

Research Report on Plastic Greenhouses

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Research Report on Plastic Greenhouses

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Horticulturists have recognized for some time the need for a practical, low-cost, plant-growing structure, one that would be suitable for a grower just getting started in business, or for an established grower to use for expansion purposes. The large amount of capital needed to build and maintain glass greenhouses has kept many interested individuals from growing vegetables and flowers. The advent of plastic film to cover greenhouses has, to a large extent, met this need in a practical and economical manner.

British scientists first made polyethylene as a sheet film in 1938 (18), and this thin material has since become very important in horticultural practice. In 1954, Emmert(3) advanced the idea of building an inexpensive greenhouse covered with polyethylene. Research work was initiated at V.P.I. in 1954 (9) to study the construction and use of plastic greenhouses and evaluate them as plant growing structures. These and other studies (1, 7, 14, 16, 17) indicated that such low-cost structures could be used quite successfully in growing vegetable and flower plants. However, improvements appeared necessary to provide a structure and facilities to meet acceptable greenhouse requirements.

MATERIALS AND METHODS

Seven years ago, the Departments of Horticulture and Agricultural Engineering at Virginia Polytechnic Institute began a comprehensive experiment on plastic greenhouses. The objectives of this study were: I, To develop improved unit construction, including framing, heating, ventilating, and plastic coverings; and II, To study plant growth rate and yield of vegetables when grown in glass and plastic greenhouses.

The following procedures were used to accomplish Objective I.

Structural Design

New concepts of greenhouse structural design were prepared on the drawing boards, scale models built and finally, full-size greenhouses were constructed to test the practicality of the design (4, 5, 8). Different foundations for plastic

greenhouses were tested for durability, economy, and other considerations. Framing dimensions, materials, and fabrication were studied with respect to design, simplification, durability, and cost.

Covering Materials

New test methods were developed in order to obtain objective data on the durability and physical characteristics of plastic covering materials. An experimental weathering test-rack was designed to evaluate simultaneously numerous plastic film samples. Data were recorded on the weather and the number of days to failure of the samples. The number of layers of plastic film as related to heat loss, heat gain, and light transmission was studied. Methods and procedures were studied for applying plastic cover relative to labor required and durability.

Heating

A serious problem encountered in plastic greenhouses was excessive moisture accumulation when cold weather prevented the introduction of outside air. The heating systems commonly available did not adequately heat the structures and usually caused high relative humidity. These conditions favored the spread of diseases. Consequently, an important phase of the research program was directed toward developing a heating system to solve these problems. An investigation of many heating units for plastic greenhouses was made, including design and experimental development work. Data were recorded on each unit to determine furnace capacity needed, heat distribution, heat loss, and relative humidity.

Temperatures and relative humidities were recorded at various locations inside the greenhouse and at several outside points. A 16-point Brown recording potentiometer was used to record temperatures. Hygrothermographs recorded relative humidities. Several instruments were used to measure light intensity and energy with respect to duration and quality.

Ventilating

The conventional side ventilators in greenhouses proved impractical in plastic greenhouses.

