to being packed into the trays. Once the trays were seeded, they were placed on three layers in the solar barn.

Seedling emergence began approximately 7 to 8 days after seeding. Germination rates of 95-97% were obtained on each layer (Fig. 2). The automatic misting system and auxiliary lighting are shown in Fig. 3 for the multiple-tier transplant system in solar barn. Variations in light levels and misting both within and between layers contributed to visible non-uniform growth. This growth variation was noticable after 3-4 weeks. To correct this environmental growth problem, the lower leaves of the larger plants were removed. This action tended to normalize the plant canopy and keeps plants at approximately the same size.

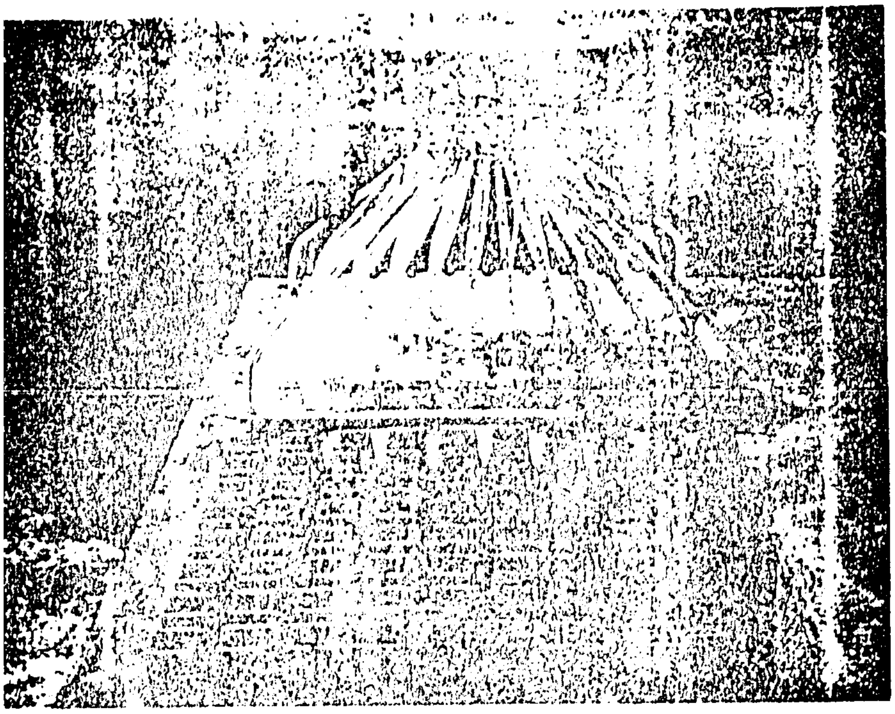


Fig. 1. Automated precision seeder and seedling growing and handling tray.

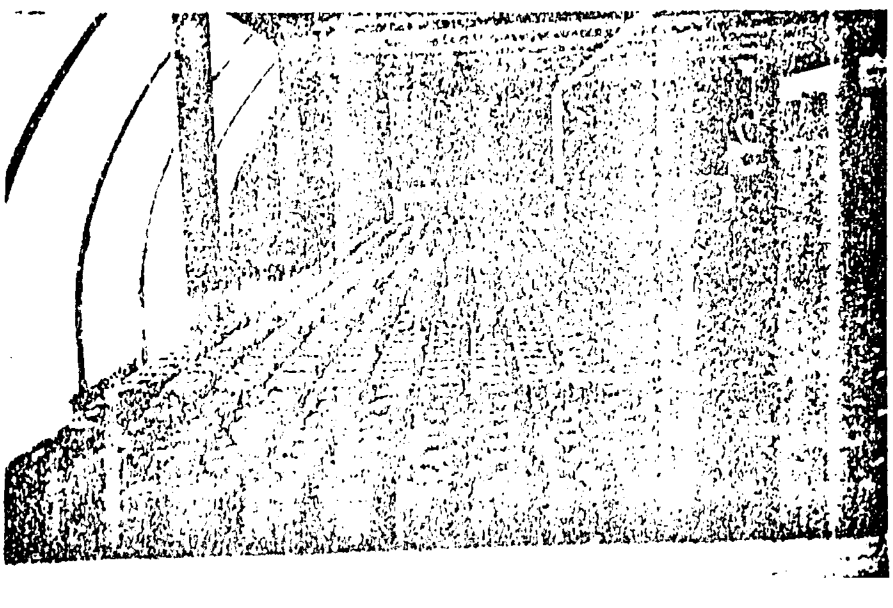


Fig. 2. Excellent germination of 97% obtained in multiple tier transplant production system in solar barn.

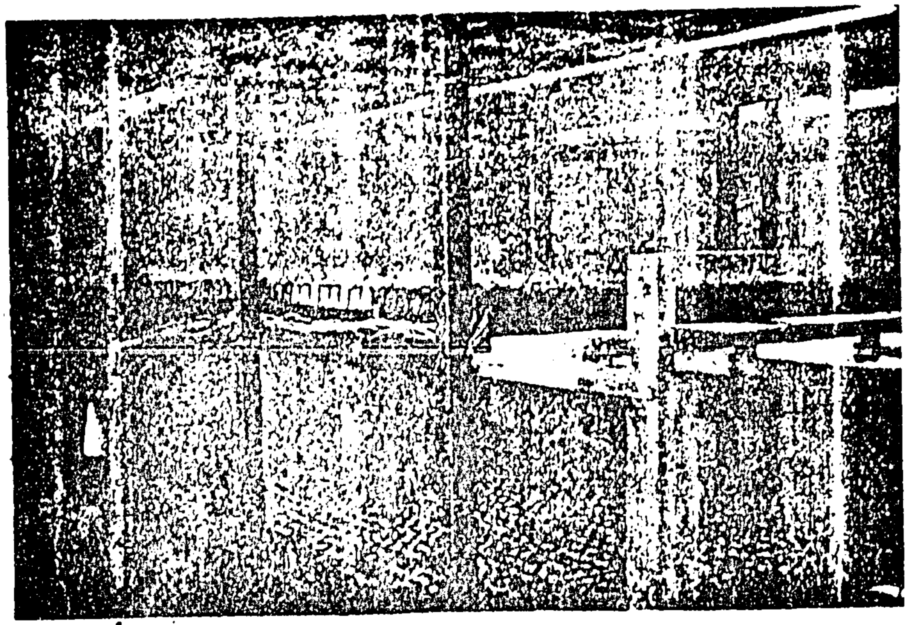


Fig. 3. Automated misting system and auxiliary lighting for multiple tier transplant production system.

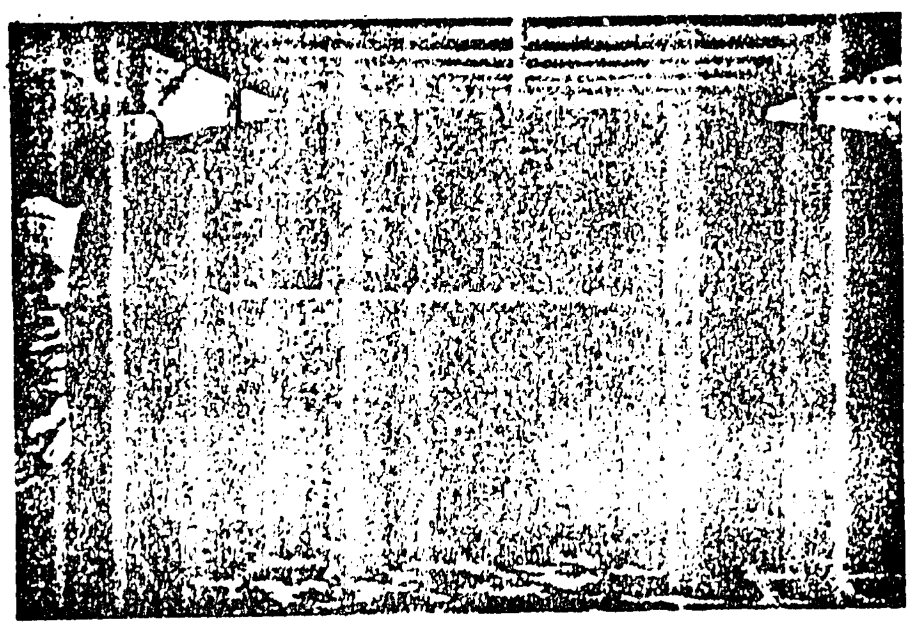


Fig. 4. Open bottom of seedling growing and handling tray showing air pruning of root system for better growth.

The pyramid or cone design of the tray cells provides good root orientation for future growth. Figure 4 shows the excellent air pruning effects of root system at the open bottom. This prevents the roots from tangling for better growth, easier removal and transplanting by the automatic transplanter.

Tobacco transplant production on multiple layers should be achievable with appropriate lighting and watering. Transplants acceptable for tobacco can be grown in 6 to 8 weeks (Fig. 5) in the solar barn.

B. Automatic Transplanting

A commercial version of a two-row automatic transplanter (Fig. 6), made by the Harrington Manufacturing Company, was field tested using the tobacco seedlings grown in the solar barn. The automatic two-row machine was designed, based on a prototype one-row automatic transplanter which was illustrated in the Annual Report of Accomplishments in Tobacco Research in North Carolina (April 1, 1973 through March 31, 1974). The transplanter was designed as a three-point hitch, tractor-drawn machine. It operated at a speed of about 2 mph.

Plastic seedling, growing and handling trays to be used with the automatic transplanter were made by the Summit Plastic Corporation. Each tray holds 80 potted tobacco plants (8 by 10), serves as a growing container in the greenhouse plant-bed, and functions as an indexing grid-cartridge during automatic transplanting. The trays were designed to adapt to the transplanter indexing frame. This frame holds six trays or 480 plants.

Improvements were made on the commercial transplanter by adding ridge scrapers, depth control wheels and separate suction systems for each drop tube. The ridge scrapers and depth wheels were needed for precise depth control and furrow opening prior to the setting of the tobacco transplant. Suction for removal of the potted plant from the seedling, growing and handling tray and for placement in the furrow had to be controlled independently in each drop tube. Additionally, the vacuum was stopped prior to opening the bottom of the drop tube so as to enhance the setting

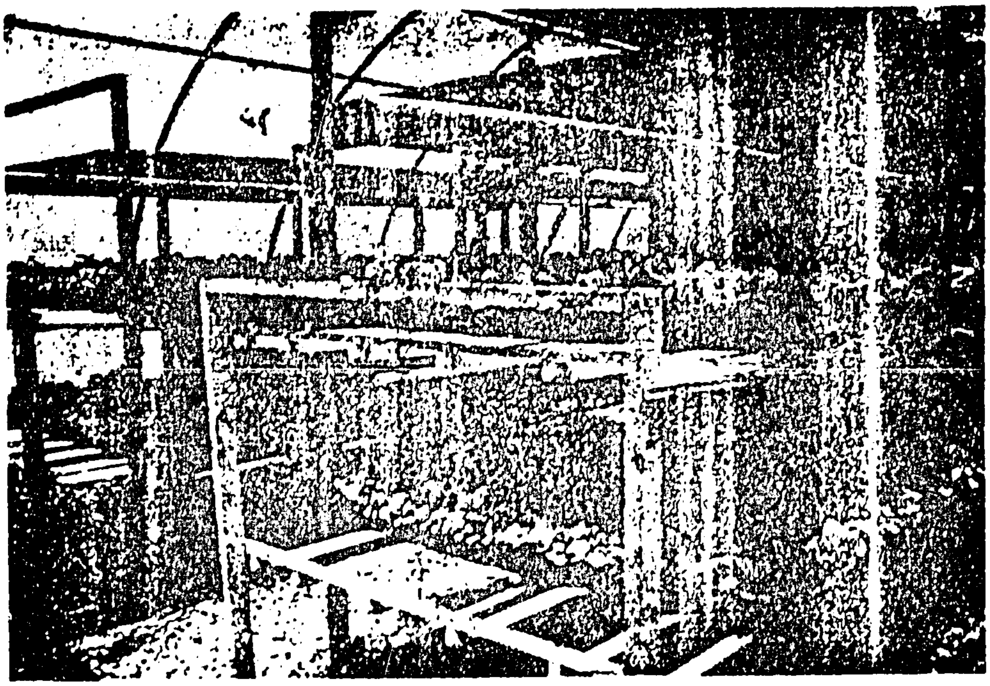


Fig. 5. Tobacco transplants grown in multiple tiers in solar barn.

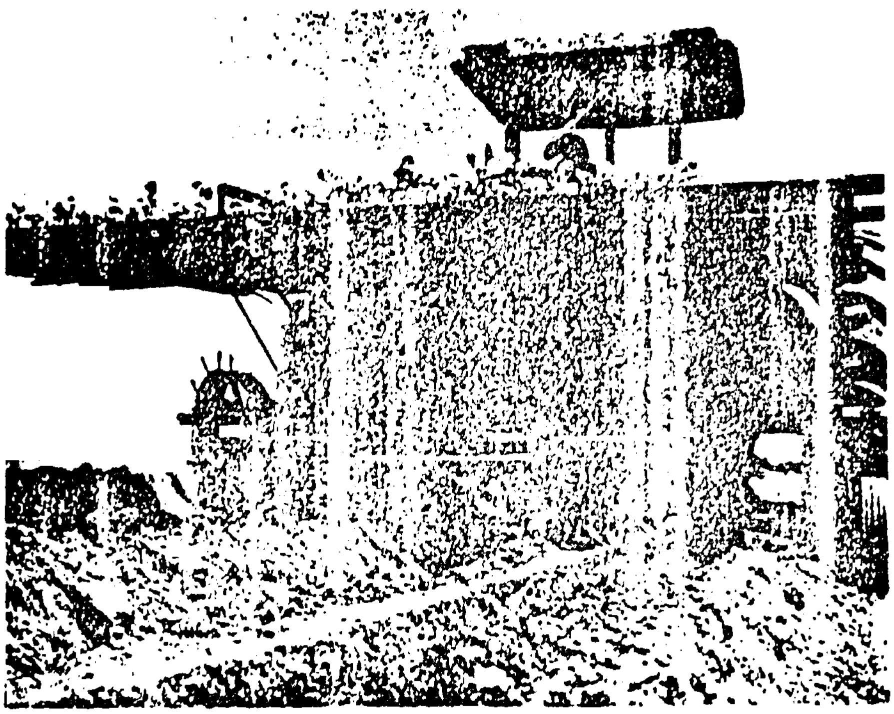


Fig. 6. Commercial version of two-row automatic transplanter.

of the transplant. The electro-hydraulic system for operation of the transplanter is shown in Fig. 7.

Field tests with the commercial transplanter were conducted to evaluate the improvements made on the machine. The depth control and suction systems functioned well. Problems were encountered with microswitches which physically sensed the passing of the transplant prior to opening the bottom of the drop tube. The physical contact tended to cause jamming of the drop tube and break-up of the potted transplant. It is anticipated that photoelectric cells will solve this contact problem.

C. Curing Operation of Greenhouse Bulk Curing Solar Barn

Energy studies were conducted with the greenhouse bulk curing system to determine fuel savings of this system as compared to conventional bulk curing. Being basically a greenhouse structure with a modular, solar energy bulk curing unit inside (Fig. 8), the system uses solar energy as a first priority source of energy for curing. Solar energy collected by the blackened side and top heat absorber panels preheats air used for the curing process or used to store energy in gravel for later use. The motorized vents and shutters within the structure control air flow modes for optimum solar energy collection and utilization.

A microprocessor based data acquisition and control system was used in the solar barn to record environmental, curing, and energy data and to provide set-point control for system operation. Data collected for analysis included direct and diffuse solar energy, wind speed and direction, outside wet and dry bulb temperatures, inside wet and dry bulb temperatures, surface temperatures of absorber panels, and tobacco temperatures. Temperatures within the curing chamber and preheated air temperatures of the solar absorbers were monitored by the microprocessor for control of air flows. Based on set-point temperatures programmed into the microprocessor, the motorized shutters, and vents and auxiliary gravel fan were automatically controlled by the microprocessor through relay action so as to optimize solar energy collection,

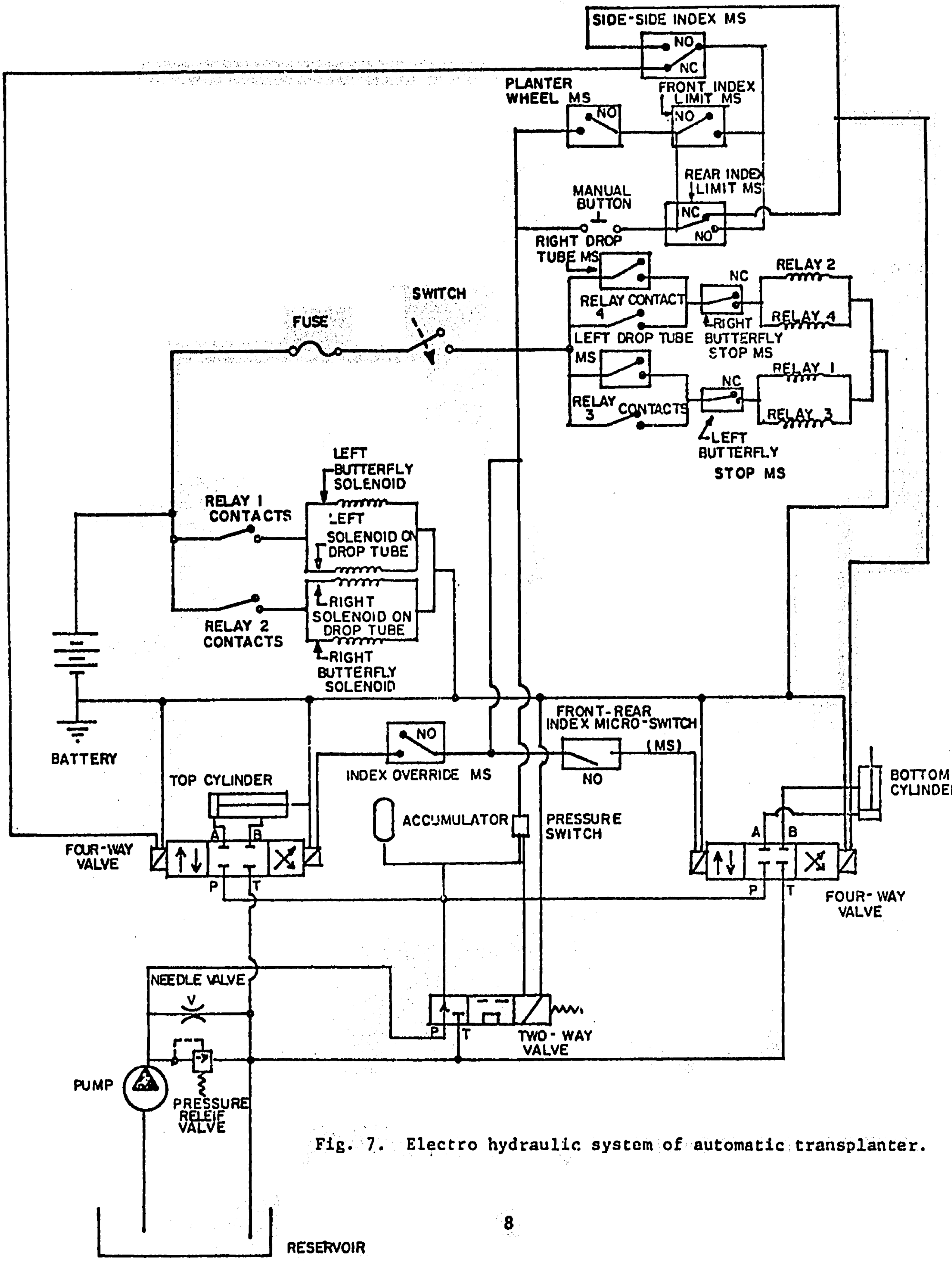
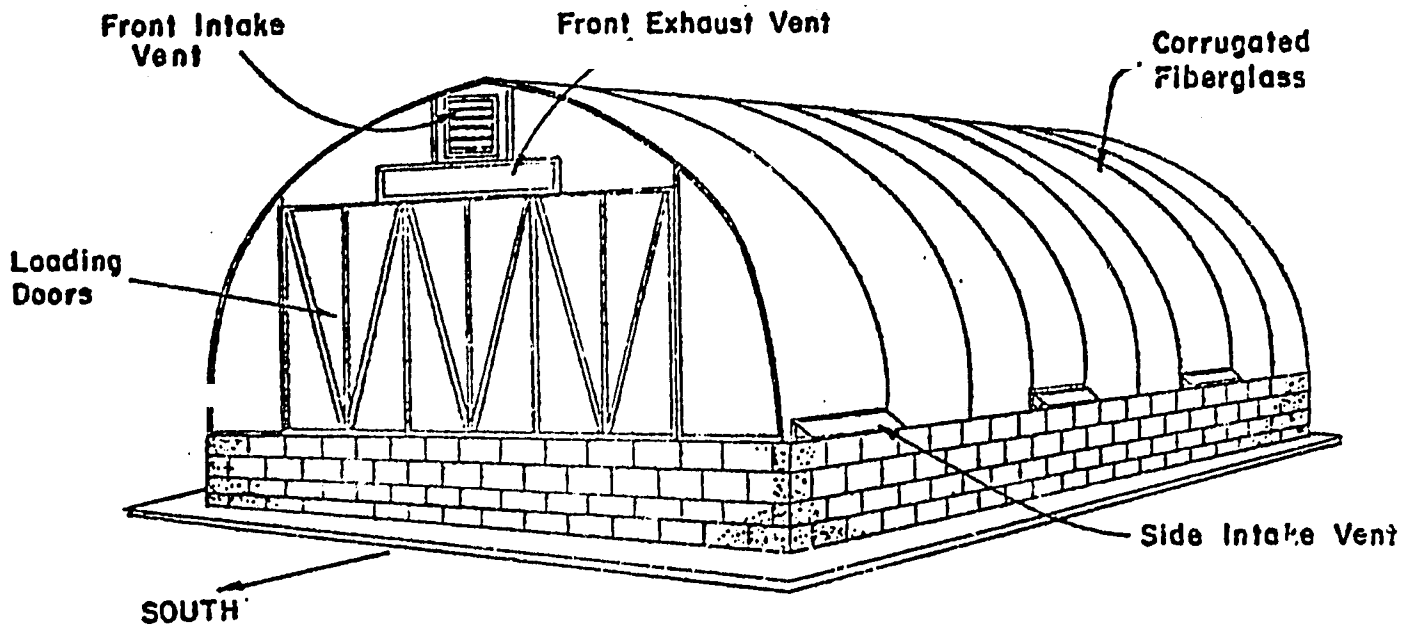
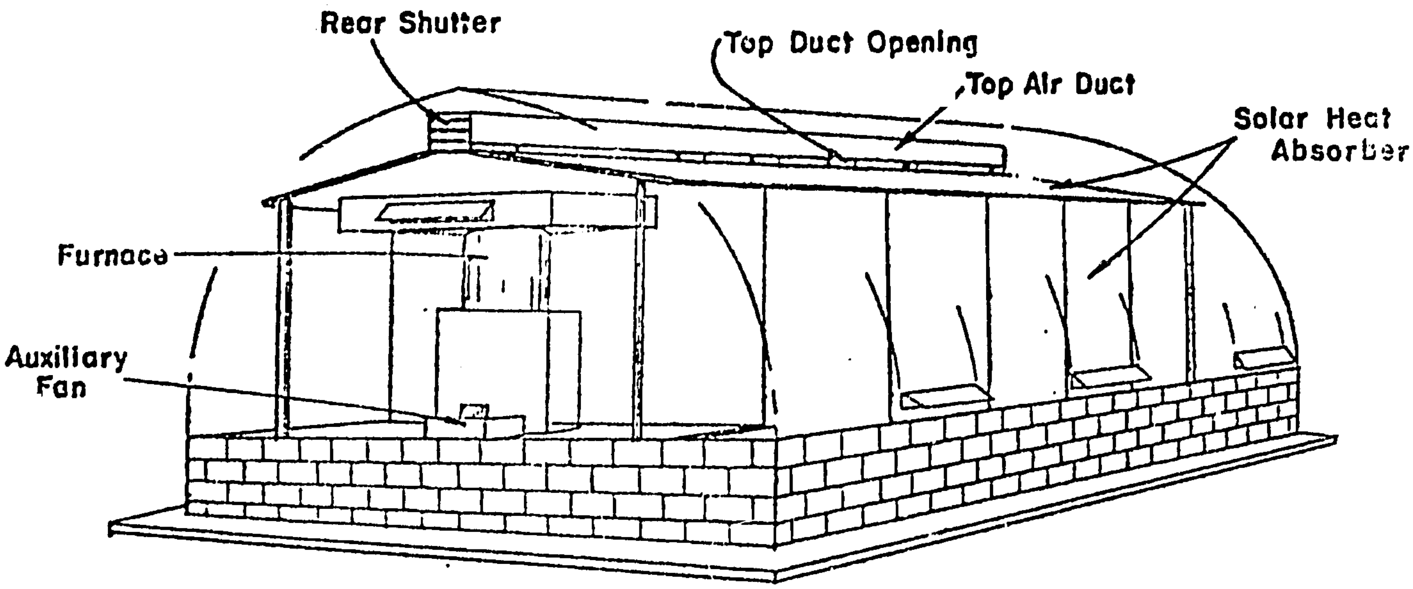


Fig. 7. Electro hydraulic system of automatic transplanter.



(a)



(b)

Fig. 8. Greenhouse bulk curing system (a) front view and (b) rear view.

storage and utilization in the curing process. Data were collected for the system by the microprocessor for all cures during the Summer of 1977, but only the last cure was operated by set-point control of the microprocessor. Controls were operated manually for the other cures.

Solar energy utilization tests were conducted during July, August and September, 1977. Four complete cures were made in the greenhouse solar curing barn (Fig. 9). Missing tobacco weight data for the conventional commercial bulk barn prevented a direct comparison for the Summer, 1977. The prior two year's average was used to compare fuel consumption of the solar barn and conventional barn. Curing procedures within the solar barn were approximately the same from cure to cure with minor variations as required by the individual cures. The general curing procedure was as follows

(1) Bulk racks were filled in the field and placed in the barn.

(2) The furnace system was turned on, and a typical bulk curing schedule followed for temperature and air ventilation rates. The temperature curing schedule generally consisted of two-three days yellowing at 32-35°C, three days of leaf drying with the air temperature being advanced from 32°C to 76°C at 1 to 1.5°C per hour with certain temperature levels being maintained as determined by tobacco conditions, and one day of stem drying at 76°C. The air ventilation rate was usually 10% or less for yellowing gradually increased during initial leaf drying until it was about 40% for temperatures of 54 to 60°C, then gradually reduced during later stages of leaf drying, and held at 10% or less intake during stem drying.

The overall fuel savings achieved by the greenhouse solar curing system as compared to the prior two year average of the conventional bulk curing barn was 41 percent. The average LP fuel consumed in gallons per pound of cured (and ordered) tobacco was 0.0685 for the solar barn and 0.1155 for the conventional bulk barn. The curing time, fuel consumption and tobaccos used in the greenhouse solar barn are given in Table 1. The 0.0685 gallons LP per pound of cured tobacco is approximately 9 percent lower than last year's average of 0.075. This increased savings is attributed mainly

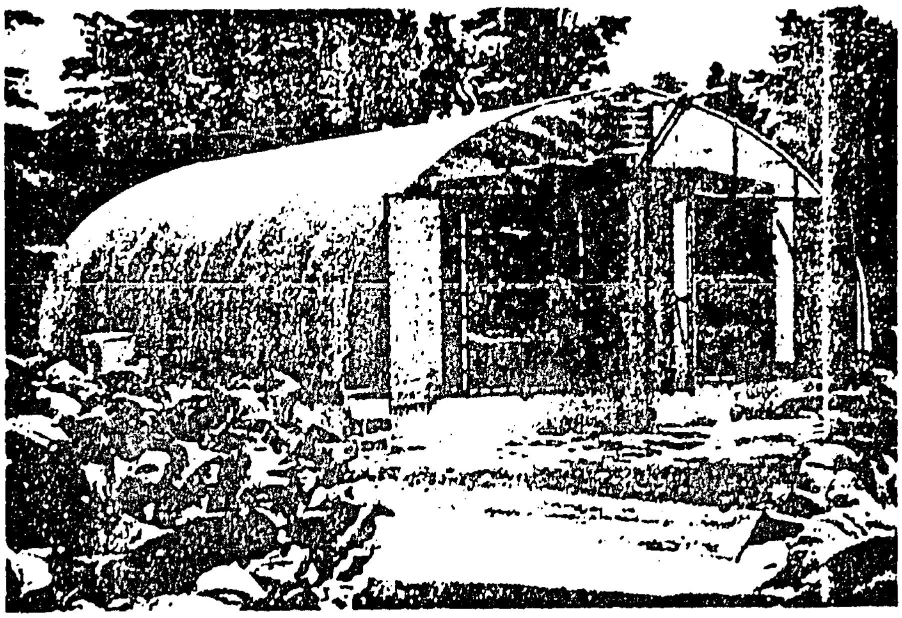


Fig. 9. Greenhouse bulk curing solar barn in tobacco curing mode of operation.

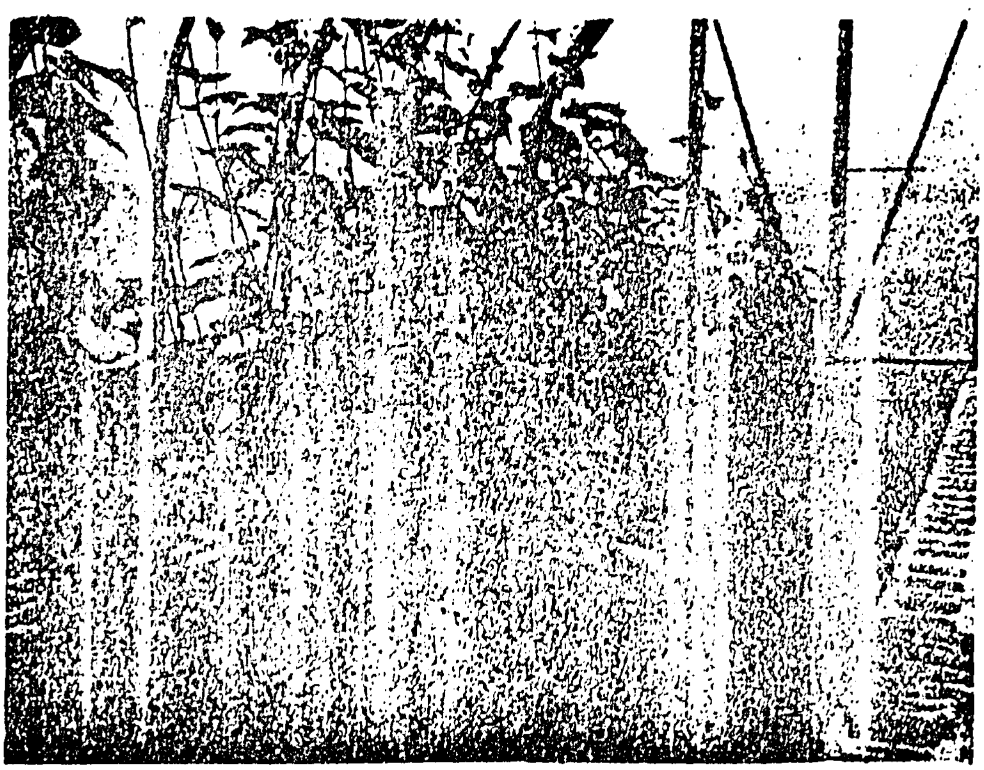


Fig. 10. Greenhouse bulk curing solar barn in greenhouse mode of operation for growing cucumbers.

to increased insulation of the side absorber panels (1/2 inch aluminum faced polyurethane panels instead of 1/2 inch plywood) and insulation of the furnace room. This 9 percent figure represents the increased 10 percent predicted in last year's report for increased insulation.

Table 1. Tobacco Curing in Solar Barn Summer, 1977.

Curing Time (days)	Tobacco McNair 944	Fuel Used (gal/lb tobacco)
9	Bottom 4 leaves	0.0891
7.5	5th-9th leaves	0.0804
7.5	10-14 leaves	0.0618
7	Top of stalk	0.0538
Average		0.0685

In order to compare fossil-fuel energy consumption in the greenhouse bulk curing solar barn with other bulk curing systems, energy data is presented in Table 2 for various types of curing and types of fuel. In general, direct fire LP curing is more efficient energy-wise than indirect fire oil curing. Also, as shown by the NCSU/BAE extension studies, the fuel crisis and education of tobacco farmers to bulk curing management have significantly reduced fuel consumption for some farmers (Part of this decrease is attributable to yearly crop variation). As shown by Table 2, the original solar barn system and the improvements made over the past three years can contribute significantly to reduced fossil-fuel consumption in tobacco curing. The cost and operation of the solar barn system are approximately the same as a conventional bulk barn.

Table 2. Energy Consumption in Tobacco Bulk Curing.

Bulk Curing Study	Year	Average BTU/lb of Ordered Tobacco	Low Cure or Average (BTU/lb)	Type of Cure	Types of Fuel Energy*
"Energy & U.S. Agriculture" USDA Publication		22,454		Sticks & Rack	LP, Oil, NG
Canadian Survey	1974-1975	16,400		Sticks & Rack	LP, Oil, NG
		12,695	7,754(LP)	Bulk (Rack)	LP, Oil, NG
NCSU/BAE Extension Energy Studies of Commercial Barns	1976	21,836	15,609	Bulk(Box & Rack)	Oil
		11,979	10,819	Bulk(Box & Rack)	LP
	1977	16,598	11,586	Bulk(Box & Rack)	Oil
		9,138	8,481	Bulk(Box & Rack)	LP
Central Crops Res. Station Commercial Bulk Barn	1975	11,327		Bulk(Rack)	LP
	1976	9,776		Bulk(Rack)	LP
Cross-Flow Barn Being Developed by NCSU/BAE	1975	9,076	6,340	Bulk(Box)	LP**
	1976	11,440		Bulk(Box)	LP
Solar Barn Being*** Developed by NCSU/BAE	1975	7,101		Bulk(Rack)	LP**
	1976	6,885		Bulk(Rack)	LP
	1977	6,282	4,932	Bulk(Rack)	LP

*Types of fuel are LP-liquid petroleum, oil-fuel oil, and NG-natural gas. LP and NG heating units are direct fire, and oil is indirect fire.

**These barns only have the commercial heating units.

***Solar energy collected and utilized by solar barn was in addition to the energy figures (BTU/lb) given in table.

D. Greenhouse Operation of Greenhouse Bulk Curing Solar Barn

At the end of the tobacco curing season the solar barn at the Central Crops Research Station was converted to a greenhouse mode of operation for growing tomatoes and cucumbers. The solar absorber panels and portable frames used in tobacco curing were removed, and appropriate greenhouse equipment for plant production was moved into the structure. Two approaches were taken to utilize the solar barn for horti cultural crop production: (1) grow plants in the individual pots and irrigate with automatic watering system, (2) grow plants in plenum areas of the solar barn with hydroponic culture.

(1) Plant Production with Containerized Soil Culture in NCSU Campus Structure

Cucumber seeds were started in mid-February, 1977. In mid-March twenty cucumbe seedlings were transplanted into 5 gallon plastic pots filled with peat-soil mix. These plants were placed in two rows of one plenum of the solar barn. The watering system consisted of a Chapin moist-scale used in conjunction with the water-loop tubes. One pilot, potted plant was placed on the control or moist-scale. This scale activated a microswitch turning a watering solenoid valve on and off. This pilot plant is supplied with water from a tube the same as the plants in the plenum. As the pilot-plant soil dries and becomes lighter through loss of moisture, the scale activates the solenoid switch to water all the plants. As the weight of the pilot plant increases during watering, the scale shuts the watering system off. Automatic watering control is achieved based on the weight of moisture in the soil. Both the frequency of watering and amount to be applied can be adjusted to provide optimum watering or maximum growth. As a result of the increase in plant size, the scale needs to be adjusted every 7 to 10 days to compensate for the added plant weight. The moist-scale control system closely correlates water application with depletion of soil moisture in the potted plants.

The cucumber fruits (Fig. 10) were harvested from April 24, 1977 through September, 1977. The total weight of cucumbers harvested for 20 plants was 61,821 g, or the average harvest per plant was 3091.05 g. The average fruit size was 192.59 g.

(2) Plant Production with Hydroponic Culture at NCSU Greenhouse Solar Barn

To facilitate the conversion of the solar greenhouse bulk curing system from the curing mode to the greenhouse mode, a study was initiated to develop a hydroponi plant production system for the structure. The water culture technique was selectec for the following reasons: (1) The three plenums of the structure could be used to contain the nutrient solution for the hydroponic culture, and (2) The nutrient solution could be used for solar energy storage during plant production period. This approach would minimize handling of growth media and containers normally required for greenhouse production.

Three hydroponic set-ups (Fig. 11) were examined to determine the feasibility of the water culture technique in the solar barn. In all three set-ups considered, black plastic was used to cover the tank surface to prevent green algae growth in the nutrient solution. Algae compete for nutrients, reduce the solution acidity, and hence interfere with root development and other plant functions. To provide plant support in a hydroponic water culture, an artificial means of support has to be provided. In the system shown in Fig. 11(a), 1.27 cm thick, wood fiber pads were laid over 1.27 cm hole diameter, perforated sheet-metal set 3.81 cm above the tank bottom. Plant roots started on the pads and then extended into the nutrient solution. Figure 11(b) shows a grid system with 5 cm diameter holes over a wire mesh with 1.27 cm square openings. The 5 cm holes were initially filled with growth media for starting the plant root system. Plastic baskets with side and bottom openings were used in the system shown in Fig. 11(c). Gravel was used in these baskets to provide plant support.

