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This circular was prepared by J. W. Courter, Assistant Professor of Horticulture.

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(This circular replaces Circular 857)
PLASTIC GREENHOUSES

SINCE 1938, WHEN POLYETHYLENE SHEET FILM WAS first made by the British, scientific developments and refinements have made possible the manufacture of plastics suitable for use in greenhouse construction. This is a matter of great interest throughout the United States at the present time because plastic materials are relatively inexpensive and are adaptable for both small backyard greenhouses and commercial enterprises. A polyethylene plastic greenhouse can often be constructed for one-third or less the cost of a glass greenhouse, which is one of the obvious reasons for the popularity of plastic as a greenhouse material. And while well-built structures (covered with semi-permanent plastic and having proper heating and ventilating systems) can cost as much as glass greenhouses over the long run, a grower can reduce his initial costs by building a plastic greenhouse with his own labor, using his own materials, while fitting the job into his own work schedule.

Greenhouses covered with plastic films can be used to grow any crops that are currently grown in glass greenhouses. Some growers have expanded operations by adding plastic houses to their glass range and have used them successfully for year-round production of flower and vegetable crops. However, because of low cost, plastic greenhouses have distinct advantages for seasonal use such as the growing of spring bedding plants or summer flower crops. In this case, the structure can remain unheated and unused during the severe winter months.

Many plastic greenhouses are temporary structures and for this reason they have a tax advantage. They usually have a lower tax assessment than a glass greenhouse or are not subjected to any tax at all. Also, the cost of the structure can be depreciated over a relatively short time. Many plastic greenhouses cannot be insured because of their construction or their impermanent nature.

One must not think, of course, that plastic greenhouses offer all the advantages of glass greenhouses. Most plastic structures are not as neat and attractive as glass greenhouses. In many ways, more exact cultural treatment and management is required to grow crops under plastic. Plastic differs from glass in both physical and chemical characteristics, the results being different light conditions, different temperatures, and different humidity. Well-made plastic greenhouses — those in which adequate ventilating and heating systems have been installed — may, however, under proper management conditions, be ex-
tremely satisfactory structures in which to grow crops. It has been said that crops can be of even better quality when grown under plastic. This may or may not be true, but experience indicates that equally high quality crops can be produced under plastic.

BUILDING LOCATION

The location of a new greenhouse must be carefully considered. For convenience there should be access to a good road. Nearness to electricity and an adequate supply of clean water will reduce the initial cost. Large amounts of water are needed to produce certain crops and for this reason a good water supply cannot be overemphasized. It has been estimated, for example, that more than 330,000 gallons of water are needed to grow one acre of tomatoes under glass.

It is advantageous to build a greenhouse on a deep, well-drained soil. Locations with an unusually high water table should be avoided. The site should have good air and water drainage. Do not build near trees, buildings, or objects that will shade part of the greenhouse or where limbs, stones, or debris may be dislodged and cause damage. To help save fuel, build in an area that is protected from strong winds and winter storms. Allow ample room for future expansion and for construction of headhouses or other work areas.

Orientation is not considered to be critical. A north-south orientation probably gives the best year-round light, especially for long-season crops or for spring or summer production. An east-west orientation, especially with widely spaced north-south rows, provides maximum light for mid-winter growth.

Naturally, it is desirable to locate close to your market and to a source of reliable labor.

PLASTIC GLAZING MATERIALS

The choice of plastic film or panel is important and depends on durability, intended use, type of greenhouse structure involved, and cost. A grower may need a long-lasting film or only a protective cover for a few months. For the latter use, polyethylene, which is inexpensive and breaks down after relatively short exposure, would be the best choice. For longer durability, vinyl or polyester films, and rigid fiberglass or vinyl panels are available. Each has its advantages and disadvantages.

In addition, new glazing films are being developed and tested. For example, the DuPont Company is testing a polyvinyl fluoride film called Tedlar which has lasted through twenty years of exposure tests.
The National Agricultural Plastics Conference organization tests plastic films in seven locations throughout the United States and Canada. Samples of experimental plastics, submitted by cooperating commercial companies, are mounted on special racks and evaluated for durability, ability to remain clear, and other characteristics.

in Florida. Tedlar is not available for greenhouse use but is currently being laminated on the surface of lumber and aluminum siding and to rigid fiberglass panels.

Transmission of light through the plastic films is adequate for good crop growth even though it is not the same as transmission of light through glass (see Table 1). Polyethylene and some of the vinyls transmit more of the ultraviolet spectrum than glass, but this increased ultraviolet energy has not been shown beneficial to plant growth. The light transmitted through some plastic materials is diffused, although this does not necessarily mean reduced light penetration. Some plastics transmit less visible light than glass but this may be of negligible significance since most plastic structures have less overhead structural framework and correspondingly less shading.

Below are descriptions of plastics presently available for covering greenhouses. The cost in terms of square footage of ground covered
Table 1. — Light and Heat Transmission Characteristics of Some Plastic Films Compared to Glass

<table>
<thead>
<tr>
<th>Film</th>
<th>Thickness</th>
<th>Transmission of visible light</th>
<th>Transparent to</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>percent</td>
<td>Ultra-violet</td>
</tr>
<tr>
<td>Polyethylene*</td>
<td>2</td>
<td>87</td>
<td>Yes</td>
</tr>
<tr>
<td>Polyvinyl chloride*</td>
<td>13</td>
<td>87</td>
<td>Slight</td>
</tr>
<tr>
<td>Polyvinyl chloride*</td>
<td>3</td>
<td>88</td>
<td>Yes</td>
</tr>
<tr>
<td>Polyester*</td>
<td>4</td>
<td>88</td>
<td>No</td>
</tr>
<tr>
<td>Fiberglass (clear)</td>
<td>125</td>
<td>80–90</td>
<td>Slight Intermediate</td>
</tr>
<tr>
<td>Glass*</td>
<td>125</td>
<td>90</td>
<td>No</td>
</tr>
<tr>
<td>Water*</td>
<td>2</td>
<td>96</td>
<td>Yes</td>
</tr>
</tbody>
</table>


can be estimated by multiplying 2.0 or 2.4 times the film cost for a 1,000- or 4,000-square foot house, respectively. The cost naturally would be lower for larger houses.

**Polyethylene**

Polyethylene is available in thicknesses of 1 to 8 or more mils (1 mil equals 0.001 inch) and in widths up to 40 feet folded or 16 feet unfolded. For greenhouse covering, 4- or 6-mil polyethylene is recommended for the outside covering, and 2- or 4-mil for the inside. (The advantages of double layering are discussed below.) Thinner gauge polyethylene can be used but it punctures more readily and deteriorates more rapidly. Polyethylene permits passage of much of the heat energy given off by the soil and plants inside the greenhouse. Therefore, after sunset, heat will be lost more quickly from a polyethylene greenhouse than from a glass greenhouse.

Regular polyethylene will not last through the summer in Illinois because ultraviolet light energy causes it to break down. This first occurs along or over rafters or along creases where the film was folded. In Illinois, polyethylene applied in September or October will begin to weaken the following April or May, and will completely tear from the rafters by July. Intensive sunlight in early summer will also break down polyethylene applied during February or March.

Improved ultraviolet-resistant (weatherable) polyethylenes contain a UV-inhibitor and last longer than regular polyethylene because the inhibitor prevents the rapid breakdown caused by ultraviolet light. UV-resistant polyethylene is available in 2, 4, and 6 mil thicknesses up
Polyethylene is the most inexpensive and the most temporary plastic film. Polyethylene deteriorates rapidly during the summer, breaking down first where folded or over rafter members. Because polyethylene greenhouses must be recovered annually they are generally not suitable for continuous year-round use.

to 20 feet wide. Unfolded (lay-flat) UV-resistant polyethylene is available up to 16 feet wide.