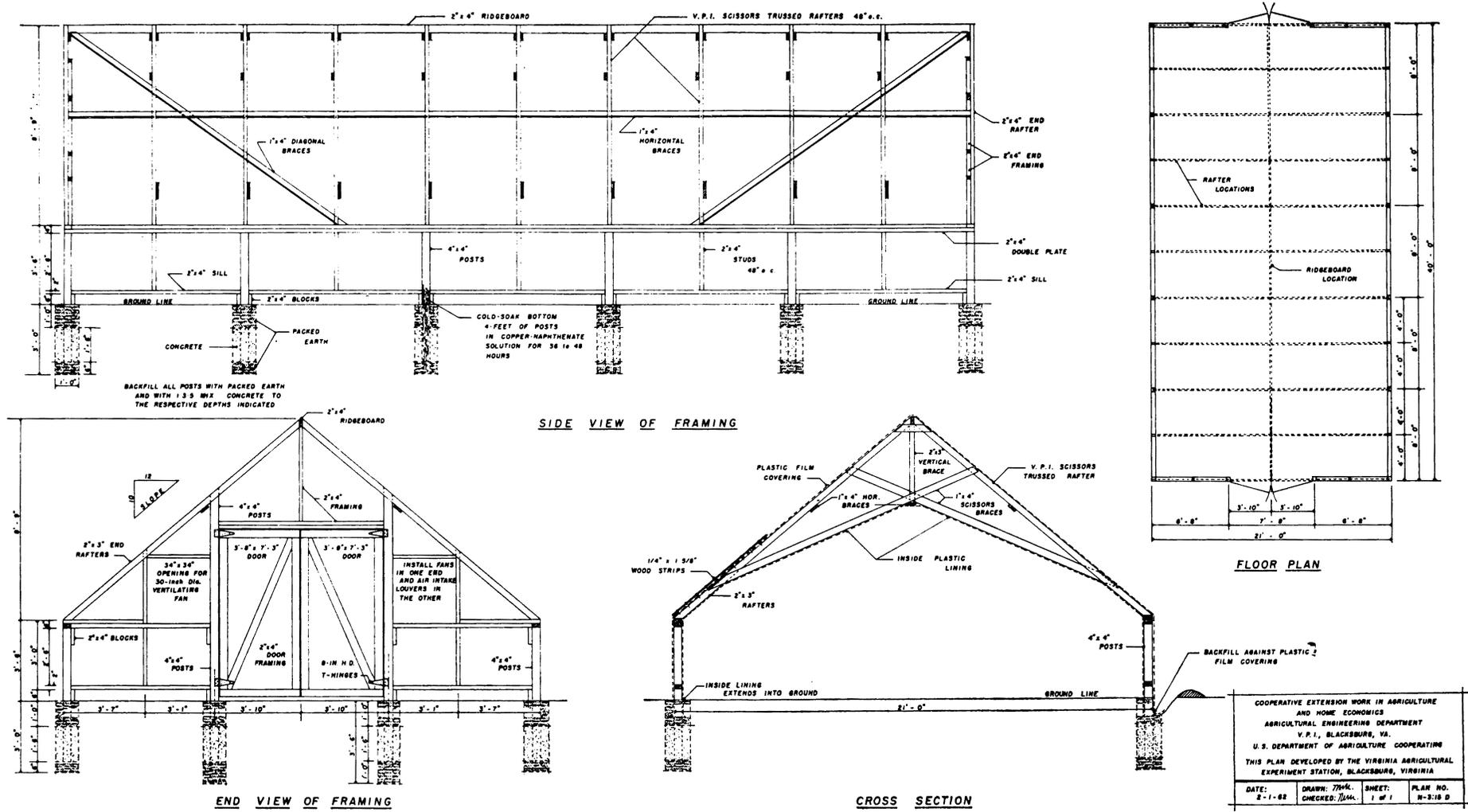


Figure 1.

Therefore, new ventilating facilities were designed and tested under standard operating conditions.

The following procedures were used to study plant growth and yield of several vegetable crops — Objective II.

Horticultural Crop Production

A homogeneous soil mixture was prepared and placed in four gallon crocks which were used as growing containers in these experiments. Composite soil samples were analyzed for Truog phosphorus, exchangeable calcium, magnesium, potassium, and organic matter. Seed of standard varieties of lettuce, peppers, and tomatoes were planted directly in the crocks. The seedlings were thinned to one plant per crock. Uniform fertilizer applications were made to all crocks as needed. Soil moisture was kept at a favorable level by using tensiometers: the plants were watered when 50% of the available soil moisture was depleted. Automatic heating and ventilating controls were set to maintain practically identical growing conditions in glass and in plastic greenhouses.

Growth measurements were taken at regular intervals and the yield and quality of the crops

was determined. All experimental data were analyzed statistically (2).

RESULTS AND DISCUSSION

Objective I

Structural Design

Numerous greenhouse designs have been developed and tested at V. P. I.; two of these designs are reported on in this publication.

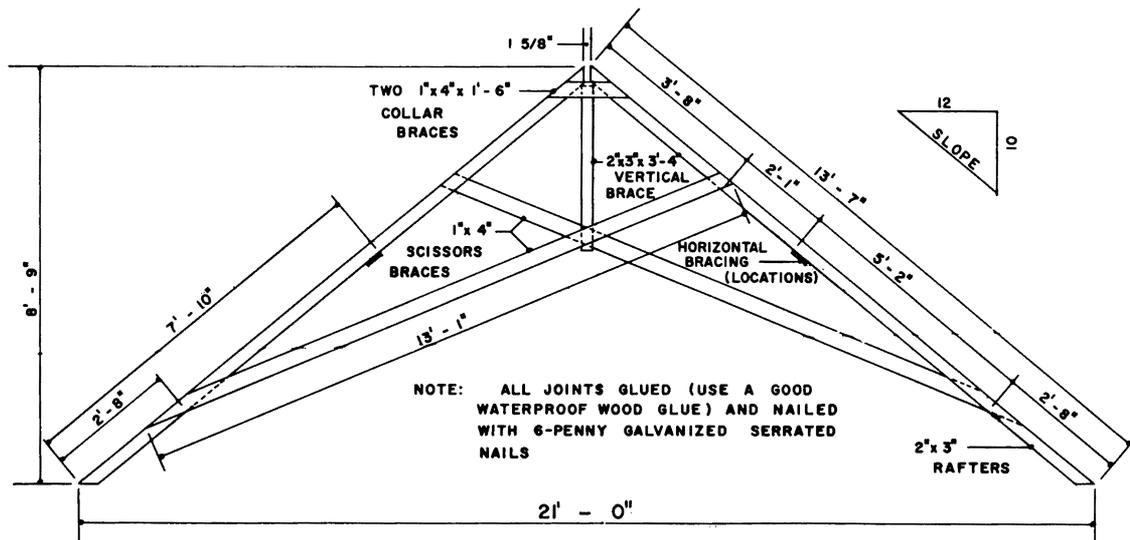
SCISSORS-RAFTER GREENHOUSE

Shown in Figure 1 is the plan for a well-designed 21' wide and 40' long, scissors-rafter plastic greenhouse. This planted-post type structure featured especially designed scissors-type trussed rafters, Figure 2, made up of 2" x 3" and 1" x 4" members.

All joints were glued and nailed together to form light-weight, rigid, trussed rafters that contained only 25 board feet of lumber each (12). Figure 3 shows a newly constructed greenhouse of this type.

GOTHIC GREENHOUSE

Another of the better experimental plastic greenhouses, Figure 6, featured a Gothic shaped structure (5, 13). This greenhouse was compos-



SCISSORS-TYPE TRUSSED RAFTER

SCALE: 1/2" = 1'-0"

Scissors-Type Trussed Rafter

Fig. 2.—Using proper 10/12 cuts, and dimensions shown, cut 3 rafters. Lay out trussed rafter design on a wood floor and place 2 straight rafters in proper position; use a 2" by 4" block to space for ridgeboard. Place 2 scissors braces on rafters in their proper locations; mark and make cuts. Also cut 1 extra scissors brace for pattern. Install vertical brace in perpendicular position, and lay collar braces in position. Temporarily nail all rafter members in place. Using blocks of proper thickness, make a jig around the assembled trussed rafter so that each member may be positioned in its proper place as other trussed rafters are assembled; all trussed rafters will then be identical. With a small paint brush spread good quality weatherproof wood glue on the rafter joints, and nail each glued joint securely with 6-penny galvanized serrated nails.