The approach adopted in this study for root aeration was based on fluctuating the nutrient solution in the vicinity of the root system. With determination of appropriate fluctuation ranges and frequencies for each growth stage, it would be possible to correlate the fluctuation data with the plant growth patterns and

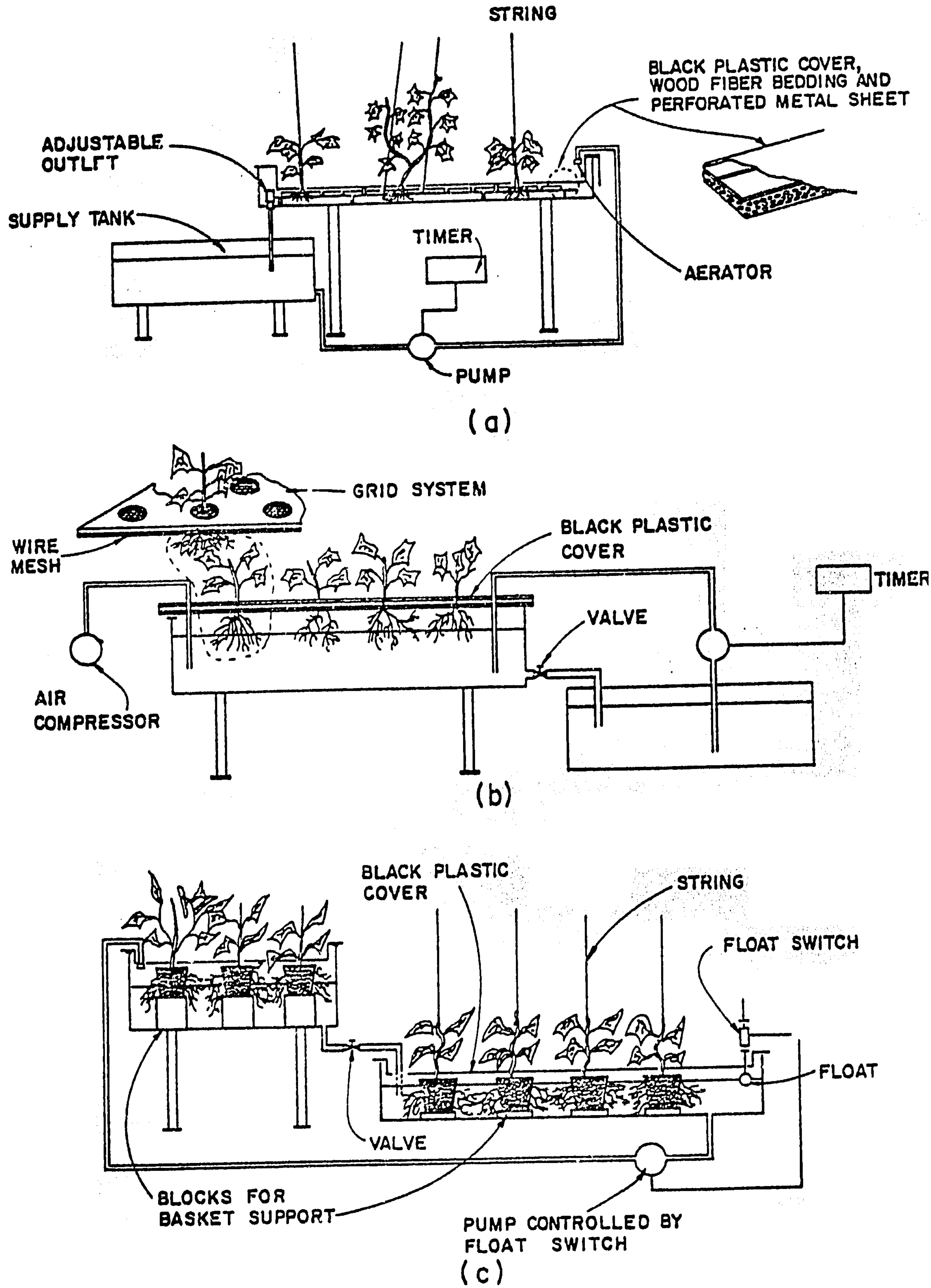


Fig. 11. Hydroponic culture set-ups (a) perforated sheet system, (b) grid system, (c) baskets sy

determine the most suitable aeration conditions for all phases of growth. The aeration process used in all three set-ups was accomplished by continuously fluctuating the nutrient solution between the crown and the extension of the roots The fluctuation cycle comprised two phases: The solution was initially pumped from a lower tank to a certain level in an upper tank, then drained back to the lower tank by gravity. This process was found to be quite acceptable for the cucumber and tomato plants grown in the fiberglass greenhouses. Fluctuation ranges from 1.27 cm to 12.7 cm with half an hour to four hour frequencies were tested in this study.

Commercially available fertilizers such as 20-20-20 Nurish, 7-6-19 Hyponex, 12-6-6 Ortho, as well as the N.C.S.U. Phototron nutrient solution (Downs and Bonaminio 1976) were used for the water culture systems. Daily observations were made for both shoot and root growth. The solution pH level was periodically checked in order to conform with appropriate pH values for tomatoes and cucumbers as recommended by Matlin (1940).

(a) Solar Energy Collection and Storage

As shown in Fig. 12 solar energy is collected and stored in the greenhouse in two ways. First, solar energy is collected by the greenhouse itself and stored in the two outside gravel beds. An auxiliary, reversable gravel fan in the furnace room, Fig. 12(a), circulates air within the greenhouse and gravel beds for energy storage and temperature control. In the second way, the nutrient solution in the plenums acts as a heat sink, collecting its energy from the solar panels mounted on the furnace room and from the internal surroundings of the greenhouse. A reversal of this process occurs during the nighttime. The nutrient solution discharges its stored energy to the panels and the surroundings. The 11 solar energy panels mounted on the furnace room are each 1.2336 m wide by 2.4672 m long with flow passages distributed longitudinally. The total panel area represents about 70 percent of the plenum area which is within the recommended area for solar heating of swimming pools.

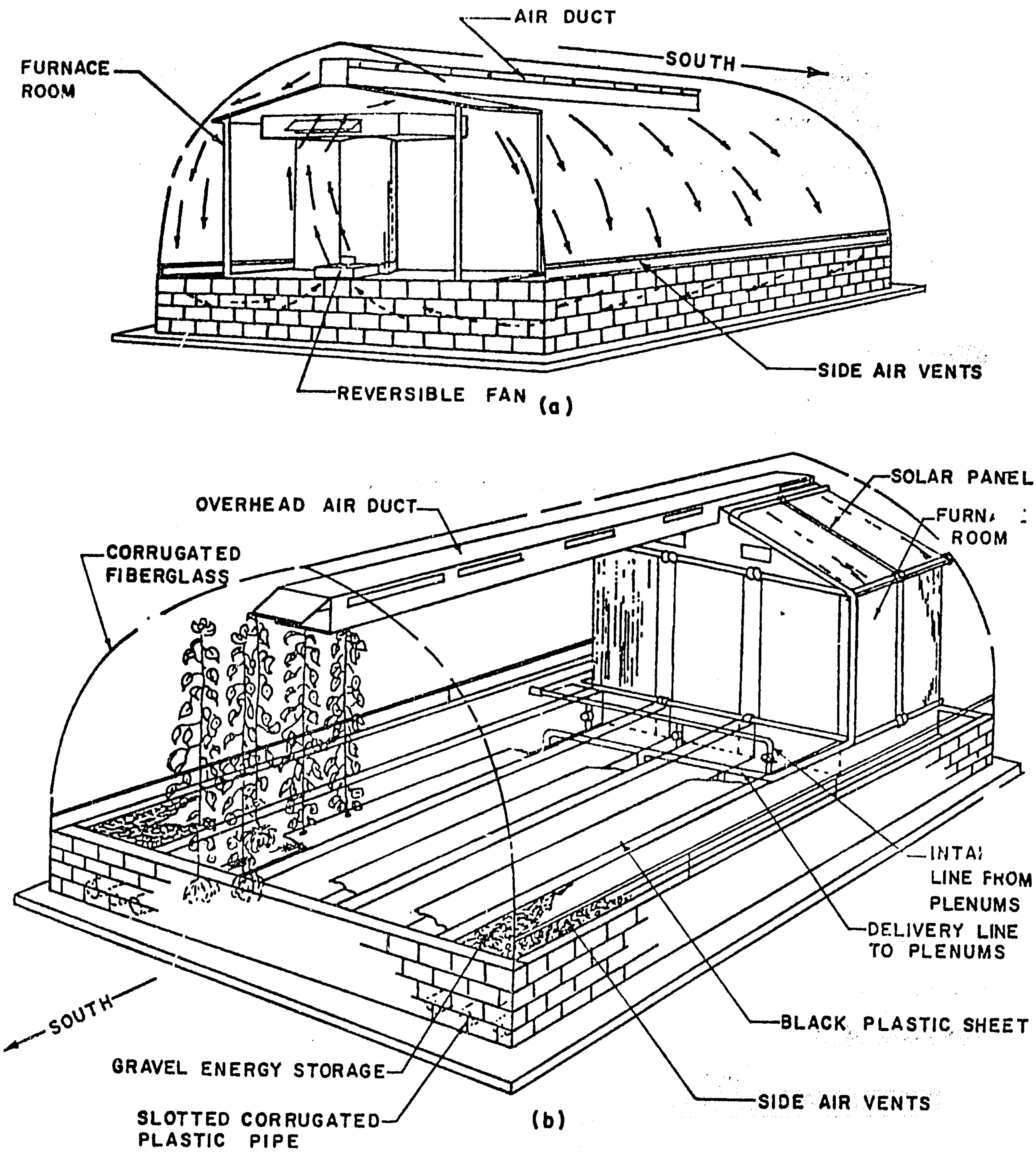


Fig. 12. Greenhouse operation of solar barn (a) A storage system, (b) Hydroponic culture with nutrient solar energy collection and storage system.

Using a modified version of Chandra's solar energy simulation model (1975) the total radiation intensities received on each of the five sides of the furnace room were evaluated for each of the following days: June 21, October 21 and December 21, 1977, assuming 100% of possible sunshine. The results are summarized in Table 3. For the arrangement shown in Fig. 12(b) and for panel specification area of 3.043 m^2, absorptivity of 92%, and collection efficiency of 75%, the percentage ratio of the total radiation received by the panels to solar radiation received by the greenhouse was determined as 10.57%, 13.25% and 14.63%, respectively for each of the three days.

The thermal energy collected by the solar panel system will cause a unit change in temperature of the nutrient solution. This may be defined as:

$$C = \frac{Q}{\Delta T} = \frac{C_p \gamma V}{\Delta T}$$

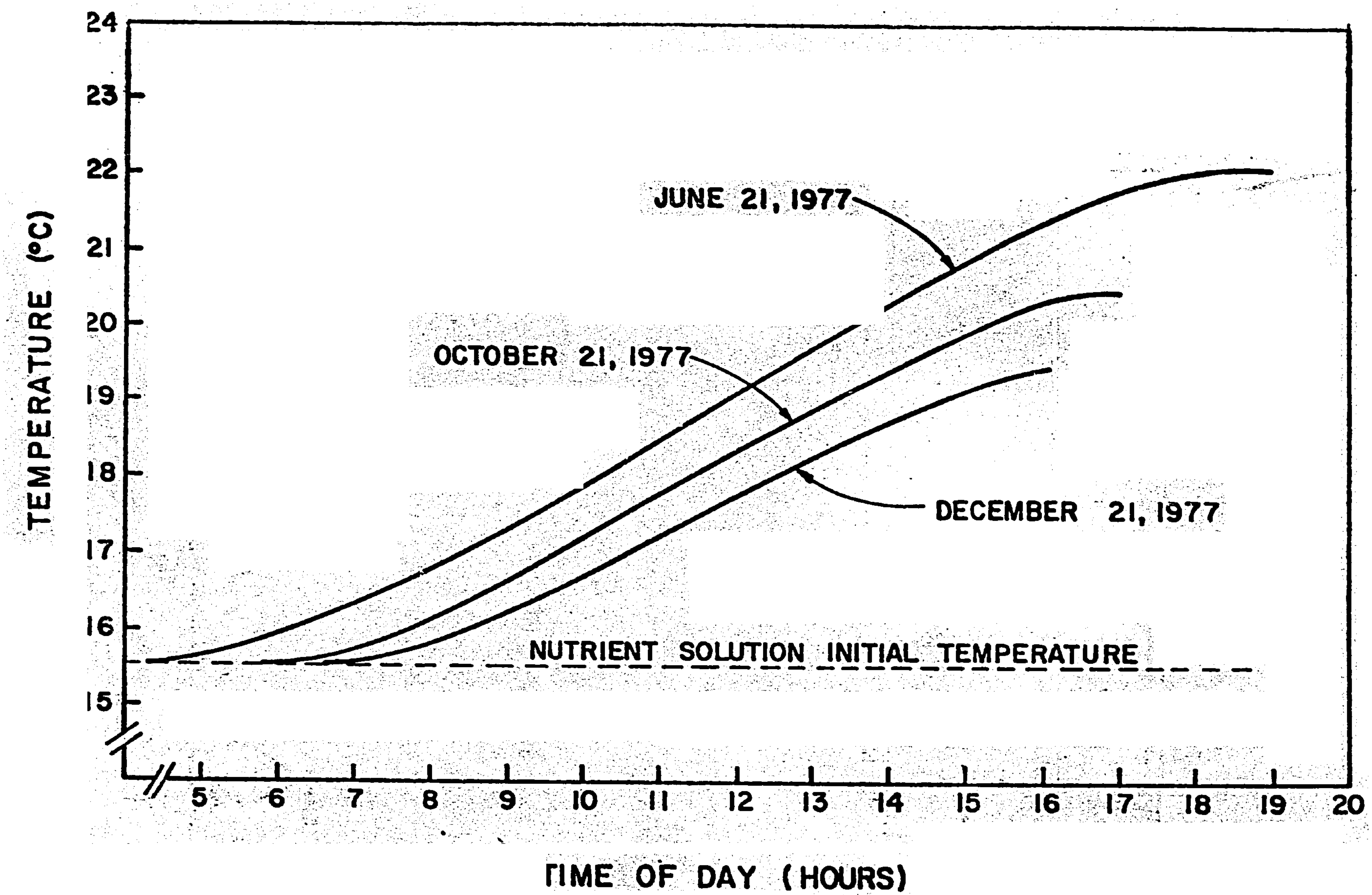
where Q is the thermal energy required for a unit raise of temperature, C_p is the specific heat capacity, γ is the density, ΔT is the temperature rise, and V is the volume of the solution. C_p and γ are assumed constant over the temperature interval considered. For a solution volume of 11.2 m^3 and an initial solution temperature of 15.5°C, the temperature profiles of the nutrient solution as determined by solar heating from the panels alone for the days considered are plotted in Fig. 13. A 4 to 7°C rise in nutrient temperature is achievable from solar energy. The nutrient solution in the plenums is continuously pumped from a plenum through the panels then equally discharged into the three plenums.

(b) Water Level Fluctuation

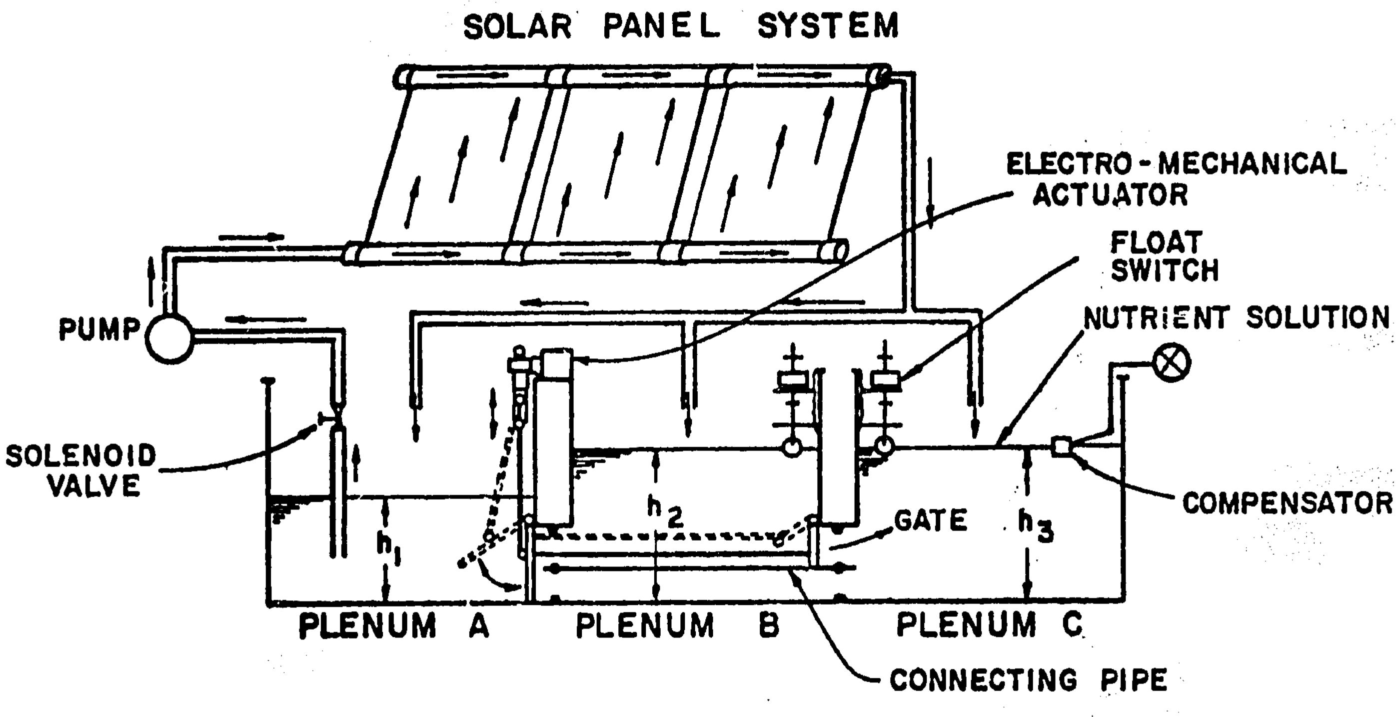
To insure proper plant root aeration, an automatic control system was developed to create the required fluctuation of the nutrient solution in each plenum in a cyclic manner. All plenums were connected together through gates controlled by an electromechanical actuator, as shown in Fig. 14(a). For proper adjustments

Table 3. **Predicted daily total solar energy and radiation intensities (North-South orientation of greenhouse axis with 100% of possible sunshine in Raleigh, N.C.).**

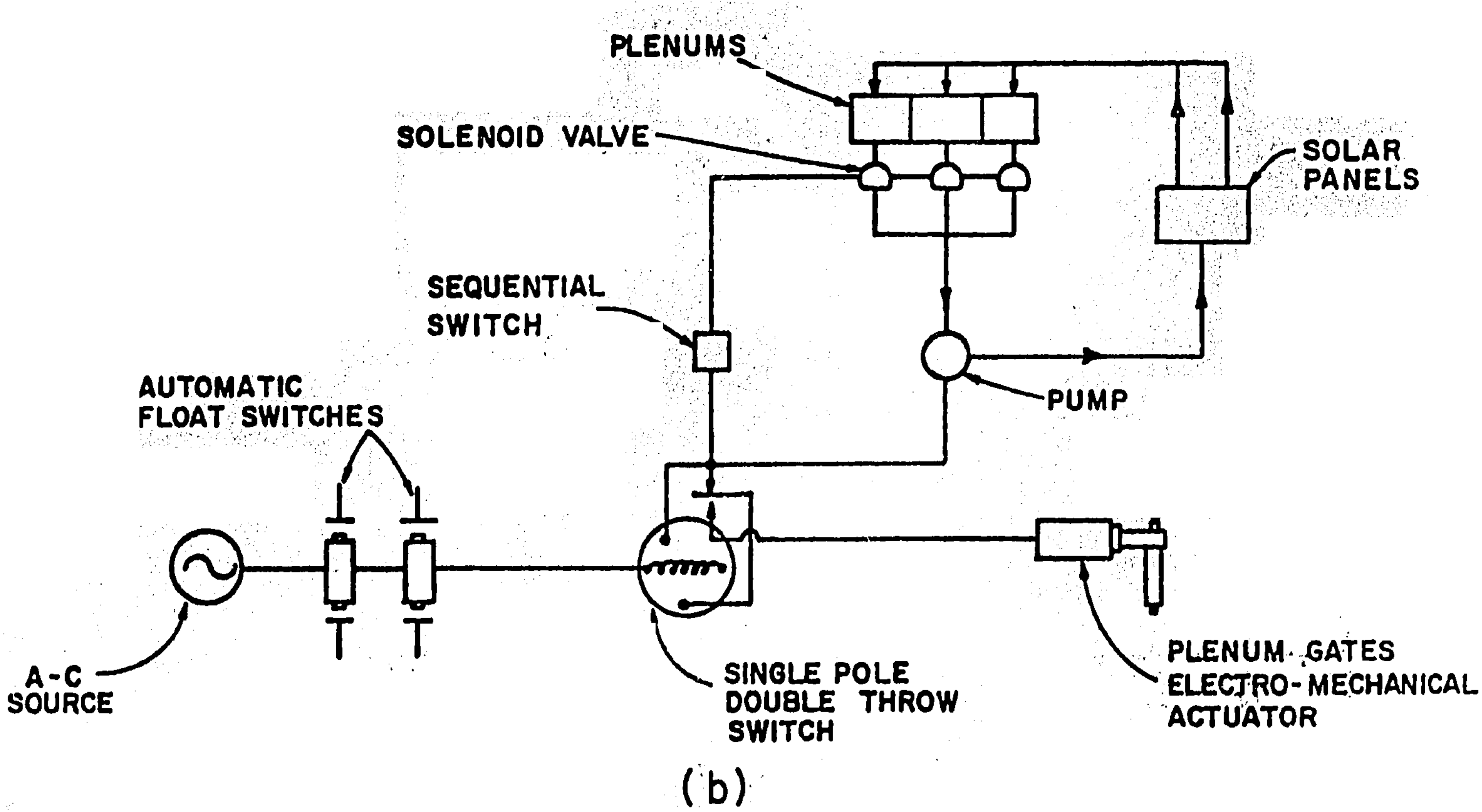
Date of Solar Prediction 1977	South Facing, Vertical Surface (W/m^2)	West (or East) Facing, Vertical Surface (W/m^2)	West (or East) Top Inclined Surface (W/m^2)	North Facing Vertical Surface (W/m^2)	Greenhouse Top Surface (W/m^2)	Solar Energy on Greenhouse (KJ)	Solar Energy on Panels (KJ)	Solar Energy Ratio of Panels to Greenhouse
June 21	1555.7239	3999.9065	8401.9192	1495.8371	13820.3155	197853.2097	20916.4503	10.57%
Oct. 21	5922.0928	2778.6385	4746.3645	301.8911	8392.0737	139175.3272	18446.8464	13.25%
Dec. 21	6591.2255	2080.4804	3233.2370	203.4836	5935.8405	108029.9224	15811.6973	14.63%



g. 13. Water temperature rise due to solar energy.



(a)



(b)

Fig. 14. (a) Water level fluctuation control system (b) control system circuit.

of the solution level in each plenum, two automatic float switches were used. These switches sense the initial and maximum solution levels in the plenums. One sequential switch was used to scan a plenum for pumping, Fig. 14(b).

The full cycle comprises three sequential pumping phases for each plenum. Each phase is composed of two modes of operation: (1) a pumping mode in which a certain amount of the solution is pumped from one plenum through the solar panel system and returned evenly to the three plenums with all plenum gates closed; and (2) a decay mode in which all plenum gates are opened by activating the electromechanical actuator, thereby leveling off the solution in all plenums due to gravity.

To evaluate the performance of this physical system, its dynamic characteristics must be expressed in terms of its various parameters. The development and analysis for describing the dynamics of each pumping phase, as shown in Fig. 14(a), are presented by Huang and Nassar (1977). Computer simulation (CSMP III Structure Statements 1972) was used to determine the total system dynamics for one full cycle. Figure 15 shows the CSMP III graphical plot for one full cycle display, illustrating the dynamics of the water level fluctuations in each plenum -- h_1, h_2 and h_3. The responses for the three phases of the cycle were computed assuming a pump discharge of 0.09464 m^3/min., an initial solution level of 0.2286 m and a gate to plenum area ratio of 0.0006536.

Experimentally, it was found that a fluctuation range of about 2.5 to 4 cm with 90 minute frequency provided suitable aeration for the tomatoes and cucumbers from post transplanting until the flowering stage. Using larger fluctuation ranges or frequency intervals would result in overexposure or drying of the root system. Using smaller ones, the roots would experience drowning. At the flowering stage, however, both tomato and cucumber plant root systems have developed and expanded into the nutrient solution to allow larger fluctuations. It was observed at this stage that a fluctuation range between 5 to 7.5 cm with a frequency between 60 to 90 minutes

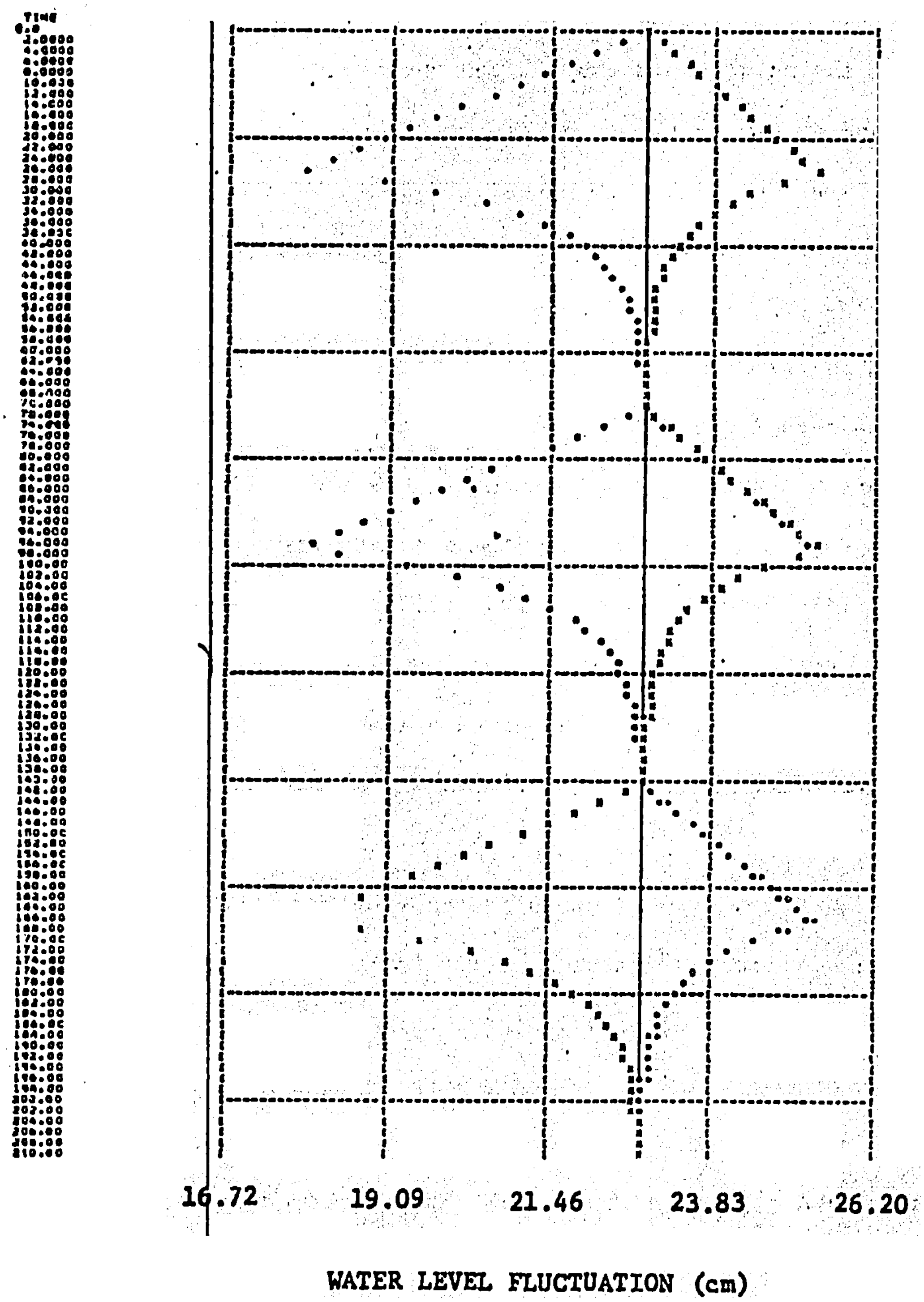


Fig. 15. Computer generated plot of water level fluctuation $h_1(+)$, $h_2(*)$ and $h_3(x)$ for one complete cycle

provided sufficient aeration conditions for all plants. These times are greater than the simulation given in Fig. 15, but pumping rates can be adjusted to achieve these times. The cycle time was frequently changed during the 24 hours to compensate for the drastic temperature variations between day and night.

Figure 16 shows the tomato plants and their well developed root system. A commercially available fertilizer was found to be satisfactory provided the pH of the nutrient solution was frequently adjusted and maintained between 6.5 and 7.0. The pH level was watched daily throughout the experiment and adjusted to the range mentioned.

(3) Hydroponic Plant Production in Central Crops Research Station Solar Barn

An alternative hydroponic set-up is being studied in the Central Crops Research Station solar barn. A schematic of this system is shown in Fig. 17. This trough system sets over a plenum in the solar barn with the storage tank down in the plenum.

The PVC plant troughs with intake and exhaust troughs form a nutrient solution distribution system and a base support for the basketed plants. Nutrient solution is pumped from the storage tank to the intake, distributed to the troughs and allowed to stand. This initial time period in the cycle is 3 to 5 minutes depending upon growth storage. It is shorten for later growth when the root system has developed. After this initial operation, the solution is drained from the trough to the storage tank by gravity; the pipe in the exit trough is lowered by a shutter motor. This entire cycle is controlled by a trip timer; pumping in 3-5 minutes, draining in 5-10 minutes, and waiting 15-20 minutes before the next cycle begins. The total cycle time is 30 minutes.

Tomatoes are germinated and grown in small peat pots prior to being placed in small baskets which are approximately a 7.5 cm cube. These baskets are filled with gravel to provide plant support and then placed in the trough on 45.7 cm centers. Black plastic covers the trough to prevent algae growth.

(a)

(b)

Fig. 16. (a) Hydroponically grown tomato plants and (b) well developed tomato plants root systems

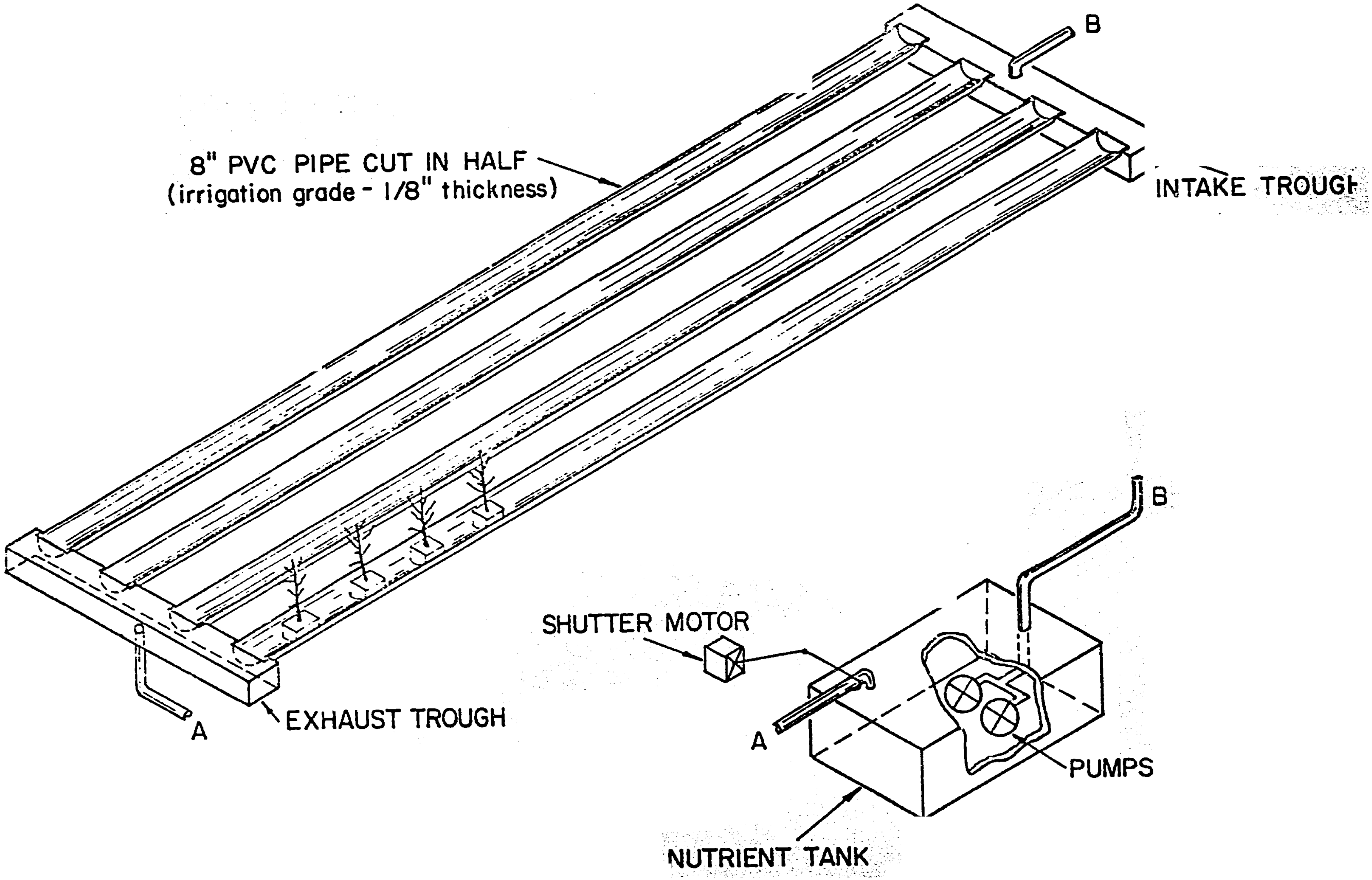


Fig. 17. Hydroponic set-up for cyclic nutrient flood and aeration of root zone.

Environmental conditions are continuously monitored for solution temperature, wet and dry bulb temperature in the greenhouse, air root zone dry bulb temperature of trough, and outside dry bulb temperature. Air temperatures are maintained for daytime between a maximum of 29.5°C and minimum of 22°C. Nighttime temperatures are kept above 18°C.

Plant growth, pH, and solution volume are monitored daily, pH is maintained between 5.5 to 6.5, and total solution volume is kept at 318 liters for the 48 tomato plants being grown. The nutrient solution used is Hoaglands #1 and is analyzed once or twice each week to maintain nutrient levels.

Initial results show excellent plant growth and root development. Data is being taken on flower set and fruit production.

II. GRADUATE STUDENTS IN TOBACCO RELATED PROJECT:

C.G. Bowers, Jr. and A.H. Nassar

III. POST-DOCTORAL FELLOWS IN TOBACCO RELATED PROJECT:

None

IV. PUBLICATIONS:

Huang, B.K. and C.G. Bowers, Jr. 1977 Solar-Energy Utilization Using Greenhouse Bulk Curing and Drying System. Proc. Solar Crop Drying Conf. 117-145.

Huang, B.K. Solar Curing and Drying Structure and Method of Utilizing Solar Energy Associated with Available Solar Radiation in Curing and Drying Various Materials. U.S. Patent 4,069,593 Jan. 24, 1978. United States Patent Office, Washington, D.C.

Huang, B.K. Seed Singulating and Dispensing Apparatus. U.S. Patent 4,072,251 February 7, 1978. United States Patent Office, Washington, D.C.

V. MANUSCRIPTS IN REVIEW:

Behroozi-Lar, M., B.K. Huang, and H.D. Bowen. Circuit Simulation of Soil Temperature Profile.

Huang, B.K. Systems Engineering of Precision Automatic Transplanting.

Huang, B.K., C.F. Abrams, L.L. Coats and C.G. Bowers, Jr. Development of Greenhouse Bulk Drying Systems for Solar Energy Utilization and Plant Production.

VI. PAPERS PRESENTED AT PROFESSIONAL MEETINGS:

Huang, B.K. and A.H. Nassar. Hydroponic Plant Production in Greenhouse Bulk Curing Solar Barn. 1977 ASAE Annual Meeting. Raleigh, N.C. June 26-29, 1977.

Huang, B.K. and C.G. Bowers, Jr. Solar Energy Utilization Using Greenhouse Bulk Curing and Drying System. Solar Crop Drying Conference. Raleigh, N.C June 30, 1977.

Huang, B.K. Dynamic Simulation of Wheel-Vehicles Using Highway-Vehicle-Object Simulation Model. 75th Annual Meeting of Southern Assoc. of Agric. Scientists. Houston, Texas Feb. 5-8, 1978.

Huang, B.K., C.G. Bowers, Jr. and A.H. Nassar. Effective Solar Energy Utilization Using Year-Round Crop Production System. 75th Annual Meeting of Southern Assoc. of Agric. Scientists. Houston, Texas. Feb. 5-8, 1978.

9

SECTION II

Hyman, E.L., Small Holder Tree Farming in the Philippines: a comparision of two credit programmes

30

unasylva

an international journal of forestry and forest industries

vol. 35 no. 139 1983

Mangroves — what are they worth? | 2 | Bo Christensen

Musk-deer | 16

The deer with a fatal scent | 18

Smallholder tree farming in the Philippines | 25

Tree stumps | 32

Books | 40

The World of Forestry | 46

Environment | 50

Unasylva is published quarterly in English, French and Spanish editions. Subscription price: one year, $8.00, payable to the Distribution and Sales Section, FAO, Via delle Terme di Caracalla, 00100 Rome, Italy, or to any of the FAO sales agents listed on the inside back cover.