When covering during late summer or early fall, either 6- or 8-mil polyethylene or, better yet, 4- or 6-mil weatherable (UV-inhibited) polyethylene should be used. For spring use only, regular 4-mil polyethylene applied in winter or early spring should be satisfactory. Weatherable polyethylene should last through the summer when applied in the spring, but it is doubtful if 4-mil weatherable polyethylene will last through two growing seasons (winter, summer and winter) as the intensive ultraviolet light during the summer greatly weakens the film. Failure of 4-mil weatherable film after exposure during the summer months has been noted in Illinois. Lay-flat film should be used when maximum serviceable life of the film is desired.

Polyethylene (4-mil) in large quantities costs approximately 1 cent per square foot. Ultraviolet-resistant polyethylene costs about half again as much.

Polyvinyl chloride (PVC or vinyl)

Several vinyls, 3 to 12 mils thick, are available for greenhouse glazing. Like polyethylene, vinyls are soft and pliable; some are transparent, others translucent. They are usually available only in 4- to 6-
foot widths, but larger covers can be made by electronically sealing several narrow panels together. Many of the first vinyls were not satisfactory for greenhouse films because they attracted dirt and dust from the air and were subjected to attack from fungi, becoming quite dark after a short period of use. Also, many of the early vinyls were not temperature stable and, particularly in northern areas, contracted in cold weather to the point of bursting. Present vinyls will generally last from 12 to 24 months and cost from 3 to 10 cents per square foot. When carefully installed, 8- or 12-mil weatherable (UV-inhibitor added) vinyls have held satisfactorily on greenhouses in Illinois for more than four years. When dirt accumulates, vinyl-covered greenhouses must be washed.

Rigid polyvinyl chloride (PVC) panels are sufficiently lower in price than top quality rigid fiberglass panels to attract considerable interest. Clear, corrugated panels, 26 to 34 inches wide, are available in 6 to 12 foot lengths. The thickness ranges from .04 to .045 inches. Presently, costs of rigid vinyl panels are 12 to 15 cents per square foot. PVC panels are easy to apply.

The retention of satisfactory light transmission and durability of PVC panels are not known. Limited observation of commercial greenhouses indicates that the PVC panels will withstand sub-zero temperatures and that such construction appears practical.

Rigid PVC panels, however, cannot be fully recommended at this time for covering greenhouses. They lack structural strength (compared with equivalent weights of fiberglass), become quite brittle at low temperatures, and their color stability is unknown.

**Polyester (Mylar¹)**

Mylar is a high-strength weatherable film with excellent temperature properties. It is not affected by extreme heat or cold, having essentially a zero expansion coefficient from $-60^\circ$ to $200^\circ$ F. Mylar has light-transmission characteristics quite similar to glass. It will withstand most hail.

Mylar is available in a 5-mil thickness in widths from 36 to 51 inches. Cost is 12 to 14 cents per square foot. When properly installed, Mylar will last four years on roofs exposed at a 45° angle to the sun. Applied on vertical sidewalls, Mylar will last as long as seven years. Some growers object to noise created by rattling of the film in windy weather. Mylar is likely to fail when put on poorly constructed frame-

¹Registered trademark for duPont polyester film.
Plastic Greenhouses

A steel-truss greenhouse covered with rigid polyvinyl chloride panels.

works that warp, twist, and sway in the wind. Because of the shortcomings of many structures and the requirements for successful application of Mylar, Geo. J. Ball, Inc., West Chicago, Illinois, has designed several structures specifically for covering with this film. Further information on these structures is found below (page 14).

**Rigid fiberglass**

Reinforced panels of rigid fiberglass are becoming more and more popular for greenhouse construction. Fiberglass covered greenhouses are being used successfully in western areas where light intensity is high, and in other areas for growing foliage plants and orchids. Fiberglass panels are lightweight, yet they are strong and practically hailproof. Fiberglass panels, particularly corrugated types, contribute considerable structural strength. The large panels have further advantages in ease of application.

Corrugated or flat panels are available in 6- to 12-foot lengths, in rolls, and also in glass-sized panes. Widths vary from 24 to 51 1/2 inches.
Thin shell greenhouses are being investigated at Pennsylvania State University. This one employs multi-barrel cylindrical vault construction. Each "barrel section" is composed of a 4' x 12' sheet of flat fiberglass. The high strength properties of reinforced plastic panels are utilized to carry loads by direct stress rather than by bending, as in common post and frame construction.

Special panels are available up to 25 feet in length. There is a wide range of thicknesses, as shown in this table.

<table>
<thead>
<tr>
<th>Approximate weight per square foot (ounces)</th>
<th>Approximate thickness (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>.030</td>
</tr>
<tr>
<td>5</td>
<td>.038</td>
</tr>
<tr>
<td>6</td>
<td>.045</td>
</tr>
<tr>
<td>8</td>
<td>.060</td>
</tr>
<tr>
<td>12</td>
<td>.090</td>
</tr>
</tbody>
</table>

Prices range from approximately 20 to 75 cents per square foot.

Weathering of the surface of fiberglass panels has been one of the problems of inexpensive grades. When this occurs loose fibers are exposed and dust collects on the surface. Weathered panels can be treated with an application of liquid acrylic coating. Premium grades may be granitized with extra resin on the panel surface for greater durability. Because of the tendency for surface deterioration, some manufacturers of fiberglass panels are bonding a thin film of polyvinyl fluoride to the exterior surface. Poor and inexpensive grades of fiberglass may discolor to further reduce light penetration.

Five ounce or preferably heavier grades of fiberglass panels with a 10- to 20-year durability guarantee are recommended. In selecting fiber-
glass panels consider only the clearest grade. Colored fiberglass should be avoided. Detailed installation tips, available from fiberglass manufacturers, should be obtained before construction.

**TYPES OF CONSTRUCTION**

An ideal plastic greenhouse affords maximum light penetration, is easily ventilated, adequately heated, sufficient in width, and constructed to provide for the use of more permanent glazing films as they become perfected and available. In building a plastic greenhouse careful consideration should be given to the purpose for which the structure is intended, economy of size, and future expansion needs.

Because plastic is available in large widths and is light in weight, the framework can be designed for maximum light penetration, with rafters and supporting members widely spaced. Furthermore, the many available widths and weights of plastic permit flexibility of shape, size, and type of construction. Plastic structures can range from rather crude wooden frameworks to completely air-supported houses. Listed below are some types of greenhouse construction that have been developed and proven satisfactory by various agricultural experiment stations and private industries. No attempt is made to cover all possible designs and modifications, since many growers have developed structures that suit their own particular needs. A list of available plans is included, and the interested grower may write for whichever plan seems most suitable for his purposes. (See Table 3 on pages 24-27.) In addition many suppliers of commercial greenhouses offer greenhouse structures covered with either film plastics or fiberglass (see Table 2).

Costs of plastic greenhouses cannot easily be compared with costs of glass greenhouses. This is because most plastic greenhouses are temporary structures, designed to last from 5 to 15 years, involve high maintenance costs, and are often built and used for different purposes than glass greenhouses. Wooden structures covered with temporary plastic films generally have little salvage value after a period of usage, although the serviceable life of such structures can be easily extended by forethought at the time of initial construction, and by careful maintenance. A fiberglass greenhouse is generally constructed as a permanent facility and may be as expensive to build as a glass greenhouse. Glass greenhouses should last for at least 40 years, and a useful span of 60 or more years is not uncommon. A large range of glass including erection costs, ventilators, and heat pipes, can be built for $1.00 to $1.50 per square foot. Small (1,000 square foot) glass greenhouses may cost as much as $2.75 to $3.50 per square foot. Table 3 will be helpful in
Table 2. — Partial List of Greenhouse Manufacturers and Construction Companies