Inspect completed trussed rafter, and if satisfactory, cut all of the members for the number of trussed rafters needed. Use patterns which were cut in making the first rafter.

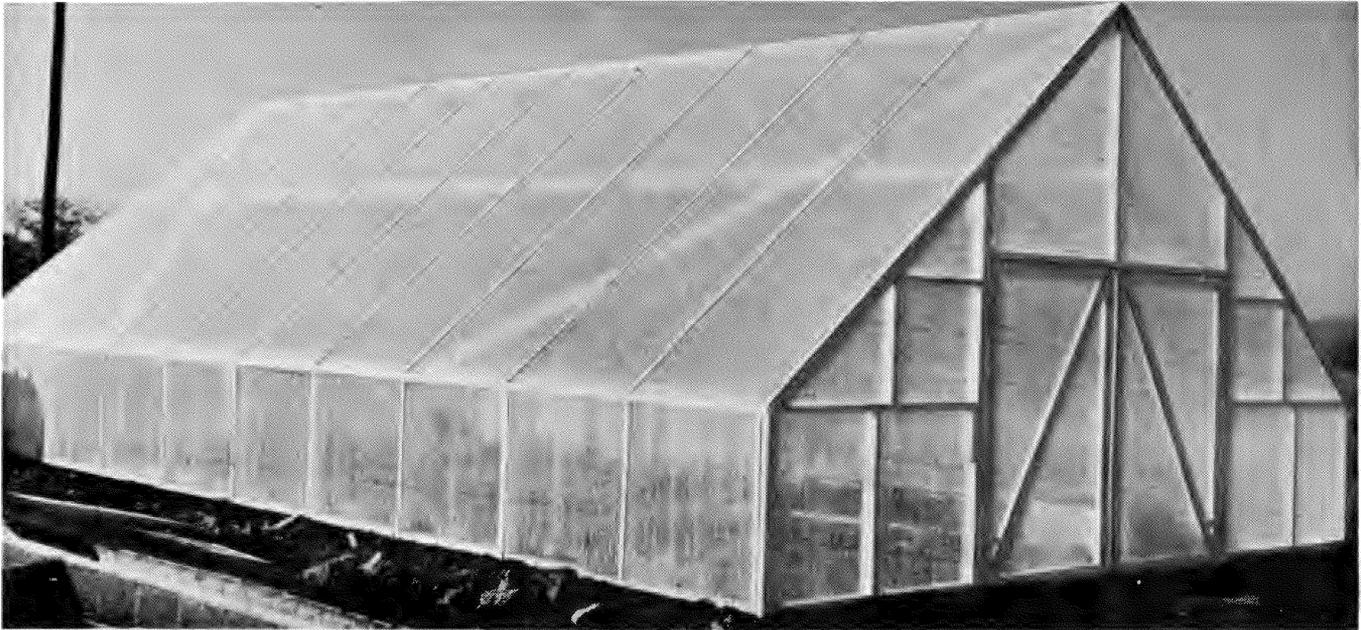
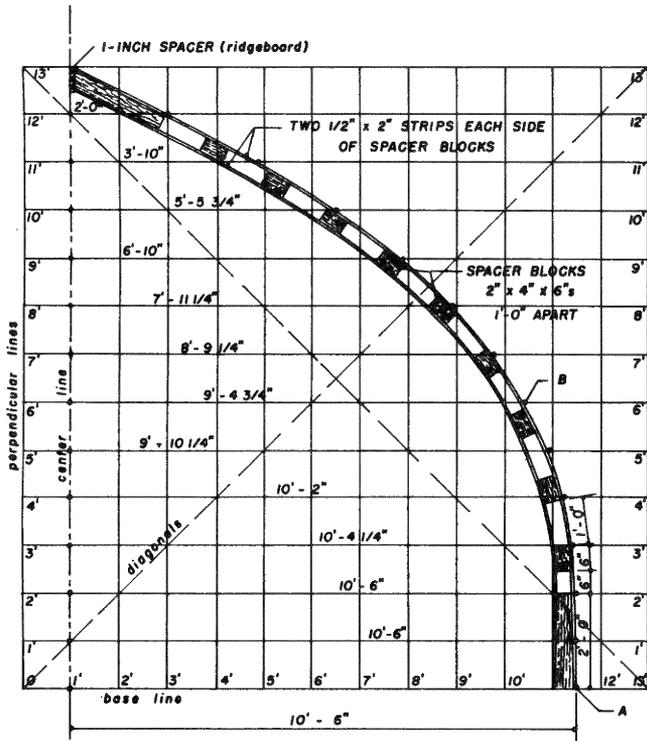


Fig. 3.—This 21' wide and 40' long greenhouse is covered with 4-mil plastic film. Framing and rafter spacings are 48" on centers.

ed of built-up, rib-type, curved rafters, attached to planted posts. These structures had a distinct and pleasing appearance which made them quite attractive. The rafters, Fig. 4, made up of 2" wide x 1/2" thick lath strips and 2" x 4" x 6"



V.P.I. GOTHIC RAFTER

Fig. 4.—V.P.I. Gothic Rafter.

Two of these rafters cover the 21' span of the greenhouse. Measurements are from one black dot to the next on the grid and dimension lines. Grid blocks are 1 ft. sq.