31

Smallholder tree farming in the Philippines

A comparison of two credit programmes

E.L. Hyman

The increasing awareness of the importance of forestry to the economic, social and environmental well-being of developing countries has prompted international aid agencies and governments to look for new ways to encourage tree farming. One way to do this is to remove the financial constraints caused by lack of credit that make it difficult for small, private landowners to establish tree farms even if the potential profits are large. In conjunction with the Development Bank of the Philippines (DBP), the World Bank selected this market-oriented approach for two tree-farming projects. This analysis is based on a survey of participants and interviews with officials.

The first project involves loan financing of small landowners in the vicinity of the mill of the Paper Industries Corporation of the Philippines (PICOP) for pulpwood production. The second project aims at reducing the fuelwood shortage affecting small tobacco farmers in a different region of the country. Additional components of the second project, not discussed here, are for other purposes and in different parts of the country — wood for industrial charcoal use, leaf meal for fodder, and continued financing of pulpwood tree farming under the PICOP project. The second project also broadens the range of potential beneficiaries to include "kaingineros" — landless slash-and-burn farmers.

Other countries or aid agencies interested in replicating this approach elsewhere should be aware of the experience of these two projects and the differences in the specific factors that affected their partial success in one case and failure in the other. This comparison points out the possible dangers of applying a development model that works in one area to diverse conditions elsewhere, even within the same country. Another key question is whether this approach has any potential for improving the welfare of kaingineros, who differ economically, socially, and culturally from small landowners.

PICOP is the sole domestic producer of newsprint and a major producer of paper in the Philippines. It is one of the few large pulp and paper operations using short-fibre tropical hardwoods as its primary source. After depleting the "red" pulpwood (*Shorea negrosensis* and *Eucalyptus deglupta*) from the concession it received from the Philippines Government, PICOP began in 1968 to enlist nearby private landowners into tree farming by guaranteeing technical assistance and a minimum purchase price for a fast-growing "white" species (*Albizzia falcataria*). However, the programme did not gain momentum until 1972 when PICOP entered into an agreement with DBP for provision of credit to the participants.

I. The PICOP Project

The programme expanded after the World Bank granted US$2 million in financing in 1974. Loans were offered to tree farmers to cover 75 percent of the costs of tree-farm development and maintenance (excluding land acquisition or harvesting costs); the other 25 percent was expected to be provided by the tree farmers in the form of household labour.

The basic goal of the World Bank project is the supply of 284 000 cubic metres of pulpwood to PICOP's mill by 1985, representing about 44 percent of its annual demand. The target requires an estimated 10 400 ha of new tree farms.

A second goal is the generation of additional income for small landowners.

A third goal is to provide wage employment for the substantial number of kaingineros in the project area. However, the landless were not eligible for the loans for tree-farm development under the PICOP project.

E.L. Hyman is an environmental planner with the Office of Technology Assessment of the United States Congress. He wrote this article as a result of work in the Philippines under a grant from the Environment and Policy Institute of the East-West Center, Honolulu, Hawaii. The author would like to acknowledge in particular the assistance of E. Seggay, B. Bareng, R. Joves and C. Sarsadias of the Development Bank of the Philippines.

32

The fourth goal is the improvement of environmental quality by reducing the depletion of forests and maintaining a forest cover on private lands that are supposed to be submarginal or marginal for agriculture.

The project was conceived as a sustained management system for agroforestry based on area control. Under the original plan, smallholders were expected to (*i*) plant 80 percent of the site with *falcataria* over a four-year period; (*ii*) follow a 4 × 4 metre spacing; (*iii*) apply fertilizer twice a year in the first and second years; (*iv*) weed three times a year during the first two years and remove underbrush in subsequent years; (*v*) harvest one-eighth of the total area planted each year, starting in year nine and continuing until year fifteen.

The loan agreement has created an assured market for the wood since PICOP has agreed to purchase all of the pulpwood of the financed tree farms (eight years or older) at a set minimum stumpage price. PICOP is responsible for providing seedlings and technical assistance to participants as well as undertaking some road construction and insect control in the project area. PICOP also pays a small log-loading subsidy and hauling costs for tree farms located within 70 km of the plant.

The project area covers a 100-km radius of the Bislig Bay plant on the island of Mindanao. Five hectares are considered the minimum economically viable tree-farm size for these loans. Loan applicants were required to show either a legal title to the land or proof of legal occupancy. The loans carried a 12 percent interest rate if secured by land collateral or 14 percent if unsecured. Land covered by homestead or free patent leases was not accepted as loan collateral until 1975 when the policy was liberalized due to its limiting effect on recruitment. There is an eight-year grace period for repayment of the loan. Repayment is deducted by PICOP from the harvesting revenues paid to the tree farmer.

Profile of the participants. Of the 3 805 tree farmers recruited by PICOP as of January 1981, over 1 159 (30 percent) received financing from the DBP. Over 62 percent of the financed tree farms are 10 ha or less, while barely 9 percent exceed 26 hectares. The average size is 11 hectares. Practically all the borrowers already owned the land for their tree farm, which eliminated land-tenure disputes as a problem, but meant that the project did not reach the landless poor. Although few of the borrowers are rich, the average reported income of those in the sample (8 700 Philippine pesos) exceeds the national average of 3 179 Philippine pesos and survey respondents generally understate their incomes. (In December 1982 the exchange rate was 9.4 Philippine pesos per US dollar.) The sites have an average distance of 1.3 km to the hauling roads and 58 km to the PICOP mill. Most of the labour for plantation development and harvesting is provided by the households that own the land although there is some hiring of labour at peak periods.

In order of prevalence, the surveyed sites previously had been used for growing food crops, non-food crops, and trees for fruit, firewood, construction wood, or pulpwood. Only 25 percent of these sites previously had been idle or covered with a grass species of little economic use (*Imperata cylindrica*). Thus the use of this land for tree farming has an opportunity cost. For the most part, the project's contribution has been the conversion of land to a higher-value use rather than the expansion of cultivated areas.

Changes in project design during implementation. In the course of implementation, some aspects of the project design have been changed. These changes include the tree-farm development period, agroforestry approach, frequency of fertilizing and weeding, and harvesting schedule.

The original staggered planting scheme has proved impractical. The majority of tree farmers planted their entire area at once for good reasons: lower labour requirements and costs in clearing and planting land and taking care of even-aged tree farms.

In actual fact, the agroforestry approach has never been implemented. Because of a DBP policy against mixing loan purposes, the 20 percent loan portion for financing other crops or livestock has not been provided. Participants who are interested in raising crops or livestock are required to take out separate loans for those purposes. PICOP management and some tree farmers also mentioned that it is better to devote more resources to tree farming because it is more profitable and requires less labour.

Hardly any of the tree farmers applied extra fertilizer to their sites and few weeded as often as recommended,

The PICOP project

Positive features

An assured market exists;

There is good technical assistance;

Recruitment of participants is boosted by extensive publicity;

The basic infrastructure for supply of seedlings and for tree farming in general already exists;

Smallholders can produce pulpwood at low costs;

Land is converted to a higher-valued use.

Negative features

Harvesting costs are not included in the financing;

Harvesting bottle-necks are not foreseen;

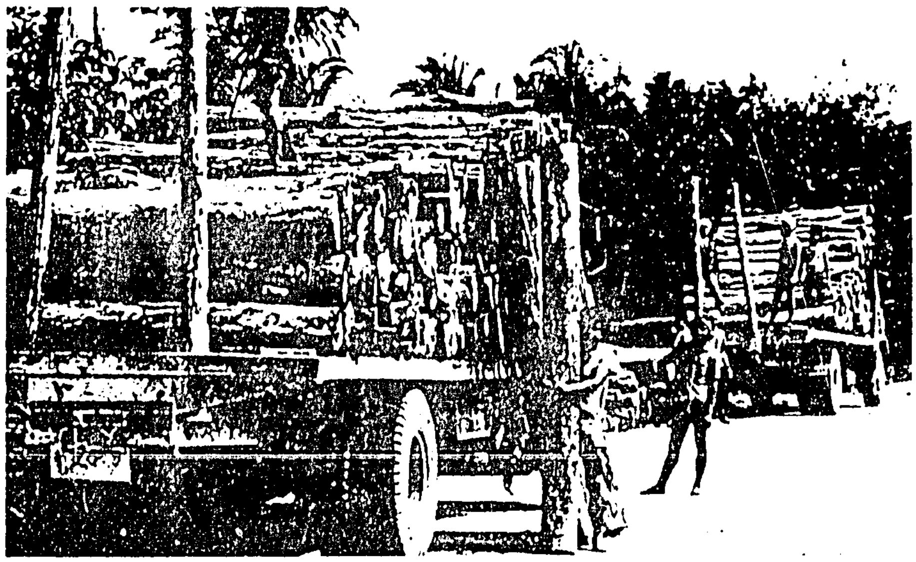
Government price controls limit the mill-gate price of pulpwood;

The species that was selected is prone to typhoon damage;

Due to inflation, the size of the loans granted cannot cover the full costs of tree-farming activities as they were prescribed in the conditions for the loans.

stating that it was not necessary. Not unexpectedly, a number of the inspected tree farms did not appear well-maintained in terms of weeding and brushing.

The most serious deviation from the project design is the cutting cycle, and this has caused serious bottlenecks in harvesting. Since tree farmers plant their entire area at one time, they harvest the entire area at age eight in order to recoup their investments as soon and as simply as possible. Also, the tree farmers have no incentive to let their trees grow longer because PICOP does not provide any premium for older logs, even though fourteen-year-old logs are more valuable since they are suitable for export.



LOADING 8-YEAR-OLD LOGS FOR NEWSPRINT PRODUCTION
PICOP's assured market guarantees success

Aggregate production. The financed tree farms would have produced 3 137 700 solid cubic metres of pulpwood at a per hectare yield of 250 cubic metres or 2 510 200 cubic metres at a yield of 200 cubic metres per hectare if all targets had been achieved. Although the appraisal report for the project (World Bank, 1974) assumes the lower of the two yields, PICOP states that the higher yield is likely for undamaged tree farms. These financed tree farms were expected to yield 58 percent of the wood produced by smallholders for PICOP. Due to a freak typhoon in 1982, the actual production will be lower than predicted.

It is difficult to estimate how much of this land would have been developed for tree farming in the absence of the loans. Since a sizeable portion of the tree farmers did not borrow funds from DBP, credit could not have been the sole factor in recruitment. Yet, average-income tree farmers would find it difficult to afford tree-farm development costs exceeding 10 000 Philippine pesos for five hectares.

The net economic benefits of the project to the tree farmers depend on (*i*) whether tree farmers follow prescribed tree-farming practices or do the more typical amount of fertilizing and weeding; (*ii*) the assumed yield; (*iii*) mortality rates. Following the typical tree-farming practices, the internal rate of return would be 31 percent at high yields (250 solid cubic metres per hectare) or 22 percent at low yields (200 solid cubic metres per hectare). These figures drop to 18 percent and 10 percent respectively if the recommended tree-farming practices are followed. Even when yields are lower at a reduced intensity of maintenance activities, the labour savings outweigh the losses if household labour is valued at the market wage. When labour is shadow-priced to reflect the social costs of tapping under-employed workers, the recommended practices appear more cost-effective. All those estimates assume a 20 percent mortality rate of seedlings in the first year which are replanted in the second year, and no significant subsequent mortality of trees. Since the estimates also are based on the intended submarginality of the sites for agriculture, any returns from previous land uses should be deducted from them.

Of course, the economic benefits of tree farming are very sensitive to the mill-gate price which was 77.25 Philippine pesos per solid metre including the loading subsidy, as of August 1981. Many tree farmers claimed that this was too low in relation to harvesting costs. However, PICOP stated that it is unable to raise the price because of government price controls on the newsprint produced from the pulpwood. Tree farmers are not bound to sell to PICOP if they are offered a higher price and notify PICOP in advance. Dugan (1982) notes potential alternative markets for *falcataria* in Taiwan (China), Japan, the Republic of Korea or the Democratic People's Republic of Korea for non-paper products at roughly triple the price offered by PICOP. At present, the farmers do not have *access* to an organized alternative market in the area. Since tree farmers who decide to sell to PICOP must first obtain harvesting permits from the company, they are anxious to maintain good relations with the company.

One of the most serious problems encountered in the project has been harvesting bottle-necks and cost. There is a shortage of harvesting contractors because lucrative gold panning in the Agusan River has drawn away potential labourers and the cost of harvesting equipment is high. Moreover, since financing does not cover harvesting costs, tree farmers with cash-flow problems are at the mercy of contractors who will accept deferred payments in return for a large share of the surplus value. It is common for harvesting contracts to appropriate 45 percent of the mill-gate price of the pulpwood. This problem was not foreseen in the original design of the project because it was expected that household labour could handle the harvesting of one-eighth of the sites each year over eight years. Many tree farmers also complained about hauling delays. Better arrangements with the private sector for harvesting and hauling are needed.

Another problem is that many tree farmers realize that other crops (in particular, coffee, oil palm, rubber, or another tree — *Leucaena leucocephala*) would be more profitable. Mostly for that reason, only 38 percent of the tree farmers interviewed in 1981 stated that they would continue raising *falcataria* after their harvests. Another 12 percent said that it would depend on the specifics of the agreement or on their own personal circumstances. Those who were willing to participate again cited low labour requirements of *falcataria* (the "lazy man's crop"). Many of these participants lived some distance from their tree farms.

Another critical factor, although unrelated to the design of the project, was the occurrence of a freak typhoon in the Bislig area in 1982. Although *falcataria* is a brittle tree that cannot withstand strong winds, the project area is considered outside the typhoon belt and is typified by even rainfall throughout the year, unlike most of the Philippines. This storm caused damage worth 200 million Philippine pesos to the tree crops of both the smallholders and the PICOP concession. A total of 1.6 million cubic metres of wood was damaged with 1.2 million cubic metres recoverable. However, PICOP plans to accept only 342 000 cubic metres from the smallholders' recoverage in order to recoup 679 500 cubic metres from the company's own concession. As a result, many tree farmers may find it difficult to repay their loans and a local political controversy is brewing (Perez, 1982, p. 10). Since the farmers know that typhoons are rare in the project area, the weather itself should not present a barrier to their future participation in tree farming. However, potential participants may perceive that the company does not act in their interests when a risky situation occurs and current participants may be discouraged by the size of their losses.

Regarding other natural risk factors, only 8 percent of the tree farmers noted problems with pests or diseases, but 64 percent found it hard to protect trees from grazing animals.

The Ilocos project

Positive features	Negative features
A fuelwood need exists both for households and cottage industries;	Local cultural attitudes against incurring debt are not foreseen;
The landless poor are eligible for the project;	Because of inadequate publicity the people who needed this project most are unaware that they are eligible for it;
Leaf-meal fodder is seen as a secondary product;	Hired labour is inadequately supervised;
A nitrogen-fixing species is selected.	The participants are unfamiliar with tree farming and technical assistance or extension services are not provided;
	Soil conditions are unfavourable and soil tests are not carried out;
	Grazing animals are difficult to control;
	Jealousy and political rivalry result in arson;
	The dispersed characteristics of the fuelwood market result in high transactions costs.

One major reason for the successful growing of trees (before the typhoon calamity) was the good job PICOP had done in providing technical assistance and supervision to the tree farmers. This included the hiring of one sector officer per 173 tree farmers to visit the sites, monthly meetings with tree-farmer associations, and a daily radio programme.

Secondly, the existence of an assured market encouraged tree farming. The minimum price guarantee was not sufficient by itself, due to inflation. More important is a willingness to adjust the price as well as the loan size regularly to compensate for inflation. Thirdly, the World Bank project built on the previous experience of DBP and PICOP in the area contributed to the success of tree farming. The basic infrastructure for seedling supply and tree farming already existed in the project area and reliable data were available on the costs and yields of *falcataria* tree farms.

The project was a success from the viewpoint of the company. It reduced the uncertainty in the supply of inputs essential to continued mill operation and was an inexpensive way for PICOP to gain access to pulpwood with low overhead and labour costs. Prior to the controversy following the typhoon, the project also served to improve the company's public relations, especially important because of the prevalence of "New People's Army" agitators in the project area.

From the viewpoint of the participants, the project has been a mixed success, mainly due to the typhoon, the low purchase price, and the harvesting costs. If these issues were to be resolved to the satisfaction of the tree farmers, the project could continue in the future, benefiting both the smallholders and the company.

35

II. The Ilocos project

The Ilocos project is one component of a US$4.4 million loan from the World Bank to the DBP in 1978. Following a variation of the PICOP model, the loan provides for 8 000 ha of fuelwood tree farms in the Ilocos region of northern Luzon (as well as an additional 20 600 ha for other purposes elsewhere in the country which are not discussed in this paper).

The Ilocos region is the production centre for Philippine Virginia Tobacco, which consumes large quantities of wood in flue curing. The average tobacco farmer has less than 0.75 ha and cures all his own tobacco before selling it to private or government trades. Households are also facing increasing scarcities of domestic fuelwood. Ilocos is one of the most deforested regions in the country (Philippine Natural Resources Management Center, 1977).

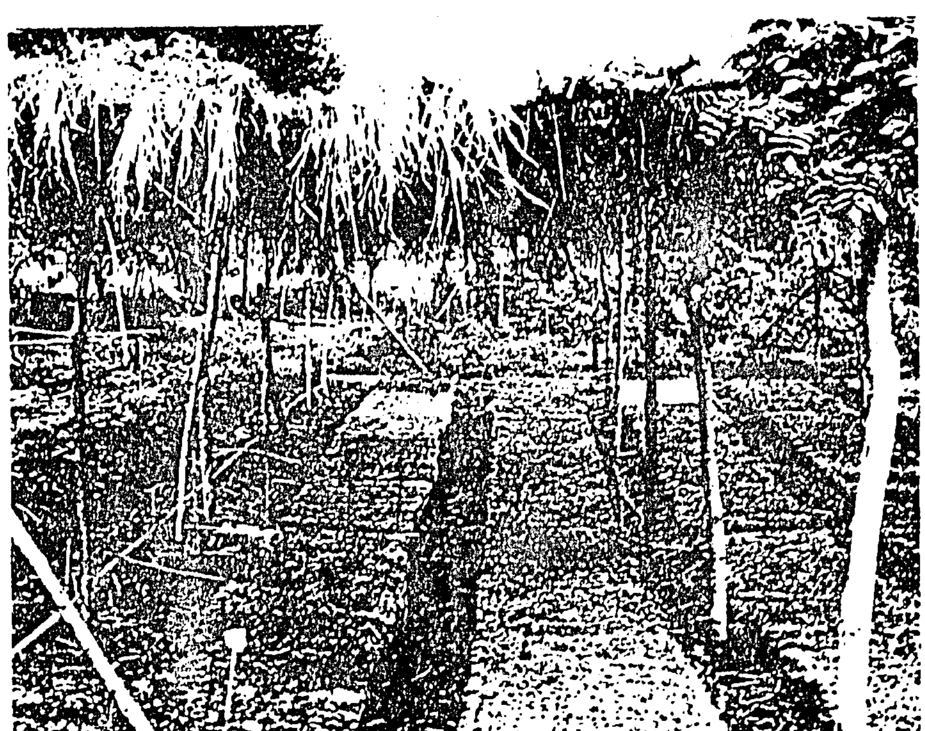
The basic goal of the Ilocos project is the annual supply of 360 000 solid cubic metres of fuelwood on a sustained yield basis. A second goal is to provide additional net income and employment for the rural poor. The project also has an environmental quality goal of restoring the productivity of denuded or idle cogon-grass lands. Lastly, an equity objective limits sites to a maximum of 50 ha with no more than 25 percent of the financed area in sites larger than 25 hectares. In contrast to the PICOP project, landless kaingineros are eligible for this loan programme if they have obtained public land occupancy permits from the Bureau of Forest Development. In 1975, Presidential Decree 705 removed the threat of prosecution of kaingineros who were already in place if they obtained permits for remaining on the land and complied with the forest occupancy management code. In 1982, under the Government's new "Livelihood Programme" the emphasis was changed to "assistance in place" rather than resettlement of kaingineros.

The project provides financing for 90 percent of the costs of tree-farm development (but not land acquisition or harvesting) of a fast-growing leguminous tree, the giant ipil-ipil (*Leucaena leucocephala*). There is a four-year grace period on loan repayments. Loans carried the same interest rates as in the PICOP project until late 1981 when the rate on secured loans was raised to 15 percent. Starting in 1979, chattels on the future production of fuelwood were accepted as collateral instead of land and thus kaingineros became eligible for the lower interest rate on secured loans.

The tree-farming plan is based on "coppice rotations". In other words, the trees would be cut back at age four to a height of 30 cm and allowed to resprout for three- or four-year cutting cycles. The seedlings supplied by the Bureau of Forest Development are planted at a close spacing, 1 × 2 metres. The sites are supposed to be submarginal for agriculture; consequently, tree farmers are expected to apply fertilizer in the first and second years. Weeding and singling are required in the first three years. Fertilizer and extension services are supposed to be supplied to tree farmers by the Bureau of Plant Industry (BPI) in exchange for coupons provided by DBP (World Bank, 1977, Annex 1, p. 4). Unlike the PICOP case, the Ilocos tree farmers do not have a tie-in with a corporate buyer, nor do they receive any marketing assistance from DBP.

All of the participants in the Ilocos region are landowners. Although kaingineros are eligible to take out loans, none have done so. Four-fifths of the participants admit annual household incomes exceeding 6 000 Philippine pesos, while two-thirds are above 10 000 Philippine pesos. Although these people are not rich, they have more than the average income for the region and the nation. The mean size of financed tree farms is 12.5 ha while the median is 8.0 hectares.

The tree-farm sites tend to be in the uplands away from the tobacco-growing centres along the coastal plain and often are distant from the residences of the participants. Before planting ipil-ipil, only 5 percent of the sites had been idle. In order of prevalence, the sites had been used for grazing livestock, wild trees kept for fuelwood



GIANT IPIL-IPIL SEEDLINGS AT ILOCOS PROJECT NURSERY
a fast-growing fuelwood species

or polewood, rice growing, and fruit trees.

Changes in project design during implementation. The main change in project design has been the need to open up the geographic eligibility for the project to the entire country due to the low recruitment rate in the project area.

Within the region, some tree farmers have taken short cuts by relying on direct seeding rather than the transplanting of seedlings and those tree farmers generally failed to produce viable plantations. Few of the tree farmers have done the recommended amount of fertilizing and weeding. In actuality, the coupon system for fertilizer and extension services that was part of the design of the project has never been implemented despite a memorandum of agreement between DBP and BPI.

As of April 1981, only thirty-six participants had signed up for the project, comprising a total of 442 hectares. Slightly more than 30 percent of this area is in sites larger than 25 hectares. From an economic point of view, government plantations would have been a more effective way to meet the wood demands of the tobacco industry and households, but this would not have achieved the social goals of the project.

The reasons for the low participation rate in this project include regional cultural attitudes toward debts, insufficient publicity, competition from other government tree-farming programmes, perceptions regarding land collateral requirements, and tree-farm size restrictions.

Landed Ilokano farmers dislike borrowing money from banks for any purpose. Instead, they rely on their own relatively high rates of savings and the equity of relatives. In some cases when the younger generation is willing to take out a loan, older members of the household who control the land titles are not.

Furthermore, kaingineros are subsistence farmers unaccustomed to a cash economy. Thus, it is not surprising that they are wary of loans that may tie them to the Government and could land them in jail if they fail to repay them. In addition to covering the labour and material costs of tree-farm development, these people still have to meet their daily needs for food and do not have any savings that allow them to take risks.

One of the applicants, a journalist, blamed inadequate publicity as a cause of the low project recruitment rate. Most of the applicants first learned about the project by word-of-mouth through other participants or friends and relatives rather than radio announcements, newspaper articles, advertisements, or public meetings. A broader-based campaign might have sparked the interest of more than a few élite. Nor was there any special outreach programme for kaingineros who live in remote areas and have little contact with the media. Kaingineros need to be reached through face-to-face communication with people they have learned to trust over a period of time.

Some of the demand for tree farming in the region has been deflected by other government programmes. For example, the Bureau of Forest Development leases a small number of one-hectare plots of public land for agroforestry, but does not offer loans.

The public's perception of land collateral requirements may also have been a barrier despite a much more liberal collateral policy for this project than for the PICOP project. In fact, DBP tried to help arrange public land leases for potential participants, but the Bureau of Forest Development did not want to deal with small individual leases which it defined as those below 1 000 ha and it wanted tree farmers to deposit 20 percent of the leased area as collateral.

Restrictions on maximum tree-farm size slowed the achievement of tree-planting goals. Malliari (1981) notes that many Filipinos imitated successful examples of large landholders. This view is borne out by the number of participants who cited one large tree farmer as their source of information on the project. Because smallholders are risk-averse and short of capital they want to see that an undertaking is economically worthwhile.

The economic analysis of this project is very sensitive to the yield assumption (Hyman, in press (b)). The base yield of 123 solid cubic metres per hectare is taken from standard tables for giant ipil-ipil on site class 13 in the Philippines (Bonita, 1981). The "medium yield" estimate further assumes 100 percent replacement of dead seedlings. The "low yield" estimate accounts for a net seedling mortality of 30 percent. Economic analysis is also sensitive to the wage rate since most of the costs are for labour. There are some variations in wages paid for casual, daily labour. Including an allowance for food, common wage rates ranged from 13 to 18 Philippine pesos per person per day. At the "medium yield", the internal rate of return to the tree farmers exceeds 18 percent at both wage rates. Yet, at the "low yield" which better approximates reality, the rate of return exceeds 14 percent. However, the opportunity costs of converting the land to tree farming should be deducted from these figures.

The tree mortality rates of the Ilocos participants have been quite high — about half the tree farmers estimated mortality at more than 40 percent. This poor performance has resulted from unfavourable natural conditions, lack of tree-farming knowledge, bad labour relations between tree-farm workers and absentee owners, grazing animals, the dispersed nature of the fuelwood market, fires, and infrastructure underdevelopment.

In general, the soils in the Ilocos region are poor; they are rocky and acidic. Although it is well established that low soil pH greatly retards the growth of ipil-ipil, there has been an over-reliance on this species in all forestry programmes in the Philippines (Hyman, in press (a)). The soils are not tested on the sites before the loans are granted and repeated applications of lime to increase pH would be expensive due to the lack of commercial sources in the region and extra labour involved.

Climate has also been a problem. The Ilocos region experiences a long dry season of seven to eight months followed by a period of intense monsoons and destructive typhoons.

Most of the participants had no previous experience with forestry and two-thirds of them have never been visited by a forester or extension agent offering tree-farming advice. The responsible government agencies were lax in this regard.

Many of the participants live in urban areas distant from their tree farms and entrust management to a caretaker. In some cases, that worked out well, but often it led to inadequate supervision of badly motivated and poorly paid hired labourers.

Nearly 44 percent of the participants have found it hard to protect trees from grazing animals (carabaos, goats and cows) or rodents.

The demand certainly exists for the output relative to the existing market in the region, but the location of some of the tree farms is remote and the transaction costs of sales to small tobacco farmers and individual households would be high. Tree farmers might find it inconvenient to locate small buyers. In addition, wood is bulky and hence expensive to transport.

Five of the tree farms have been totally destroyed by fires. Arson was suspected in those cases for motives of economic jealousy or local social or political conflicts.

About 17 percent of the tree farmers criticized DBP branch officials as "uncooperative" or "unhelpful", citing rigidity in collateral requirements, tight availability schedules or too many demands before loan releases, and too rapid a willingness to cancel subsequent loan releases or declare borrowers in default and subject to immediate repayment. Most of the low evaluations of DBP were made by unsuccessful tree farmers.

III. Financing smallholder tree farming

Some general principles for the financing of smallholder tree farming can be drawn from these two projects.

Under the right conditions, credit can be a useful lever for encouraging effective tree farming by small landowners. However, this requires paying close attention to local cultural factors and the complementary inputs and services provided to borrowers. Otherwise, such a project will be doomed to low participation rates or high failure and default rates. It is also questionable whether loans at subsidized, but nevertheless, high interest rates can provide sufficient incentives for impoverished, landless farmers who are unable to bear risks.

One of the important conditions for success in smallholder tree farming is to have a cooperating institution that is active in supporting the project and marketing the output. In certain countries, a responsible corporation with a direct economic stake in the success of the tree farmers may be necessary. However, an active government agency with sufficient resources and a decentralized organization can be very successful as the experience in the Republic of Korea (Gregersen, 1982) and Gujarat in India (Khanchandani, 1981) demonstrates. In Scandinavia, some paper companies work through tree-farmer cooperatives as a way of organizing the farmers for their economic protection and as a means of turning them into better tree farmers. The success of cooperatives depends on cultural values and their political acceptability. Due to the orientation toward the family, cooperatives have generally been unsuccessful in the Philippines. The availability of technical assistance is critical where most participants are new to tree farming.

In addition, wood-pricing policies should be fair to provide incentives for participation. Arrangements should also be made for harvesting and transportation of wood if the existing infrastructure is underdeveloped or if the private sector is exploitative. Extensive publicity campaigns will be necessary to ensure participation and should include direct contact with the rural poor in remote areas. Project designs may also have to be more flexible if landless people are to be reached rather than the more well-to-do educated residents of villages or provincial towns.

Natural factors may pose constraints to tree farming although their effects can be minimized by matching the proper tree to the requirements of the site. There is no single "miracle tree" for all purposes. Lastly, cost-effective protection against grazing and fires can be critical in ensuring the success of this type of programme. ■

References

BONITA, M. Timber management and 1981 harvesting criteria for mass selection of fuelwood species. In *Proceedings of a conference on fixing criteria for mass selection of fuelwood species.* Honolulu, East-West Center Resource Systems Inst.

CRUCILLO, D. (Central Office, DBP). 1981 Pers. comm.

DUGAN, P. (Forester, US Agency for 1982 International Development, Manila). Pers. comm.

GREGERSEN, H. *Village forestry development in the Republic of Korea: a case study.* 1982 Rome, FAO. Report GCP/INT/347/SWE.

HYMAN, E. Forestry administration and policies in the Philippines. *Environmental Management.* [In press (a)]

HYMAN, E. Loan financing of smallholder treefarming for fuelwood production in the Province of Ilocos Norte, Philippines. *Agroforestry Systems.* [In press (b)]

KHANCHANDANI, M. Establishment of 1981 forest energy resource base in Gujarat. *The Indian Forester,* 107: 777-784.

MALLIARI, A. (Laoag Branch, DBP). 1981 Pers. comm.

PEREZ, R. Falcata growers urge PICOP 1982 to buy damaged trees. *Philippine Daily Express* (11 May 1982): 10.

PHILIPPINE NATURAL RESOURCES MAN-1977 AGEMENT CENTER. *Forest inventory of the Philippines using landsat multispectral scanner digital data.* Quezon City, Govt of the Philippines.

WORLD BANK. *Philippines: appraisal of* 1974 *a smallholder treefarming project, loan 998-PH.* Washington, D.C., World Bank.

WORLD BANK. *Philippines: appraisal of* 1977 *a smallholder treefarming project, loan 1506-PH.* Washington, D.C., World Bank.

SECTION III

Vicente-Chandler, J., F. Abruna and S. Silva.
Effect of Shade Trees on Yields of Five Crops in
the Humid Mountain Region of Puerto Rico.

VOL. L JULY 1966 NO. 3

THE JOURNAL OF AGRICULTURE
of the
UNIVERSITY OF PUERTO RICO

RESPONSE OF FILLER TOBACCO CROP TO DIFFERENT PLANTING DATES
A. Acosta Matienzo, C. González Molina, and G. Samuels 161

STABILITY OF SOIL AGGREGATES TREATED WITH DISTILLERY SLOPS OR BLACKSTRAP MOLASSES...*Raúl Pérez Escolar* 174

FUNGOUS DISEASES OF PAPAYA IN THE U.S. VIRGIN ISLANDS
Julio Bird, Arnold Krochmal, George Zentmyer, and José Adsuar 188

EFFECTS OF CHLORETHANOL AND THIOUREA ON THE GERMINATION AND RELATIVE YIELD OF THE YAM (*DIOSCOREA ALATA* L.)
Héctor R. Cibes and José Adsuar 201

RECLAMATION OF A SALINE-SODIC SOIL BY USE OF MOLASSES AND DISTILLERY SLOPS...*Raúl Pérez Escolar* 209

EFFECT OF SHADE TREES ON YIELDS OF FIVE CROPS IN THE HUMID MOUNTAIN REGION OF PUERTO RICO
José Vicente-Chandler, Fernando Abruña, and Servando Silva 218

EFFECTS OF YIELDS, SHADE, AND VARIETIES ON SIZE OF COFFEE BEANS
Fernando Abruña, Servando Silva, and José Vicente-Chandler 226

POLLEN FERTILITY AS A MEANS OF SELECTING MALE-PARENT PLANTS IN PINEAPPLE BREEDING ....*Oscar D. Ramírez* 231

EFFECTS OF DIFFERENT LEVELS OF FOUR HERBICIDES USED AS PREEMERGENT TREATMENT ON THE ESTABLISHMENT OF CENTIPEDE LAWN GRASS (*ERIMOCHLOA OPHIUROIDES*).................*S. J. Rodríguez and Angel R. Feliberty* 241

CHROMOSOME NUMBER OF CUBIU, *SOLANUM SESSILIFLORUM*, DUNAL, A SOLANACEOUS FRUIT OF THE BRAZILIAN AMAZONAS...............*Caridad M. Purcell* 247

RESEARCH NOTE:
An Inexpensive Laboratory Method For Cassava-Starch Extraction
Arnold Krochmal and Bárbara Kilbride 252

PUBLISHED BY
UNIVERSITY OF PUERTO RICO
AGRICULTURAL EXPERIMENT STATION
RÍO PIEDRAS, P. R. 00928

Second-class postage paid at San Juan, Puerto Rico 00900.

Effect of Shade Trees on Yields of Five Crops in the Humid Mountain Region of Puerto Rico[1]

José Vicente-Chandler, Fernando Abruña, and Servando Silva[2]

INTRODUCTION

With the exception of coffee, cacao, and tea, there is little information available on the effect of shade trees on tropical crops. This information could be useful in many ways. Tropical forests thinned in preparation for planting shade-grown coffee, cacao, or tea, could be planted to shade-tolerant crops while the main crop comes into production. Even the classical "conuco" system of farming, in which a plot of land is cleared of trees, burned over, and cropped until soil fertility is depleted, could be improved through the use of shade-tolerant food crops. Instead of clearing the land completely, desirable trees could be left to reseed the area after the land is abandoned, thus improving the forests on a long-term basis while helping to feed the rapidly increasing tropical population. Information on shade tolerance is also important in developing economic systems of intercropping.

In Puerto Rico, thousands of acres of steep, shaded coffee plantings are being abandoned as production shifts to smaller, higher yielding, sun-grown plantings. If shade-tolerant crops could be grown under the existing shade trees, economic production could be combined with essential soil protection on these steep lands.

This paper presents the results of a study on the effects of shade trees on yields of taniers, corn, plantains, tobacco, and bananas under typical conditions in the Humid Mountain Region of Puerto Rico.

MATERIALS AND METHODS

The experiment was conducted during 1963-64 near Jayuya, on a site 2,500 feet above sea level and exposed to the trade winds (NNE. exposure). Annual rainfall was about 73 inches, fairly well distributed throughout the year, except for a marked dry season from January through March. Mean annual temperature was about 72° F., with maximum variations

[1] This paper presents the results of an experiment carried out cooperatively by the Soil and Water Conservation Research Division, Agricultural Research Service, USDA, and the Agricultural Experiment Station of the University of Puerto Rico. Appreciation is expressed to Mr. Luis A. Becerra, on whose farm near Jayuya the field work was conducted.

[2] Project Supervisor, Soil Scientist, and Agricultural Technician, respectively, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, stationed at the Agricultural Experiment Station of the University of Puerto Rico, Río Piedras, P.R.

41

ranging from 55° to 82° F. A thick growth of trees and shrubs covered the land, formerly in shaded coffee but essentially abandoned during the last decade.

The soil is Los Guineos clay on a 40-percent slope with the following characteristics in the surface 6 inches:

pH		4.8
Organic matter	Percent	7.4
Nitrogen	Do.	.3
Cation-exchange capacity	Meq./100 gm.	21.5
Exchangeable calcium	Meq./100 gm.	3.8
Exchangeable magnesium	Meq./100 gm.	1.3
Exchangeable potassium	Meq./150 gm.	.5
Exchangeable manganese	P.p.m.	46
Exchangeable aluminum	Do.	121
Bulk density		1.1
Pores drained at ⅓ atm. of pressure	Percent	15.5

All vegetation was removed from the unshaded plots, but sufficient trees—mostly guavas (*Inga inga* (L)) were left in the shaded plots to provide about 50-percent shade which was maintained by periodic pruning. Individual plots were 60 x 20 feet with 40-foot borders between plots. The treatments were replicated three times with each crop in a randomized block design.

All crops were planted in the undisturbed soil since Vicente-Chandler *et al.*[3] have shown that it is not necessary to till these soils. The crops were managed according to the best practices, and pests and diseases were controlled with the exception of the Sigatoka disease, a leaf spot caused by *Cercospora musae*, of bananas and plantains. This disease was not controlled, since spraying is not practiced at present in Puerto Rico because of the difficulty of carrying out this operation on the steep mountain lands at the required 10- to 15-day interval. Table 1 provides information on the crops tested.

Crop yields were determined for each plot. Average sunlight intensity in each plot was determined at noon on a clear day in July 1964, by making 10 measurements at random in each plot, using a Weston Model 603[4] sunlight meter.

[3] Vicente-Chandler, J., Caro-Costas, R., and Boneta, E.G., High Crop Yields Produced with or without Tillage on Three Typical soils of the Humid Mountain Region of Puerto Rico, *J. Agr. Univ. P.R.*, *50*(2): 146-50, 1966.