<table>
<thead>
<tr>
<th>Company Name</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Greenhouses, Inc.</td>
<td>14615 Lorain Ave., Cleveland, Ohio 44111</td>
</tr>
<tr>
<td>A. Dietzsch Co.</td>
<td>2640 Sheffield Ave., Chicago, Illinois 60614</td>
</tr>
<tr>
<td>Greenhouse Mfg. and Builders</td>
<td>4227 Spring Grove Ave., Cincinnati, Ohio 45223</td>
</tr>
<tr>
<td>Albert J. Lauer Co.</td>
<td>2450 S. Lexington Ave., St. Paul, Minnesota 55118</td>
</tr>
<tr>
<td>Chas. M. Lease</td>
<td>7100 W. Devon Ave., Chicago, Illinois 60631</td>
</tr>
<tr>
<td>Lord and Burnham, Division of Burnham Corp.</td>
<td>Irvington, New York, and Des Plaines, Illinois</td>
</tr>
<tr>
<td>Ludy Greenhouse Mfg. Corp.</td>
<td>P.O. Box 85, New Madison, Ohio</td>
</tr>
<tr>
<td>Metropolitan Greenhouse Mfg. Corp.</td>
<td>1873 Flushing Ave., Brooklyn, New York 11237</td>
</tr>
<tr>
<td>Modern Greenhouse Mfg. Co.</td>
<td>2511 Jackson St., N.E., Minneapolis, Minnesota</td>
</tr>
<tr>
<td>National Greenhouse Co.</td>
<td>Pana, Illinois</td>
</tr>
<tr>
<td>J. A. Nearing Company, Inc.</td>
<td>Brentwood, Maryland</td>
</tr>
<tr>
<td>W. S. Rough Sales Co.</td>
<td>1208 S. Bunn St., Bloomington, Illinois</td>
</tr>
<tr>
<td>Rough Bros.</td>
<td>4229 Spring Grove, Cincinnati, Ohio 45223</td>
</tr>
<tr>
<td>Slifer and Oehmsen</td>
<td>Ruland Road, Melville, New York</td>
</tr>
<tr>
<td>A. T. Stearns Lumber Co.</td>
<td>98 Taylor St., Neponset, Boston, Massachusetts</td>
</tr>
<tr>
<td>Trox Mfg. Co.</td>
<td>18 Angell St., Battle Creek, Michigan</td>
</tr>
<tr>
<td>Turner Equipment Company, Inc.</td>
<td>Goldsboro, North Carolina</td>
</tr>
<tr>
<td>Winandy Greenhouse Constr., Inc.</td>
<td>P.O. Box 597, Richmond, Indiana</td>
</tr>
<tr>
<td>Peter H. Winandy &amp; Sons</td>
<td>1716 Kendale Dr., Glenview, Illinois</td>
</tr>
<tr>
<td>Thomas P. Winandy Sons</td>
<td>1295 Des Plaines Ave., Des Plaines, Illinois</td>
</tr>
<tr>
<td>Yoho and Hooker</td>
<td>Box 1165, Youngstown, Ohio</td>
</tr>
</tbody>
</table>

Determining the initial material costs of various kinds of plastic greenhouses.

A-frame

An A-frame structure for covering with plastic was designed at the Agricultural Experiment Station of the University of Kentucky in the early 1950's. This type of construction has been quite successful and there have been several modifications. The Texas A & M and University of Florida plans have added diagonal bracing wires to provide added strength. In general, these structures are among the least expensive and least difficult to build. Consideration must be given to the placement of the cross-rafters. When the cross-rafter supporting members are placed one-third of the distance or lower on the rafters, it is
A Kentucky A-frame structure. If an insulating layer of polyethylene is to be installed, it is best done from the outside because of the low cross-rafter support members.

difficult to work around the members and apply an inner insulating layer of polyethylene. When the cross-rafter support is high in the peak of the house — especially in narrower houses — an essentially clear-span type of structure permits easy application of the inner layer of plastic. The inner layer can be applied under the cross-rafter supports, leaving a small triangular air space in the peak of the house.

**Scissors truss**

This structure, designed by the Virginia Polytechnic Institute, uses 2” x 3” rafters to form a scissors truss which provides an exceptionally strong framework and has the advantage of a smooth obstruction-free inner surface for double layering. Unfortunately, the insulating qualities of the dead air space are reduced because of the large air volume in the peak of the structure. However, the smaller volume of air heated inside the greenhouse compensates somewhat for this loss. One possible disadvantage of this plan is the low (3-foot) sidewall, although this can be overcome by erecting the trusses on a higher sidewall.

**Truss rafters**

Truss-rafter structures are well suited to the large scale commercial flower or vegetable growing operation. Truss-rafter construction has
This 17' x 66' A-frame plastic greenhouse was designed and built by Andrew Sitter of Cobden, Illinois. It is built over four hotbed flues and is heated very economically using wood as a fuel. Double layering is used to save heat.

been adapted for economical covering with film plastics or with rigid fiberglass panels. Several growers in Illinois have designed and constructed their own truss-rafter structures.

Very strong truss-rafter structures have been designed by Geo. J. Ball, Inc., specifically for covering with Mylar film. These are excep-
The Virginia Polytechnic Institute scissors-truss greenhouse. This is a planted-post structure, 21 feet wide with 3-foot sidewalls, and is covered by polyethylene. It uses scissors-type trussed rafters built from 2" x 3" and 1" x 4" members.

Geo. J. Ball, Inc., has designed this 24-foot-wide truss-rafter structure which is made especially for application of Mylar. A plan is also available for a 30-foot wide structure of the same type.
A 98' x 96' range of Mylar covered greenhouses owned by Schaefer's Greenhouse in Montgomery, Illinois. The basic plan is a 24-foot-wide Geo. J. Ball, Inc., truss-rafter structure, which is adaptable for ridge-and-furrow construction.

A 20-foot-wide truss-frame structure designed by the Hill Greenhouse Construction Company, Apopka, Florida. Welded perma-netting wire is used to support the plastic sheeting. Clear vinyl covers the greenhouse shown here.
An exceptionally sturdy pipe-truss structure, 22 feet wide. This is one of three such houses designed and built for his own use by Walter Ahrens of Danville, Illinois.

The Geo. J. Ball, Inc., 30-foot-wide center-post structure. Plans are also available for a 21½-foot-wide structure.
tionally sturdy structures and have been designed for 24- and 30-foot widths in multiple lengths of 14 feet. The large trusses, however, are heavy and awkward and may require special equipment and costly labor for erection, especially in the wider houses. For larger structures it is wise to employ professional carpenters, and for this reason labor cost for truss-rafter structures can be two or three times the actual cost of materials. These are among the best semi-permanent structures thus far designed for plastic greenhouses. Ball’s plan 58 for ridge-and-furrow construction is recommended for large ranges in Illinois.

**Center-post construction**

Greenhouses utilizing support posts within the structure are generally somewhat easier and less expensive to build than clear-span types. For some crops the center posts can be helpful in installing supports (for tomatoes for example), while in other instances the center posts may interfere. Post construction of plastic greenhouses is popular in the Leamington, Ontario area in Canada. Using rough posts and rough lumber, large greenhouses have reportedly been built for as little as 18 cents per square foot, including all labor and material.

This panel greenhouse with center-post construction is used for spring plant production. The panels are removable for winter storage. Flat-roof construction, such as this, is satisfactory in Illinois for small greenhouses used during spring and summer.
Inexpensive polyethylene greenhouses, 40 feet wide, are used in the Leamington area in Ontario. Center-post construction using rough timber and rough lumber was used to keep construction costs at a minimum. One commercial lumber company is currently building similar greenhouses in the Leamington area.
Rigid frame

Rigid-frame structures, which have no interior supporting members, have been designed in widths up to 40 feet. These structures have been designed to use laminated frames, and exterior and interior gussets with further modifications such as slanted sidewalls with glued or nailed gussets.

Cornell University has designed a 20-foot-wide exterior gusset house which has proven very satisfactory in New York for bedding plants. Plans for the "Cornell Twenty-One" Plastic Greenhouse (see Table 3) give complete construction, heating, and ventilating instructions. Material costs, including heating and ventilating system, are approximately 50 cents per square foot. The New Jersey slant rigid frame is basically an exterior gusset design for 17- and 26-foot widths. It provides maximum ground coverage with minimum structure without sacrificing structural strength. The Michigan State University design is an 18-foot-wide interior gusset rigid-frame structure. The Illinois and Kentucky Agricultural Experiment Stations have interior gusset rigid-frame de-
Plastic Greenhouses

Plans for 13- or 21-foot-wide exterior gusset plastic greenhouses are available from Cornell University. The prefabricated frames are quickly erected and covered with polyethylene.

designs which are among the best available for year-round commercial production. Plans are available for 20-, 30-, 36-, or 40-foot widths.