ESTATE TYPE GREENHOUSE

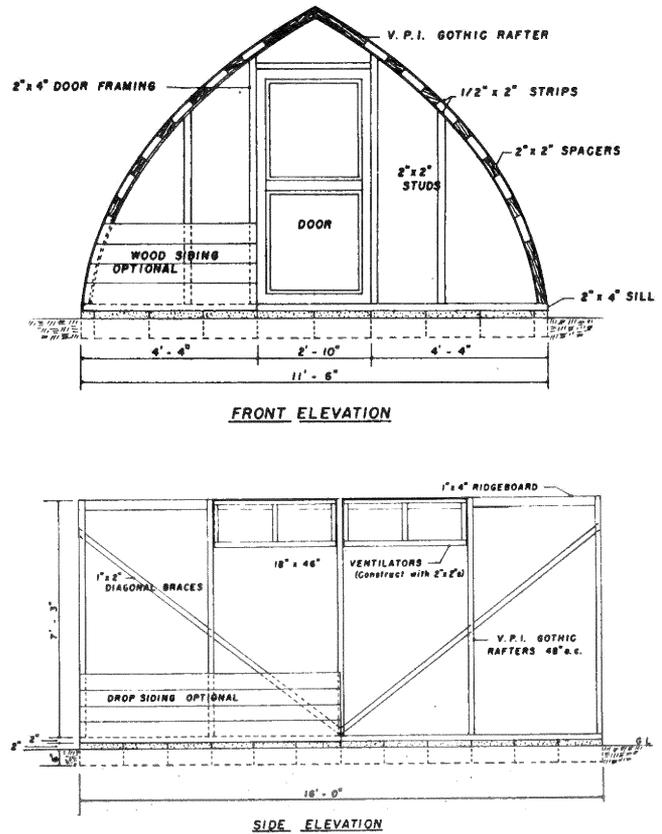


Fig. 5.



Figure 7.

spacer blocks, were glued and nailed together in a jig that determined their shape.

Erection was simple, the rafters being spaced 48" from center to center and bolted to short foundation posts at the bottom. The lateral and diagonal bracing was built into the rafter ribs, leaving a clear span inside the structure. The greenhouse has a pleasing and modern shape and can be covered with plastic film or fiberglass.

Publications are now available giving complete construction plans for both the scissors-rafter and Gothic shaped greenhouses (4, 5, 10). Either of the 21' x 40' structures can be built for \$400, including the cost of lumber, plastic, hardware, wood preservative, concrete, and labor.

Covering Material

An experimental weathering test rack, Figure 8, was developed (15) in order to evaluate many

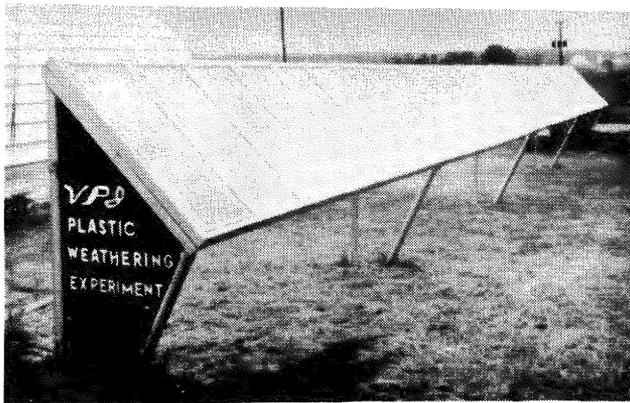


Fig. 8.—A test rack for evaluating simultaneously numerous plastic film samples. This testing procedure is designed to evaluate the durability of plastic films under naturally occurring environmental conditions.

plastic films simultaneously to determine their suitability as greenhouse covering materials. Some of the kinds and thicknesses of plastic that have been evaluated are: standard polyethylenes, ultra-violet inhibited polyethylenes, poly vinyl chlorides, poly vinyl fluorides, terylene, and fiberglass. The most promising films observed in the experimental racks were tested further on plastic greenhouse structures.

Results of the tests indicated that the ultra-violet inhibited polyethylene film of 4 mil thickness was a good economical material to use as a greenhouse cover. This low-cost film has remained on 2 test greenhouses for 14 months and is still in good condition.

The structural research indicated that by using the 4 mil film, the rafter spacing could be increased to 4' on centers. This wider spacing gives more sunlight in the greenhouse and a saving in lumber of about 20

Research at V.P.I. and Cornell University (14) demonstrated that an inner lining, second layer, of plastic film reduced the heat loss from the greenhouse by approximately $\frac{1}{3}$.

Heating

The requirements for heating systems in plastic greenhouses are in general the same as for conventional glass greenhouses. They, of course, have to overcome the heat losses from the structure and maintain the desired temperatures within the greenhouse. To determine heating capacities required, it was necessary to accept some U-value for the plastic film covering. Since the plastic film was being used in the place of glass,

it appeared reasonable to begin with the heat transmission values as determined for sheet glass, U being equal to 1.13 (6). All of the experimental heating systems were used in greenhouses covered with two layers of plastic film, having a 2½" to 3½" air space between layers. Taking into consideration the roof slope and a factor of .9 to compensate for the wood framing of the structure, it was concluded that this roof and wall construction would approach the determined U-value of .75 for wood-sash windows plus removable wood storm windows (6).