[4] Trade names and company names are included in this publication to provide information to the reader, and do not imply endorsement of the product listed by the U.S. Department of Agriculture or the Agricultural Experiment Station of the University of Puerto Rico, nor any claim for superiority over any other concerns or products.

RESULTS AND DISCUSSION

SUNLIGHT INTENSITIES

The following tabulation shows the foot-candles of light in the shaded plots: *i.e.*, Measurements were made immediately above the crop:

Replicate	*Average*	*Maximum variations within plots*
A	5,460	(2,400—10,400)
B	7,070	(2,400—11,400)
C	6,430	(2,100—10,800)
Average	6,320	

Sunlight intensity in the shaded plots was about half that in the unshaded plots (11,700 ft.-c.) and varied greatly from one location to another in the same plot.

TABLE 1.—*Information on crops tested in this investigation*

Crop	Variety	Plants per acre	Fertilization
		Number	*Lb./acre/crop*
Taniers	Morada	7,260 (3′ x 2′)	1 ton 10-6-20
Corn	Mayorbela	14,520 (3′ x 1′)	½ ton 14-4-10
Plantains	Maricongo	726 (6′ x 10′)	1 ton 10-6-20
Tobacco	Olor	9,680 (3′ x 1½′)	¾ ton 6-9-10
Bananas	Cavendish (Monte-Cristo variety)	622 (7′ x 10′) and 871 (5′ x 10′)	1 ton 12-6-16

TOBACCO

The following tabulation shows the effect of shade trees on pounds of cured tobacco produced per acre:

Replicate	*Unshaded*	*Shaded*
A	1,771	1,644
B	2,119	1,656
C	1,195	1,310
Average	1,695	1,537

Similar high yields of cured tobacco were produced both in full sunlight and under shade trees. Shading did not affect appearance of the tobacco, which was all graded CLF or X1F, *i.e.*, of highest quality. This excellent crop of tobacco was grown during the off-season (March—July).

TANIERS

The following tabulation shows the effect of shade trees on pounds of taniers produced per acre:

43

Replicate	*Unshaded*	*Shaded*
A	13,100	2,400
B	12,500	3,000
C	7,800	3,500
Average	11,133	2,966

Shade trees reduced tanier yields to less than one-third of those produced in full sunlight.

CORN

The following tabulation shows the effect of shade trees on pounds of fresh corn on the cob produced per acre:

Replicate	*Unshaded*	*Shaded*
A	4,270	1,730
B	4,390	—
C	4,740	2,230
Average	4,470	1,980

Corn yields were severely decreased when grown under shade trees.

PLANTAINS

The following tabulation shows the effect of shade trees on pounds of plantains produced per acre:

Replicate	*Unshaded*	*Shaded*
A	16,520	14,350
B	16,870	15,540
C	15,190	11,900
Average	16,193	13,930
Fruits per acre	25,422	22,342
Fruits per bunch	36	32
Weight of fruit (pounds)	.64	.64

Shade trees slightly depressed plantain yields by decreasing the number of fruit per bunch. Fruit size was not affected by shading.

The following tabulation shows that shade trees almost prevented the development of leaf spot (Sigatoka) disease on 7-month-old plantains:

Replicate	*Percentage of heavily infected leaves*	
	Unshaded	*Shaded*
A	17.7	0
B	22.1	1.8
C	22.3	0
Average	20.7	0.60

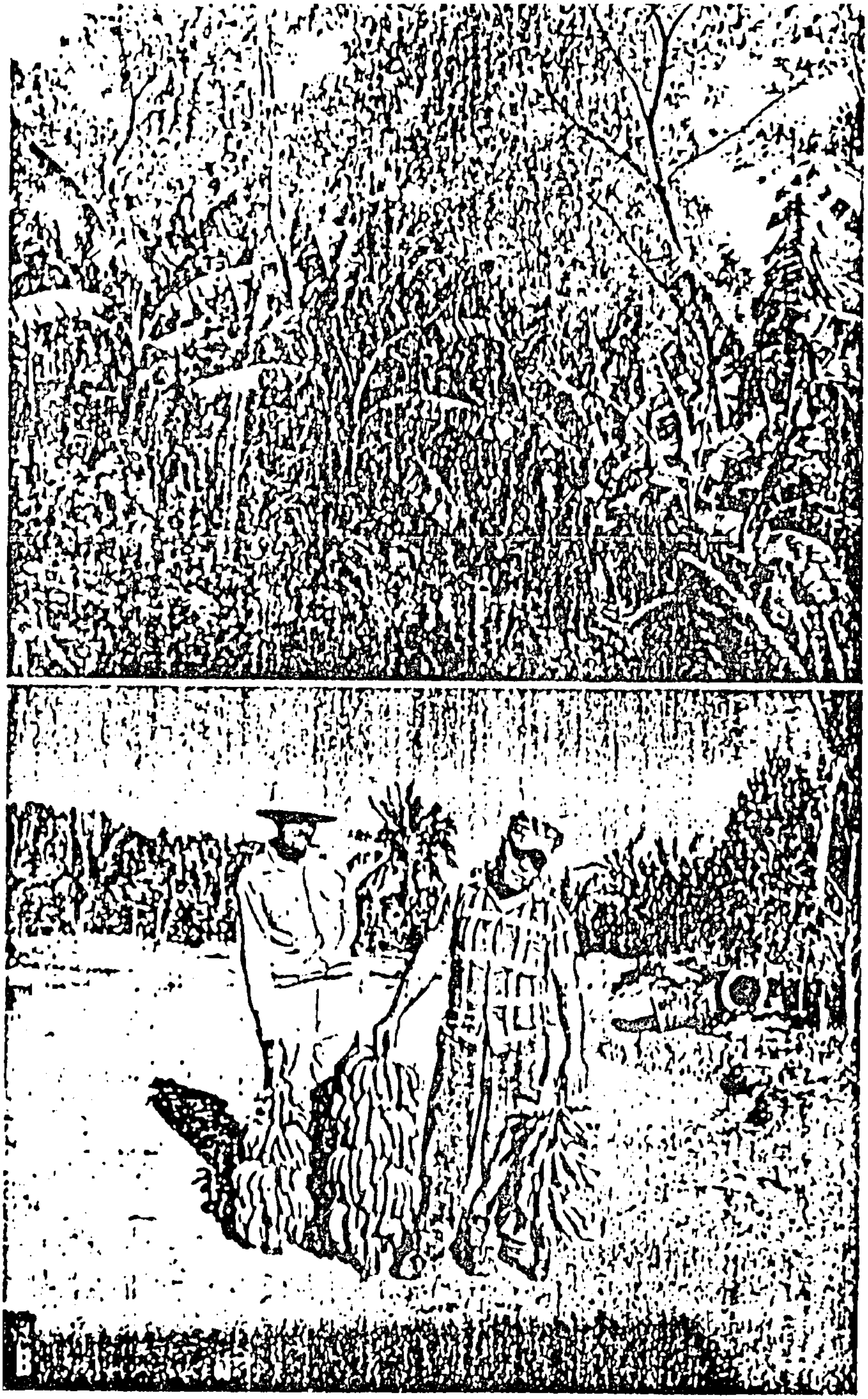


FIG. 1. A, Well-fertilized, healthy bananas growing in partial shade provided by "guava" (*Inga inga* (L.)) trees. Note excellent protection afforded this steep soil by the shade and banana trees and by the close-growing ground cover. B, Shaded bananas (center bunch) yielded 12 tons of marketable fruit per acre compared to only $6\frac{1}{2}$ tons, produced in full sunlight where damage by leaf spot often prevented full development of the fruit (see left and right bunches).

BANANAS

Increasing population from 600 to 800 plants per acre increased yields of marketable bananas by about 5,000 pounds per acre, both in full sunlight and under shade trees (table 2). Bunch-size was not appreciably affected by population.

Twice as high yields of marketable bananas were produced under shade trees (fig. 1,A) than in full sunlight (table 1). Yields of over 12 tons of fruit produced with 800 plants per acre under shade trees are considered excellent.

The higher yields produced under shade resulted from the production of

TABLE 2.—*The effect of shade trees and plant population on pounds per acre of bananas produced at Jayuya*

Replicate	Unshaded		Shaded	
	600 plants per acre[1]	800 plants per acre[1]	600 plants per acre	800 plants per acre
A	9,360 (14,760)	12,480 (18,320)	21,060	23,200
B	7,440 (12,480)	12,160 (16,490)	16,800	21,160
C	8,880 (13,920)	14,400 (19,410)	20,520	27,360
Average	8,560 (13,720)	13,013 (18,080)	19,460	21,907
Average weight per bunch, pounds	14.3 (22.9)	16.3 (22.6)	32.4	31.1
Average hands per bunch, number	3.6 (6.3)	4.1 (6.3)	7.1	7.1

[1] Figures in parentheses are for total yields. All bananas produced under shade were marketable.

heavier bunches due to better development of the fruit (fig. 1,B). This, in turn, is explained by the lower incidence of leaf spot as shown in the following tabulation giving the percentage of banana leaves severely damaged by leaf spot when the planting was 7 months old:

Replicate	*Unshaded*	*Shaded*
A	51.0	16.1
B	50.0	26.2
C	47.7	32.7
Average	49.4	25.0

Leaf spot damage increased so rapidly as the plants matured, that many of the sun-grown plants had no healthy leaves at all and were incapable of developing the lower hands (fig. 1,B). The attenuating effect of the shade trees on leaf spot is apparently related to reduced dew formation on the shaded banana leaves.

The shaded bananas matured somewhat later and at a more uniform rate than those growing in full sunlight. Only 38 percent of the shaded bananas ere harvested during the sixteenth and seventeenth months after planting, compared to 65 percent of those grown in full sunlight. The high elevation accounts for the rather late maturity in both cases.

The production of high yields of bananas under shade trees, in locations where spraying for control of leaf spot is impractical because of steepness of the land, small size of holdings, lack of trained personnel, etc., has important implications. Under such conditions, the production of bananas under shade trees could be a practical and profitable enterprise. In some cases it might be possible to improve tropical forests by thinning to leave only desirable trees to reseed the area, and planting bananas as a temporary cash or food crop. In Puerto Rico's Mountain Region, thousands of acres of shaded coffee plantations are being abandoned as production shifts to smaller, higher yielding, intensively managed, sun-grown plantings. There are few alternative uses for this land, much of which, with shade trees extant, could be put into profitable, stable production by planting to bananas. Cost of bringing an intensively managed, lightly shaded banana plantation into production over a 1-year period is estimated at $200 per acre, with a net profit of $100 to $200 per acre yearly thereafter.

This system of producing bananas allows for excellent erosion control in the steep mountains which are the main source of the Island's limited water supply. Part of the tree cover is retained, the bananas are planted directly in the undisturbed soil and the natural ground cover is maintained. Since bananas bear for many years the soil is protected continuously by the combination of ground cover, banana and shade trees (fig. 1,A).

SUMMARY

The effects of trees, providing about 50 percent of shade, on yields of tobacco, corn, taniers, plantains, and bananas were determined in the Mountain Region of Puerto Rico, with annual rainfall of about 73 inches and a mean annual temperature of 72° F.

Shade trees severely reduced yields of taniers and corn, reduced those of plantains only slightly, and did not affect yields of tobacco.

Bananas produced twice as high yields of marketable fruit under shade than in full sunlight because of reduced damage by leaf spot (Sigatoka) disease. The possibility of converting abandoned, shaded coffee plantations to high producitivity, together with conservation, by growing bananas

47

in undisturbed soil with natural ground cover under shade trees is promising.

RESUMEN

Se determinó el efecto de una sombra de aproximadamente 50 por ciento producida por árboles, sobre los rendimientos de tabaco, maíz, yautía, plátanos y guineos en la Región Montañosa de Puerto Rico, con lluvia de 73 pulgadas anuales y una temperature media de 72° F.

La producción de maíz y yautías se redujo marcadamente a la sombra y la de plátanos muy levemente. Sin embargo, la sombra no tuvo efecto sobre la producción de tabaco.

La producción de guineos para el mercado fué dos veces mayor a la sombra que a pleno sol, debido a una menor incidencia de la mancha de las hojas (Sigatoka) cuando se sembraron a la sombra. Se discute la posibilidad de producir guineos lucrativamente en plantaciones de café abandonadas, dejando poca sombra y la vegetación cobertora natural, para proteger el suelo contra la erosión.

48

SECTION IV

Arnold, J.E.M. and J. Jongma, Fuelwood and Charcoal in Developing Countries

unasylva

an international journal of forestry and forest industries

vol. 29 no. 118

Fuelwood and charcoal in developing countries	2	J.E.M. Arnold and J. Jongma
Forestry education and research	10	J.L. Marley
Panels, paper and paperboard from agricultural residues	12	Leo Lintu
The utilization of low-quality tropical timber	18	K.F.S. King
Guatemalan conifers	25	T.T. Veblen
World of Forestry	33	

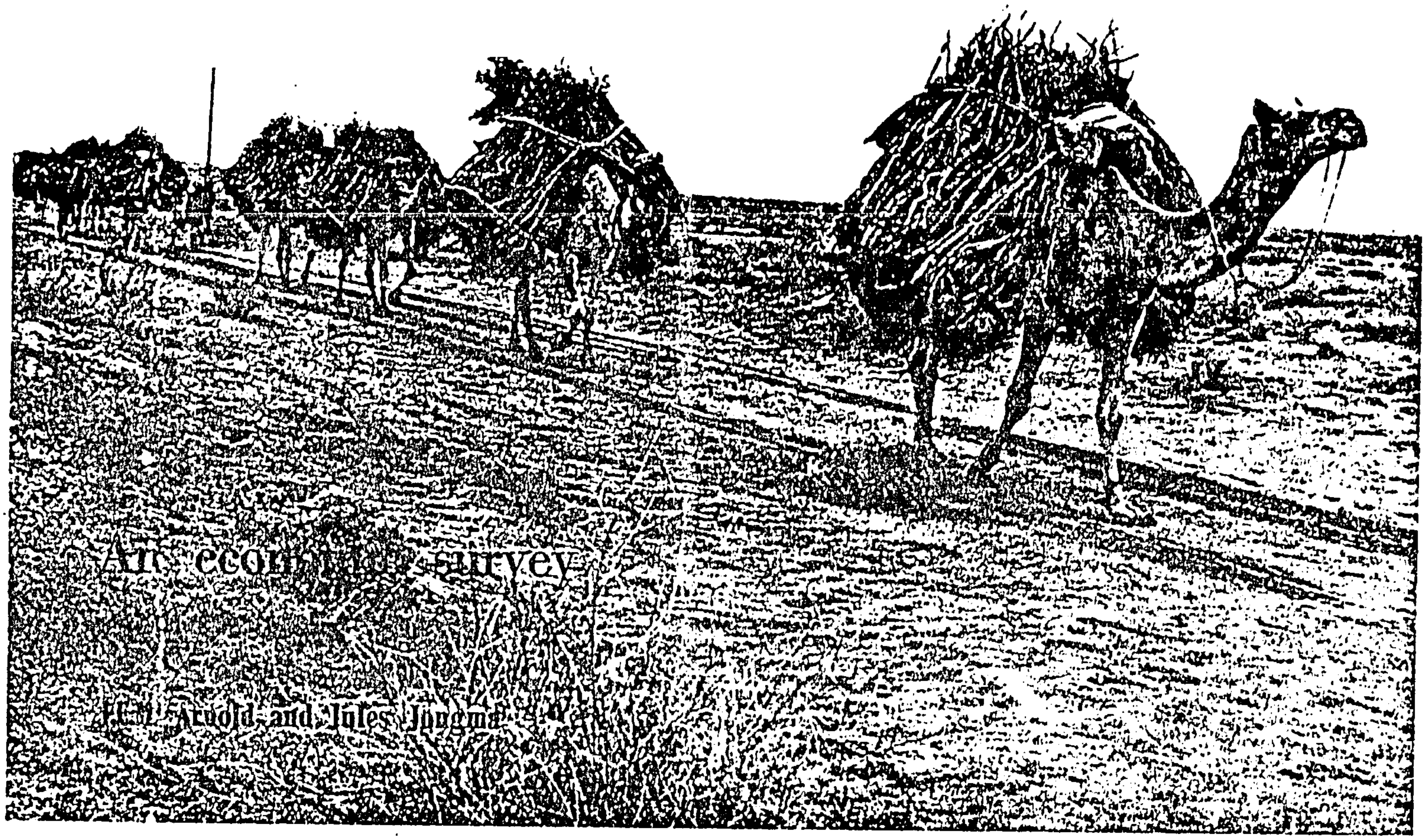
Unasylva is published quarterly and is available in English, French and Spanish editions through subscription. Price: one year, $8.00, payable to the Distribution and Sales Section, FAO, Via delle Terme di Caracalla, 00100 Rome, Italy. Orders in local currencies may be placed with any of the FAO sales agents listed on the inside back cover.

COVER:

Collecting fuelwood in Mali

Photograph by Franco Mattioli

Fuelwood and charcoal in developing countries



For the poor in developing countries, both urban as well as rural, wood is usually the principal source of energy for cooking food and for keeping warm. In these countries an estimated 86 percent of all the wood consumed annually is used as fuel. As populations have grown, this dependence has led inexorably to pressures on the wood resource which all too often have resulted both in the destruction of the forest and in a worsening of the situation of the hundreds of millions of people whose life is conditioned by the products of the forest.

J.E.M. ARNOLD is Chief of the Plans Unit of the FAO Forestry Department and JULES JONGMA is a Dutch forest economist. This article is a preview of a position paper to be given at the 8th World Forestry Congress in September 1978 in Djakarta.

Available data on wood fuel consumption are based largely on estimates, as the greater part of wood fuel production and usage occurs outside commercial channels and thus goes unrecorded. On the basis of the latest information available and some recent household surveys, the total annual output and use of all wood for fuel in the developing countries is estimated to reach 1 200 million m^3 (Table 1). This compares with roughly 150 million m^3 used annually in developed countries. About half of this wood fuel is used for cooking, about one third for heating the house, boiling water, etc., and the remainder for other domestic purposes, for agricultural processing and for industry. Consumption takes place mainly in the form of fuelwood (firewood), with charcoal accounting for a minor, but apparently substantial, part of the total.

Wood fuels account for two thirds of all energy other than human and animal energy used in Africa, for nearly one third in Asia, for one fifth in Latin America, and for 6 percent in the Near East. This compares with the one third of 1 percent of total energy use which wood fuels account for in developed countries.

In the rural areas of most developing countries, the dependence on wood and other non-commercial fuels is often almost total. The principal non-commercial fuels other than wood are animal dung and crop residues. It was recently estimated that energy from the use of animal dung as fuel is at present equivalent to around 13 percent of the energy being used in the form of wood fuel, and that energy from crop residues is at a level equivalent to about 16 percent of the energy produced from animal dung (Earl, 1975). In aggregate, wood fuels therefore account for about 85 percent of all non-commercial energy in developing countries, other than human and animal energy. Even in India, with a well-developed commercial energy sector and a shortage of wood in most rural areas, wood fuels were estimated to account in 1970/71 for 34 percent of total energy consumption, and all non-commercial organic fuels, including animal dung and crop residues, accounted for 56 percent of total energy (Henderson, 1975), and for 93 percent of rural domestic energy requirements (Revelle, 1976).

An impression of the role of wood fuel in rural villages in developing countries is given in Table 2, which reproduces estimated energy budgets, including human and animal energy, for a number of prototypical composite villages in Asia, Africa and Latin America (Makhijani and Poole, 1975). In four of them, energy from wood fuel is equivalent to the total domestic use of energy, and to 65-85 percent of total energy use, including agricultural and processing uses. Only in Bihar in India, where wood is in extremely short supply, and in northern Mexico, where higher incomes permit the use of commercial fuels, does wood not dominate the energy total.

Results from a number of surveys of wood consumption in various countries in Africa and southeast Asia are summarized in Table 3. In these countries nearly all wood fuel is used for domestic purposes and for local agricultural processing, and it is the principal fuel for nearly all rural households and about 90 percent of urban households. The pattern of household use of wood fuels differs between urban and rural areas. Though use of fuelwood is generally much lower in towns than in the country, urban use of wood fuels can in aggregate be high, because of the often substantial use of charcoal. Urban use can lead to very large concentrates demands.

Use in Bangkok in 1972, for example, amounted to 3 million m³ of wood according to FAO's de Backer and Openshaw.

Though of much smaller magnitude than household use, wood fuel for processing and service activities in developing countries is still very substantial, accounting for between 2 and 15 percent of total use in the countries in Africa and Asia where surveys have been carried out. Though some of these uses are dispersed, such as charcoal for commercial food preparation and for ironing, or firewood for brickmaking and cement, others give rise to very large demands concentrated in single locations or small areas. For example, tobacco-curing is estimated to have required 1.1 million m³ of fuelwood in Tanzania in 1970 (Openshaw, 1971) and, together with rubber preparation, nearly 300 000 m³ in Thailand in the same year. Demand in such processing uses is now growing much faster than household demand.

What the overall shares of firewood and charcoal might be in the total consumption of wood fuel can only be guessed at. Quantitative information about charcoal use, other than on a large scale for industry, is practically confined to such scattered survey results as are summarized in Table 3. These suggest that charcoal is much more heavily used than is usually believed — in Thailand, for example, nearly half of all wood fuel is first transformed into charcoal; also, that its use is rising much faster than that of fuelwood, for a variety of reasons, as we shall see.

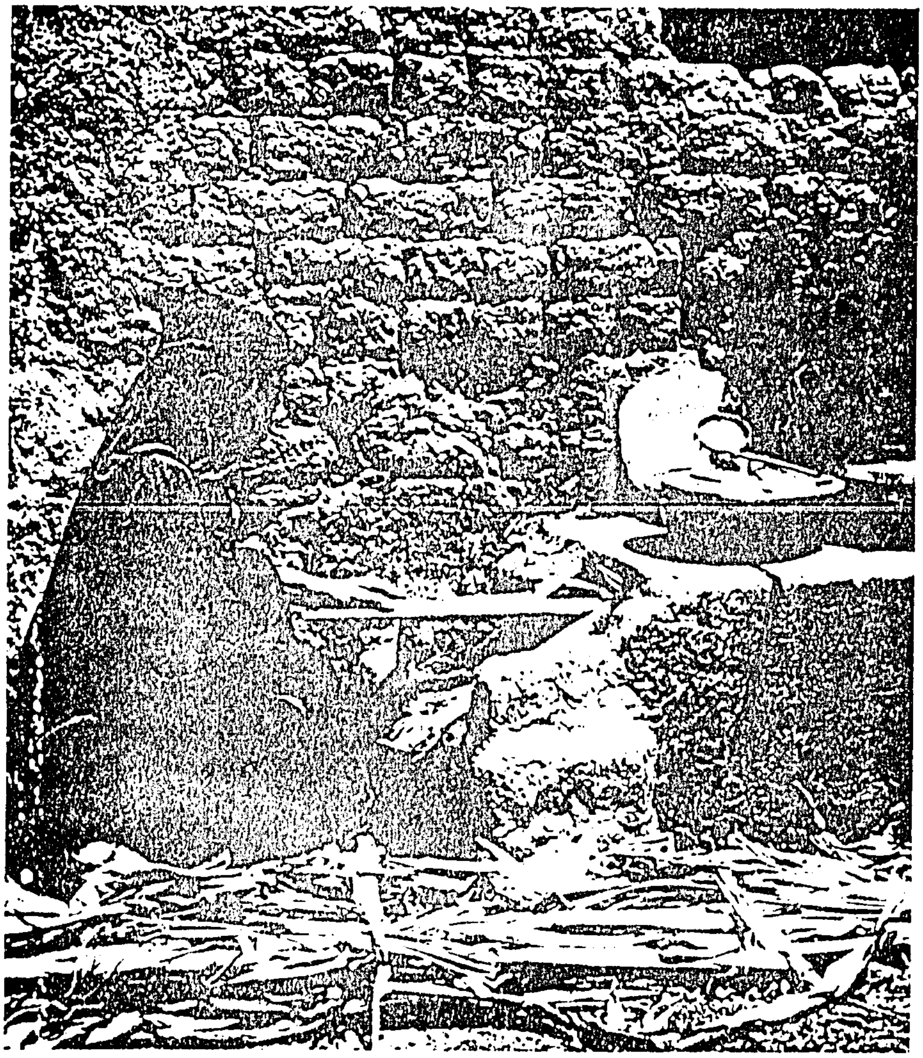
Domestic energy requirements vary with climate, family size and cooking habits. In general they may be estimated to range from about 1.25 million kilocalories energy input per caput per year (cooking food on an open-fire stove in the warm lowland tropics) to over 6 million kilocalories (cooking and heating in cold upland areas). This would be equivalent to an annual requirement of from about 0.5 m³ to well over 2 m³ of air-dry fuelwood per person.

In most countries, use of wood fuel in the rural areas is predominantly in the form of fuelwood, and lies mainly outside the monetary economy. In Tanzania, for example, less than 5 percent of all rural wood fuel used in 1967 was purchased. Therefore, the paramount factor determining the actual level of consumption of wood fuel that takes place to meet rural domestic energy needs is physical avail-

TABLE 1. — Estimated use of wood for energy in 1971

	Consumption of wood fuel [1]		Energy from wood fuel	
	Total	per caput	Coal equivalent [2]	Percent of total energy [3]
	Million m³	m³	Million tons	
Asia and Pacific				
Southeast Asia and Pacific	278	0.91	92	62
South Asia	267	0.38	88	43
China and other Asia	148	0.18	49	9
Total	693		229	29
Near East	13	0.15	4	6
Africa				
North Africa	55	0.50	18	41
West Africa	110	0.92	33	75
East Africa	117	1.14	39	75
Total	282		93	66
Latin America				
Central America [4]	33	0.36	11	9
South America	199	1.03	66	29
Total	232		77	20

Source: FAO estimates of wood fuel; UN Statistical Yearbook, 1973.
[1] Fuelwood plus wood for charcoal. — [2] CE = coal equivalent: assumes one cubic metre of wood is equivalent to 0.33 ton of coal. — [3] Total energy excludes organic fuels other than wood, and human energy and animal labour. — [4] Includes Caribbean.



COOKING WITH REED CANES IN EGYPT
fuel is where you find it, if you find it

ability. Thus migrants from the wood-poor hills of Nepal to the forested Terai region of that country have been found to use twice as much fuelwood as their companions remaining in the hills (Earl). In Thailand the household use of fuelwood in the wood-poor central region is less than half what it is in the rest of the country. In the plateau area of northern Tanzania the difference in household use of wood fuels between villages in wooded areas and villages with little or no surrounding woodland is more than threefold.

The best estimates of consumption of wood fuels, summarized in Table 1, indicate that in general, in the regions where wood resources are still quite abundant and conveniently distributed relative to population — southeast Asia, Africa south of the Sahara, South America — average annual consumption of wood fuels per caput is usually close to 1 cubic metre. In the regions where, either through heavy population pressure or a poor natural forest endowment, wood is scarce — China, south Asia, the Near East and north Africa — consumption drops to 0.5 cubic metre and below. The information in Table 3 from consumption surveys in a number of countries illustrates something of the variation within these averages.

Given that most of its use does lie outside the monetary economy, it is not surprising that, over most of the range of income prevailing in developing countries, fuelwood use appears relatively insensitive to change in income. An analysis of national per caput averages in 1971 disclosed a slight negative correlation between fuelwood consumption and income growth in Asia, but no discernible correlation in Africa and Latin America. Evidence from within countries is similar. In Thailand, for example, average household consumption of wood fuels in four of the five different income groups was approximately the same, while in the highest income group it was somewhat lower. In Tanzania, there was again no significant difference in average per caput consumption in the income groups covering the poorest 90 percent of the rural population, while in the highest income group it was 10 percent less.

In urban areas, the correlation between wood fuel consumption and income is somewhat more pronounced, as more wood is usually sold or bartered. The income elasticity of demand is possibly slightly positive, except for the upper income classes.

In monetized fuel markets, where price becomes a paramount factor, wood eventually becomes less competitive because of its low efficiency and high delivery costs. On the other hand, other fuels require investment in stoves before they can be used, which may be an important consideration for low-income households, even if the relative prices of these fuels would later allow lower operating costs. Thus the major obstacle to the substitution of other commercial fuels, even in towns and cities, is quite simply that people are too poor to buy the necessary equipment to use them.

When fuelwood is displaced, it is usually first displaced by another wood fuel, charcoal, which has twice the heat value per unit of weight of wood and is more energy efficient in application.

Charcoal is in fact in many respects a high-quality fuel and in terms of efficiency of domestic use it may actually be cheaper than fuelwood. Many factors contribute to the preferences in its favour: it is smokeless; its burning characteristics; the flavour it imparts to food; ease of storage; simplicity of charcoal stoves, which make possible the use of the fuel with very little cash outlay.

Because between 30 to 50 percent of the heat value of wood is lost during conversion to charcoal, it may be more efficient to use fuelwood where transport distances are short and transport costs low. With its advantage of increased transportability (partly offset by its bulky nature and its susceptibility to losses in handling due to pulverization), charcoal becomes increasingly attractive over longer distances. The balance between fuelwood and charcoal, and the limits of economic supply for the latter, depend on production costs, transport costs and market prices of charcoal and alternative fuels. In a recent study in east Africa, it was found that fuelwood was more attractive up to a road distance of 82 km, and charcoal beyond that distance (Earl, 1974). In many areas charcoal supplies are transported over distances of several hundred kilometres and charcoal enters international trade.

As most fuelwood which is used is collected for own-use as the need arises, and as collection and transport of wood fuel in rural areas are mainly by human and animal labour, its supply is generally limited to areas within walking distance of the consumer. In a recent survey in India, it was found that villages located inside or adjoining the forest meet their total fuel requirements from the forest (fuelwood and other vegetative material). In areas within 10 km of forest boundaries about 70 percent of the fuel used comes from the forest; beyond 10 km, the use of fuelwood from the forests diminishes steadily until at about 15 km it is almost nil (Mathur, 1975). This type of pattern has been reported from many other areas.

Although fuelwood for the market moves over considerably greater distances, supply zones still tend to be very limited.

Wood is relatively energy-inefficient fuel, compared with other fuels. As fuelwood has a high ratio of weight to calorific output and hence to value, it can seldom absorb the costs of transport over any but short distances. In the savanna region in Nigeria, for example, although fuelwood is transported by road for distances of up to 100 km, a more normal limit on supply distance is less than 50 km.

The consequence of the localized character of fuelwood supply is to put increasingly heavy pressure on the tree cover and other woody vegetation close to centres of population and to processing activities using wood fuel. It also tends to put an increasing premium on other, more accessible, sorts of wood, such as tree crops, logging residues, processing residues, and used wood. As a result, a substantial part of fuelwood supplies tend to come from sources other than the standing forest tree. In Thailand, for example, it was found in 1972 that 57 percent came from cutting outside the forest and from wood residues. In Sri Lanka, over half came from rubber and coconut plantations. In Tunisia, in 1973, some four fifths came from shrubs and tree crops.

It can therefore be wrong to equate wood fuel use exclusively with drain on the forest, and to do so can lead to misleading conclusions in planning future wood fuel supplies. Eventually, however, such intense pressures can lead not just to destruction of the forest but to complete removal of all tree and scrub cover. In the densely popu-

TABLE 2. — **Energy budgets of prototypical composite villages in different regions**

	Bihar, India	E. Hunan, China	Tanzanian plateau	Northern Nigeria	Northern Mexico	Bolivian Andes
	Million kilocalories/caput/year [1]					
Organic fuels						
wood fuel	0.25	5.00	5.50	3.75	3.57	8.33
other [2]	0.75		—	—		—
Commercial energy	0.04	0.87	—	0.03	9.19	—
Human energy	0.75	0.75	0.75	0.71	0.89	0.83
Animal labour	1.88	1.25	—	0.18	1.78	2.50
Total	**3.67**	**7.87**	**6.25**	**4.67**	**15.43**	**11.66**
(a) for domestic use	1.00	5.00	5.50	3.75	4.25	8.32
(b) for agriculture	1.82	2.07	0.57	0.72	10.25	1.68
(c) other [3]	0.85	0.80	0.18	0.18	0.90	1.65

Source: adapted from Makhijani and Poole, *Energy and Agriculture in the Third World*, Ballinger, Cambridge, USA.

[1] All data refer to gross (input) energy. — [2] Animal dung and crop residues. — [3] Transport, crop processing, etc.

TABLE 3. — **Pattern of consumption of wood fuels in selected countries**

	Year	Average use per caput/yr	As charcoal	For household use	For urban use (share of total household use)
		m^3	percent		
Gambia	1973	1.61	26	85	25
India	1970	0.38	—	—	—
Kenya	1960	1.00	6	98	—
Lebanon	1959-63	0.17	37	98	20
Sudan	1962	1.66	42	98	15
Tanzania	1960-61	1.14	—	97	3
	1968-69	2.29	3	93	4
Thailand	1970	1.36	46	91	12
Uganda	1959	1.53	—	92	—

Source: Reports of FAO-assisted surveys in Kenya, Lebanon, Sudan, Tanzania, Thailand and Uganda; unpublished report of ODA survey in Gambia; National Commission on Agriculture, India (see References).

A CHARCOAL PROJECT IN TUNISIA
getting more calories out of scarce wood

lated Gangetic plain, for example, the forest cover has been reduced to 0.35 percent of the land area in West Bengal and to about 2 percent in Uttar Pradesh.

The impact of demand for wood fuel is felt most heavily around centres of population and processing, where demand is concentrated. The use of 3 million m³ of wood for fuel in Bangkok, for example, is felt over a large part of Thailand. Even in the Sahel, a sparsely populated region, areas surrounding small and medium centres of population are largely deforested, and around a fishing centre in the Sahel, where the drying of 40 000 metric tons of fish annually requires 130 000 tons of wood, the deforestation extends as far away as 100 km. Moreover, the affected area grows with frightening speed. It is reported from one large town in the Sahel that while until recently nobody used to haul fuelwood more than 50 kilometres, now it is common to go 100 kilometres.

Not the least consequence of urban demand is to put a monetary value on fuelwood supplies, so that they become inaccessible to rural populations dependent on subsistence collection. In a recent study in central Java it was found that this was particularly prevalent in the poorest areas, precisely because they offered so few alternative sources of cash income (Wiersum, 1976).

There are a number of other consequences of heavy fuelwood use. Where it becomes scarce or costly, the two most frequent substitutes are animal dung and crop residues, which could reduce the production potential of the soil. The diversion of dung from use in agriculture is equivalent to burning food in order to cook food. It has been estimated that each ton of cow dung burnt may mean a loss of the order of 50 kg of foodgrain. Although estimates vary widely, total use of cow dung for fuel in parts of Asia, the Near East and Africa may be in the order of 400 million tons wet weight.

Under conditions of population growth, a cumulative process may be started or accelerated by this diversion of nutrients from crop production. Unless compensated by the application of fertilizer, the use of animal dung as a fuel will lead to lower yields per hectare, which is likely to create additional pressure to bring more land under agricultural crops. Where this can be achieved only by further encroachment on the forest, future domestic energy prospects may worsen and even more dung may have to be diverted to meet energy requirements.

As fuelwood becomes scarcer, finding fuel for the household becomes an increasingly arduous burden, which usually bears most heavily on the rural woman. Fuelwood that could be collected in the immediate vicinity of most households a few years ago now has to be gathered and carried from a distance a half-day's walk away. In the process, progressively more rural labour has to be diverted to the supply of fuelwood. Even in conditions of usually widespread rural unemployment, fuelwood gathering could become a significant constraint on other activities in those seasons of the year when agricultural labour is in demand.

The shortage of gatherable organic fuel weighs disproportionately heavily on the poorest. If it had to be purchased at prevailing prices, fuel would absorb up to 25 percent in the poorer parts of the Andean sierra and the Sahelian zone. For the poor, the option of substituting commercial fuels as organic fuels disappear is very limited. The most important consequences of growing fuelwood shortages for millions of people is thus the progressive disappearance of the means to cook food and to ensure an essential minimum level of warmth.

The question of how to respond to this massive dependence on wood for fuel in developing countries needs to be approached with some caution. Because wood is the predominant fuel at present does not mean that it will necessarily remain the most appropriate fuel. In the course of the five to ten years that it will take for a fuelwood plantation to produce wood of harvestable size, it might be possible to raise incomes in a particular area to the level where kerosene or some other commercial fuel could be used. The resources that would have to be deployed to create the plantation might thus be better employed in this direction. Similarly, the erodable slopes laid bare by fuelwood cutting might better be replanted with an income-generating tree crop than with fuelwood species. The burning of animal dung and crop residues might more appropriately be prevented by use of biogas plants, which convert organic matter to a usable form of energy, methane, and at the same time produce organic fertilizers as a by-product.

Urgency

However, for the foreseeable future, locally available wood and other organic materials will continue to meet the bulk of the energy requirements of the rural peoples in the developing countries. At the levels of poverty that are all too likely to prevail, the poorer people will be unable to afford anything else. To meet the growing demand for wood fuels, and to limit the negative effects of using the forests for this purpose, a more urgent and widespread attempt is needed to actively meet domestic energy requirements, in particular in areas such as the Sahel, the Gangetic plains, parts of Java, the Andes and possibly regions in China, where shortages of organic fuels already occur or are imminent.

In addition to these critical areas, there are many where wood could be the rational choice over other available sources of energy. Its widespread occurrence and its renewability make it suitable for dispersed, remote markets. It can be used, and created, with very little in the way of capital expenditure, with no outlay of foreign exchange and with easily acquired skills. It can make use of land unsuitable for crops and make organic matter available for the production of food.