A commercial prefabricated structure built with curved laminated wood rafters is available from the Trox Manufacturing Company of Battle Creek, Michigan. The Trox house (23 or 30 feet wide) has low sidewalls (low headroom), and to produce crops such as tomatoes or cucumbers the structure must be raised on low foundation sidewalls. This is an attractive house for growing plants in a retail roadside business.

Light-weight steel truss frames are being used for greenhouse construction in Florida. The steel frames are available in 30- and 40-foot widths.

It must be remembered that rigid-frame structures have no interior members and supports for crops must be added separately.

Gothic arch

The Virginia Polytechnic Institute has designed a very attractive gothic-rafter structure. The framework consists of built-up, rib-type curved rafters which are easily constructed. An inner layer of polyethylene can be very easily applied because the interior is obstruction-free. This greenhouse is exceptionally pleasing to the eye.

One sheet of 20-foot-wide polyethylene film is used to cover each side of this greenhouse. Attachment of the film to the structure is necessary only at the ends, along the sidewall, and at the ridge. Fastening at each rafter is not needed as the curved design permits an even
Plans for 17- and 26-foot-wide slant-leg rigid-frame plastic greenhouses are available from Rutgers University.

A low-cost, clear-span plastic greenhouse built with light-weight steel truss frames by Imperial Utility Builders, Apopka, Florida. The frames are placed on 14 foot centers and each greenhouse is 40 feet wide.
flow of winds over the structure without undue "flapping" of the plastic film. This is a distinct labor-saving advantage of this curved-rafter structure.

The Canadian Farm Building Plan Service has also designed a gothic-arch greenhouse built of curved laminated wood rafters. Con-

A 23-foot-wide commercial Trox greenhouse built with curved, laminated rafters. This attractive structure is also available in 30-foot widths.

A very attractive 21-foot-wide gothic-arch greenhouse designed by the Virginia Polytechnic Institute. The rib-type curved rafters are nailed and glued to shape in a jig. The rafters are made of 2" x 1/2" lath strips and 2" x 4" x 6" spacer blocks.
<table>
<thead>
<tr>
<th>Type of structure</th>
<th>Size</th>
<th>Estimated initial cost for materials per square foot&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Origin of structure&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10' x 16'</td>
<td>20–30¢</td>
<td>Louisiana State University, Baton Rouge, Louisiana. Plan 48-6 (10' x 16') and Plan 48-7 (20' x 150') by N. O'Rourke.</td>
</tr>
<tr>
<td></td>
<td>21' x 40'</td>
<td>20–30¢</td>
<td>University of Arkansas, Agricultural Extension Service, Fayetteville, Arkansas. Plan 601011.</td>
</tr>
<tr>
<td>Truss rafters</td>
<td>24' or 30' x 56'</td>
<td>25–35¢</td>
<td>George J. Ball, Inc., West Chicago, Illinois. Plan 58 (24' or 30' wide, clear span). All built in multiple lengths of approximately 14'.</td>
</tr>
<tr>
<td></td>
<td>large range</td>
<td>15–20¢</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20' x 150'</td>
<td>25–35¢</td>
<td>Louisiana State University, Baton Rouge, Louisiana. Plan 48-6 (10' x 16') and Plan 48-7 (20' x 150') by N. O'Rourke.</td>
</tr>
<tr>
<td></td>
<td>25' x 88'</td>
<td>75–90¢</td>
<td>Stuppy Supply Company, 1014 Oak Street, Kansas City, Missouri. Suitable for ridge and-furrow construction.</td>
</tr>
<tr>
<td></td>
<td>(designed for fiberglass)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20' x 100'</td>
<td>35–45¢</td>
<td>Hill Greenhouse Construction Company, Box 68, Apopka, Florida.</td>
</tr>
<tr>
<td>-------------------</td>
<td>---------------------</td>
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<td>----------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Rigid frame</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>40' x 104'</td>
<td>55–65¢</td>
<td>Econ-A-Frame Greenhouses, Imperial Utility Builders, Box 651, Apopka, Florida. Suitable for ridge and-furrow construction.</td>
</tr>
<tr>
<td>Illinois rigid frame</td>
<td>20' or 30' x 96'</td>
<td>30–40¢</td>
<td>University of Illinois, Department of Agricultural Engineering, Urbana, Illinois. Plan S. P. 505.</td>
</tr>
<tr>
<td>Kentucky rigid frame</td>
<td>16' to 40' x 96'</td>
<td>25–40¢</td>
<td>University of Kentucky, Department of Agricultural Engineering, Lexington, Kentucky. (Charge for plans.) Plan Ky. 11.771-6 16'–20' span nailed construction. Plan Ky. 11.771-5 30'–40' span nailed construction. Plan Ky. 11.771-2 16'–20' span glued construction. Plan Ky. 11.771-1 30'–40' span glued construction.</td>
</tr>
<tr>
<td>New Jersey slant leg (exterior gusset)</td>
<td>16' or 26' x 96'</td>
<td>25–30¢</td>
<td>Rutgers—The State University of New Jersey, Department of Agricultural Engineering, New Brunswick, New Jersey. Plan 135 (26' span) (Charge for plan). Plan 136 (16' span) (Charge for plan).</td>
</tr>
<tr>
<td>Michigan rigid frame</td>
<td>18' x 96'</td>
<td>25–30¢</td>
<td>Michigan State University, Agricultural Engineering Department East Lansing, Michigan. Plan 795-C1-6 (rigid frame) and Plan 795-C1-7 (same with panels).</td>
</tr>
<tr>
<td>Trox house</td>
<td>23' or 30' x 96'</td>
<td>35–40¢</td>
<td>Trox Manufacturing Company, Battle Creek, Michigan.</td>
</tr>
<tr>
<td>Gothic arch</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Table is continued on next page)
Table 3.—Types and Costs of Plastic Greenhouse Structures (Concluded)

<table>
<thead>
<tr>
<th>Type of structure</th>
<th>Size</th>
<th>Estimated initial cost for materials per square foot</th>
<th>Origin of structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quonset houses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gro-Mor</td>
<td>11' to 37' x 96'</td>
<td>65–85¢</td>
<td>Lord and Burnham, Des Plaines, Illinois, and Irvington, New York.</td>
</tr>
<tr>
<td>Conduit pipe</td>
<td>10' to 16' x 96'</td>
<td>25–40¢</td>
<td>Homemade, local materials.</td>
</tr>
<tr>
<td>National (Ideal)</td>
<td>16' or 20' x 97/6&quot;</td>
<td>35–60¢</td>
<td>National Greenhouse Company, Pana, Illinois.</td>
</tr>
<tr>
<td>Porta-Green</td>
<td>22' x 55'</td>
<td>45–50¢</td>
<td>Rough Brothers, 4229 Spring Grove, Cincinnati, Ohio 45223, or Dao Corporation, Terre Haute, Indiana.</td>
</tr>
<tr>
<td>Rough</td>
<td>16' or 20' x 97/6&quot;</td>
<td>43–77¢</td>
<td>Rough Brothers, 4229 Spring Grove, Cincinnati, Ohio 45223.</td>
</tr>
<tr>
<td>Panel houses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canadian Farm Building Plan Service</td>
<td>17' x 40'</td>
<td>40–45¢</td>
<td>Canadian Farm Building Plan Service, Ontario Agricultural College, Guelph, Ontario, Canada. Plan A 158-8095 Polyethylene greenhouse with removable panels.</td>
</tr>
<tr>
<td>Structure Type</td>
<td>Size</td>
<td>Cost Range</td>
<td>Source and Notes</td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------</td>
<td>------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Handi-panel house 78</td>
<td>11' x 41'</td>
<td>$1.00 - $1.15</td>
<td>George J. Ball, Inc., West Chicago, Illinois. Plan 68 (24' wide clear span identical to Plan 58, but adapted to use Handi-panels), and Plan 78 (11' wide for use as small plant house). All built in multiple lengths of approximately 14'.</td>
</tr>
<tr>
<td>Ridge and furrow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plan 58</td>
<td>large range</td>
<td>15-20¢</td>
<td>George J. Ball, Inc. West Chicago, Illinois.</td>
</tr>
<tr>
<td>Air supported</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without end-walls, homemade</td>
<td>20' x 80'</td>
<td>15-25¢</td>
<td>For further information on air-supported greenhouses write to Washington State University (address above) for their latest publications.</td>
</tr>
</tbody>
</table>