The heating requirement for a 18' x 40' double-layer plastic greenhouse, having a design temperature differential of 60°, was determined to be 70,560 B.t.u. per hour. A 85,000 B.t.u. ca-

capacity warm-air furnace was able to maintain uniform 70° F. inside temperatures in the plastic greenhouse in cold weather that averaged 10° F. for periods of 12 hours or longer. On a particular night in January 1959, between 9:00 p.m. and 3:00 a.m., with outside air temperatures averaging 12° F., this warm air furnace, equipped with a fuel nozzle rated at .75 gallon per hour operated ⅔ of the time in order to maintain an inside temperature average of 70° F. The furnace was located in the space being heated and the stack pipe ran inside the greenhouse for 30' or more before exhausting to the outside. The furnace efficiency was considered to be high and estimated at 90%. Using the above data, it is possible to estimate the U-value of two-layer plas-

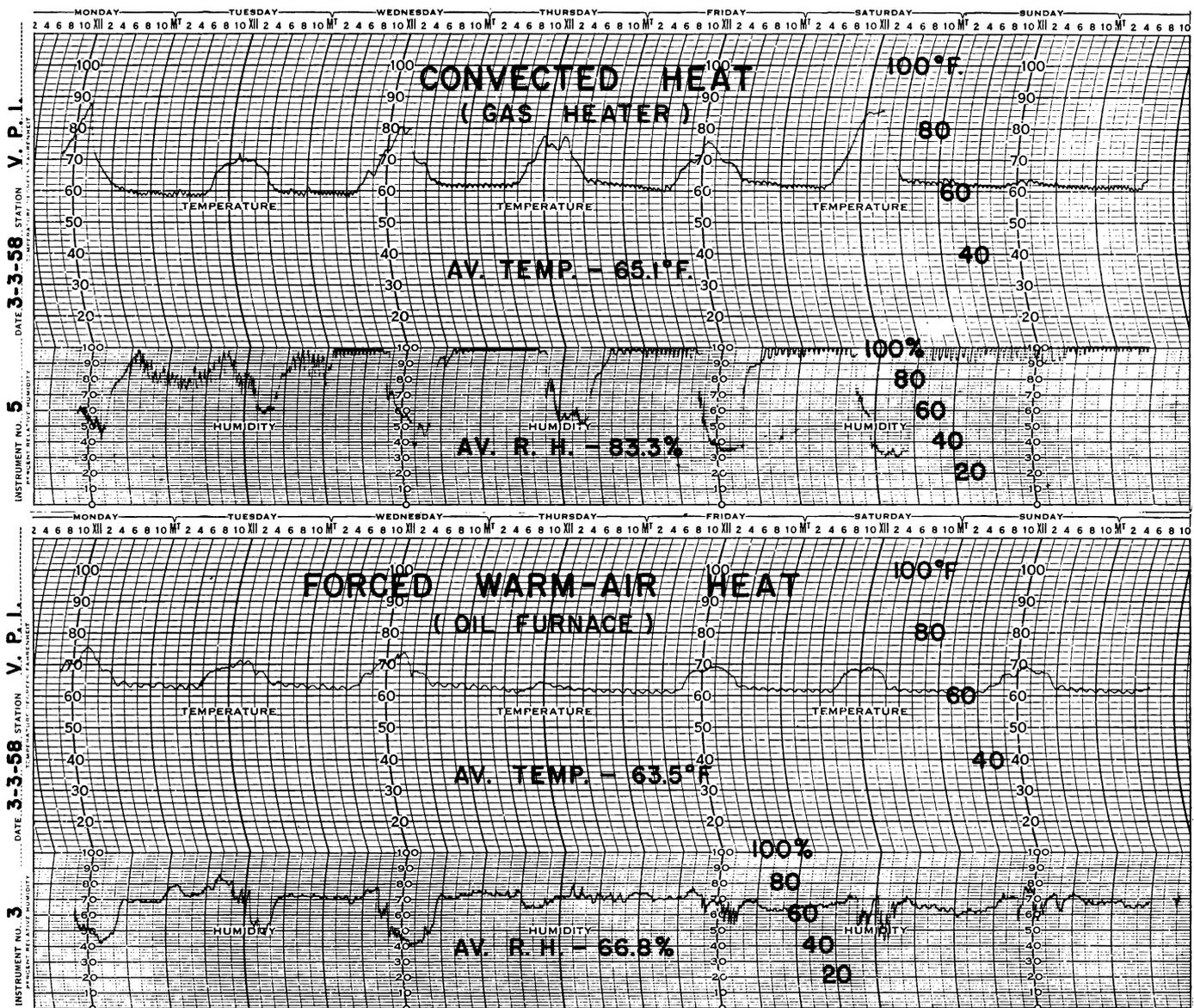


Fig. 9.—The heating systems, maintaining approximately the same conditions of temperature, show significant relevant differences in humidity.

tic greenhouse construction in the strictly non-laboratory test. As figured, the heat loss amounts to 63,000 B.t.u. per hour. Since the temperature differential was 58°, the apparent U-value in this instance was .69, which is reasonably close to the .75 U-value used in designing the system. This apparent U-value, .69 B.t.u. per hour, has been substantiated by subsequent research at Cornell University (14).

Natural gas heaters were used in most of the early Kentucky houses and LP gas heaters were used in Virginia at first. In these systems the heat and burned gases were conducted around the perimeter of the structure in 6" diameter furnace pipe and the greenhouse was heated by convection. The length of furnace pipe had to be such that all of the generated heat was given off in the greenhouse before the burned gases were exhausted to the outside; this required approximately 250 linear feet of 6" furnace pipe in a 18' x 40' structure. The gas heaters were controlled by special thermostats. Liquid petroleum gas heating systems were expensive to operate where design temperature differentials were

60° F. or more. Double layer plastic greenhouses are nearly air tight, and a system of convection heating tended to promote moisture condensation in the greenhouse. This was objectionable from the horticulturalists' viewpoint as being a disease-promotion factor.

The heating system that has proven most satisfactory is an automatically controlled forced-warm-air furnace with heat distributing ducts and registers, Figs. 10 and 11. The counter-flow type furnace, where the heated air moves downward through it, as well as the horizontal type furnace, have been used with good results. The fact that the air in the greenhouse is recirculated through the furnace when it is running, results in more uniform air temperature and less condensation of moisture. In similar plastic greenhouses of the same size, hygromographs recorded the average relative humidity conditions, Figure 9.