Options

Within the framework of meeting demand for energy with wood fuels, a number of options exist. The first is by using fuelwood more efficiently. The traditional ways of burning wood for cooking and heating are in general not energy efficient. Energy requirements for cooking on open, slow-burning fires have been estimated to be about five times as high as for coking with a kerosene stove (Makhijani and Poole, 1975). In a study in Indonesia it was found that on the usual types of fuelwood stove 94 percent of the heat value of the wood was wasted. Simple improvements in wood preparation, in stove design and in cooking pot design reduced the consumption of fuelwood for cooking by 70 percent (Singer, 1961). The cash outlay on stove and pot are an evident constraint in achieving such improvements. However, the costs involved are small, and probably smaller than those required to adopt any other fuel.

The renewable nature of the forest also offers potential for sustained output of wood for fuel, provided appropriate harvesting and management can be instituted before destruction reaches an irreversible point. Though this can often imply a degree of control which can be difficult to organize and administer, this need not necessarily be so. Efforts of this nature have often been thwarted due to an essentially negative approach to the management and control of pole and fuelwood cutting, which centres on prohibitive legislation. More positive and imaginative approaches are needed. In an area of central India, for example, destructive cutting of the forests was halted and sustained fuelwood production built up, by devising a control system which could be implemented by the local people within the framework of their established tribal customs and practices (Chakravarti, 1976).

Another important means of extending the wood-based fuel base is through transforming wood into charcoal. Because charcoal can be transported economically over longer distances, production of wood-based fuel in the form of charcoal can be extended over a much wider area than the production of wood to be burned as fuelwood.

Though the properties of charcoal vary with the wood raw material and particular woods have to be used for charcoals for certain special purposes, virtually all woods can be converted into charcoal. Charcoal production can therefore be based on the large volumes of wood of other than commercial timber species which are otherwise destroyed in land clearing for shifting or settled agriculture in the tropics, or which are left unused in tropical forests after logging. In recent studies of what volumes might be available for charcoal manufacture, estimates were arrived at of 100-200 m^3/ha in tropical high forest in Surinam, 75 m^3/ha in the Terai area in Nepal, 50 m^3/ha in Ivory Coast and about 88 m^3/ha in the cerrado region of Brazil. While parts of these volumes might equally be used for pulpwood or poles, use as fuel is often likely to be an appropriate outlet.

With the steady shift to clear-felling and planting in tropical forestry, charcoal manufacture based on the non-commercial component of the standing volume is coming to be seen as an important tool of forest management. In Uganda, for example, successful introduction of charcoal manufacture from harvesting residues brought about an increase of charcoal production over ten years from 200 to 63 700 tons (Earl, 1975). Uncontrolled working of the forest for charcoal, however, can be as destructive as uncontrolled fuelwood cutting.

Charcoal can also be based on plantation-grown wood, but the low conversion factor tends to make charcoal-making unprofitable when the cost of growing the wood has to be taken into account. Plantations can be competitive, however, where they concentrate supplies close to the market, and so produce an offsetting reduction in transport costs.

A feature of charcoal is the ease with which it can be produced. The bulk of the charcoal produced in the world is made in kilns. The simplest earth kilns are simple indeed and require little investment and no specialized skills.

A much higher conversion efficiency can be obtained by producing charcoal in retorts. Retorts can also permit gas and distillable by-products to be captured. However, the capital cost of retorts is relatively high, and they require further substantial investment in generating, refining and storage equipment in order to make use of the by-products. As they are best operated on a relatively large scale, retorts are generally used for industrial applications. Considerable attention has recently been directed to the development of such systems as portable retorts, which combine the advantages of kilns and retorts.

Wood fuel resources can also be created, or recreated, by growing suitable tree species for the purpose. As the inputs are predominantly land and labour, and time, fuelwood plantations may enable poor rural populations to generate fuel supplies at an acceptably low cash cost. Growing fuelwood may therefore be the most viable solution for populations too poor to afford the cash outlay required for all other fuels — except organic — or for those living in areas too remote to allow economic access to commercial fuels.

The success of some self-help schemes to create fuelwood plantations (e.g., in China, India and the Republic of Korea) seems to be largely attributable to success in involving the people concerned. The problems of doing so are not just those of getting people to set aside land and to provide labour, but also to get acceptance of the concept that wood is no longer a "free good" to be gathered from the forest at will.

Another factor noticeable in most successful fuelwood plantation schemes is the availability of adequate technical support, in terms both of planting stock and expert advice and assistance. In Korea, for example, where 11 000 villages are establishing new or additional village fuelwood plantations during 1976/77, with labour provided by the villagers, the Government, through a well-staffed extension arm of the forest service which was set up for this purpose, provides the technical expertise needed to select suitable areas for planting, to organize the production and distribution of seedlings and to provide technical advice on establishment and tending. The costs of this supervision, and of seedlings, fertilizer and other materials are fully subsidized by the Government.

The subsidizing of rural fuelwood plantations that is entailed in such provision of technical services is an implicit or explicit recognition that the benefits are likely to extend to more than just the value of the fuelwood itself. Very little work has been done so far on the socio-economic costs and benefits of fuelwood plantations, but such few tentative results as are available suggest that the environmental benefits, and the improvements in agricultural productivity consequent upon better environmental protection, can be substantial, and can contribute to strongly positive benefit: cost relationships. One feature that these results do underline is the sensitivity of the competitiveness of fuelwood plantations to the value of labour. The choice between fuelwood planting and other energy solutions could therefore change quite rapidly over time.

The economics of wood fuel production become a little clearer in the case of plantations established to produce fuelwood as a cash crop. Generally speaking, the commercial viability of fuelwood production is highly sensitive to distance from the market, site productivity and the cost of fuelwood from existing forests. A recent study in northern Nigeria, for example, showed that the break-even distance for Neem fuelwood plantations could be three times greater on site quality I than on site quality III, and that on site quality IV the commercial production of fuelwood would not be possible in any location. It was also found

Measuring wood fuel use

The scarcity of quantitative information about the use of fuelwood and charcoal in developing countries is mostly due to measuring problems: because fuelwood is cut and gathered locally by members of the household that will use it, the whole cycle of use goes largely unrecorded. Very little of it appears in production records. Very little of it passes through commercial channels, or moves through transport systems which maintain records. Therefore, the only way to measure this activity is at the place where fuelwood is consumed. In fact, all the information summarized in Table 3 was obtained through consumption surveys of one sort or another. Such surveys can be carried out only on a light sample basis because consumption is dispersed very widely and thinly. The design of accurate sample surveys can be difficult when, as is the case here, very little is known about the pertinent characteristics of the population to be sampled.

Other measurement problems arise from the physical characteristics of fuelwood: it is difficult to measure the volume of stacks of small, irregular pieces of wood; and the relationship between volume and weight, which can be assessed more readily, will vary, often very appreciably, with species, moisture content, etc. Moreover, use tends to vary with the season of the year. An accurate assessment would therefore require continuous or repeated measurements throughout a twelve-month period. This is why the estimates in Table 3, which were extrapolated from measurements taken at one particular time, cannot be expected to be very accurate, as is suggested, for example, by the two sharply differing Tanzanian estimates.

that, other costs being equal, if fuelwood from existing forests could be purchased at source for half the stumpage cost of plantation fuelwood, the former would break even with the latter at double the distance, and if it could be obtained free of charge at three times the distance (Ferguson, 1973).

Fuelwood production requires careful selection of appropriate species and development of afforestation techniques suited to local conditions. As branches, twigs and virtually all parts of trees except leaves store carbon, and hence energy, the primary criterion for choice of species as a source of energy is production of dry matter per hectare per year. The best fuelwood species may be quite different from the best timber or pole species. Furthermore, a quite different approach to density, spacing and rotation may be needed to maximize production of dry matter. For farm woodlot use, the trees will have to be species that are easily established and managed. In many situations a further important criterion is likely to be joint production of other products with fuelwood (building poles, fodder, oils, fruits, etc.) or the provision of other benefits in addition to wood (shade, shelter, etc.).

Wood fuel has been rightly perceived to be "the other energy crisis", which "will probably be longer and more difficult to overcome" than the energy crisis associated with the rise in petroleum costs (Eckholm, 1975). Roughly one third of the world's population depends upon wood for energy. For the very large part of the developing world for which commercial sources of energy are not a viable alternative, the problem of maintaining supplies of sufficient wood or other non-commercial fuel to sustain minimum essential needs assumes an importance at least as great as the problem that the impact of petroleum costs constitutes for that part of the world which can and does use commercial energy.

Supplying more wood fuel can be only one of the solutions toward meeting the continuing energy needs of those now dependent upon wood for this purpose. Nevertheless, it is clear that hundreds of millions of people will continue to be so poor that they will have no choice but to derive their household energy from wood and other organic fuels. The potential for expanding the supply of wood fuels is in fact substantial. Wood can be used much more efficiently, existing fuelwood forests can be managed more productively, the supply base can be expanded by first converting wood into charcoal, more fuelwood can be grown or can be produced in conjunction with other crops.

The technical knowledge required is available. Though much must be done to adapt it to particular situations, the main information gap is institutional and economic in nature. Much more remains to be known about how much wood fuel is used in different situations. What exactly happens when wood fuel begins to run short? Which of the alternative solutions to the consequent environmental, economic and social problems would be most effective and efficient in a given situation? How can the people who are affected by all this be best encouraged to adopt this solution, and what help will they need to implement it? ■

References

ARNOLD, J.E.M., DE BACKER, M.F.E.
1962 and PRINGLE, S.L. *Present wood consumption and future requirements in Kenya.* Report No. TA 1503. Rome, FAO.

DE BACKER, M.F.E., ARNOLD, J.E.M.
1962 and PRINGLE, S.L. *Present wood consumption and future requirements in Tanzania.* Report No. TA 1536. Rome, FAO.

DE BACKER, M.F.E. and OPENSHAW, K.
1972 *Present and future forest policy goals. A timber trends study,* 1970-2000. A report prepared for the Government of Thailand, Report No. TA 3156. Rome, FAO. (And, *Timber trends study, Thailand: Detailed description of surveys and results,* FO:DP/THA/69/017 Project Working Document, Rome, FAO.

EARL, D.E. *Forest energy and economic*
1975 *development.* Oxford, Clarendon Press.

ECKHOLM, E.P. *The other energy*
1975 *crisis: Firewood,* Worldwatch Institute, Washington, D.C. and *The little-known crisis: firewood scarcity in the human habitat,* Ceres, November-December 1975, Rome, FAO. (This material also appears in: *Losing ground: environmental stress and world food Prospects,* New York, W.W. Norton, 1976.)

FAO/SIDA. *Bilan de la production et de*
1975 *la consommation des combustibles ligneux en Tunisie.* Project working document.

FERGUSON, I.S. *The economics of plan-*
1973 *tation forestry in the savanna region.* FO:DP/NIR/64/516, Project working document, Samaru, Nigeria, FAO.

HENDERSON, P.D. *The energy situation*
1975 *in India.* World Bank report, Oxford University Press.

GOVERNMENT OF INDIA. *Interim Report of*
1972 *the National Commission on Agriculture on Production Forestry - Manmade Forests.* New Delhi, Ministry of Agriculture.

MAKHIJANI, A. and POOLE, A. *Energy*
1975 *and agriculture in the third world.* Cambridge, U.S.A., Ballinger.

MATHUR, R.S. *Certain trends in the*
1975 *consumption of wood in India. Indian Forester,* January 1975.

OPENSHAW, K. *Present consumption and*
1971 *future requirements of wood in Tanzania,* FO-SF/TAN 15, Technical Report 3. Rome, FAO. (And, *Timber trends study: detailed description of survey and results, 1971,* FO-SF/TAN 15, Project working document. Rome, FAO.

OPENSHAW, K. *The Gambia: A wood*
1973 *consumption survey and timber trend study, 1973-2000.* London, Report to the Overseas Development Administration.

PRINGLE, S.L. and ARNOLD, J.E.M. *Pres-*
1960 *ent wood consumption and future requirements in Uganda,* Report No. TA 1287. Rome, FAO.

REVELLE, R. *Energy use in rural India,*
1976 *Science,* Vol. 192, 4 june 1976.

SAINI, T.S. *Present wood consumption and*
1964 *future requirements in Sudan.* Report No. TA 1820, Rome, FAO.

SINGER, H. *Improvement of fuelwood*
1961 *cooking stoves and economy in fuelwood consumption.* Report No. TA 1315, Rome, FAO.

VELTKAMP, J.J. *Present wood consump-*
1963 *tion and future requirements in Lebanon.* Unpublished draft. Rome, FAO.

WIERSUM, K.F. *The fuelwood situation*
1976 *in the upper Bengawan Solo river basin.* INS/72/006, Project working paper. Rome, FAO.

SECTION V

Madeley, J., Deforestation heats up tempers and temperatures

JOURNAL/Sri Lanka

Deforestation heats up tempers and temperatures

By John Madeley
London Observer Service

KANDY — "Kandy used to be a cool place," said a flushed hoteller sweating in 95-degree heat in this hill-country town. "Now look what's happened."

No longer are tourists sure to find a cool change here from the sweltering, riot-torn capital city of Colombo. Scientists' forecasts about deforestation causing temperatures to rise have come true.

In the past 10 years, vast areas of forest have been cleared from nearby hillsides to make way for tobacco cultivation.

"When trees cover the ground," a soil conservation officer said, "the soil is protected and gives off comparatively little heat." Hack out the trees, he went on, "and the soil is open to the sun and gives off far more heat during daytime."

The hotter days may be partly responsible for the short tempers flaring in Sri Lanka's latest wave of separatist violence. In Kandy, however, politics has given way to weather as a favorite topic of conversation for its 103,000 residents.

Maximum temperatures here during the first six months of this year and in 1982 were around 95 degrees. During the same period in 1952 and 1953, average maximum temperature was in the upper 80s.

"The fundamental reason for the denuding of the hillsides around Kandy is tobacco cultivation," said Dennis Fernando, secretary to Sri Lanka's Mahawell Authority.

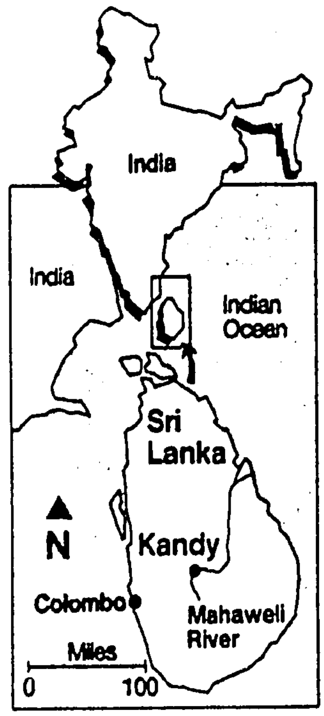
Ceylon Tobacco Co., a subsidiary of British American Tobacco Industries, reportedly encouraged each family in the area to clear an acre of common land and plant tobacco. An estimated 25,000 families in the area now grow tobacco.

A spokesman for British American described the area as "almost totally unproductive before we started to cultivate tobacco there."

Tobacco is cured in slow drying barns for which more wood is required, Fernando said. "Seven tons of wood are used in those barns to dry each acre of tobacco. The whole thing is a scandal."

Added another official: "When people in the West think of tobacco, they think of smoking and health. But we think of the damage it is doing to our land."

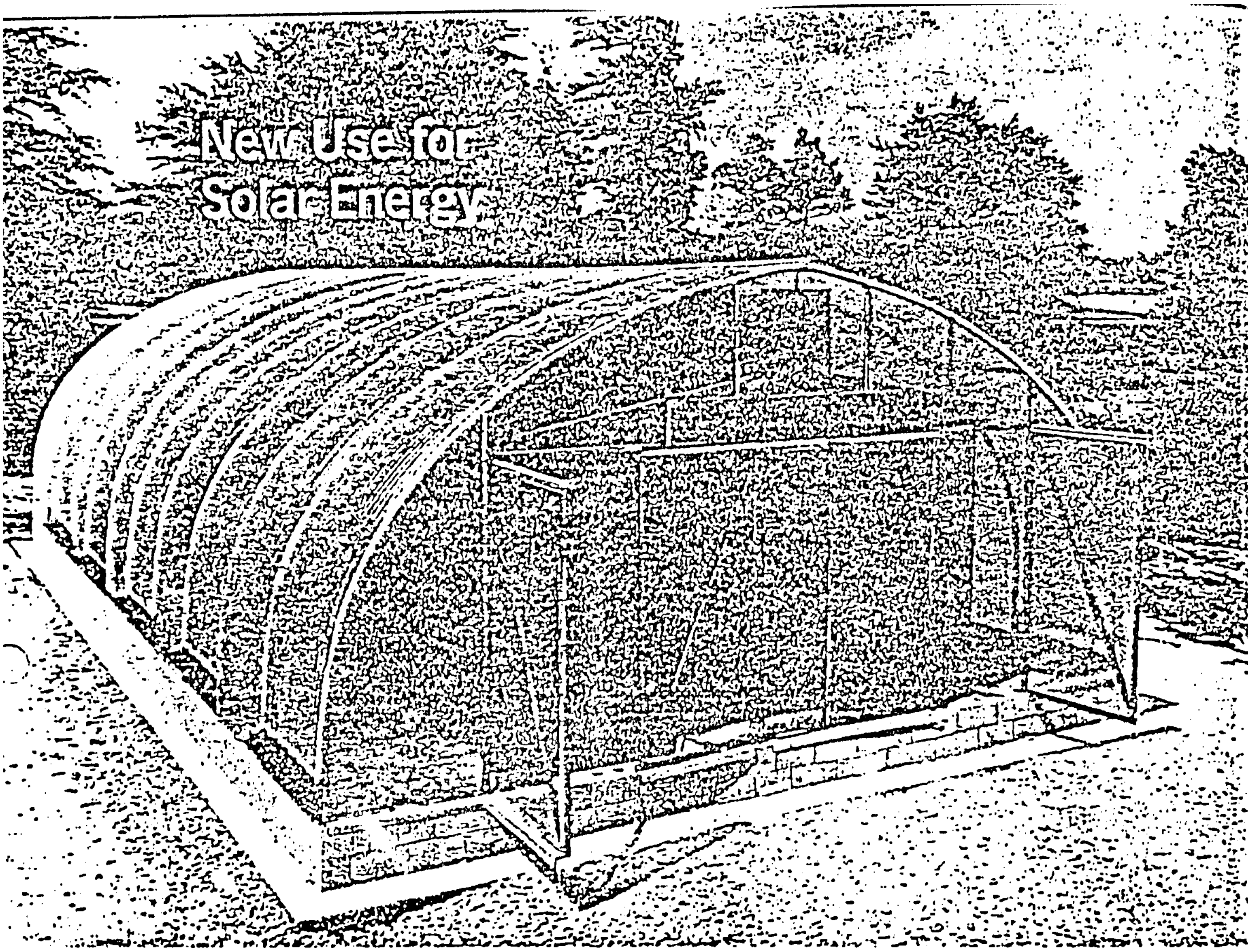
Cooler times, though, may return. Nearby Victoria Dam will boast a 9,000-acre reservoir next year — and residents hope the water will cool the air.



68

SECTION VI

Hudson, J., A Greenhouse That Cures Tobacco



A Greenhouse That Cures Tobacco

These men have found better uses for the sun than making your fieldwork hot.

By JIM HUDSON

The same scorching sun that bakes your brain every summer in the tobaccofields is now helping some innovative tobacco growers cut their tobacco curing costs by up to 25%. And these same growers are learning to use their solar-heated barns for growing plants before and after they cure their tobacco.

"I've used my solar barn for two full years, and I'm using it again this year," says Ray Harvell, Willow Spring, N.C. Harvell grows 135 acres of tobacco with his two sons Ray and Bobby and cures it all in five Powell bulk barns and one solar barn.

Harvell's main interest in the solar barn is the savings it gives in curing fuel costs. "The regular bulk barns do a good curing job, and I like my solar barn just fine," Harvell continues. "Last year I figure we got about a 25% fuel savings with the solar barn."

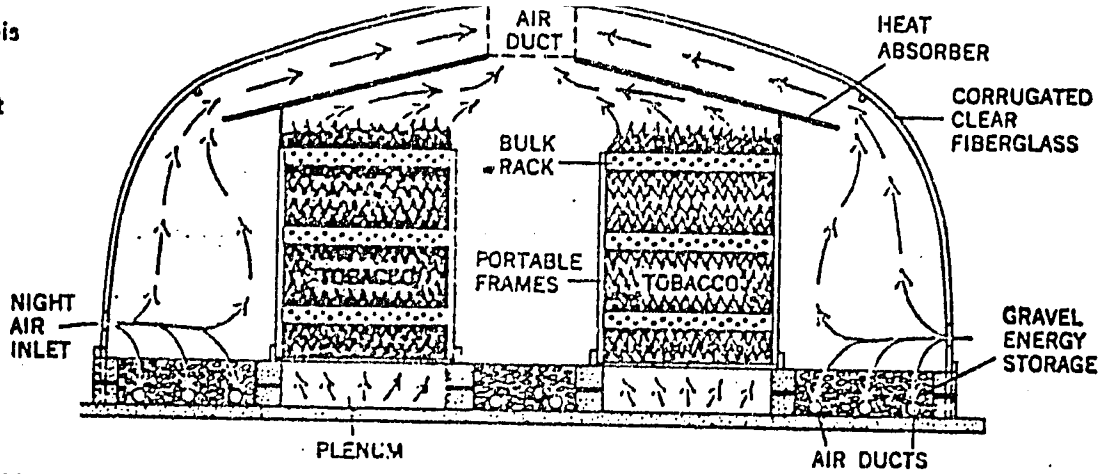
Harvell's solar barn is exactly like a regular bulk barn in size and shape. A concrete block wall foundation built on a concrete slab forms the base for the standard perforated bulk barn floor used. And a standard Roanoke bulk barn heating unit with temperature, humidity, and air flow controls provides heat at night and on cloudy days. Even the framework of Harvell's solar barn is similar to that of a standard bulk barn. Upright studs form the walls of the two-room barn and support the rack rails.

But nothing else about the solar barn is like any conventional bulk barn you've ever seen. Instead of plywood outer walls covered with metal sheets, Harvell's solar barn has black plastic sheets covering the inside walls and ceiling studs, and transparent, corrugated fiber glass sheets covering the entire exterior. Removable plywood sheets separate the rooms, leaving a narrow access room between the two curing rooms.

The structure looks like a greenhouse shaped like a bulk barn. Ac-

62

You can grow plants inside this solar-heated tobacco barn when you're not curing tobacco.



cording to Dr. B. K. Huang, North Carolina State University agricultural engineer who designed the barn, that's exactly what it is, "a fully temperature-controlled, permanent greenhouse."

Sunlight shines through the clear fiber glass walls and is absorbed by the black plastic. This heat stays in the barn and helps cure the tobacco. "When we are yellowing tobacco, our heating unit doesn't fire up at all on sunny days," Harvell explains. "It fires up at night only. We keep the fan running all the time to keep air circulating in the barn."

Huang adds, "To achieve even curing and drying, it's very important to keep forced air continuously moving through the system. The black plastic heat absorber also helps keep the heated air confined to the area around the tobacco. Since no heated air escapes from the barn, efficiency of the curing process is increased."

A temperature sensing device in the air ducts controls proper air flow and furnace heating, when needed, to ensure proper curing conditions.

Huang is not content to stop with a solar barn that will save only 15% to 25% in curing costs. He is now working on another solar barn that should be even more efficient.

His new barn is a commercial Quonset-type greenhouse with a few inside modifications. (See photo and diagram.) The shell is made from an aluminum framework painted flat black, covered with transparent corrugated fiber glass, which rests on a cinder block foundation.

Inside the barn, blocks form the foundation for two curing rooms and one center access room. This leaves considerable space between the outside walls of the curing rooms and the fiber glass barn walls.

Huang installed plastic pipes or ducts like seepage lines on the floor of the barn under the access room and the areas nearest the outside walls of the barn. Then gravel, to be used as a heat absorber and storage area, was poured over the air ducts.

"During the daytime, outside air enters the barn from air inlets in the sides. Air is preheated as it passes over side and top heat absorbers and the heat-absorbing gravel. It then enters an air duct in the top, and is blown through the furnace blowers and under the curing room floors where it passes through the tobacco and back into the top air ducts," Huang explains.

As the inside temperature builds higher than is necessary to cure the tobacco, some of the heat is stored in the gravel. Then at night, when no heat is provided by the sun, the air flow is reversed so stored heat from the gravel can supplement the heat supplied by the furnace.

Special frames similar to the trailers used to haul bulk racks slide into the curing rooms as frames for bulk racks or boxes to hang on. Heat-absorbing panels of polyeurathane insulation boards fit snugly against the front, rear, and all sides of the curing frame to hold the heated air in the tobacco. This material also forms a top over the curing frame which directs the heated air from the tobacco back into the top air duct.

As efficient as this solar barn is, it is not so expensive as a conventional bulk barn. You can build it yourself with little trouble, and the greenhouse frame should last indefinitely. But better than that, you can use your solar-heated barn after the tobacco curing season as a fully temperature-controlled greenhouse.

"To use your solar barn as a greenhouse, no matter which design you choose, simply remove the heat absorbers," Huang says. "By using the structure for purposes other than crop curing and drying, you can further justify the initial investment."

Huang suggests growing greenhouse tomatoes, peppers, or cucumbers as cash crops; growing flowers for sale or your own enjoyment; growing seedling trees for transplanting; and especially growing your tobacco transplants. It's the opportunity to grow transplants that gets Huang most excited.

"You can grow transplants in a shorter time and get more uniform plants in a greenhouse," he points out.

The number of plants which can be grown in one barn depends on arrangement of the plant growing trays. Huang suggests placing one layer of plants on trays on each rail level of the barn. This will allow enough plants for several acres to be grown in one barn. Huang says you can count on transplanting about 95% of all the seed planted in the greenhouse.

By using a solar barn instead of plantbeds to grow the plants, you can sow transplants later than you normally could. Tobacco seed should be planted in the greenhouse before mid-March instead of in January. This eliminates the need for preparing plantbeds during the colder months of the year. And the greenhouses protect plants from adverse weather or disease and insect damage. These uniform plants bring us one step closer to fully automatic tobacco transplanting.

If you'd like to learn more about these solar barns, get in touch with Huang through the NCSU Agricultural Engineering Department.

63

SECTION VII

Huang, B.K., Greenhouse Bulk Curing Solar Barns

March 1, 1977

GREENHOUSE BULK CURING SOLAR BARN

B.K. Huang, Professor
Department of Biological and Agricultural Engineering
North Carolina State University, Raleigh, N.C. 27607

The greenhouse bulk curing solar barn consists of a bulk curing module inside a specially designed greenhouse. It uses two basic approaches to the capture and storage of solar energy. First, as a bulk curing structure incorporating dehydration and electric power saving features, it was designed to directly collect, store and use energy from the sun to cure tobacco. Second, as a greenhouse solar energy is used for photosynthesis for maximum plant growth under controlled environment. This multi-purpose farm structure provides an efficient means of utilizing solar energy in tobacco and greenhouse crop production, so that the investment can substantially be utilized all the year round for an effective farm operation.

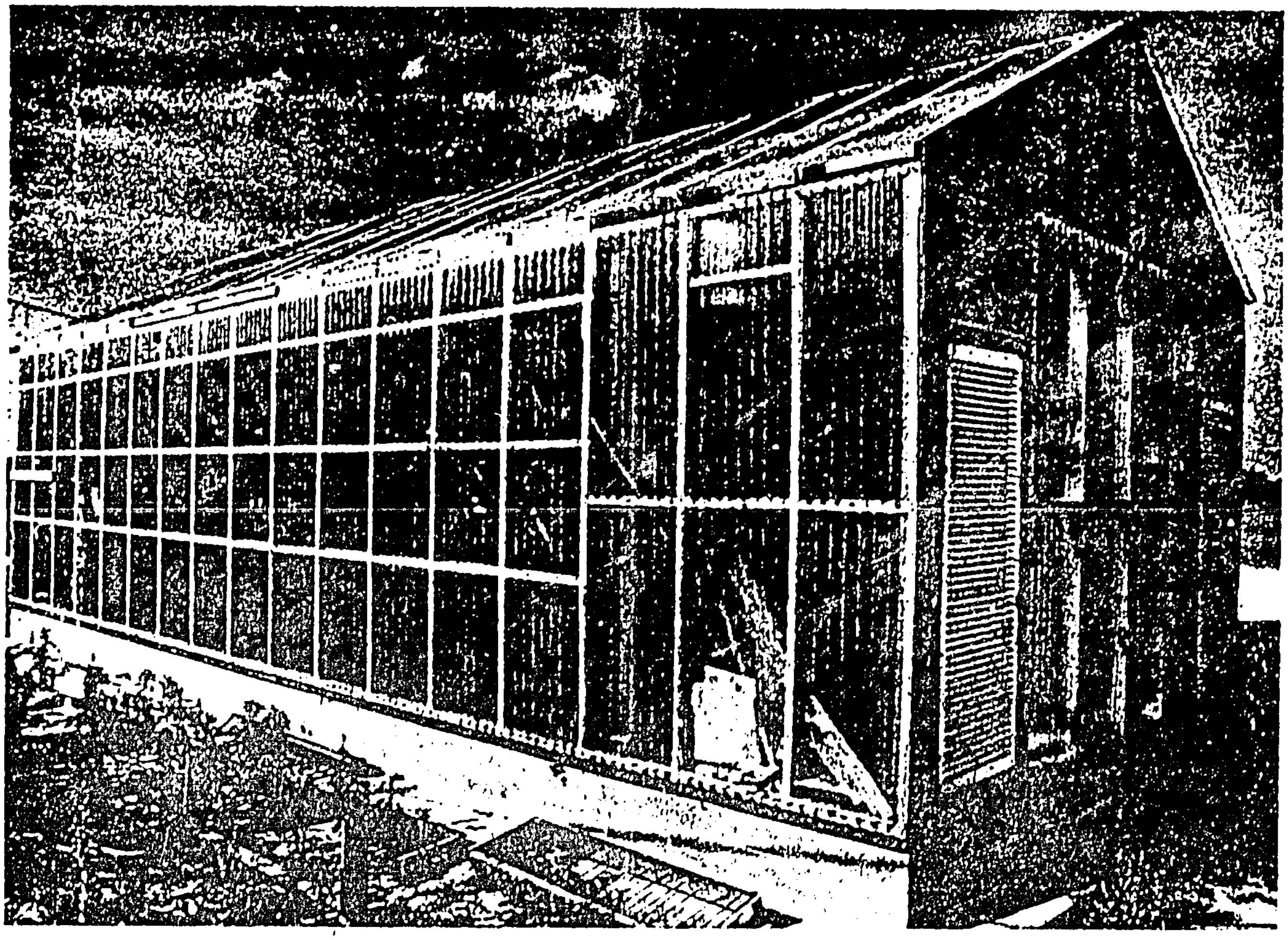
The first greenhouse bulk curing solar barn was constructed and tested in the summer of 1973 with the cooperation of Ray Harvell, a farmer who grows some 100 acres of tobacco in the Willow Springs area of southern Wake County, N.C. Material assistance was provided by Harrington Manufacturing Company of Lewiston, N.C. Four-year field use of this solar barn showed effective solar-energy utilization, high quality cured tobacco, and fuel saving of about 25% as compared to conventional bulk-curing barns. The second unit was constructed and tested at the Central Crops Research Station of North Carolina State University in the summer of 1975 supported by a grant from the National Science Foundation (NSF). Two years of field tests indicated the solar barn provided good curing and resulted in 30-40 percent fuel saving as compared to a conventional bulk barn. The electricity required for the conventional main furnace fan costs almost as much as does the fuel (Costs for fuel and electricity based on current rates). The solar barn auxiliary fan could substitute for the main fan during latter drying and would only require about one-fourth the power of the main fan. The program was later transferred from NSF to the Energy Research and Development Administration (ERDA). The program activities are currently jointly supported by the Division of Solar Energy of ERDA and U.S. Department of Agriculture. The third unit is located at the Department of Biological and Agricultural Engineering, North Carolina State University. National Geographic magazine carried a full page picture (page 396) of the second unit tobacco operation in its March 1976 issue (Vol. 149, No. 3) as part of a feature on solar energy. At the end of the tobacco curing season the solar barn conventional plantbed and transplanting operations for fully automatic transplanting.

As efficient as this solar barn is, it is not so expensive as a conventional bulk barn. You can build it yourself with little trouble based on the attached four drawings showing foundation/floor plan; perspective view of solar barn with mobile bulk handling system; cross-sectional views of solar barn using as plant growing facility for tobacco seedling production and for horticultural crop production; and cross-sectional views of solar barn using as tobacco curing facility either using regular bulk racks or big boxes. The outer walls are made of corrugated clear fiberglass that traps the sun's rays. The heat is distributed by a system of fans and ducts. Surplus heat during the day is piped through gravel energy storage system in the foundation. The gravel stores the energy for use as the sun cools. A furnace switches on when additional heat is needed. The solar barn can be built at an estimated cost of $11,000-$12,000, compared to $9,000 for a conventional bulk curing barn. However, the unit can cure more than one and a half times the capacity of conventional bulk barn. In other words a farm can buy a solar barn constructed with higher quality materials with many extra features, at lower price than he pays for a conventional bulk barn. But better than that, a farmer can use his solar-heated barn after the tobacco curing season as a fully temperature-controlled greenhouse. By using the structure for purposes other than crop curing and drying, he can further justify the initial investment.

Jack Miller
Seri Landsa Desk
Dept. John Erickson (PAC)
Mission Director

SECTION VIII

Hammons, N., Solar curing barn cuts fuel costs, aids mechanization



Solar curing barn can cut fuel costs 15-20%—makes mechanization easier.

Solar curing barn cuts fuel costs, aids mechanization

By Nora Hammons
Associate Editor

A sun-heated bulk-curing barn that cuts fuel costs 15-20% may also prove to be a major advance in the tobacco industry's continuing effort to mechanize what has been called "America's last great unmechanized crop—tobacco."

According to its developer, Dr. B. K. Huang, North Carolina State University's Agricultural Experiment Station, the combination solar-heated curing barn and greenhouse and more automated equipment, has the promise of:

—Providing multiple use of barns for growing seedlings, bulk-curing tobacco during harvesting season; growing horticultural plants during the off-season.

—Eliminating laborious, inefficient plantbed operations.

—Making automatic seeding and field transplanting possible.

—Reducing the seedling growth period to less than half that required by conventional methods.

—Controlling the timing of transplanting to eliminate damage due to adverse weather.

—Providing the possibility of automated transplanting, harvesting and curing.

—Making bulk curing more feasible.

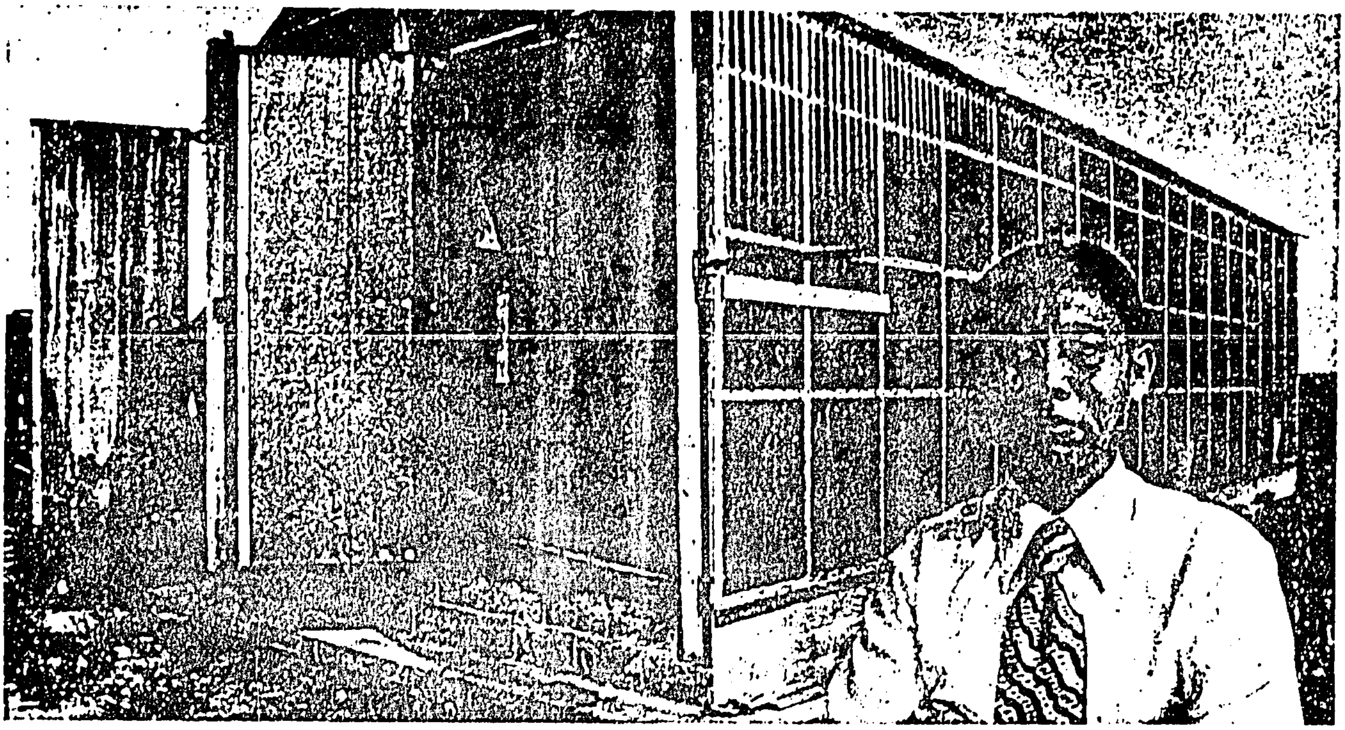
—Providing an efficient way to use the sun's energy for plant growth and bulk curing. This naturally leads to reduced fuel consumption costs.