* Cost when using polyethylene except as noted. Polyester film (Mylar) will increase the cost by approximately 32 cents per square foot of ground covered for a 1,000-square-foot house, and 27 cents for a 4,000-square-foot house. Labor may cost from 10 cents to 40 cents per square foot depending on local rates and difficulty of construction. Costs of course will also vary with size, and many of the designs can be constructed to longer lengths, possibly reducing cost on a per foot basis. Costs for heating and ventilating equipment can run from 25 cents to 85 cents on a square-foot basis, depending on how elaborate a system is installed.  

* Plans available for all except commercial and privately built houses.  

* Including Mylar Handi-panels.
An exceptionally well-constructed range of gothic arch plastic structures, designed and built by H. Patterson and Sons of Bergenfield, New Jersey. These 22-foot-wide greenhouses are constructed of curved, laminated, redwood rafters. Note the provision for summer cooling and ridge ventilation in addition to fan ventilation. The greenhouses are covered with flat rigid fiberglass.

construction involves considerably more labor than the VPI gothic arch structure. A unique feature is a ridge vent running the length of the greenhouse.
Quonset-type construction

There are several kinds of semicircular or quonset-type greenhouse structures. Some have been constructed of wood, but usually their frames are of metal. One advantage is the ease with which the outer layer of plastic can be applied. A large single sheet of plastic covers the entire structure and is held down by wire, rope, or wire netting. These
A Lord and Burnham quonset-type plastic greenhouse covered with one piece of polyethylene. Note the specially designed aluminum ribs in which cables firmly secure the plastic.
Plastic Greenhouses

structures, however, must be erected on a short sidewall to use space efficiently for tall growing crops such as tomatoes. This increases the initial cost.

Of the several commercial and prefabricated quonset-type plastic greenhouses, that made by Lord & Burnham is formed of specially designed aluminum ribs in which a covered cable fits snugly to secure the plastic. Those made by National, and Rough (see Table 3 on pages 24-27) use metal tubing. Large-mesh wire attached over the conduit frame supports the plastic which is pulled taut and fastened to the sill plate on each side of the house. The Porta-Green structure is covered with polyethylene sleeves to form a double-walled structure.

All of these metal-frame quonset structures, and particularly the Porta-Green, can be erected and covered rapidly and more easily than many of the wood frame structures. Most of them, except the Porta-Green, cannot easily be double layered. Some growers have constructed home-made quonset plastic houses using ½- or ¾-inch electrical conduit tubing. Several 10- to 16-foot-wide home-made structures are in use in Illinois and are very satisfactory.

Panel houses

Panels can be covered with plastic and used on several of the preceding frameworks. The width of most panel houses is limited to the size of the panel used. Geo. J. Ball, Inc., has designed a 24-foot-wide structure (Plan #68) specifically for covering with Mylar Handi-panels. A plan for a narrower house of this type can also be obtained from the Ball company (Plan #78). Advantages of panels are that they can be easily covered indoors and quickly installed. They can be taken down and stored during the summer, often doubling or tripling the life of the plastic. Houses built with sliding panels are easily ventilated.

Panel houses require exacting carpentry, and construction costs are also likely to be somewhat higher because of the added lumber and labor needed to build the panels. Panel houses are really a modification of the old-time sash houses used for spring plant growing, and they can be used to good advantage for this purpose. Although quite expensive, rigid fiberglass sheets of the proper size make good panels.

Air-supported houses

Air-supported greenhouses create a lot of interest because of the theoretically low cost involved where no supporting framework is necessary. Basically, such a greenhouse is made by inflating a large sheet
A Cornell panel greenhouse, 16' x 96'. Sliding panels, each 4' x 10', provide ventilation and are removable for storage during the summer.

of plastic (e.g. 40' x 100' polyethylene) which is held down around the four edges to create a "plastic bubble."

Air-supported greenhouses are largely experimental, although some are in use by commercial growers. Successful air-supported structures have been developed by Washington State University where techniques have even been developed for a two-layered structure, both layers being supported by differential air pressure. The second layer appears to help stabilize the structure during high winds.
A unique 22-foot-wide greenhouse designed by Franklin Gronemeier, Bloomington, Illinois. The structure is built with 4' x 16' redwood panels which are covered with special polyethylene sleeves to provide a double-layered greenhouse. The panels have tongue and groove edges and fit snugly together.

Practical air-supported greenhouses, 12 to 28 feet wide, have been developed at Washington State University. Shown are two such greenhouses in commercial use.
Air-supported greenhouses are temporary since polyethylene lasts only for one winter season and often tears easily at the folds after use. Air-supported structures are not difficult to heat but they often create cooling problems. Adequate ventilation with an exchange of large volumes of air is hard to achieve while maintaining the pressure needed to keep the building erect. In wintertime, cold outside air blown into the greenhouse should be deflected upward to prevent injury to plants near the intake. The use of two or more fans operated at different temperatures, each combined with a louver weighted to open at differential pressures, seems to provide adequate ventilation.

The end walls should be framed out of lumber to permit a smooth surface for attachment of the plastic sheeting and installation of fans and doors. Sharp corners cause rapid weakening of the film.

**Ridge-and-furrow construction**

Ridge-and-furrow greenhouse construction enables covering of large ground areas, facilitates installation of heating systems, and offers greater efficiency for tending crops. Furthermore, this type of greenhouse is somewhat less costly to build and to heat.

In western and southern areas where there is little or no snow, large ranges of plastic greenhouses are built of relatively lightweight materials and with rather flat roofs. In Illinois and in northern latitudes, ridge-and-furrow construction for plastic greenhouses is not generally recommended. If it is to be used, careful consideration should be given to the snow loads which the structure must bear. Some ridge-and-furrow greenhouses have failed because the supporting framework caved in from the weight of accumulating wet snow. The Geo. J. Ball, Inc., Plan 58 (see Table 3) is adaptable for large ranges of ridge-and-furrow construction in the midwest. This structure will support a live load of 26 pounds per square foot, which is equivalent to a vertical snow load of 12 pounds per square foot plus a wind load of 15 pounds per square foot perpendicular to the roof.

**Other types of construction**

Individual growers often modify plans for their specific needs. For example, structures can be built only to protect summer crops or for spring plant growing, and these can be designed with light frameworks and flat roofs, provided the plastic is removed during the winter. Growers interested only in spring plant growing may choose structures that have minimum sidewalls. Plans can be modified to meet almost any
A ridge-and-furrow greenhouse range made up of 12-foot-wide even-span sections. This structure, designed by Aart Van Wingerden, Allentown, New Jersey, is covered by two layers of polyethylene from the outside. The special rig which rides on adjoining ridges, facilitates the covering operation. A bottom layer of polyethylene is put over the rafters followed by 6' x 10' wire-mesh reinforced frames. Then the second layer of polyethylene is fastened over the frames by wood battens.
Two ridge-and-furrow greenhouses covered with corrugated fiberglass panels which were built according to plans available from Stuppy Supply Company, Kansas City, Missouri. Each greenhouse is approximately 25 feet wide.

A 20-foot-wide plant growing structure with low sidewalls, and covered with removable panels. Such a greenhouse can be built and heated inexpensively to provide space for spring bedding and vegetable plants.
need, but the grower should keep in mind the basic building tips offered in the next section.