In addition to maintaining more desirable relative humidity conditions, the forced-warm-air heating system, with heat distributing ducts and

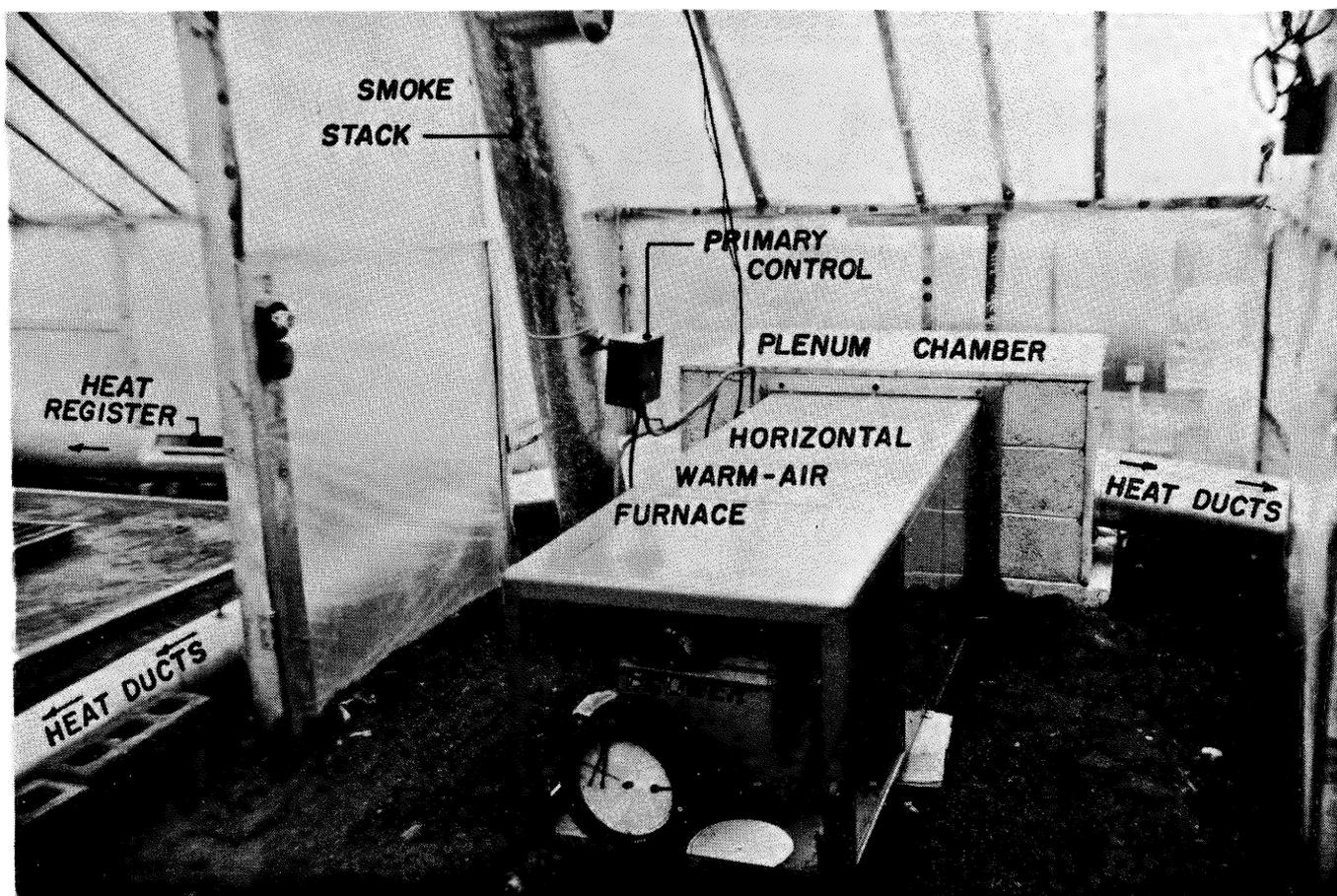


Fig. 10.—An efficient horizontal-type forced-warm-air furnace with 8" galvanized-pipe heat ducts and registers.