Two years field tested

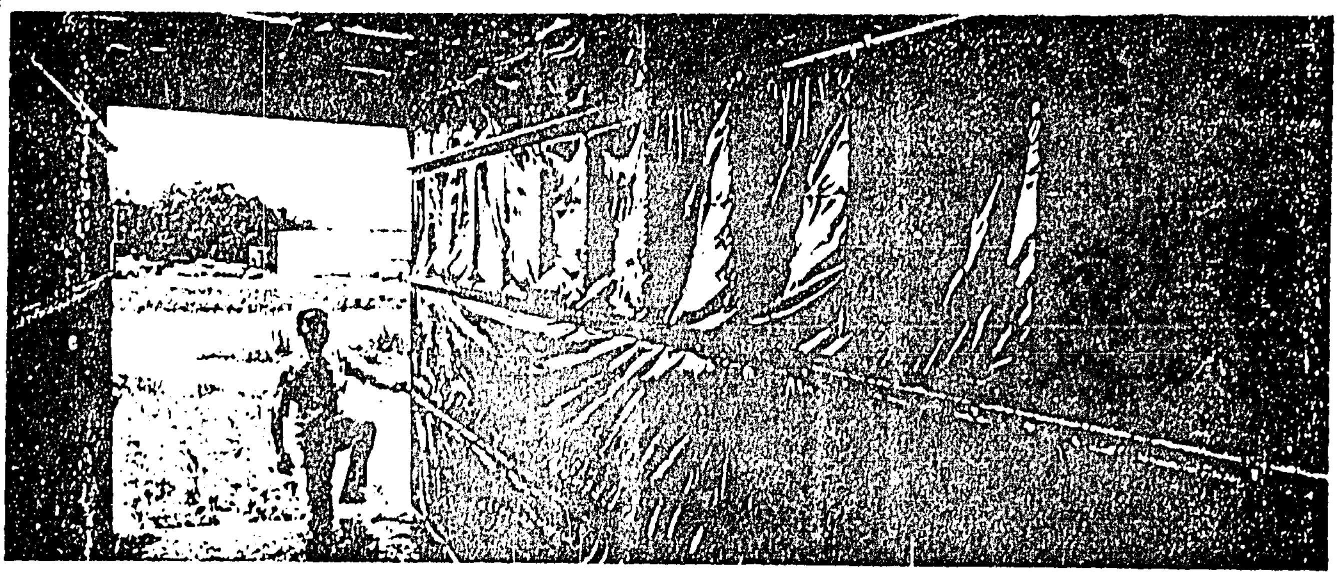
Dr. Huang's claims for his solar-heated greenhouse/curing barn are not just speculation. He, and his team of biological and agricultural engineers, have tested the barn and the mechanization possibilities it provides for more than two years.

The barn, as designed by Huang, is about the size of a conventional bulk-curing barn but it

62



Dr. B. K. Huang and his solar barn. He, and his team of biological and agricultural engineers have tested the barn and the mechanized possibilities it providas for more than two years.



With the black inner wall secure, the greenhouse-curing barn will provide a controlled environment for growing tobacco seedlings and drying and curing the leaves after harvest.

(Continued on p. 11)

69

has two special walls. An outer transparent wall, made of corrugated fiberglass, traps the sun's rays. A black inner shading and insulating wall absorbs the sun's heat. The radiant energy collected between the walls provides the heat needed to cure tobacco.

At the seeding stage, the solar barn is used as a greenhouse. Seedlings are planted in growing and handling trays set in multi-level portable frames. **(Fig. 1a)** The trays, made from a low-cost thin plastic sheet or metal foil, are lined with small pots for seedling growth.

Automatic seeder, transplanter

The seeds are deposited by an automatic seeder in pyramid-shaped soil-filled cups. The bottom end of the cup is open which makes it easy to "drop" the plant during transplanting.

When the trays of seedlings are ready for transplanting, a bottom plate is inserted under the tray. **(Fig. 2a)** The tray can then be transferred to the indexing frame of an automatic transplanter by pulling out the bottom plate. **(Fig. 2b)** The index frame automatically adjusts the tray openings to prepared and uniformly spaced holes in the plantbeds.

As each potted seedling is indexed to an opening of the bearing plate, it drops into the ground through a drop tube. **(Fig 2c)** As a result, the seedlings are transplanted directly at the rate of travel of the transplanter and a systematically predetermined intervals. Manual handlings of the plants is virtually eliminated.

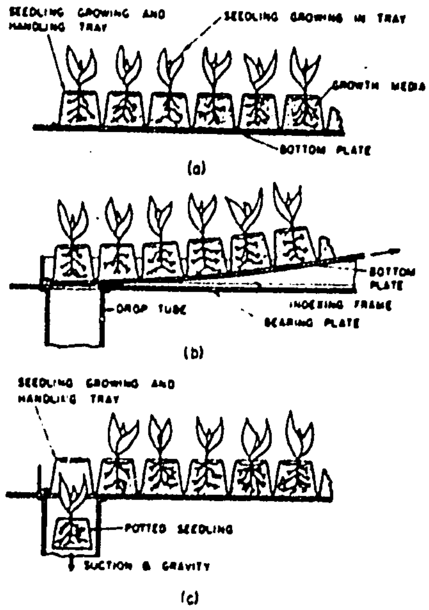


Fig. 2 Operation of seedling growing and handling system: (a) Cross-sectional view of seedlings, tray and bottom plate; (b) Removing bottom plate as seedling tray is placed on the transplanter; (c) Automatic transplanting of seedlings into prepared holes in the field.

Cuts fuel costs drastically

This efficient use of solar energy for plant growth and bulk curing cuts fuel consumption to a minimum. Dr. Huang estimates that use of his system could save $50 million on fuel costs if every farmer in North Carolina used this type of curing barn.

After mechanical harvesting of the field crop, the solar-heated greenhouse system is set for the bulk-curing operation. Bulk racks loaded with tobacco leaves are laid on the same portable frames that held the seedling trays. **(Fig. 1b)** The shading and insulating unit is used to cover the loaded frames. It provides proper insulation and shields the tobacco from direct sunlight. The barn's perforated floor is covered to insure proper passage of conditioned air through the packed tobacco.

Answer to the energy crisis

On the energy crisis problem, the solar greenhouse curing barn has proved to be highly efficient in trapping the sun's energy. Normal curing and drying temperatures of 170°F are easily and economically maintained. Supplemental heat can be used at night or on cloudy days.

Year round use

The greenhouse-bulk curing system, combined with automated transplanting, provides multiple use of facilities. With the system, it's possible to grow tobacco seedlings up to the transplanting stage, transfer the plants to the field, and bulk dry and cure the leaves after harvesting. During the off-season, the system can be used as a greenhouse to grow horticultural plants. Thus it insures maximum use of capital investment the year round,

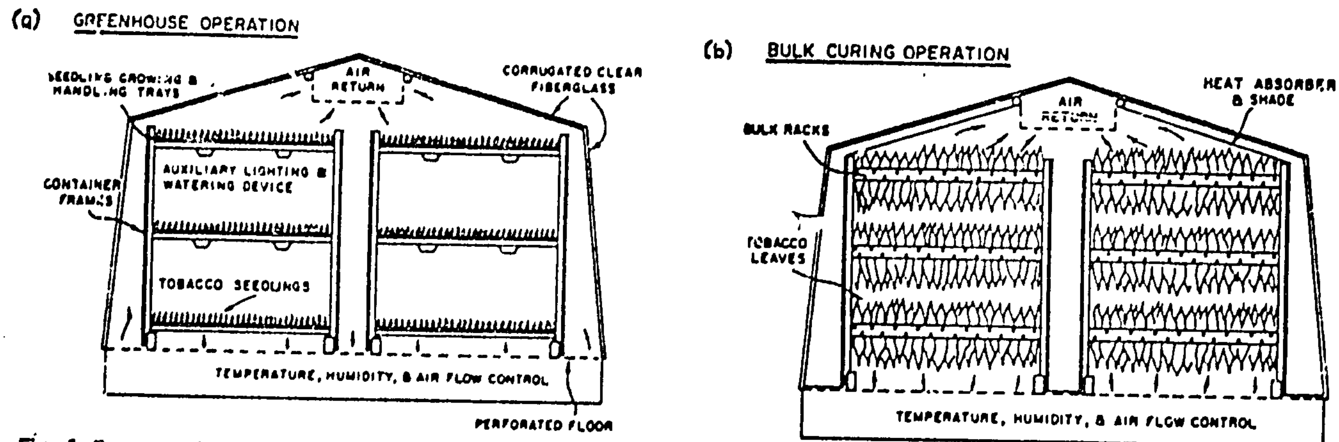
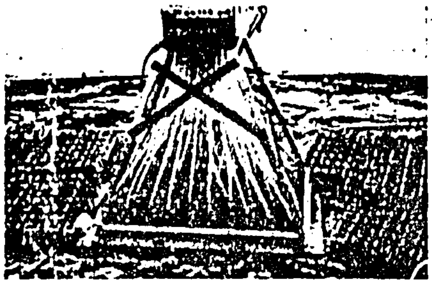
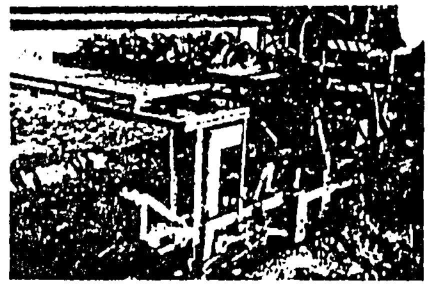


Fig. 1 Cross-sectional views of greenhouse bulk curing and drying system illustrating its uses (a) for plant growing and (b) for tobacco curing.



Automatic precision seeder with seedling growing and handling trays

Setting tray cartridges with tobacco seedlings on automatic transplanter



Field operation of one-row automatic transplanter

with substantially lower labor costs.

The system's use of solar energy, and the efficient integration of controlled seedling production with automated transplanting, harvesting and curing, are a most important development in the mechanization of tobacco production. □

SECTION IX

Huang, B.K. and C.G. Bowers, Jr., Plant Production, Automatic Transplanting, and Greenhouse Solar Curing Systems. 1977

72

GREENHOUSE BULK CURING SOLAR BARN

B.K. Huang, Professor
Department of Biological and Agricultural Engineering
North Carolina State University, Raleigh, N.C. 27607

13

BIOLOGICAL AND AGRICULTURAL ENGINEERING

State 2501: System Approach to Tobacco Mechanization

PLANT PRODUCTION, AUTOMATIC TRANSPLANTING, AND GREENHOUSE SOLAR CURING SYSTEMS

B.K. Huang (Project Leader) and C.G. Bowers, Jr.

ABSTRACT

The continuing efforts were made to accomplish the systems engineering of the total cultural operations from plant-bed preparation, seeding, seedling handling, automatic transplanting, to harvesting and curing, by integrating these operations into a highly efficient system for practical application.

The greenhouse bulk curing system utilizes solar energy as a first priority energy source to cure tobacco in the summer months and to grow greenhouse crops and tobacco seedlings the remainder of the year. Seedlings growing and handling trays were used to grow the transplants in multiple layers for automatic transplanting. The production of uniform transplants was enhanced by controlled environment of the system. Excellent germination rates of 95-97 percent were achieved, using solar energy for tobacco curing again demonstrated a 30-40 percent fuel saving compared to a conventional bulk curing barn.

Computer modeling and analysis for design optimization of solar barn for maximum solar energy utilization and minimum fossil-fuel and electrical energy consumption were under development. The thermal-electrical systems analogies were applied to study temperature responses of the solar collectors and tobacco curing under time-varying solar radiation and ambient air temperatures. Simulation results conformed well with the field data for various stages of curing.

I. SUMMARY OF RESEARCH

A. Greenhouse Operation of Greenhouse Bulk Curing Solar Barn

During greenhouse operation the solar absorbers and portable frames used in tobacco curing are removed, and appropriate greenhouse equipment for growing plants is moved into the structure. The temperature, humidity and watering are automatically regulated to provide a controlled environment for optimum plant production. When more solar energy is available than is needed to heat the greenhouse during the daytime, it is stored in the gravel to reduce the heating requirement at night.

The structure was converted to the greenhouse mode of operation in October, 1975. A crop of Klanchoe flowers in 13 cm pots were grown in it from November 20, 1975 to March 18, 1976 (Figure 1). The automatic temperature and watering controls combined with efficient utilization of available solar energy produced an excellent crop of flowers. A second crop, patio tomatoes in 13 cm pots, was added February 18, 1976. The tomatoes were arranged in 9 blocks (two plants each) down the length of the house and 4 blocks across the house. The Klanchoes were removed March 3, 1976 and measured for height, width, and fresh weight. The tomatoes were removed March 18, 1976 and the dry weights were measured. Neither the Klanchoe nor the tomatoes exhibited any significant block effects in any of the measured variables. This indicates that the system did not adversely affect growth uniformity. It was estimated that a flowering crop such as the Klanchoes would provide between $700 to $800 income in a 4 month growing period.

Temperature gradients and running times were used to calculate the energy supplied by the heater Q_h, the energy stored in the rock beds Q_s, and the energy vented to the outside Q_v. These quantities are shown in Tables 1 and 2 for two 6-day periods in January. Table 1 represents a particularly severe period and Table 2 a more moderate one. The energy recovered from the rock beds was not included in these tables because neither the heat conducted into the greenhouse nor

15

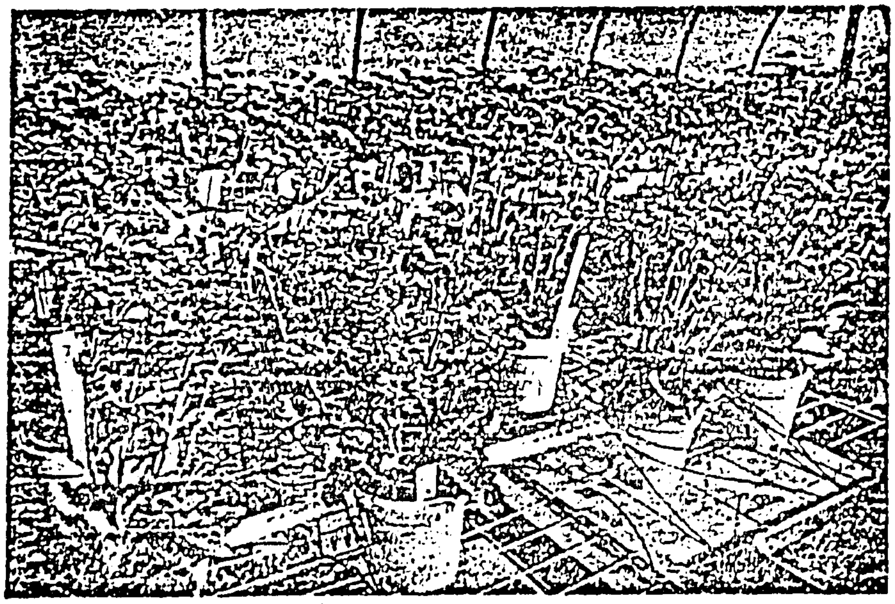


Figure 1. Greenhouse bulk curing and drying system during greenhouse operation for growing flowers.

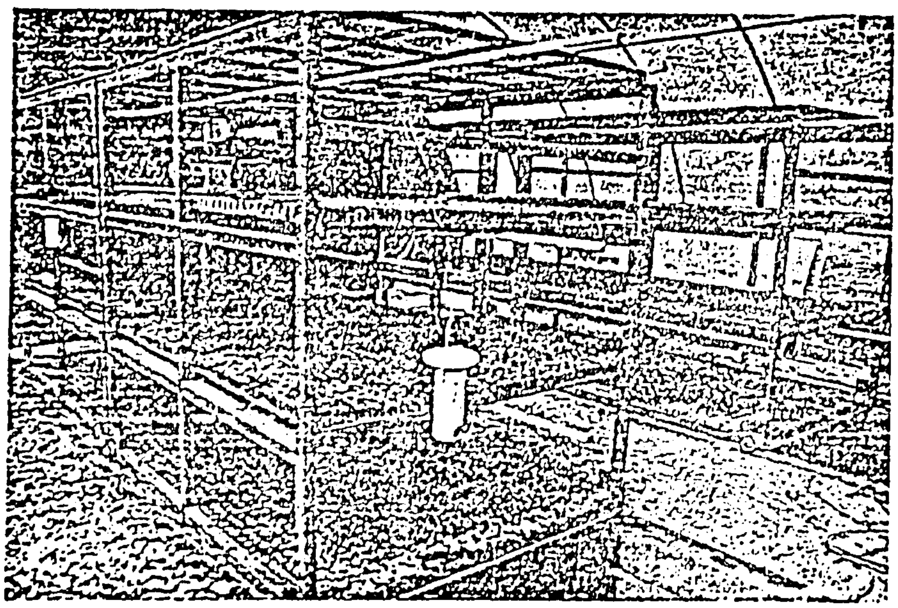


Figure 2. Tobacco transplant production in greenhouse bulk curing and drying system.

16

that lost to the outside environment were monitored during this initial study.

A limitation in analyzing the data in Tables 1 and 2 is the lack of information about the total energy lost from the structure during a given period. A transient analysis to determine this information would require, among other things, knowledge of wind speed and cloud cover, variables which were not monitored during this study. An approximation of the total heat loss during a 24-hr period can be made, however, by noting that the energy stored within a given period was always depleted within that same 24-hr period and that the thermal capacitance of the structure, excluding the rock beds and furnace room, was small. This allows the total heat lost during a 24-hr period to be estimated by the sum of the energy stored in the rock beds and the energy supplied by the heater. Thus, the energy stored during each of the two periods considered becomes 7.7% and 15.9%, respectively, of the total estimated heat loss of the structure.

Table 1. Energy stored and vented versus energy supplied by the auxiliary heater for the period January 1-6, 1976.

Date	Q_h[1/] (GJ)	Q_s (GJ)	Q_v (GJ)	Ambient Low (°C)	Degree Days[2/]
January 1	0.42	0.13	0.037	6.8	8.0
January 2	0.55	0.13	0.057	-2.2	11.8
January 3	0.62	0.0	0.0	3.7	6.6
January 4	0.85	0.10	0.0	-0.7	14.8
January 5	1.13	0.04	0.0	-13.1	21.0
January 6	1.21	0.00	0.0	-12.4	19.8
Totals	4.78	0.40	0.094		82.0

1/ Based on 20.4 kJ/l net heating value for L.P. gas

2/ Calculated using a 15.6°C base

11

Table 2. Energy collected and vented versus energy supplied by the auxiliary heater for the period January 10-15, 1976.

Date	Q_h[1/] (GJ)	Q_s (GJ)	Q_v (GJ)	Ambient Low (°C)	Degree Days[2/]
January 10	0.86	0.16	0.0	-10.3	18.7
January 11	0.78	0.0	0.0	-4.4	12.1
January 12	0.61	0.13	0.10	-3.4	12.3
January 13	0.49	0.07	0.0	-4.4	9.0
January 14	0.28	0.14	0.18	5.7	7.7
January 15	0.63	0.19	0.16	-7.2	13.7
Totals	3.65	0.69	0.44		73.5

[1/] Based on 20.4 kJ/l net heating value for L.P. gas

[2/] Calculated using a 15.6°C base

A feeling for the potential capability of the system is indicated by adding Q_s and Q_v and comparing this to the total estimated heat loss. For the period of January 10-15, as much as 26% of the total estimated heat loss could have been supplied if the rock beds had been large enough to collect all of the available solar energy. Undoubtedly the data for February and March will show an even stronger trend in this direction.

Table 3 provides a slightly different look at the data. Here, Q_s and Q_v are shown with Q_p, the total energy incident upon horizontal and vertical surfaces with areas equal to the greenhouse floor and north wall respectively. Q_p was calculated, using the method of Liu and Jordan (1963), from the total daily radiation on a horizontal surface obtained by numerically integrating the solar insolation curve. A total diffuse to direct ratio of 0.2 was assumed along with an albedo factor of 0.2. The daily efficiencies N_s and N_{s+v} were calculated from

$$N_s = Q_s/Q_p, \qquad (1)$$

18

Table 3. Daily collection and storage efficiencies versus Φ and Δt for the period January 10-15, 1976.

Date	Q_s (GJ)	Q_v (GJ)	Q_p (GJ)	N_s (%)	N_{s+v} (%)	Φ 1/	Δt (^oC)
January 10	0.16	0.0	1.26	12.9	12.9	4	17.1
January 11	0.0	0.0	.85	0.0	0.0	6	15.8
January 12	0.13	0.10	1.47	9.1	16.0	2	21.8
January 13	0.07	0.0	.88	8.0	8.0	6	11.6
January 14	0.14	0.18	1.40	10.2	23.0	1	14.6
January 15	0.19	0.16	1.38	13.6	25.0	2	11.3

1/ Relative form factor for solar insolation curve and

$$N_{s+v} = (Q_s + Q_v)/Q_p. \tag{2}$$

The values of N_{s+v} compare quite favorably with daily efficiencies given by Close (1963) for good quality solar air heaters (25% to 50%).

The variations in N_{s+v} in Table 3 can be explained by the following discussion: For a given structure or collector, the daily efficiency varies inversely with the difference in air temperature (inside vs. outside), solar declination angle, frequency of fluctuation of solar insolation, and wind speed. Temperature difference, frequency of fluctuation, and wind speed are stochastic variables, while declination angle is a function of the time of year. Unfortunately, wind speed was not monitored during this study. However, Table 3 does include a relative form factor Φ, which describes the smoothness of the solar insolation curve for that day, and Δt, which is the temperature difference between inside and outside taken at 2:00 pm. The factor Φ varies from 1 for a smooth curve to 10 for a rapidly fluctuating one. Examination of Table 3 shows that the highest values of N_{s+v} occurred at the lowest values of Φ and Δt and that increasing Φ or Δt generally decreased N_{s+v}. The exception was on January 11 when a moderate Φ and Δt produced a zero efficiency. This more than likely resulted from higher than normal wind conditions which probably caused the heat loss to be greater than the 15.8°C would indicate. For two periods in January, approximately 8% and 16% of the total estimated heat loss of the structure was collected and stored. If the storage beds had been large enough to store the energy exhausted through ventilation, the potential savings could have been as high as 26% for a period when lows of -4°C were experienced. Undoubtedly this percentage would have been larger in February and March, when solar insolation values are higher. Nevertheless, a potential energy reduction of 26% in January indicates that a significant fuel savings can be achieved without having to resort to the more expensive conventional solar collection systems.

With the removal of the flowers and tomatoes in March 1976, the greenhouse was set up for tobacco transplant production. Portable frames were placed in the greenhouse. Each frame had four layers consisting of perforated sheet metal covered frames that slide in on the same spacing (approximately 25 inches) as the bulk tobacco racks. An automated misting system was installed on each layer to provide a fine misting for approximately 30 seconds per 30 minutes during daylight hours. Temperatures in the greenhouse were maintained between 72°F minimum and 85°F maximum during the day and 65°F minimum at night.

The tobacco seedling, growing and handling trays were seeded the middle of April 1976. The soil mixture used was Hecco number 1 soil - a spraghum peat moss mixture. The soil mixture was almost saturated prior to being placed in the trays. Once the trays were seeded, they were placed on three layers of the portable frames.

Seedling emergence began approximately 8 to 9 days after seeding. Germination rates of 95-97% were obtained on each layer (Fig. 2). Uniform growth occurred through the third week at which time the seedlings were damaged by over-fertilization. Additionally, light level variation between layers and within each layer contributed to the non-uniform growth. The light levels varied from approximately 1500-2000 foot candles on the top layer to 500-100 foot candles in the middle and bottom layers. This lighting difficulty can be easily solved by adding artificial lighting or by rotating the layers.

Tobacco transplant production can be achieved using multiple layer growing with appropriate lighting and watering system. Uniform transplants can be produced in 6 to 8 weeks.

B. Curing and Drying Operation of Greenhouse Bulk Curing Solar Barn

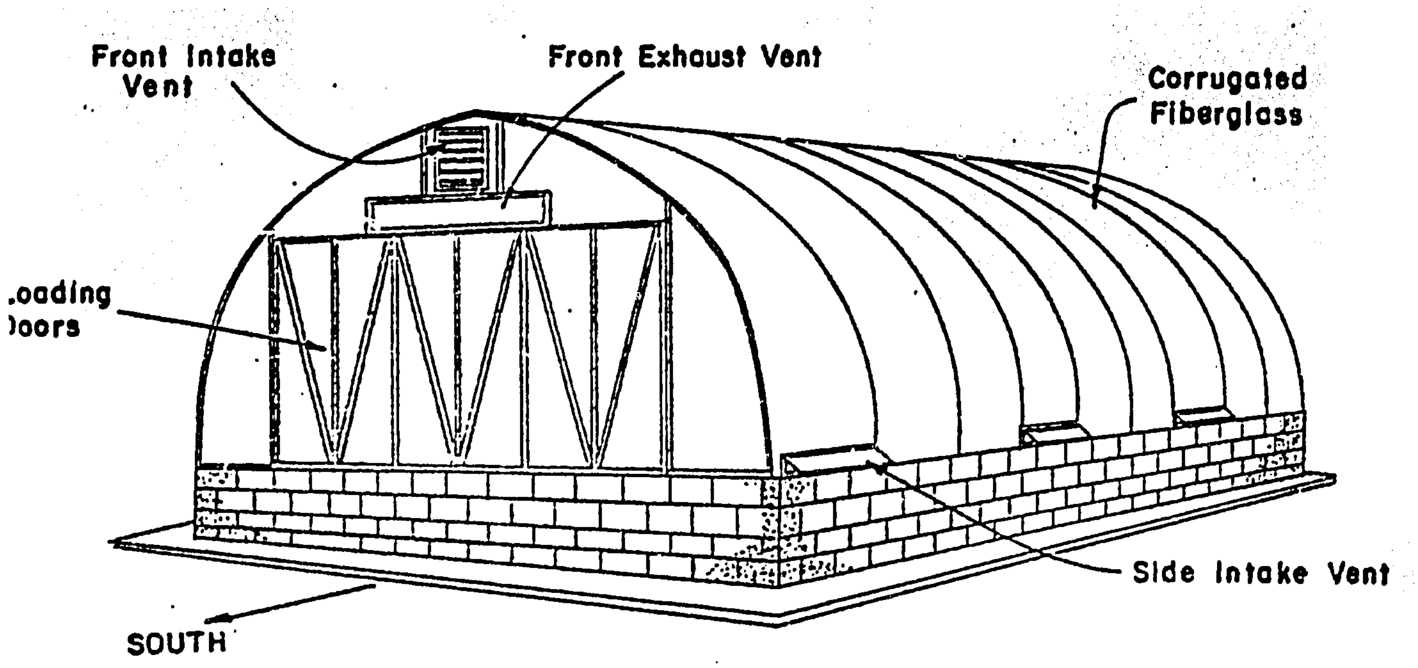
The greenhouse bulk curing system is basically a greenhouse which accommodates a solar energy bulk curing module during tobacco curing. The system, as shown in Figure 3, consists of a combination curing/growing room with facilities for curing tobacco or growing plants, furnace room with heating unit, auxiliary fan and appropriate air flow plenums, gravel energy storage system consisting of gravel and corrugated slotted ducts, top air duct with shutters and side openings for air flow control, side vents for air intake or exhaust, and portable frames to support plants or tobacco.

For tobacco curing, heat absorbers are added to the sides and tops of the portable frames to form a bulk curing module within the greenhouse (Figure 3b). Solar energy is absorbed and transferred to air moved over these black surfaces by the auxiliary and/or furnace fan(s). This preheated air is used either for curing or storage, depending upon curing requirements. Outside air enters the structure for preheating either from the front shutter or side vents (Figure 3a), depending upon the available solar energy and curing energy requirements. The top air duct and bottom gravel air ducts cause the air flow to be uniform over the absorber surfaces.

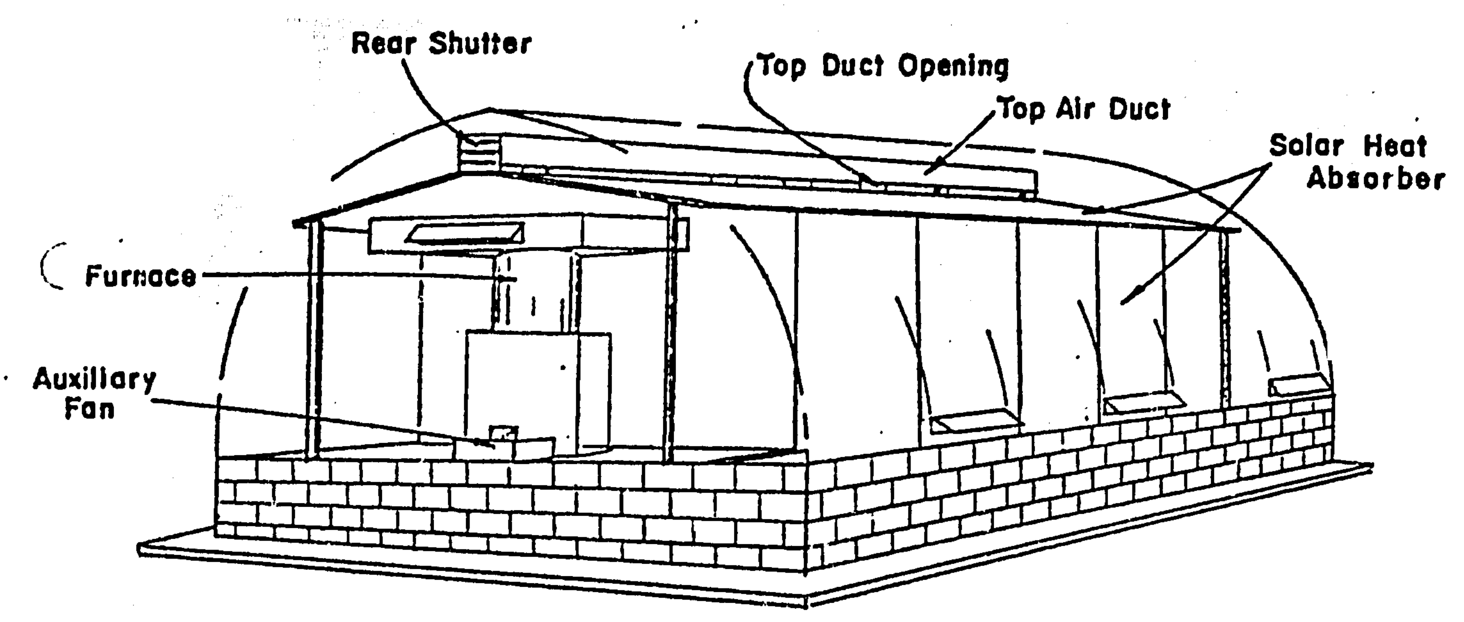
Motorized shutters were added to the front, rear, and rear bottom of the top air duct for air flow control of the preheated air. The side vents were also motorized. The preheated air for energy storage or for curing can then be easily controlled for optimum energy utilization as required by the curing stage and available solar energy. Fresh air can now be pulled in from either the top or sides of the structure to optimize the solar energy collection, storage, and utilization.

Solar energy utilization tests were conducted during July, August and September, 1976. Five complete cures were made in the greenhouse solar curing barn, and five were made in a conventional bulk curing barn used as a control. Curing procedures were approximately the same in each barn with minor variations as required by the individual cures.

82



(a)



(b)

Figure 3. Greenhouse bulk-curing system: (a) front view and (b) rear view.

The general curing procedure was as follows:

(1) Bulk racks were filled in the field and placed in the barn.

(2) The furnace was fired and a typical bulk curing schedule followed for temperature and air ventilation rate. The temperature curing schedule generally consisted of two-three days yellowing at 32-35°C, three days of leaf drying with the air temperature being advanced from 32°C to 76°C at 1 to 1.5°C per hour, and one day of stem drying at 76°C. During leaf drying, the temperature was maintained at certain levels as determined by tobacco conditions. The air ventilation rate wa usually 10% or less for yellowing, gradually increased during initial leaf drying until it was about 50% for temperatures of 54 to 60°C, then gradually reduced durin later stages of leaf drying, and held at 10% or less intake during stem drying.

For the solar curing barn, air preheated by either the absorber or the gravel was used as intake to the furnace during both day and night operation as shown in Figures 4-7 and as discussed below.

(1) The daytime yellowing configuration used to store solar energy in the gravel (Figure 4) was a closed loop circulation of the air over the heat absorbers, through the gravel to the auxiliary gravel fan and then through the top duct for recirculation. If the system temperature was resulting in a tobacco temperature above 38°C, outside air was brought into the system through the front shutter, preheated by the solar heat absorbers, pulled through the gravel by the auxiliary fan and exhausted out the back of the structure as shown in Figure 5. The air circulation within the curing room was through the furnace to the air plenum beneath the tobacco, up through the bulk tobacco racks, and to the furnace return doors for recirculation. If some drying was to be done, the furnace intake was opened slightly.

(2) For leaf drying the air flow configurations for solar energy collection and utilization were as shown in Figures 6 and 7. For the first day, outside air

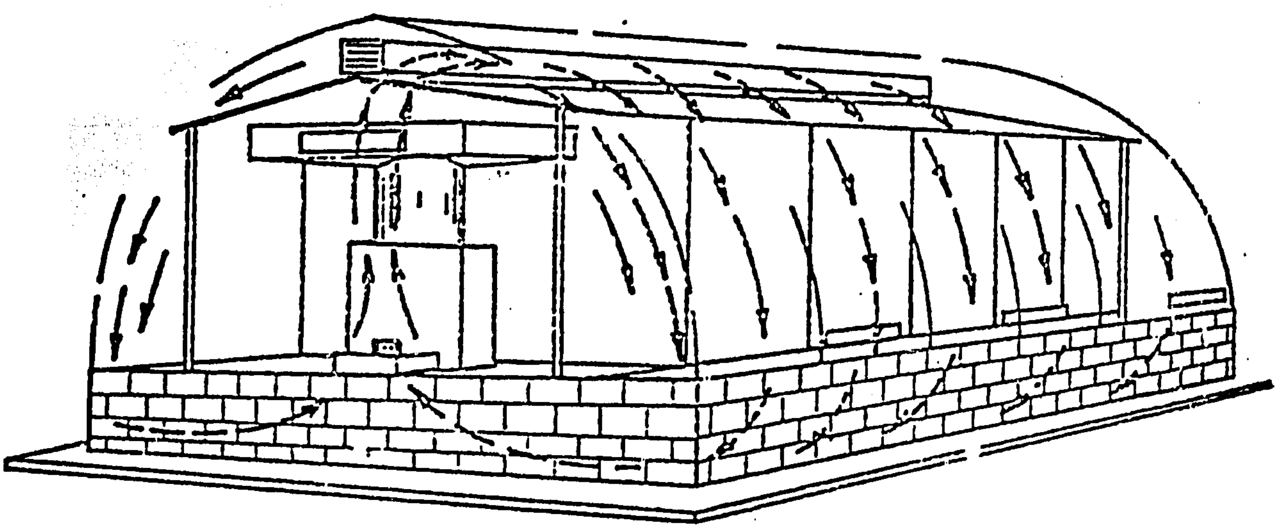


Figure 4. Air flow configuration for closed-loop energy storage during yellowing stage.

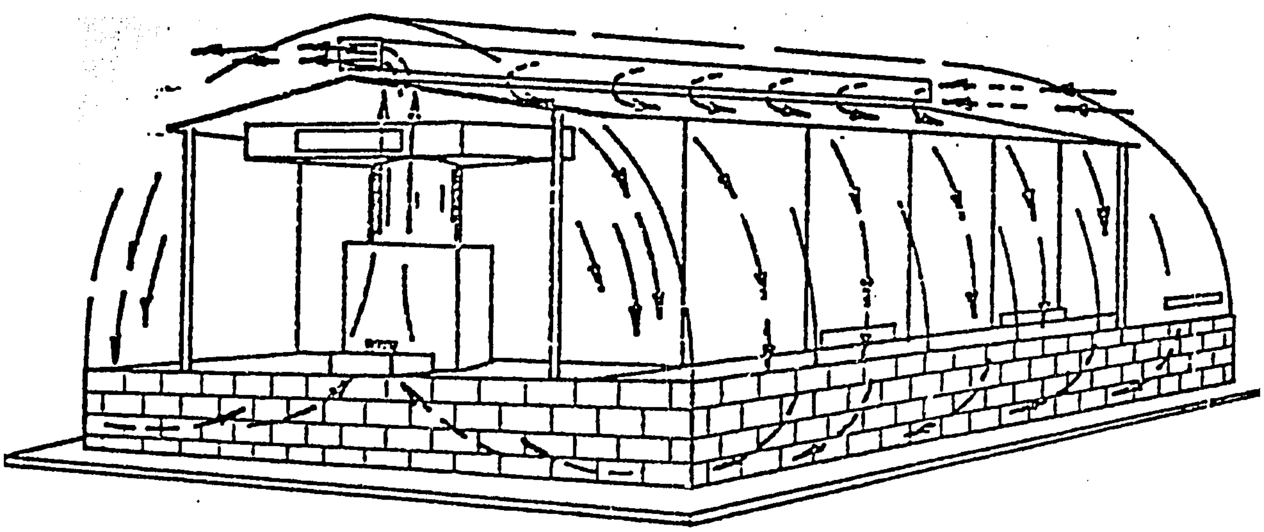


Figure 5. Air flow configuration for open-ended energy storage during yellowing stage.

95

entered the system through the front shutter as shown in Figure 6, was preheated by the absorber panels, was pulled through the gravel by the auxiliary and furnace fan for movement into the furnace intake, was pushed through the tobacco, and was either pulled into the furnace intake for recirculation or exhausted through the front exhaust. The furnace intake damper setting determined the percent recirculation. For the second and third days of daytime leaf drying, outside air was pulled in through the side vents, passed over the absorbers for preheating, and moved through the top duct and into the furnace room for intake to the furnace. The air flow configuration shown in Figure 6 was used for nighttime drying.

(3) For the stem drying stage, outside air was provided as shown in Figure 7 for daytime drying and as in Figure 6 for nighttime drying.