Because plastic is low in cost, lightweight, and versatile, it is particularly suitable for use in portable structures, temporary field greenhouses, and row covers. These structures may have rather permanent frameworks to which the plastic or plastic panels are attached, or may be merely a single wire-supported tunnel row cover. They can be used to grow several succeeding crops but also make possible rotation of the planting areas. Portable structures can be stored when not in use to extend the life of the plastic covering. There are endless possibilities for types of portable plastic structures that may be useful to the individual growers. Unfortunately, it is not feasible to further elaborate on these possibilities in the present publication.

For the home owner there are several plans available for small backyard greenhouses which vary in size and cost. The basic ideas and plans available for commercial plastic greenhouses are largely applicable to these smaller units.

**CONSTRUCTING THE PLASTIC GREENHOUSE**

**The framework**

Use good-grade and well-seasoned lumber for constructing a new plastic greenhouse. Poorly seasoned lumber will warp and twist, causing the plastic to fail. Douglas fir is often recommended for building greenhouses because it is easy to work with and does not tend to split as readily as other kinds of lumber. In some areas, cypress or redwood is available and is excellent for greenhouse construction. Paint the structure with a good white paint. Be certain that the paint contains no toxic materials, especially mercury compounds. This will not only improve the appearance but will also reflect more light. A white greenhouse paint mixture containing a fungicide is preferable.

Posts and wooden members that will come in contact with the ground should be treated (preferably pressure treated) with a good wood preservative. Copper naphthenate in a 2-percent solution is a

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1 The University of Kentucky, Agricultural Engineering Department, Lexington, Kentucky has the following plans: Plan 771-3, “Field Greenhouse—Wood Frame Construction,” a 10-foot wide field greenhouse constructed of glued rigid frames, and Plan 771-4, the same as 771-3 except construction is of 1-inch thin-wall conduit, bent in an inverted “U”-shape. Write for price of plans.

good preservative and is safe for greenhouse use. For semi-permanent structures, consider using treated wood for the entire framework. Never use creosote or pentachlorophenol in or around greenhouses where plants will be grown. Also, do not use wood preservatives that will react with the plastic when it is applied to the framework. Treating and painting can be done most quickly and effectively on the ground before the building is erected.

In general, rafters should not be spaced more than 48 inches apart, and most experiment stations recommend a 30- to 36-inch spacing. Spacing closer than 30 inches is not necessary and puts "too much wood" in the structure, thereby reducing light penetration. Spacing too far apart weakens the overall structure, and the plastic (polyethylene and vinyls in particular) will sag, reducing the effectiveness of the dead air space.

For areas receiving any appreciable amount of snow, the roof should be strongly pitched (at least 35°) and the structure and plastic must be strong enough to bear the weight of anticipated snow. Also, a strong pitch will minimize drip from water condensing on the inner surface of the film.

In planning the structural framework, consider the types of plastics available. If the plastic film is to be applied up and over the structure, space the rafters to make most efficient use of the available widths. When determining the length of the structure, remember that most plastics are available in 100-foot lengths. Therefore a wise planner will build his house 48 or 98 feet long, not exactly 50 or 100 feet.

**Installing film plastics on wood frame houses**

Apply stretchable glazing films on a calm, warm day. Pull the film taut to remove sags, but do not stretch it too tightly for it will contract in cool weather and possibly break loose from the rafters. At the same time, remember that a sagging film touching the inner layer reduces the effectiveness of the dead air space.

Remember too that polyethylene first breaks down where it was creased or folded and along the rafters. Breakdown over the rafters can largely be prevented and film life extended by using batten strips at least as wide as the rafter. Holding polyethylene down with wire netting makes it easier to apply and remove.

When applying longer-life films such as some of the vinyls and Mylar, it is advisable to use painted 3⁄8- to 1⁄2-inch thick batten strips and galvanized nails. Double-headed nails are sometimes used because they are easy to remove.
In some areas, particularly in the south and southwestern states, welded perma-netting wire is used to support plastic greenhouse coverings. The supporting frames are widely spaced with wire netting fastened tautly over the framework. Sometimes the plastic covering is held in place by a second layer of wire netting. This is not recommended for areas where snow accumulation may be a problem.

Often manufacturers will supply instruction tips for applying their particular plastics. Follow these tips to insure a longer, trouble-free life. Mylar, for example, requires very careful installation, and for this purpose, Geo. J. Ball, Inc. offers the following tips:

1. Apply Mylar film only on sturdy houses with a maximum rafter spacing of 36 inches, on center.
2. Install rigid diagonal bracing against the end rafters.
3. Apply lengthwise, overlapping a minimum of 2 inches.
4. Apply in lengths easy to handle at one time (lengths exceeding 50 feet are awkward). Don’t let the film flap in the wind or fold over and become creased.
5. Apply with even tension. Apply tightly and permit no wrinkles.
6. In fastening the film, use a $\frac{3}{8}$- to $\frac{1}{2}$-inch painted batten strip at least the full width of the rafter. Use 4-penny galvanized nails spaced 4 inches apart and staggered. Do not put nails within one inch of the edge of the film.
7. Don’t carry Mylar over eaves or ridges without frame support.

**Installing fiberglass and PVC panels**

Fiberglass and PVC panels are not only used for new greenhouse construction but also to recover structures previously covered by more temporary plastic films and to renovate old glass greenhouses. Corrugated panels are generally preferred for the roof because of the added structural strength.

The spacing of framing members for supporting fiberglass will depend on the weight or thickness of the panel and whether or not the panel is corrugated. The following maximum spacings of support members are suggested for fiberglass (based on design load of approximately 10 pounds per square foot):

<table>
<thead>
<tr>
<th>Weight of fiberglass (ounces)</th>
<th>2½&quot; Corrugated panels Maximum spacing at right angles to the corrugation (inches)</th>
<th>Flat panels Maximum spacing of rafter members (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>36</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>48</td>
<td>18</td>
</tr>
<tr>
<td>8</td>
<td>60</td>
<td>20</td>
</tr>
</tbody>
</table>
The maximum suggested spacing of purlins for 2½-inch corrugated PVC panels is 36 inches.

Rafters are sometimes widely spaced to accommodate 24- to 28-inch-wide panels. When this is done, cross member supports should be installed between the rafters at intervals of 24 to 48 inches.

Special molding strips, spacers, screws and fasteners, together with installation tips, are available from suppliers. Holes should be drilled in the panel for screws and rivets. Special rivets are used to fasten overlapping panels together.

**Double layering**

The addition of a second inside layer of polyethylene is recommended for plastic greenhouses in the middle and northern latitudes. It has been well established that the dead air space created by an inner layer of polyethylene will reduce heating costs, sometimes by as much as 40 percent. Also, moisture condensation inside the house will be lowered. The dead air space should be at least 1 inch but not more than 4 inches, and preferably between 1 and 2 inches in width. This space should be completely closed and not open to the interior of the greenhouse or the outside air. For ease of application, 2- or 4-mil polyethylene is recommended.

The second layer can easily be applied inside the frame of the scissors-type and clear-span houses by using staples over a string or twine to attach the polyethylene to each rafter. The staples may be removed simply by pulling the string. Other ways to apply the inner layer are to use a 2-inch strip of roofing felt, wood strips, and metal or cardboard buttons held in place with small nails. For quonset-type structures constructed of ¾- or 1-inch conduit or pipe, metal clips are available for attaching a layer of polyethylene to the inside of the frame. Applying a horizontal layer of polyethylene along the bottom of an A-frame or a truss rafter house is not recommended because it will bag with moisture.

Occasionally it is advisable and practical to double-layer the polyethylene on the exterior surface of the structural framework. To do this, fasten a layer of polyethylene film on the outside of the rafters with a spacing strip at least one inch deep and as wide as the rafter. Then, on the top of this spacer, apply an outer layer of plastic (polyethylene, vinyl, or Mylar) and attach it with a standard batten strip to form a one-inch air space. A polyethylene inner lining under Mylar will often last two or three seasons.
Because of the insulation created by double layering, snow may accumulate on the roof. This, of course, is undesirable, because of the weight hazard and the shading created. Therefore the structure must be strong enough to carry anticipated snow-loads and the roof should be pitched to enable snow to slide off.