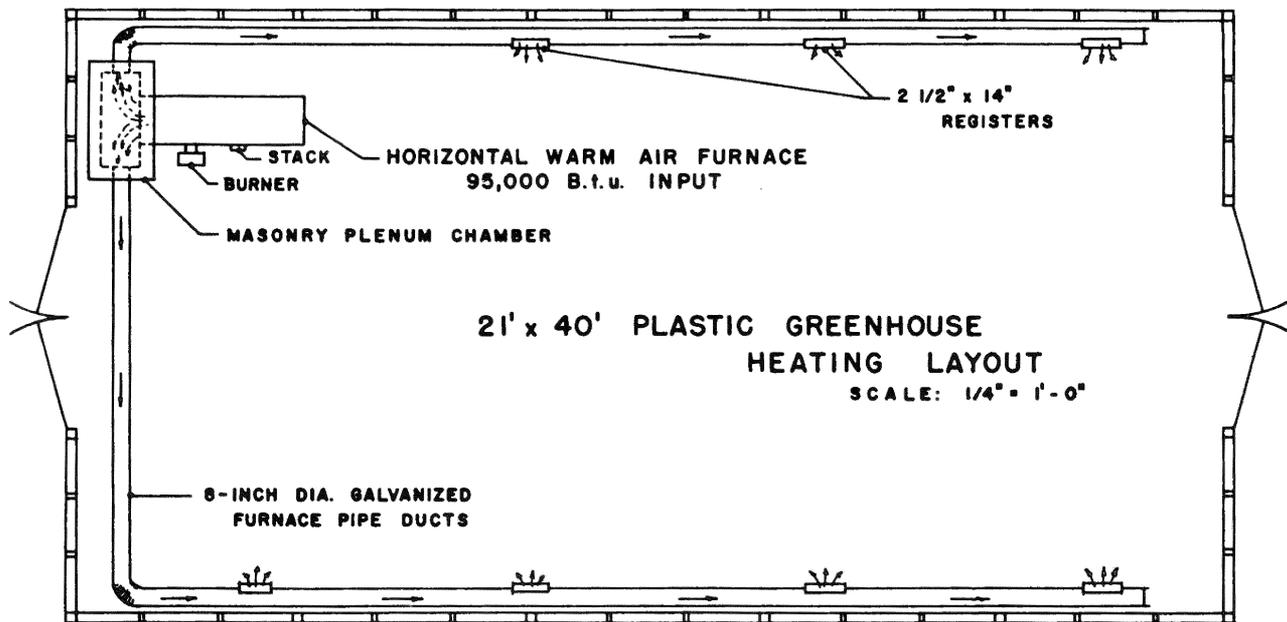


Fig. 11.—This heating system will maintain 70° F temperature in a 2-layer plastic covered greenhouse when the outside temperature is 10° F. By recirculating the air through the furnace, moisture in the greenhouse is reduced. The warm-air furnace is automatically controlled by a mercury-type thermostat located near the center of the greenhouse.

registers, kept consistently uniform temperatures in the greenhouse. A check with the Brown electronic temperature recorder, and 16 thermocou-

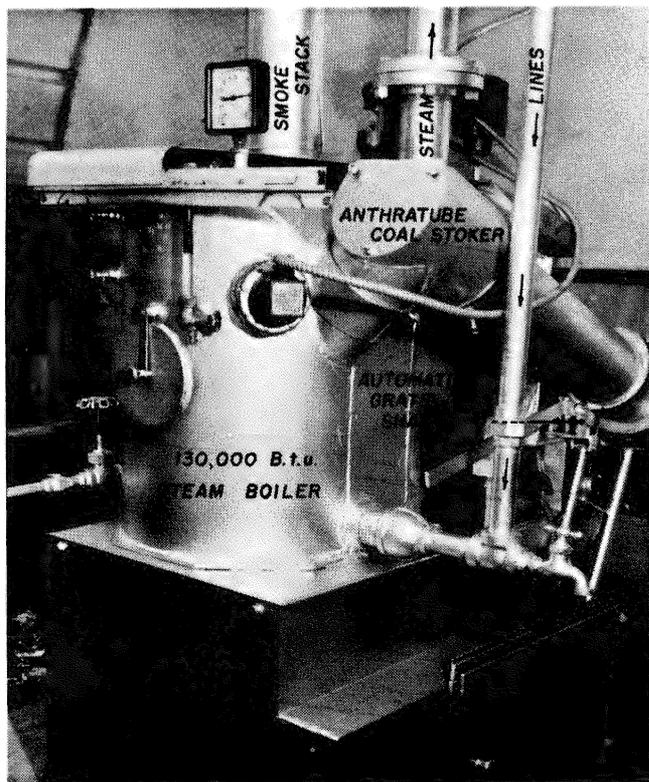


Fig. 12.—The steam boiler with anthracite coal stoker and automatic grate shaker required little attention.

ples, indicated a maximum difference of less than three degrees anywhere in the house.

The warm-air furnaces used in this study were fired with pressure-type oil burners, equipped with the usual safety controls. Under conditions where the average yearly degree days were 5,103, approximately 1200 gallons of No. 2 fuel oil were used in heating a 18' x 40' plastic greenhouse with a design temperature of 60 degrees. The 85,000 B.t.u. furnace heats this house. Commercial operators usually require larger greenhouses than the units tested. Consequently, for larger houses, the use of two or more smaller size heating systems, rather than one very large system, is recommended. A distinct advantage is that in case one furnace should fail, sufficient heat can be provided by the other system to prevent serious damage to the plants.

A low pressure steam boiler that burned cheap anthracite coal, readily available in some areas, has been tested for 2 years. The cost of the coal to heat a 21' x 40' greenhouse was approximately 50 cents per day for an average heating season. Figure 12 shows the automatically fired steam boiler that was tested.

Ventilating

The cooling of plastic greenhouses is an important problem. Often in mid-winter on bright sunny days it is necessary to ventilate green-