Instrumentation for monitoring the test conditions and variables consisted of a data system with thermocouples to measure temperature, multipoint recorders for monitoring these sensors, a strip chart recorder for monitoring radiation levels measured by a pyranometer, and an LP gas meter to measure fuel consumption. Copper constantan thermocouples were used to measure ambient air temperatures, collector-air and-surface temperatures, gravel air temperatures, and curing air/ tobacco temperatures. For air temperatures, shielded thermocouples measured both dry and wet bulb temperatures. Surface temperature measurements were made by attaching the thermocouples to the surface of the material. Thermocouples were placed within the tobacco rack to measure tobacco bulk temperatures. The locations of these thermocouples are shown in Figure 8.

Solar energy was used by the greenhouse solar curing barn to supplement the energy requirement for bulk curing of tobacco. Air intake for the furnace was preheated during the daytime by the solar heat absorbers and at night by the gravel which had solar energy stored in it during the day. Sample data for one

86

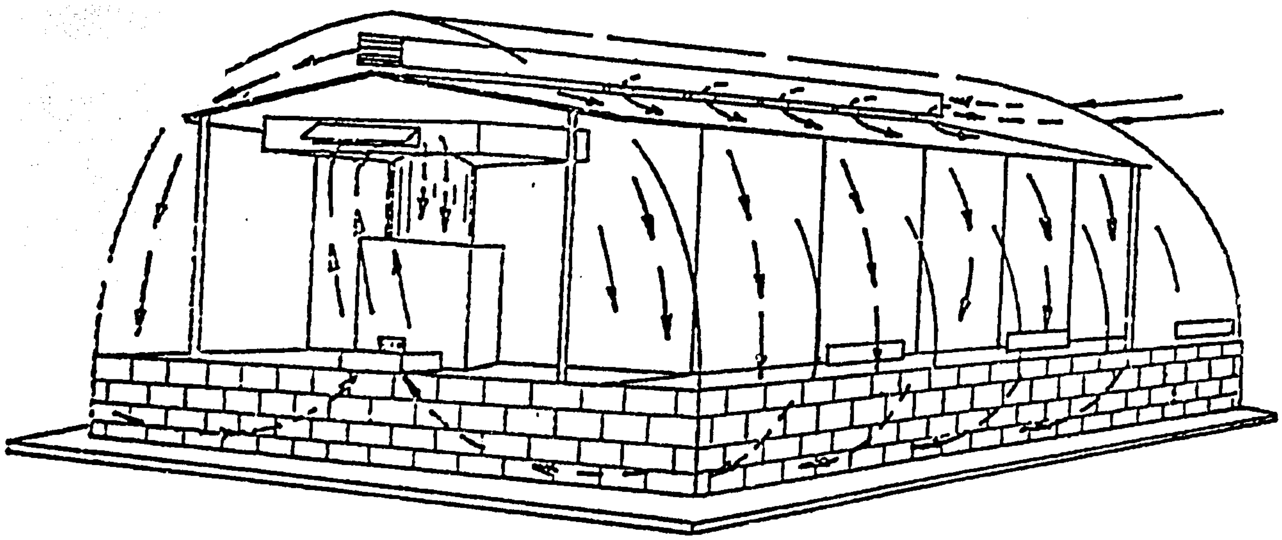


Figure 6. Air flow configuration for energy storage and supplemental heating of furnace air during initial leaf drying stage.

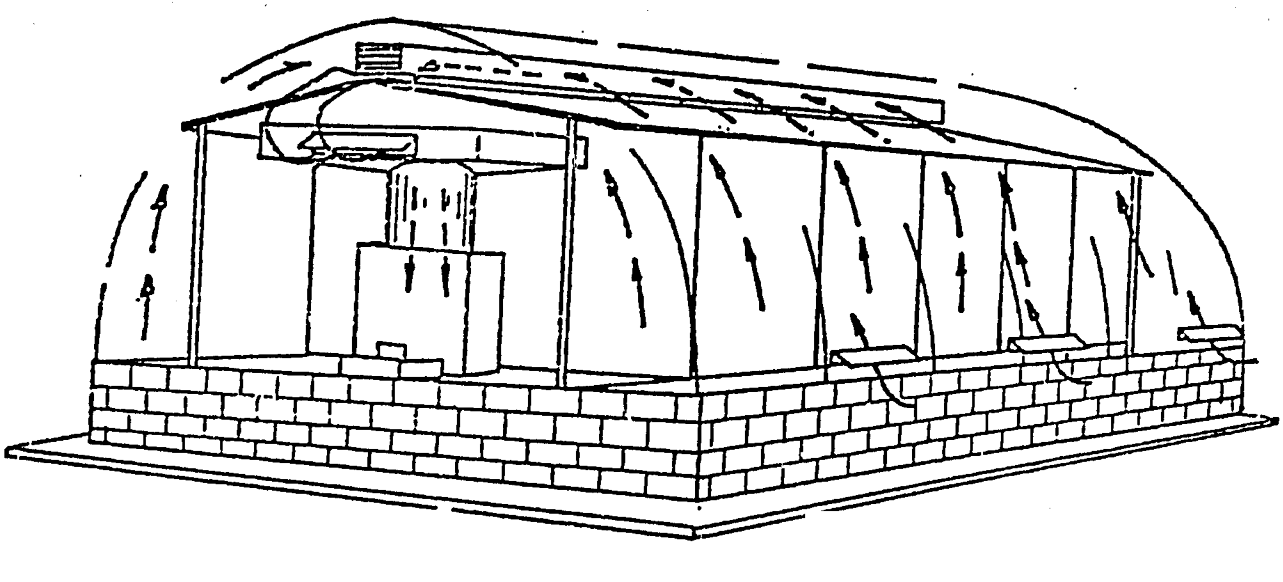
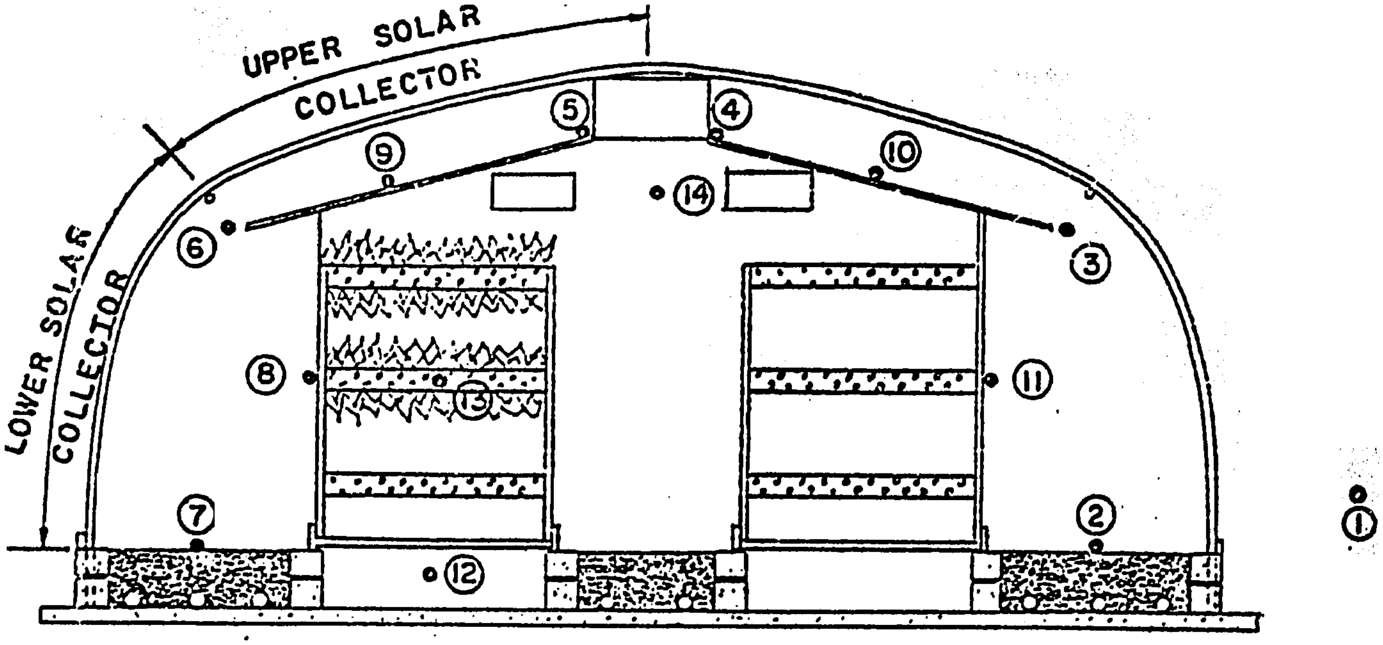


Figure 7. Air flow configuration for preheating furnace air intake during final leaf and stem drying stage.

97



(1) Outside air temperature (DB)

(2) Gravel surface air temperature (East)

(3) Midway collector air temperature (East)

(4) Top collector air temperature (East)

(5) Top collector air temperature (West)

(6) Midway collector air temperature (West)

(7) Gravel surface air temperature (West)

(8) Vertical absorber surface temperature (West)

(9) Sloped absorber surface temperature (West)

(10) Sloped absorber surface temperature (East)

(11) Vertical absorber surface temperature (East)

(12) Curing air temperature beneath tobacco

(13) Tobacco temperature within rack

(14) Curing room temperature

Figure 8. Cross-sectional view of greenhouse bulk curing system showing locations of thermocouples.

complete cure, August 26 - September 2, 1976, is presented and discussed in this report as typical results to be expected for solar energy collection, storage, and utilization by the greenhouse solar curing system.

Incident solar radiation is collected by the upper and lower solar collector sections (Figure 8) of the system. Absorber surface temperature of 82° to 97°C are reached on clear sunny days when the sun is approximately perpendicular to the absorber surfaces. Figure 9 shows the absorber temperatures for the west side, lower and upper collectors. The temperature decreases on August 27 and 28 were caused by changing the yellowing stage, air flow configuration for energy storage from closed loop (Figure 4) to open-ended (Figure 5) circulation. Energy collection and storage for the solar barn on these days was causing the tobacco temperature to increase above 38°C, an upper temperature limit for "safe" yellowing. The air flow configuration was changed to decrease this build-up. The design changes for increasing the storage capacity and air flow rates should allow the greenhouse solar curing system to store collected solar energy more efficiently. Then, the above air flow configuration change will not be necessary. The daytime temperature decrease on August 29 was caused by a thunderstorm.

Energy absorbed by the collector surfaces is transferred to air moved over them. In Figure 10, the difference between the outside air temperature and the top collector air temperature represents the degree of air heating produced by the west side, solar collector sections (Similar results were achieved on the east side). The air temperature differential across the two collector sections varied from a minimum of 18°C on August 29 to a maximum of 43°C on September 1, excluding the low collector air temperature on August 29 caused by the thunderstorm. The air ventilation rates for drying on these days were approximately 40 and 10 percent respectively which corresponded to center-line collector velocities of 0.11 and 0.02 meters per second respectively. Radiation levels on these days,

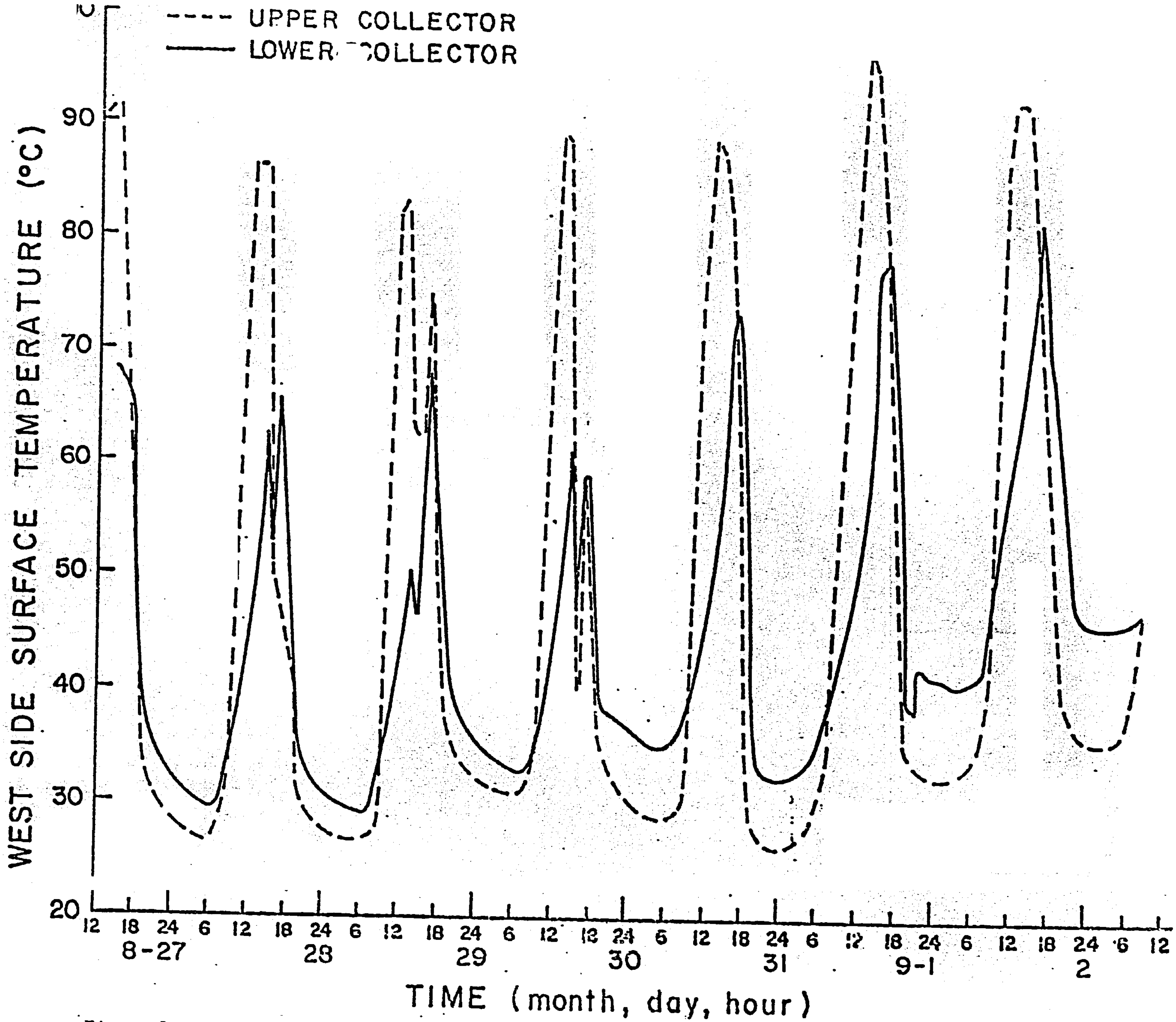


Figure 9. Absorber surface temperatures during one complete cure

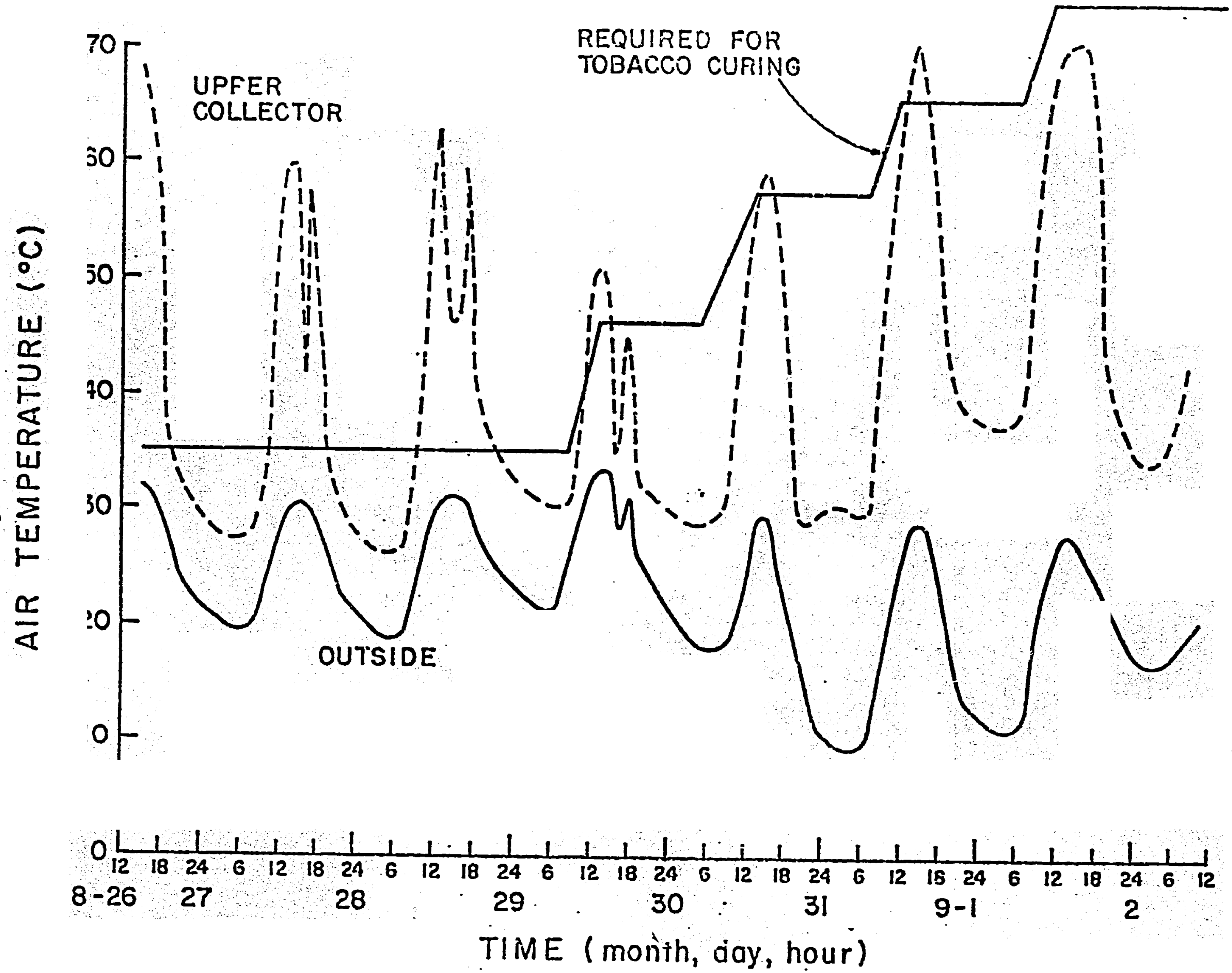


Figure 10. Air temperatures involved in tobacco curing with greenhouse solar curing system.

and also for the entire cure, were approximately the same with peak day, total hemispherical radiation being about 875 watts per square meter. The higher collector air temperatures achieved at the beginning and end of the cure occurred when air movement through the collector section was less than 0.02 meters per second.

The difference between the outside air temperature and the required tobacco curing temperature (Figure 10) is indicative of the total energy that must be supplied for curing. The energy that was supplied from fossil-fuel energy is represented by the temperature difference between the collector air and curing air. As shown by the curves of Figure 10, the energy requirement above that supplied by solar collection occurred mainly at night.

The overall fuel savings achieved by the greenhouse solar curing system as compared to a conventional bulk curing barn was 30 percent for five complete cures during the summer, 1976. The average LP fuel consumed in gallons per pound of cured (and ordered) tobacco was 0.075 for the solar barn and 0.107 for the conventional bulk barn. The curing time, fuel consumption, tobaccos used, and fuel saving per cure are given in Table 1 below. The fuel savings for the individual cures varied from a low of 7 percent for the second cure to a high of 40 percent for the fifth cure. The low fuel saving for the second cure of the solar barn was caused by two days of rain and three cool nights, temperatures of 15° to 18°C, which occurred during the peak energy requirement for leaf and stem drying in the solar barn. The conventional bulk barn's second cure had been started two days before the solar barn's second cure, and leaf drying was almost completed prior to this cool weather.

The LP fuel consumption rate of 0.075 gallons per pound of cured tobacco for this years work is only slightly better than last years rate of 0.077. The design

92

changes of increased absorber area, increased storage area, and housed furnace room contributed more to the overall savings than is apparent from the 0.075 fuel consumption rate and the 30 percent fuel savings. Because of damage to the vertical absorber panels during the previous year's work, the material for these panels was changed from one-half inch aluminum foil faced polyurethane panel to one-half inch plywood. The thermal resistance values of these materials are 0.55 and 0.20 (seconds square meters °C per joule) respectively. The increased collection/storage and the housed furnace room design changes increased the system performance so as to just offset the increased heat loss from the vertical sides due to the lower R-values. Aluminum sheet faced polyurethane panels will be used in future studies.

Table 4. Tobacco cures for greenhouse solar curing barn and conventional bulk barn

Conventional Bulk Curing Barn			Greenhouse Solar Curing System			
Curing Time (days)	Fuel used (gal/lb tobacco)	Primings/ varieties	Curing Time (days)	Fuel used (gal/lb tobacco)	Primings/ varieties	Fuel Savings (%)
8	0.148	First primings for G-28, Coker 319 and plot tobacco	7.3	0.120	First primings for G-28	19
7	0.111	Second primings for G-28 and plot tobacco	7	0.103	Second primings for G-28	7
6	0.094	Third primings for plot tobacco	8.2	0.066	Third primings for G-28	30
7	0.092	Fourth primings for Coker 319	6.7	0.057	Fourth primings for Coker 319 & G-28	38
7	0.094	Top of stalk for plot tobacco	7	0.056	Top of stalk for Coker 319, G-28 and plot tobacco	40
Average	0.107	-	-	0.075	-	30

The greenhouse solar curing barn utilized solar energy to achieve a significant energy savings of 30 percent as compared to a conventional bulk curing barn. Design improvements in collection, storage and air flow control contributed to a more efficient overall performance of the system. By using a higher thermally resistive material to form the absorber sides and tops, energy savings of 40 to 50 percent should be achievable.

C. Computer Simulation Analysis of Thermal Behavior of Tobacco Curing in Solar Barn

In order to further optimize the design of solar barn, it is necessary to investigate its thermal behavior. Computer simulation analysis representing the system and boundary conditions by a thermal circuit would provide powerful techniques for studying the thermal behavior of a complex heat transfer system.

The complete thermal circuit representing the whole solar barn is very complicated. Idealized and simplified thermal circuits are described for the solar collectors consisting of a transparent fiberglass exterior and a black surfaced insulation board heat absorber interior. Basically, the solar barn consists of four solar collectors (S.C.), namely, east-side upper S.C., east-side lower S.C., west-side upper S.C., and west-side lower S.C. as shown in Figure 11. The structure is oriented north and south longitudinally and symmetrical with respect to east and west. This orientation receives the highest annual solar radiation and also receives the highest monthly radiation for June, July, and August - the tobacco curing season.

It is assumed that the net long-wave radiation exchange between the outer surface of the fiberglass wall and the surroundings is small and can be included in its convection heat transfer. Thermal-energy transfer through all structural elements is considered to be unidirectional and perpendicular to the long dimension. All lumped thermal properties are considered to be constant over

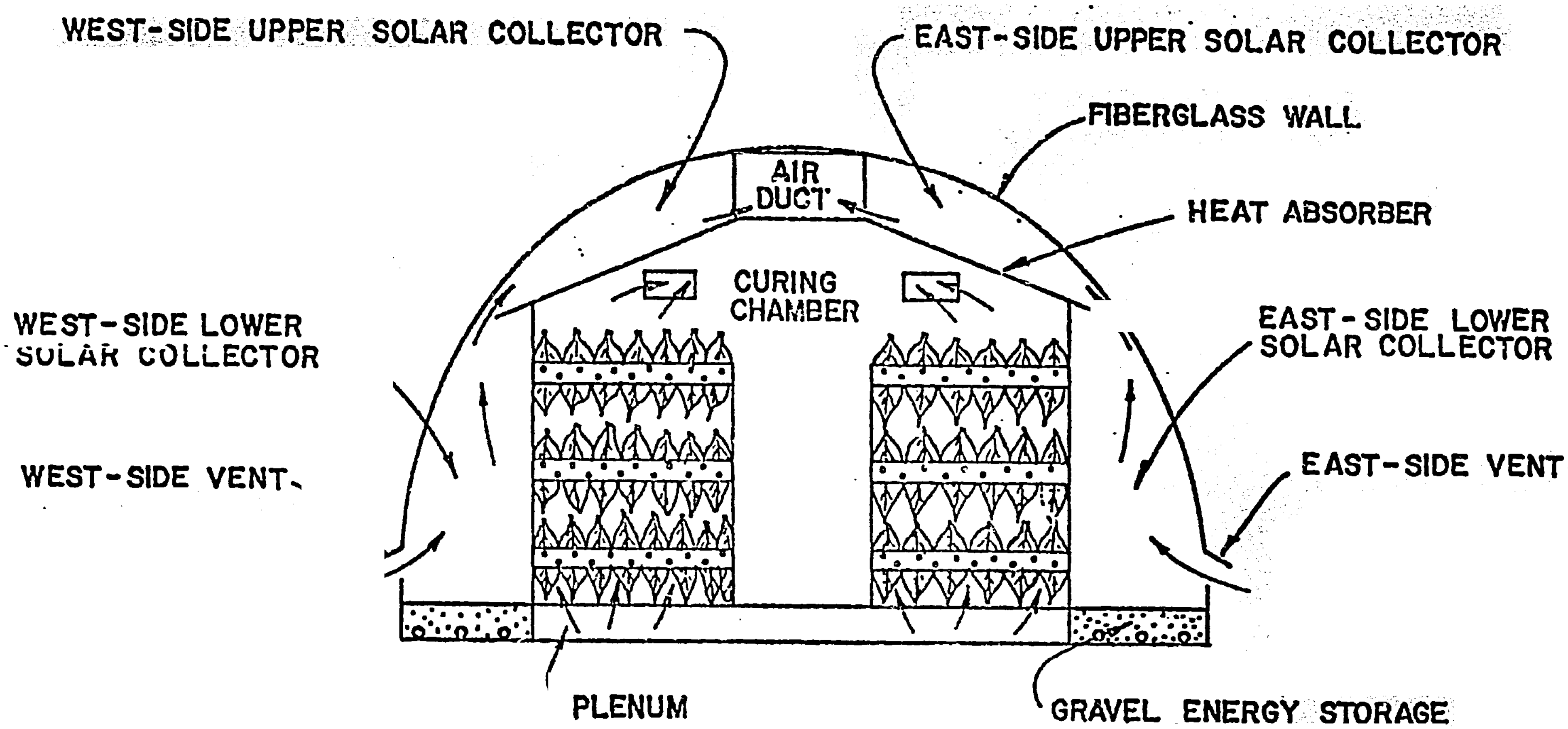


Figure 11. Schematic cross-sectional view of greenhouse bulk curing solar barn.

the temperature range encountered, and the space temperature is considered uniform at any instant.

The thermal circuits representing the upper solar collector (Figure 12) and lower solar collector (Figure 13) are shown in Figures 14 and 15 respectively.

The ratios and units of analogous electrical and thermal parameters chosen for this study are given in Table 5.

Table 5. Ratios and units of analogous electrical and thermal parameters

Quantity	Units: Thermal	Units: Electrical	Scale Factors: Ratio	Scale Factors: Value
Time	hrs	sec	$\frac{\theta_e}{\theta_t}$	2
Capacity	$\frac{\text{Kcal}}{^oC}$	Farads	$\frac{C_t}{C_e}$	4×10^6
Resistance	$\frac{^oC}{\text{Kcal/hr}}$	Ohms	$\frac{R_e}{R_t}$	8×10^6
Potential	^oC	Volts	$\frac{E}{T}$	1
Rate of Energy Transfer	$\frac{\text{Kcal}}{\text{hr}}$	$\frac{\text{Coulombs}}{\text{sec}}$ or Amperes	$\frac{Q}{T}$	8×10^6

The symbols used in Figures 14 and 15 and Table 5 are defined as follows:

Symbols

R = conduction resistance

R_{co} = outside convection resistanc

R_{ci} = inside convection resistance

R_{ri} = inside 'surface' radiation resistance

R_{xy} = inside 'space' radiation resistance

Subscripts

f_1 = tilted fiberglass wall

f_2 = vertical fiberglass wall

h = heat absorber

d = top air duct

g = gravel energy storage

96

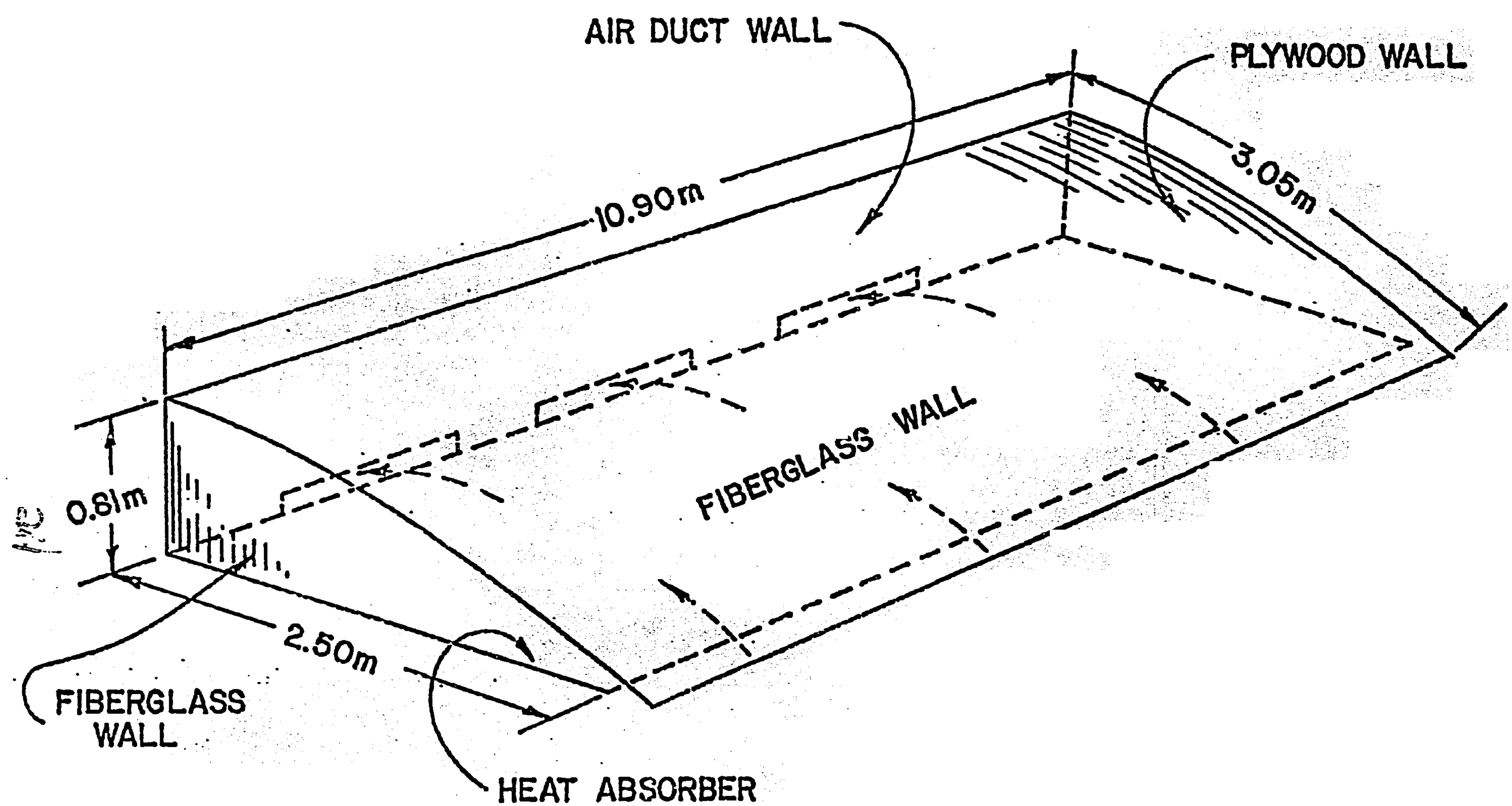


Figure 12. Schematic diagram and dimensions of upper solar collector.

97

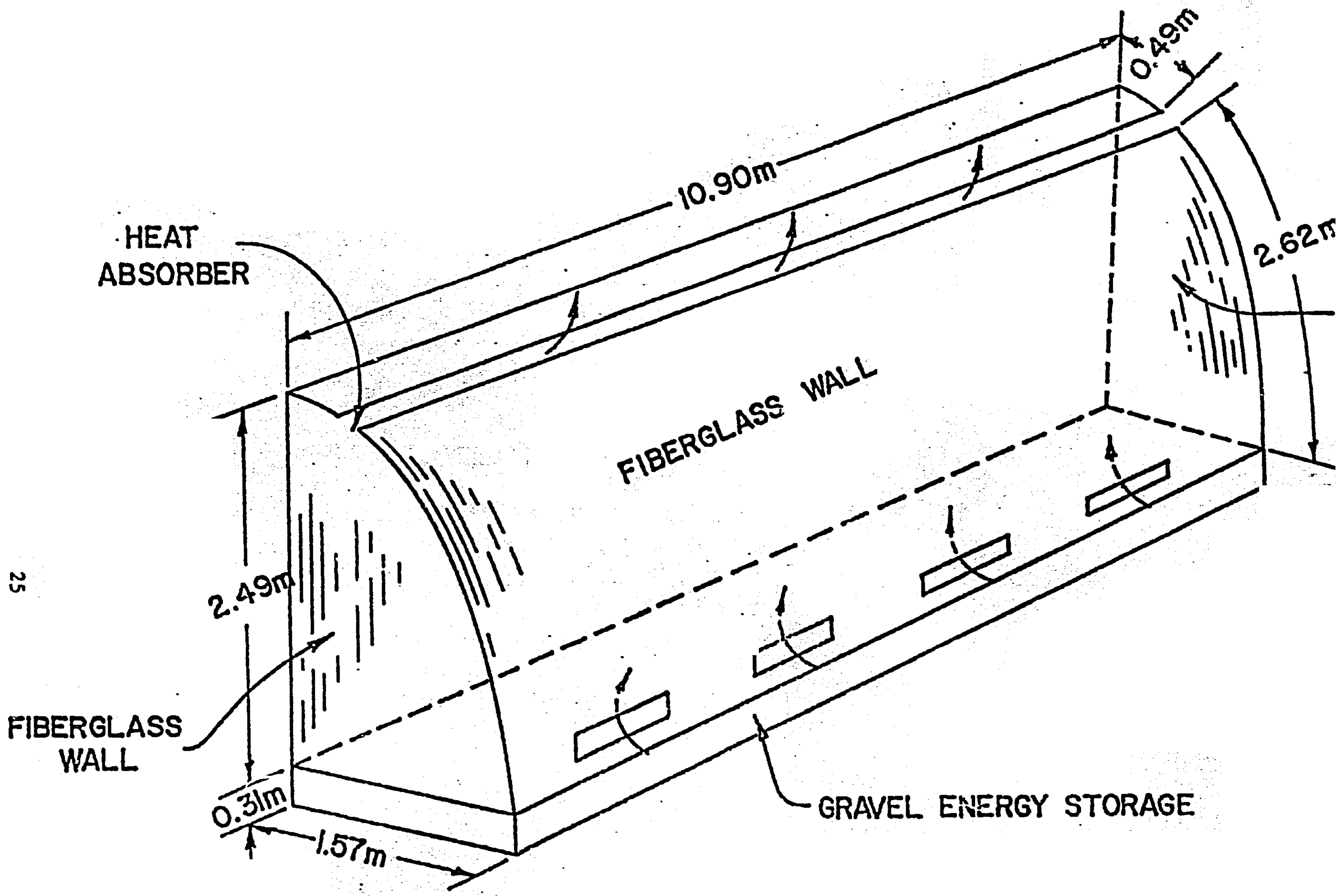


Figure 13. Schematic diagram and dimensions of lower solar collector.

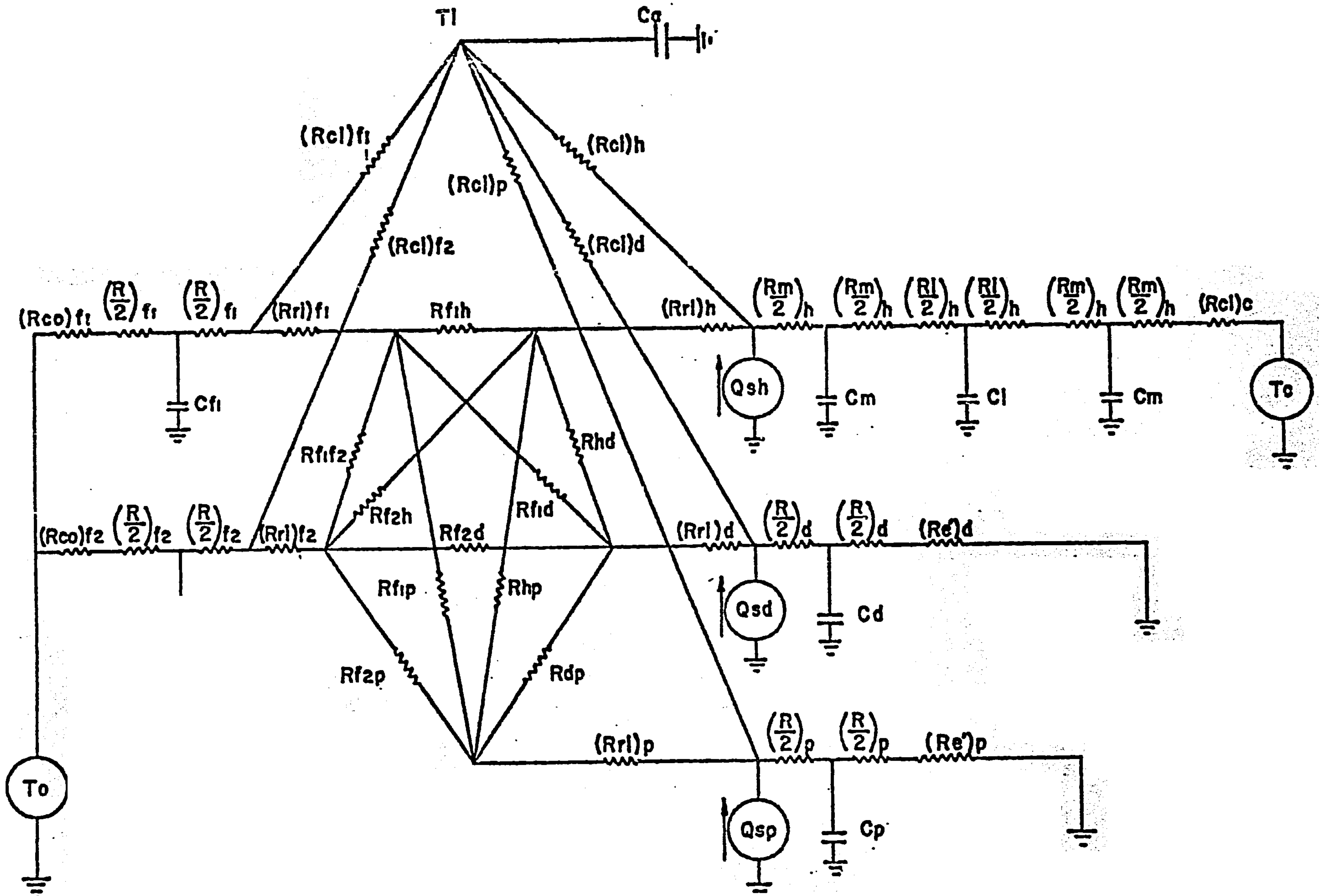


Figure 14. Thermal circuit representing upper solar collector.