VENTILATING AND HEATING

Adequate ventilating and heating are essential for healthy plant growth and maximum crop yields. Too often growers have inadvisedly attempted to cut costs by underventilating or by installing an inadequate heating system. One may in fact expect an adequate ventilating and heating system to cost as much as the structure itself. Proper ventilation, air circulation, and heating will help prevent high humidity, condensation and dripping of moisture, and stratification of cool air layers at plant level.

Ventilating

The purposes of ventilation are to supply the carbon dioxide necessary for photosynthesis, to control high temperatures, and to permit at least partial control of humidity. Ventilation is a critical problem in plastic houses because of the physical characteristics of the material.

Vents. Side and ridge vents can be used effectively for ventilation. Construction of these vents complicates and increases the cost of an otherwise rather simple structure, but it is cheaper than using fans. Panel houses are easy to ventilate by sliding the panels. Manual vents or panels require constant attention, especially during cloudy or changing weather.

1 The following plans are available from the University of Kentucky, Agricultural Engineering Department, Lexington, Kentucky (price available on request):

Ky. 11.811-1 “Automatic Summer and Winter Heating and Ventilating System for Greenhouses” — 16 to 26 feet wide. This plan has fans located on the side of the house with the heat source outside the house. This system is completely automatic. It can be adapted for any type of heat.

Ky. 11.811-2 Same as No. 811-1 except for 30- to 40-foot width.

Ky. 11.811-3 “Heating and Ventilating System for Greenhouses.” This plan has the heat source inside the house with a turbulator over each source to distribute the heat. Summer ventilation is provided by large fans in the gable ends of the house. This system is also automatic and can be adapted for many heating systems.

2 A publication, “Standards for Ventilating and Cooling Greenhouses,” is available from member companies of the National Greenhouse Manufacturers Association.
For improved winter and spring ventilation, fresh air can be drawn in through overhead plastic tubes. This prevents cold air from coming directly in on the plants and provides uniform ventilation the entire length of the structure. The tubes shown here are open to the outside at each end of the greenhouse. A 3-inch hole is cut on both sides of the tube every 30 inches. When the ventilating fans are running, cool air enters and inflates the plastic tube.

**Fans.** The most convenient way of ventilating plastic greenhouses is to install thermostatically controlled fans to exchange inside air. Some structures, such as quonset-type structures, must be ventilated by fans. A complete change of air every 1 to 1½ minutes is generally considered adequate for warm-weather ventilation. The fan is best located on the leeward end or side of the greenhouse, away from prevailing winds. Two-speed fans are desirable. Automatic outward-opening intake louvers should be located above crop level on the opposite end or side of the house. In larger houses a number of smaller ventilating fans are better than one or two large fans. To increase ventilating efficiency, the intake louvers on the opposite wall can be controlled and operated with the fan diagonally across the building. The intake louver should be at least as large in area as the exhaust fan to insure an adequate volume of air for summer ventilation.

With fan ventilation it is a relatively simple matter to add a pad and pump assembly for evaporative cooling.

During the winter be careful about bringing in cold air from outside directly onto the growing crops. It is best to run the fans on slow speed and to run only a few of the fans in a wide range. Growers
Plastic Greenhouses

sometimes install a small intake opening in the peaks of smaller houses to provide winter-time ventilation. Ventilation is needed at all times in plastic greenhouses heated with combustion furnaces.

For spring and summer production, the covering on the sidewalls or roof can easily be removed to provide maximum air movement and ventilation. Likewise, fall crops can be started before the covering is put on. Growers may cover the sidewalls of Mylar houses with polyethylene for this reason.

Ventilating tubes. Thin-wall polyethylene tubing is becoming popular for winter ventilation in greenhouses equipped with exhaust fans. Fresh air can be introduced into the greenhouse via the tube which is suspended in the peak of the greenhouse. One or both ends of the tube open to the outside. Holes are cut along each side of the tubing and are uniformly spaced the length of the greenhouse. When the exhaust fan is operating, cold air enters the tube, inflating it, and mixes with the greenhouse air without creating cold drafts on the plants below. When the exhaust fans are not operating the tube collapses. For severe weather conditions, shutters may be installed over the opening. Information on size of tubes, distribution of holes, number of tubes for different sized houses, and installation tips are available from distributors.

CO$_2$. The enrichment of the greenhouse atmosphere by maintaining higher than prevailing levels (150 to 400 ppm) of carbon dioxide (CO$_2$) is practiced for several crops in order to hasten maturity, improve quality, and increase production.

CO$_2$ is provided naturally by ventilation and from decomposition of organic matter in the soil. Supplemental sources of CO$_2$ are dry ice, liquid CO$_2$, and special combustion units which burn alcohol, charcoal, paraffin, propane, or natural gas.

Most plastic greenhouses are very suitable for injection of liquid CO$_2$ due to their tight construction. Combustion units designed for installation inside the greenhouse must be adequately vented and used with extreme caution because of the fire hazard of wood and some plastic materials.

Heating

Too frequently plastic greenhouses are inadequately heated. Because these structures are practically airtight, good distribution of heat is often a problem, especially during the winter months. Cold areas along the outside walls, settling of cold moist air, and dripping from condensation, result in poor crop growth and may promote certain
The addition of carbon dioxide (CO₂) to enrich the greenhouse atmosphere is practical for several crops. One method involves purchase of a CO₂ generator which is located outside the greenhouse (above). The CO₂ is distributed within the greenhouse by a special overhead fan and duct system (below).
Table 4.—Comparative Costs of Heating With Different Fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Heat content</th>
<th>Approximate heating efficiency (percent)</th>
<th>Available heat</th>
<th>Price</th>
<th>Cost per 100,000 BTUs (at lower price)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP Gas</td>
<td>91,500 BTUs per gallon</td>
<td>75</td>
<td>68,600 BTUs per gallon</td>
<td>12 cents per gallon</td>
<td>17.5¢</td>
</tr>
<tr>
<td>Oil</td>
<td>138,500 BTUs per gallon</td>
<td>70</td>
<td>97,000 BTUs per gallon</td>
<td>15-16 cents per gallon</td>
<td>15.4¢</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>1,000 BTUs per cubic foot</td>
<td>75</td>
<td>750 BTUs per cubic foot</td>
<td>70-85 cents per 1000 cubic feet</td>
<td>9.3¢</td>
</tr>
<tr>
<td>Coal</td>
<td>12,000 BTUs per pound</td>
<td>60</td>
<td>8,400 BTUs per pound</td>
<td>7-12 dollars per ton</td>
<td>4.1¢</td>
</tr>
</tbody>
</table>

The heat content of the fuel, the efficiency of individual furnaces, and fuel costs may vary from one area to another. The efficiency of individual furnaces or heating plants can be lower or higher depending on the kind of system and the quality of the installation. Any differences from the above figures, of course, would influence the relative heating costs of using these fuels.

diseases. These circumstances can largely be overcome by installation of a heater with sufficient capacity to maintain proper temperatures during the coldest winter weather and by providing for adequate distribution of the heat within the greenhouse.