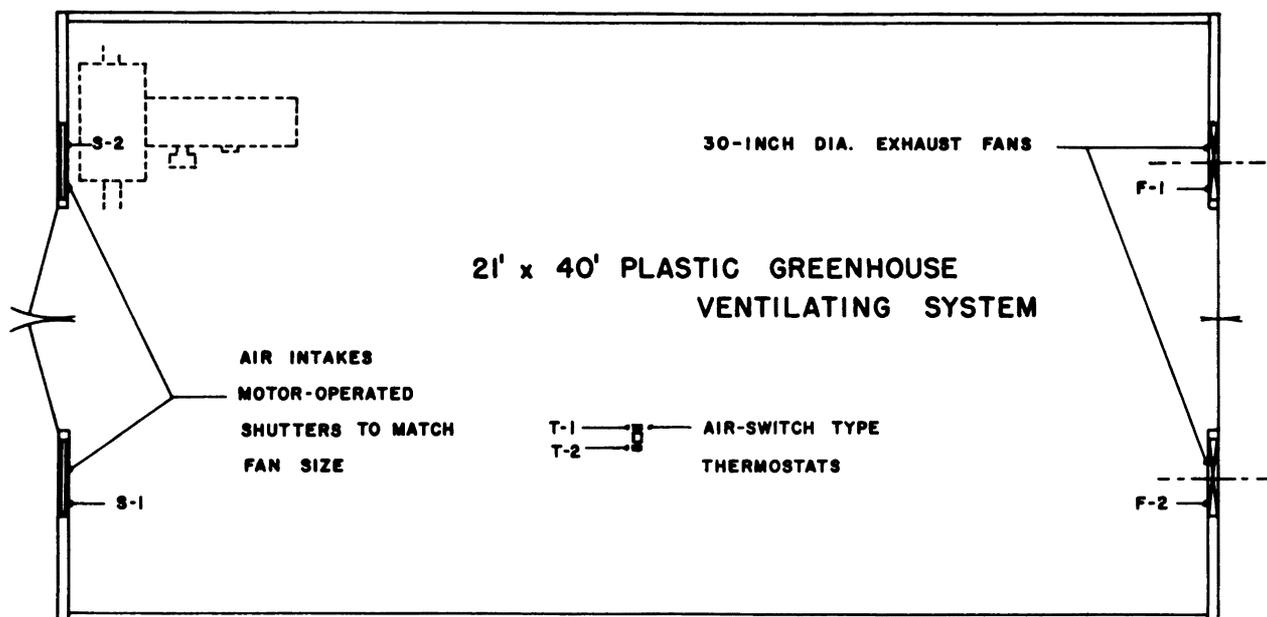


Fig. 13.—Motor-operated shutter S-1 and exhaust fan F-1 are controlled by thermostat T-1. This set of equipment is adequate for ventilating a 21' by 40' greenhouse. Motor-operated shutter S-2 and exhaust fan F-2, controlled by thermostat T-2, should be added for ventilating a 21' by 80' greenhouse.

houses to prevent excessive temperatures. Heat build-up is fast and 100° F. can be reached very quickly. Built-in side ventilators that can be opened and closed manually are often used in small plastic greenhouses; however, someone has to be on the spot to operate them at the proper time. Automatic ventilation is desirable in order to relieve the operator of having to make constant checks and adjustments to give control. V.P.I. studies indicated that exhaust fans, with proper air intakes, controlled with air-switch-type thermostats, Figure 13, will give satisfactory plastic greenhouse ventilation at Blacksburg, Virginia. A system where the thermostat, on a temperature rise, causes the motorized air intake shutters to open and the exhaust-type fan in the opposite end of the greenhouse to operate, works well. The fan, or fans, located in the leeward end, should be of such size as to provide at least one air change per minute in the greenhouse.

Objective II

Horticultural Crop Production

Lettuce, peppers, and tomatoes were grown in glass and plastic greenhouses with identical automatic heating and ventilating control settings. No consistent differences in growth rate resulted from growing the 3 crops under glass and plastic. The yield data, Table 1, indicated no sig-

nificant difference between crops grown in glass and plastic greenhouses when these vegetables were planted for several years.

Table 1.—Fresh weight of vegetable crops grown in two greenhouses, average in grams per crock of 25 plants.

Greenhouse	Year				
	1956	1957	1958	1959	1960
	Head Lettuce				
Glass	242.8 ^{a1}	116.5	199.3 ^b	187.4	
Plastic	116.5 ^b	123.1	248.1 ^a	188.2	
	Green Peppers				
Glass	828.4	589.6 ^a	804.2	1113.1 ^b	
Plastic	864.4	374.9 ^b	787.2	1347.8 ^a	
	Tomatoes				
Glass	3280.2	799.3 ^b	2840.9 ^a	1117.1 ^b	3604.8 ^a
Plastic	3139.5	922.7 ^a	2276.8 ^b	1492.6 ^a	3491.5 ^b

¹The superscripts indicate the statistical significance at the 5% level. Data bearing different superscript letters are significantly different (2).

In any given year, any one of the crops tested may have produced higher yields in the glass or plastic greenhouse. However, in about the same frequency, the same crop grown another year gave reverse effects or indicated no difference. For example, the tomato yield data indicated no significant difference in 1956 between the glass and plastic greenhouses. In 1957 and 1959, the tomatoes grown under plastic (Figure 14) yielded more than those grown under glass. The re-



Fig. 14.—Tomatoes grown in a plastic greenhouse to evaluate growth, yield, and quality, as compared to an identical crop grown in a glass greenhouse.

verse was true in 1958 and 1960. No consistent differences were observed in the time of maturity or the quality of the product with all 3 crops, and with the peppers and tomatoes, in the size and number of fruit.

These experimental data were interpreted as indicating that if adequate heating and ventilating systems were provided, no consistent yield differences would result with these crops when grown in glass and plastic structures. Since no differences were found in the yield and quality of the 3 crops when grown in the 2 structures, the authors believe that the low-cost plastic greenhouses should be more widely used in the production of these crops.

SUMMARY

Research work was initiated on plastic greenhouses at V.P.I. in 1954. Preliminary studies indicated that these low-cost greenhouses could be successfully used to grow vegetables and flowers. However, certain serious problems were found in structural design, covering materials, heating, and ventilating. Study of these problems has resulted in the following findings:

1. **Structural Design.** Two greenhouse designs,

with 48-inch rafter spacings, have been developed and are recommended as the best of several structures tested.

2. **Covering Material.** Ultra-violet inhibited polyethylene film was the most suitable of several materials tested.
3. **Heating.** Gas, oil, and coal burning heaters of many types have been tested. Automatically controlled forced-warm-air furnaces solved the problem of excessively high humidity in plastic greenhouses.
4. **Ventilating.** An automatic ventilating system has been developed which will provide one air change per minute in the greenhouse when needed.
5. **Horticultural Crop Production.** Lettuce, peppers, and tomatoes were grown in plastic and glass greenhouses. Data obtained from this research indicated that under similar conditions of heat and ventilation, no significant differences in yield or quality of the crops resulted. As plastic greenhouses cost about $\frac{1}{5}$ as much as glass greenhouses, the researchers conclude that plastic greenhouses may be used profitably to produce these horticultural crops.

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