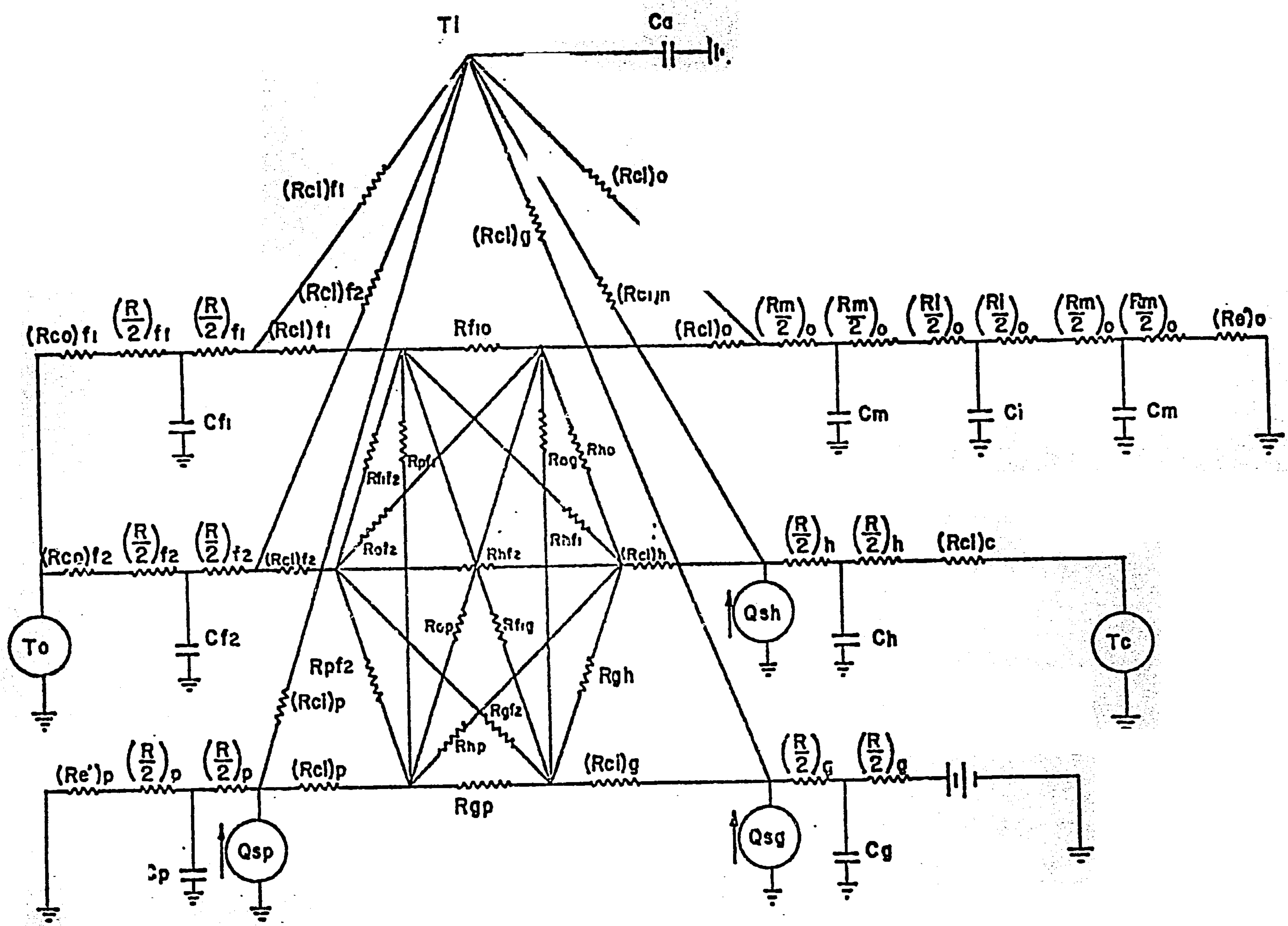


Figure 15. Thermal circuit representing lower solar collector.

<u>Symbols</u>

C = capacitor

T_i = inside air temperature

T_o = outside air temperature

T_c = air temperature of curing chamber

Q_s = solar radiation input

$R_{e'}$ = insulation resistance (5500×10^3 ohms)

θ = time

E = constant electrical potential

T = temperature

Q = heat flux

I = electric current

<u>Subscripts</u>

p = plywood wall

m = aluminum foil

i = insulating material

a = air space

e = electrical circuit element

t = thermal circuit element

o = overhang

c = curing chamber

A summary of the conduction path resistors and capacitors for the walls of the solar collectors was evaluated and is given in Table 6.

The wind velocity on Aug. 17, 1976 was measured between 2.0 - 3.0 m/sec during the day and night. Hence, the outside convection coefficient (h_c) was estimated as 6.71 Kcal/hr m^2 ^oC based on the formula by Hodges, et al (1966). It is expressed as

$$h_c = 0.053 + 0.746\ \mu_o \qquad (3)$$

where h_c is in cal/hr m^2 ^oC

μ_o is the outside wind speed in m/hr

The air velocity was small inside the solar collectors, the inside convective heat transfer was of free convection in domination. Hence, the inside h_c was estimated based on free convection and is given in Table 7.

Table 6. Values of solar collector wall conduction path resistors and capacitors

		Conduction Resistance (R x 10^3 ohms)	Capacitor (C x 10^{-6} farads)
Upper Solar Collector	Heat Absorber (h)		
	Aluminum Foil (m)	0.08 x 10^{-3}	0.20
	Insulation Board (i)	246.4	1.00
	Tilted Fiberglass Wall (f_1)	8.2	2.55
	Vertical Fiberglass Wall (f_2)	168.2	0.12
	Air Duct Wall (d)	0.028	3.17
	Plywood Wall (p)	638.7	1.47
Lower Solar Collector	Heat Absorber (h)	38.4	24.50
	Overhang (o)		
	Aluminum Foil (m)	0.4 x 10^{-3}	0.04
	Insulation Board (i)	1266.0	0.19
	Tilted Fiberglass Wall (f_1)	9.6	2.18
	Vertical Fiberglass Wall (f_2)	83.8	0.25
	Plywood Wall (p)	318.4	2.95
	Gravel Energy Storage (g)	1321.2	601.9

Table 7. Inside convection coefficients of solar collectors Unit: Kcal/hr m^2 ^oC

	Upper Solar Collector	Lower Solar Collector
Heat absorber	3.66	2.71
Tilted fiberglass wall	2.31	2.00
Vertical fiberglass wall	1.99	1.99
Plywood wall	2.28	2.28
Air duct wall	2.71	-
Overhang	-	2.31
Gravel energy storage	-	2.91
Curing chamber	2.00	2.00

A summary of convection resistance based on h_c values of Table 7 is given in Table 8.

Table 8. Convection resistances for solar collectors

		Outside Convection Resistance (R_{co} x 10^3 ohms)	Inside Convection Resistance (R_{ci} x 10^3 ohms)
Upper Solar Collector	Heat Absorber (h)	-	79.5
	Tilted Fiberglass Wall (f_1)	35.5	102.9
	Vertical Fiberglass Wall (f_2)	728.1	2451.3
	Air Duct Wall (d)	-	331.6
	Plywood Wall (p)	-	2139.4
	Curing Chamber (c)	-	145.5
Lower Solar Collect	Heat Absorber (h)	-	108.1
	Tilted Fiberglass Wall (f_1)	41.5	138.9
	Vertical Fiberglass wall (f_2)	362.9	1221.9
	Plywood Wall (p)	-	1066.5
	Gravel Energy Storage (g)	-	159.0
	Overhang (o)	-	647.3
	Curing Chamber (c)	-	146.4

An average of surface temperature of 318°K (45°C) was used in the evaluation of the network radiation within the solar collector. A summary of network resistance is Given in Table 9.

The average air flow rate inside of the solar collector was recorded as 33.98 m^3/min, which is equivalent to 146.9 x 10^{-6} farad.

103

Table 9. Inside radiation exchange network resistances ($R \times 10^3$ ohms)

Upper Solar Collector	$(R_{ri})_{f1}$	2.0	R_{f1h}	52.4	R_{f1d}	237.6
	$(R_{ri})_{f2}$	40.7	R_{hd}	385.3	R_{f2h}	2090.9
	$(R_{ri})_h$	2.4	R_{dp}	5526.0	R_{f1p}	1256.9
	$(R_{ri})_d$	7.5	R_{f2p}	96707.0	R_{hp}	2307.7
	$(R_{ri})_p$	40.7	R_{f1f2}	1641.1	R_{f2d}	5526.1
Lower Solar Collector	$(R_{fi})_{f1}$	2.4	R_{f1f2}	986.9	R_{f20}	5780.3
	$(R_{ri})_{f2}$	21.3	R_{f1h}	77.3	R_{f2g}	1926.8
	$(R_{ri})_h$	2.6	R_{f10}	4622.2	R_{f2p}	40462.0
	$(R_{ri})_o$	13.1	R_{f1g}	144.4	R_{ho}	609.1
	$(R_{ri})_g$	4.1	R_{f1p}	1155.6	R_{hg}	211.9
	$(R_{ri})_p$	21.3	R_{f2h}	1305.2	R_{hp}	2436.3
	R_{gp}	2566.4	R_{og}	549.9	R_{op}	8294.1

Drying process with heated air is an adiabatic process, in which the energy required for evaporating moisture from the agricultural product is being supplied by the air resulting in reduction in air temperature. The temperature differential existing between the bottom and top of tobacco curing chamber is primarily due to the transition of sensible heat to latent heat of vaporization (Sykes and Johnson, 1969). The wet-bulb (adiabatic humidification) lines of the psychrometric chart can be used for calculating drying heat and mass balance.

Tobacco was tightly packed in the curing chamber in three tiers (Figure 11). The thermal circuit for simulating the tobacco leaves being dried was formed and is shown in Figure 16, in which R_ℓ represents the resistance of tobacco leaves

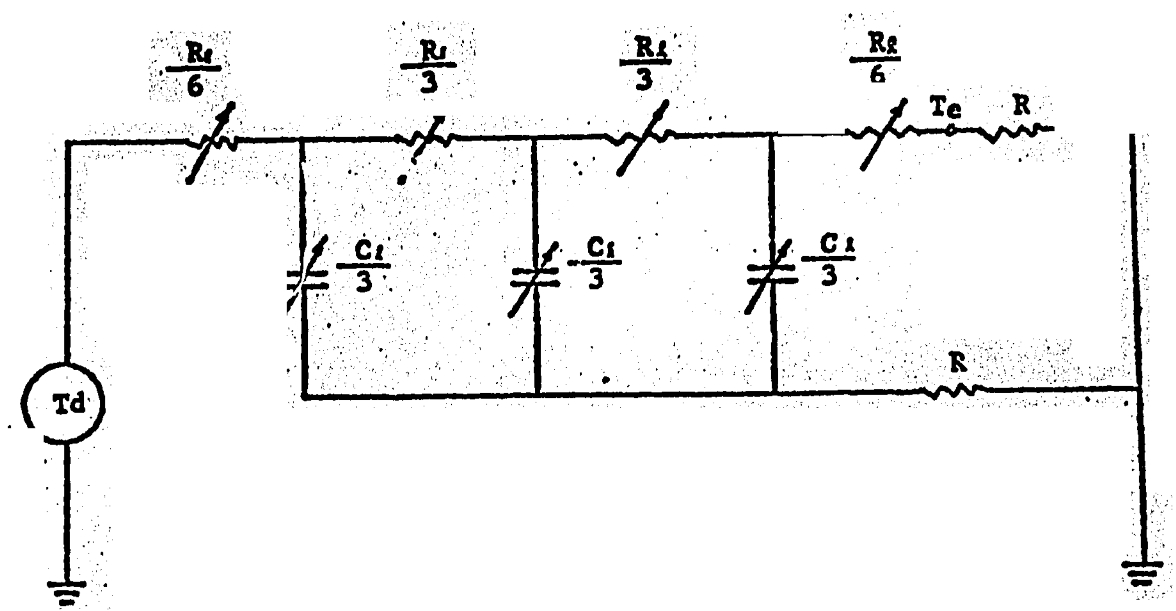


Figure 16. Circuit simulating three tiers tobacco leaves being dried.

and C_ℓ represents the capacitance of tobacco leaves. Each tier was simulated with one set of a resistor-capacitor network. Both R_ℓ and C_ℓ are time-varying parameters.

The value of C_ℓ may be evaluated based on the following equation:

$$C_\ell = C_p W \text{ (Kcal/}^\circ\text{C)} \tag{4}$$

where C_p = heat capacity of tobacco leaves (Kcal/Kg°C)

W = total weight of tobacco leaves (Kg)

and, R_ℓ may be evaluated from the following equation:

$$R_\ell = \frac{R(T_d - T_e)}{T_e} \tag{5}$$

or

$$R_\ell = \frac{R\ \Delta T}{T_d - \Delta T} \tag{6}$$

where T_d = drying air potential or entering air temperature

T_e = exiting air temperature

ΔT = the temperature difference between T_d and T_e

R = 500.0×10^3 ohms (suitable load resistance equilibrating environmental temperature)

Sykes and Johnson (1969) pointed out that the drying rate is proportional to the temperature differential across the mass of tobacco during drying and can be expressed as:

$$\frac{dw}{dt} = \left(\frac{Cs\ Q}{Las\ v}\right) \Delta T \tag{7}$$

or

$$\frac{dw}{dt} = K\ \Delta T \tag{8}$$

where $\frac{dw}{dt}$ = drying rate (Kg(water)/hr)

Cs = humid heat (Kcal/Kg(air)°C)

Las = latent heat of vaporization (Kcal/Kg(water))

Q = air flow rate (m^3/hr)

v = humid volume (m^3/Kg(dry air))

$K = \frac{Cs\ Q}{L_{as}\ v}$ = the proportionality factor (Kg(water)/hr ^oC)

ΔT = the temperature differential (^oC)

They also pointed out that the proportionality factor K was found theoretically to be practically constant for all stages of curing and to have a unique value for a given curing system. Using Eq. 8 along with assumptions discussed below and which are typical of practical curing situations, the variation of temperature differential across the tobacco can be predicted. The primary factor that influences the temperature differential is the total amount of water in tobacco. Based on data from the experiment, the amount of water can be calculated from the initial green weight and initial moisture content. If one assumes that 20% of the initial water is lost during yellowing stage, then 80% must be evaporated during leaf and stem drying stage. If the curing cycle is broken down into several equal intervals and the amount of water to be removed during each interval is specified, the drying rate may be determine for each interval. Since K can be calculated from known values of Q, Cs, Las, and v, Eq. 8 can be solved for ΔT for each interval. Then from Eq. 6, the corresponding R_ℓ is obtained.

Typical experimental data (Figure 17), which was recorded during drying stage, was selected for evaluating the circuit simulation. The entire curing cycle lasted 6.5 days with yellowing lasting 2.5 days and leaf and stem drying combined lasting 4 days. The tobacco green weight was 9179.8 Kg with an 84% m.c.(w.b.). It was assumed that 20% of water was lost during the 2.5 days of the yellowing phase (Suchinda, 1960 and Sykes and Johnson, 1969). Since the data started with the first day of drying phase, it was assumed that 18% of water was removed during the first 24-hr period of the drying stage. This 24-hr period was broken down into three equal intervals, i.e. 8 hours,

107

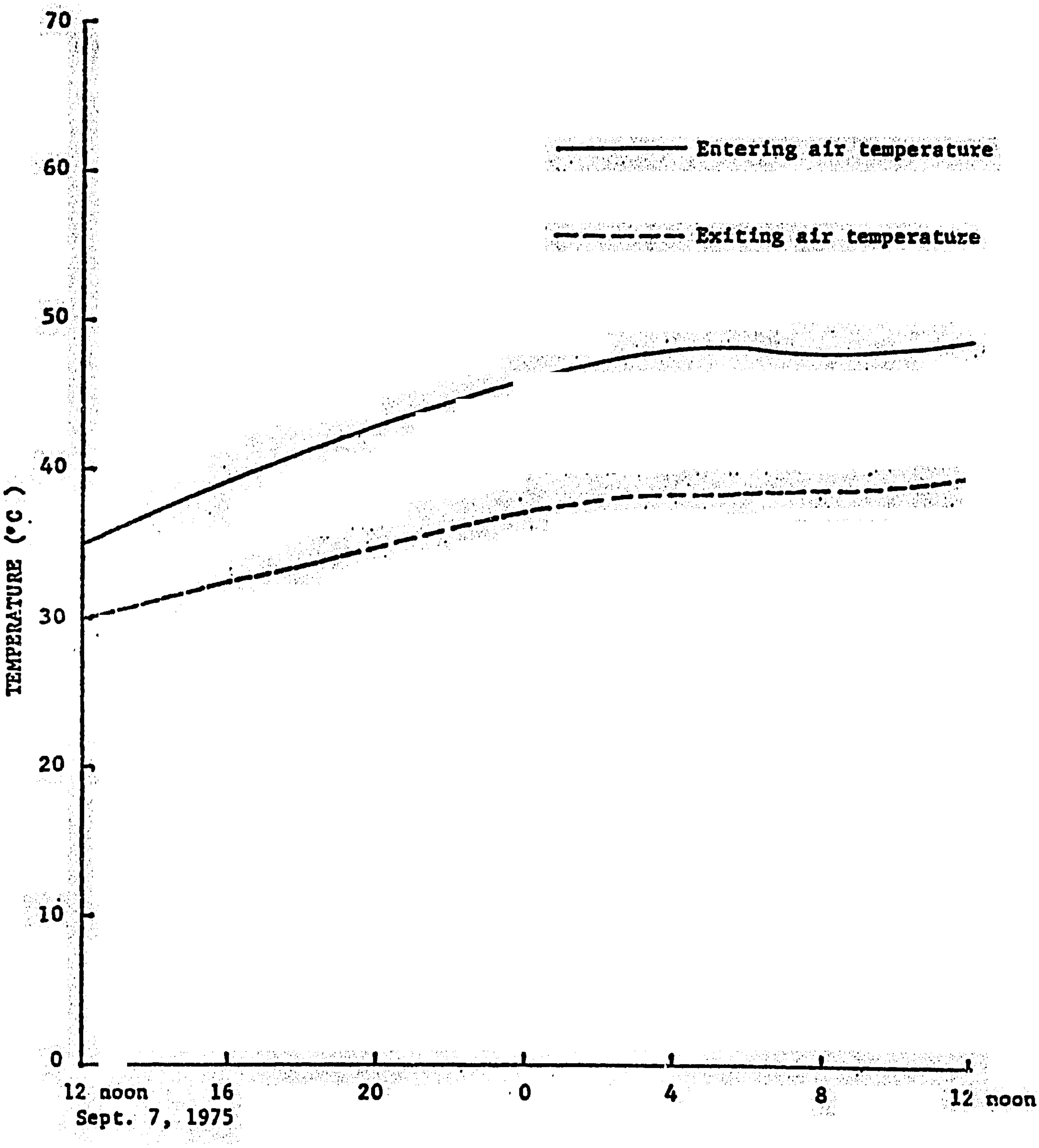


Figure 17. Typical data selected from tobacco drying experiments.

108

and the percentage of water to be removed was specified. The corresponding ΔT, W, C_p were then calculated accordingly and are listed in Table 10.

Table 10. ΔT, W, C_p values for each drying interval

Drying Interval	Percent Water Removed	$\Delta T(^oC)$	Tobacco Weight W(Kg)	Moisture Content (w.b.) %	C_p $(Kcal/Kg^oC)$ *
1	4	3.9	7329.1	0.79	0.89
2	6	5.8	6866.5	0.77	0.87
3	8	7.8	4780.8	0.76	0.86

*C_p was estimated based on 0.31 $Kcal/Kg^oC$ for tobacco of 1% m.c. (d.b.) and 1 $Kcal/Kg^oC$ for water (Brock, B.A. and M. Samfield, 1958)

The K value used in this study was evaluated as 9.8 Kg/hr ^oC. According to Table 6 and T_d obtained from Fig. 8, the corresponding R_ℓ and C_ℓ were calculated based on Eq. 3 and 1 respectively and are given in Table 11.

Table 11. R_ℓ and C_ℓ values for each drying interval

Drying Interval	T_d	$R_\ell \times 10^3$ ohms	$C_\ell \times 10^{-6}$ farads
1	39	55.5	1863.8
2	46	72.1	1475.1
3	48	97.0	1326.6

The tobacco curing experiments in the greenhouse bulk curing barn were conducted during the period of July 16 to August 27, 1976.

The PCAP (Princeton Circuit Analysis Program) computer programs for solar collectors were developed based on the thermal circuits (Figures 14 and 15), input ambient air potential (Figure 18), and solar radiation input evaluated from Figure 19. The simulation result was obtained and is shown in Figure 18. The curves show that the predicted air temperature is in good agreement with the measured temperature. Some phase delay is shown between measured and predicted values since a large capacitor was used to simulate the moving air. The peak value of the predicted temperature curve lags that of the measured one by approximately 1 hour. The adjustment for the out of phase in predicted temperature can be easily made if one becomes more familiar with the circuit simulation method.

The PCAP computer program for analyzing the drying air temperature response during tobacco curing was formed based on Figure 16 and Table 11. Switches were used to vary R_ℓ and C_ℓ values during transient analysis in the PCAP program. It was found that if the R_ℓ values of Table 11 were doubled, then the predicted drying temperature agreed well with the experimental data as shown in Figure 20. The larger R_ℓ values were needed because Eq. 6 does not take C_ℓ into consideration in determining R_ℓ. Also, better simulation results can be obtained if the number of drying intervals is increased.

This is the first phase of applying the circuit simulation technique to investigate the drying air temperature in tobacco curing. Additional studies should be conducted to (1) modify the equation for obtaining R_ℓ which will include the influence of C_ℓ and (2) reduce the number of related assumptions for evaluating R_ℓ and C_ℓ.

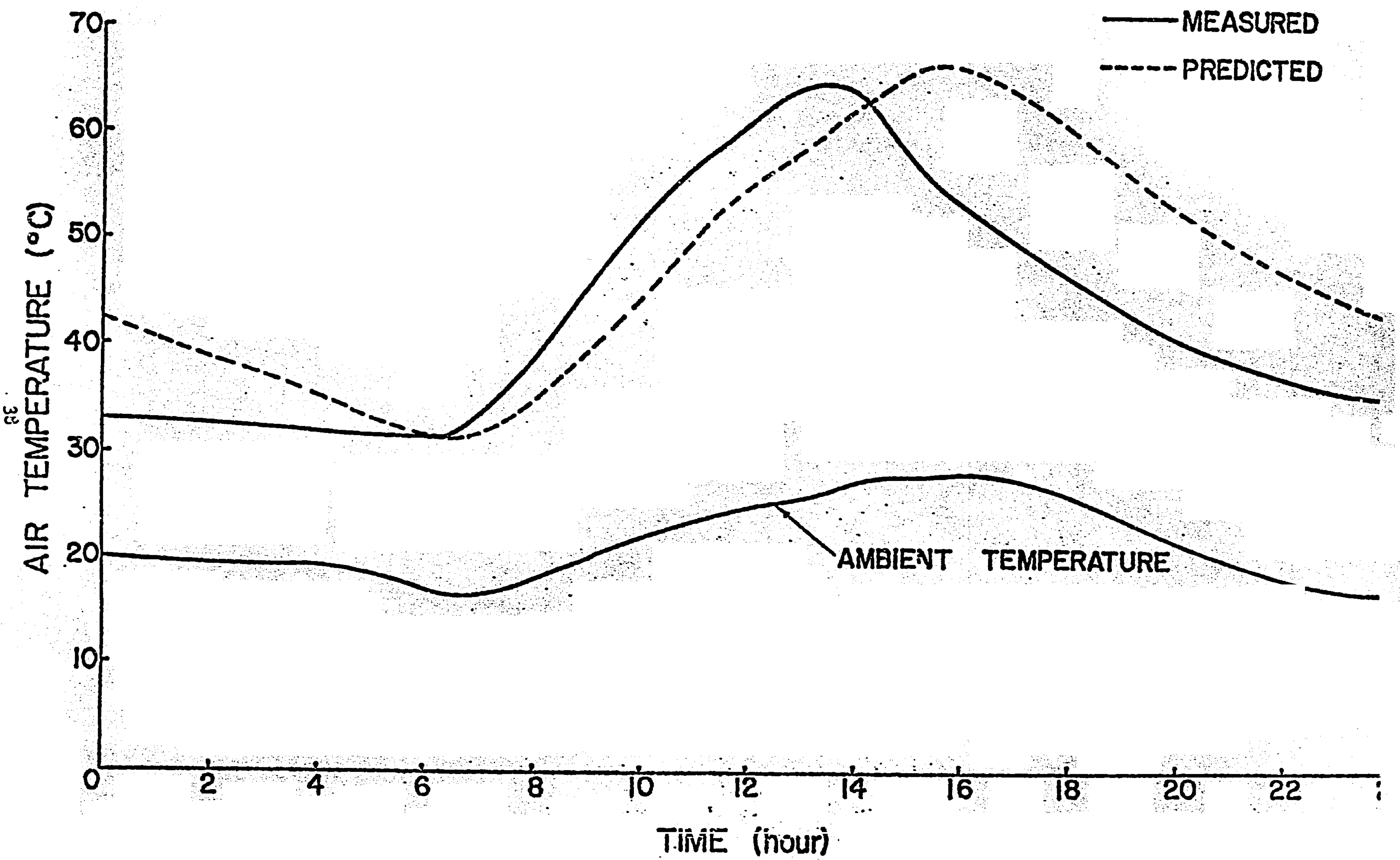


Figure 18. Predicted and measured temperatures of east-side upper solar collector (Aug. 17, 1976).

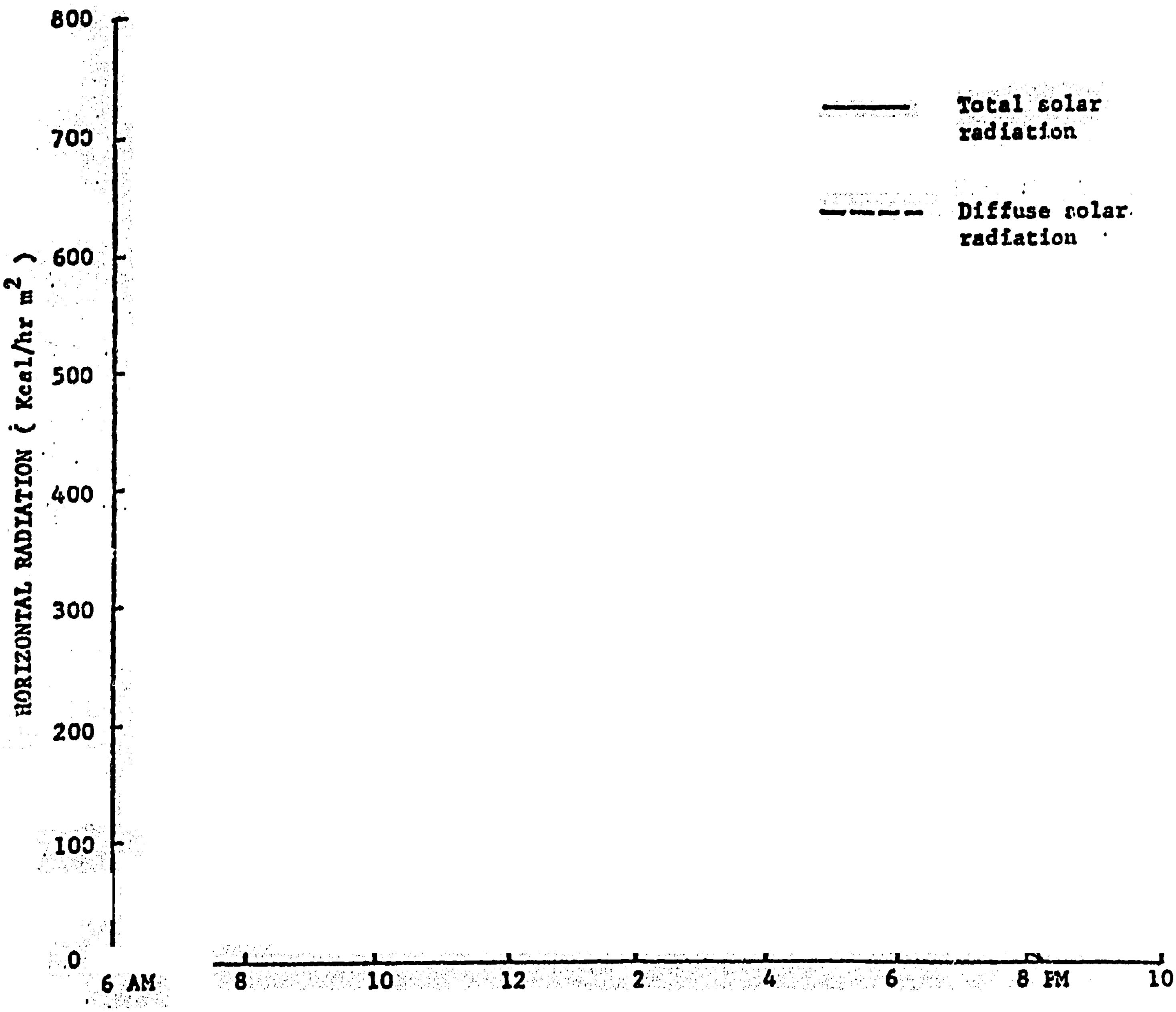


Figure 19. Observed solar radiation on horizontal surface (Aug. 17, 1976).

112

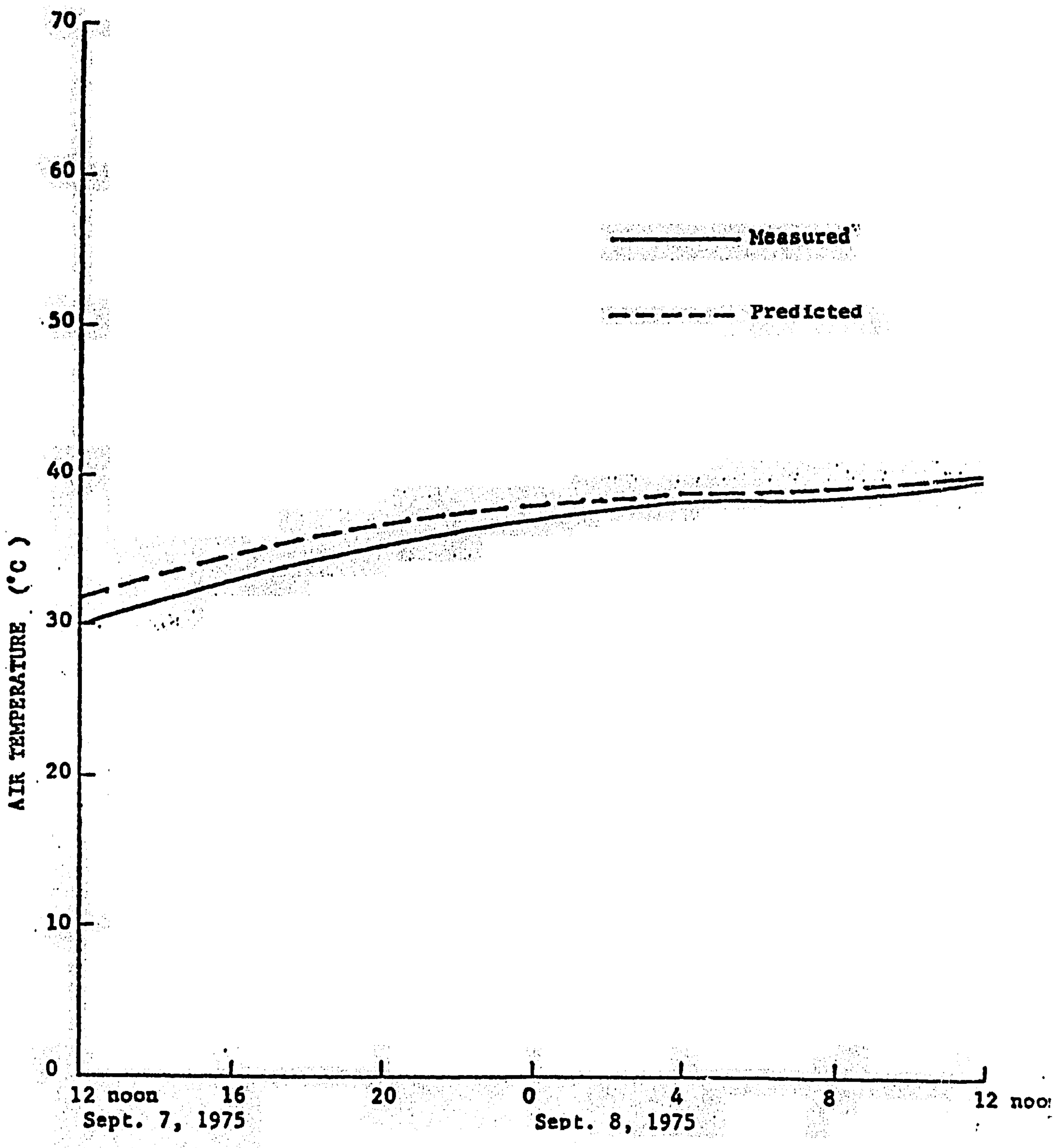


Figure 20. Comparison of predicted and measured temperatures of exiting air from tobacco leaves.

113

II. GRADUATE STUDENTS IN TOBACCO RELATED PROJECT:

H.S. Chang and A.H. Nassar

III. POST-DOCTORAL FELLOWS IN TOBACCO RELATED PROJECT:

None

IV. PUBLICATIONS:

Huang, B.K. and C.G. Bowers, Jr. Immediate Solar-Energy Utilization Using Greenhouse Bulk Curing and Drying System. PTP74-17622. 71p. 1976.

V. MANUSCRIPTS IN REVIEW:

Behroozi-Lar, M., B.K. Huang, and H.D. Bowen. Circuit Simulation of Soil Temperature Profile.

Huang, B.K. Systems Engineering of Precision Automatic Transplanting.

Su, C.S., B.K. Huang, R. Takeuchi, and Y.R. Chen. Noise Attenuation Characteristics of Plants.

VI. PAPERS PRESENTED AT PROFESSIONAL MEETINGS:

Huang, B.K. and H.S. Chang. Circuit Simulation Analysis of Heat Transfer Effect in Solar Drying. 1976 ASAE Annual Meeting. Lincoln, Nebrask June 27-July 1, 1976.

Huang, B.K., K.H. Kim, and Y.R. Chen. Simulation Analysis of Dynamic Response of Vehicle Impacting Shrub Barrier. 1976 ASAE Annual Meeting. Lincoln, Nebraska. June 27-July 1, 1976.

Chen, Y.R. and B.K. Huang. Dynamic Simulation of Wheel-Tractor Using Powered Scale Model. 1976 ASAE Winter Meeting. Chicago, Illinois. Dec. 14-17, 1976.

Bowers, C.G., Jr., B.K. Huang, and D.H. Willits. Optimization of Solar Energy Collection, Storage and Air Flow Control in Greenhouse/Solar Curing Barn. 1976 ASAE Winter Meeting. Chicago, Illinois. Dec. 14-17, 1976.

Chang, H.S. and B.K. Huang. Simulation of Thermal Behavior of Tobacco Curing in Solar Barn. 1976 ASAE Winter Meeting. Chicago, Illinois. Dec. 14-17, 1976.

Willits, D.H., C.G. Bowers, Jr., P.V. Nelson, and B.K. Huang. A Solar Energy Storage System for Greenhouse. 1976 ASAE Winter Meeting. Chicago, Illinois. Dec. 14-17. 1976.

114

VI. PAPERS PRESENTED AT PROFESSIONAL MEETINGS CONT'D:

Huang, B.K. and C.G. Bowers, Jr. Energy Savings with Greenhouse Bulk Curing Solar Barn. 27th Tobacco Workers Conference. Atlanta, Georgia. Jan. 10-13, 1977.

Bowers, C.G., Jr. and B.K. Huang. Transplant Production in Greenhouse Bulk Curing Solar Barn. 27th Tobacco Workers Conference. Atlanta, Georgia. Jan. 10-13, 1977.

115