There are many types of heaters and heating systems that are satisfactory for plastic greenhouses. The grower must decide which is best suited for the intended use of his structure on the basis of cost, economy of operation, and available fuel. Electricity, bottled gas, natural gas, oil, coal, and sometimes wood can be used as fuel for heating plastic greenhouses. In some areas coal or natural gas is readily available at relatively low cost. Gas or oil can be burned slightly more efficiently than coal; furnaces using these fuels require less labor than coal furnaces. Electrical heaters provide a clean dry heat, but heating costs can be very high. (Electric heating is not con-

1 For a detailed discussion of heating systems for greenhouses, consult the following references:


Table 5.—Estimated Costs per Year to Heat a 2,500-Square Foot Plastic Greenhouse in Illinois

<table>
<thead>
<tr>
<th>Size of furnace required (BTU output in thousands)</th>
<th>CAIRO&lt;sup&gt;b&lt;/sup&gt;</th>
<th>CHICAGO&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP Gas</td>
<td>175</td>
<td>460</td>
</tr>
<tr>
<td>Oil</td>
<td>160</td>
<td>405</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>95</td>
<td>245</td>
</tr>
<tr>
<td>Coal</td>
<td>50</td>
<td>115</td>
</tr>
</tbody>
</table>

<sup>a</sup> Costs calculated for 4,000 square feet of exposed greenhouse surface with an average heat loss of 1.2 BTUs per hour per degree difference (inside-outside) per square foot. Costs for a 20,000-square foot (ground coverage) ridge-and-furrow greenhouse can be estimated by multiplying the above figures by 6. These heating costs are based on the fuel costs shown in Table 4. Higher or lower fuel costs will change these estimates considerably.

<sup>b</sup> 0° F. used as base design temperature.

<sup>c</sup> -10° F. used as base design temperature.

<sup>d</sup> Degree days used to calculate the cost data were obtained from the A.S.H.R.A.E. Guide and Data Book, 1962, published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York.

considered practical for the Illinois climate.) If there is sufficient boiler capacity, greenhouse growers may be able to make use of an already existing heating system to accommodate a plastic greenhouse addition. Relative costs of using different fuels are shown in Table 4, and estimated costs to heat a 2,500-square foot plastic greenhouse in Illinois are shown in Table 5.

Any sizeable greenhouse should have a low-temperature warning system to warn the grower of dangerously low temperatures that may indicate failure of the heating system. A standby temporary heating system is warranted in large operations. Sometimes two smaller heaters can be used advantageously with one in each end of the greenhouse. If one fails, the other will protect the crop from freezing.

**Temporary Heaters.** For spring and early summer production, ordinary vented space heaters equipped with circulating fans can be used, although greenhouses using space heaters do not always maintain uniform temperatures. Do not use unvented heaters because fumes will be released which may be injurious to the plants in the greenhouse.

Convection-type heaters are also used for this purpose. In Kentucky, small gas (LP or natural) heaters manufactured by the Burley Burner Company are used to heat small greenhouses. They are most
Inexpensive convection gas (LP or natural) furnaces can be used to heat small plastic greenhouses. The furnace is vented through stovepipes which are installed around the perimeter of the greenhouse. No electricity is required. Humidity can be a problem with this kind of heating system since there is no forced circulation of air.

effective when equipped with a blower attachment. The L. B. White Company of La Crosse, Wisconsin, manufactures a forced draft gas heater and a new HC unit that has no fan and requires no electricity. With both the Burley and White convection-type heaters, warmed air is circulated through stove-pipe arranged around the perimeter of the greenhouse and the burned gases exhausted to the outside. This system has proved satisfactory, although the fuel cost may be high unless natural gas is available. For short term use these heaters have special merit because of their low initial cost.

Salamander heaters can be used for temporary heating and are especially useful in case of power failure or failure of the regular furnace. The salamander heater should be vented to the outside for safest use.

**Unit Heaters.** Unit heaters are usually installed in the peak of the house over the growing crop. They may consist of steam or hot water coils with a fan to distribute warm air, or they may have actual burners to supply the heat. These heaters have an advantage in not taking up usable greenhouse space. It has been demonstrated that fewer (but larger) horizontal unit heaters, which blow the heat out
Overhead unit heaters are available in vertical (above) or horizontal designs (below). The vertical type uses steam as a source of heat and the horizontal type is a gas combustion unit.
horizontally, will do the same job as several vertical unit heaters, which blow the heat downward. Therefore, as long as the horizontal heaters provide adequate distribution of heat in the greenhouse, fewer heaters need to be used, and installation costs can be held down.

For improved circulation of warm air, the fan can be run continuously with only the heating unit thermostatically controlled. It is desirable to add heat lines along the outer walls of greenhouses using unit heaters. Gas-fired unit heaters are generally expensive to operate.

**Forced Warm-Air Heaters.** These are typical residential furnaces of the kind that use coal, oil, natural gas, or propane as fuel and force warm air into the greenhouse. With adequate duct work and registers to distribute warmed air into the greenhouse, these heaters can be used with excellent results. Heating costs may be high, but installation costs are relatively low. Forced warm-air heat has been found superior to convected heat by research workers at the Virginia Polytechnic Institute. Due to good distribution and mixing of heated air in the greenhouse, it was found that air temperatures were more
This special combination heating and ventilating unit was designed by the University of Kentucky. A fan continuously circulates air in the greenhouse. Cool outside air or warm air from the furnace is introduced according to the heating or cooling demands. The baffles direct the air up around the greenhouse roof so that cool air is well mixed before it strikes the plants.

uniform. Relative humidity can be reduced from 100 percent to 60 or 70 percent with forced warm-air heat. As a result, less condensation of moisture occurred inside the greenhouse.

**Boilers.** For winter or year-round production, probably the best heating system for large greenhouses is a central steam or hot water boiler system. In some areas boilers can also be advantageously used in smaller plastic greenhouses, and furnaces can often be obtained at a reasonable cost. In areas where coal is readily available, a boiler heating system is probably the most economical type of heat for year-round production. Steam has an advantage in that it can also be used to sterilize growing beds, potting soil, etc. For plastic greenhouses one heat pipe around the outer wall of the greenhouse and overhead unit heaters with fans would be satisfactory. One possible disadvantage is the daily labor of tending the furnace, which may not be warranted in a small greenhouse.
Special equipment is available for circulating air in the greenhouse, such as the air turbulator shown here. Operating the turbulator continuously helps to provide more uniform temperatures, to lower the humidity, and to maintain higher CO₂ levels at the leaf surface.
Size of Heater. The size of the heater (BTU output) is determined by the minimum temperature requirement of the crop to be grown, the lowest expected outdoor temperature, and the exposed surface area of the greenhouse. Heat loss characteristics differ slightly for different kinds and thicknesses of plastics. The amount of wind, outside temperatures, and exposure of the site will also affect the rate of heat loss.

A heat loss value of 1.2 BTUs per hour for each degree of temperature differential (inside and outside temperature difference) per square foot of exposed surface seems to provide sufficient margin for most plastic structures. Therefore, to maintain a temperature of 55° F. inside a 25' x 100' greenhouse (with 4,600 square feet of exposed wall and roof surface) when the outside temperature is −10° F., a heater with an output of 358,800 BTUs would be required. This is calculated as follows: $1.2 \text{ BTU} \times 65° \text{ F. temperature difference} \times 4,600 \text{ square feet exposed surface} = 358,800 \text{ BTU heat requirement}$. This heat requirement should be increased 10 percent if the greenhouse is located in a windy area. The heat loss values used by commercial greenhouse manufacturers for glass and fiberglass structures are slightly different than the 1.2 BTU per hour figure used here. Any greenhouse supply company or heating engineer will be glad to determine heat loss and the size of heater required for a particular greenhouse.

Circulating Fans. Circulating fans will help to distribute air and heat throughout the greenhouse and provide more uniform temperatures. They have been reported to increase heat efficiency, improve plant growth, and reduce disease. For this purpose, numerous commercial circulating fans are available for greenhouse use.

SELECTED REFERENCES

The following universities, experiment stations and commercial companies offer publications on greenhouse construction. Single copies of many of these publications are free upon request.

California


1 A publication, "How to Calculate Greenhouse Heat Loss," is available from member companies of the National Greenhouse Manufacturers Association. This information should be used for determining heat requirements of glass or fiberglass installations.
Plastic Greenhouses 53

Florida


Illinois


Indiana


Kentucky


Michigan


Mississippi


Nebraska


New Jersey


New York


Circular 905


North Carolina

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Texas
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BLACKHURST, H. T., and LARSEN, J. E. An efficient design for a plastic greenhouse. Department of Soil and Crop Sciences, Horticulture Section, Texas A. & M. College, College Station, Texas.

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Books


