GUIDELINES FOR PLASTIC GREENHOUSE CONSTRUCTION

by

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INTRODUCTION

Greenhouse gardening is rapidly becoming a popular hobby in the United States. Greenhouses are also used for horticultural education in high schools and other institutions. In many situations, greenhouses can be self supporting and serve as a source of income for the part-time grower or vo-ag department.

Plastic covered greenhouses are relatively easy to construct and are relatively inexpensive. Construction materials, however, are considerably different in cost and durability. This manual is designed to analyze and compare costs for plastic greenhouse construction.

OBJECTIVES

The objectives of this thesis were to analyze the costs of a number of construction materials used for plastic greenhouse construction. Considerations were made for those types of greenhouses suitable for part-time production or educational use.

Results will be published in bulletin form by the Kansas State Agriculture Experiment Station.

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Polyethylene was introduced in 1938 and since then has become an important greenhouse glazing material. Plastic films can reduce the initial cost of greenhouse construction. Plastic covered greenhouses can be constructed by the hobbyist or educational institution, which also reduces the initial cost.

Another plastic material, fiberglass, has also gained in popularity since its introduction. However, fiberglass is more expensive than flexible plastic materials.

Even span and quonset greenhouses are common greenhouse structures. Three sizes were analyzed for each type of greenhouse, and construction costs were compared on a cost per square foot basis. The three sizes considered for the even span greenhouses were 20 ft. X 36 ft., 25½ ft. X 54 ft., and 25½ ft. X 104 ft. The three sizes considered for the quonset greenhouses were 20 ft. X 36 ft., 30 ft. X 44 ft., and 30 ft. X 88 ft. Commercial plans were used to estimate costs for both even span and quonset greenhouses.

Prices for construction materials were obtained from commercial catalogs (1, 2, 3, 4) and from local (Manhattan, Kansas) building supply dealers. All components were included in the cost estimations. The houses were compared on the total cost for materials and on a cost per square foot basis.

Information concerning the calculation of environmental control requirements were estimated from the Acme Engineering Handbook (5). The heating requirements were determined and the costs for fuel were estimated from Kentucky plan number KY 11811-4 (6).

THE FOUNDATION

The main purpose of a foundation is to bear the weight of the greenhouse. A good foundation is especially important in areas that have freezing and thawing conditions. The foundations considered in this analysis were individual footings at each stud or pipe bow. The size of the footing for the even span and quonset greenhouses were scaled from the plans. The footings for the even span greenhouses are 2 ft. by 2 ft. by 1 ft. deep, and have a 1 foot column of concrete above it to support the studs. The footings for the quonset greenhouses were estimated at 1 ft. by 1 ft. by 1½ ft. high.

The cost for materials to mix concrete was compared to the cost for pre-mixed concrete. It was determined that the materials for concrete would cost $16.57 per cubic yard when mixed at the site. Pre-mixed concrete costs $16.70 per cubic yard, and was used for this analysis. Costs for labor and trenching were not considered.

The costs for foundations for quonset greenhouses are less than the costs for even span greenhouses. The size of the footings required for the quonset houses are not as great as for even span greenhouses. The quonset greenhouses require less cubic feet of concrete than the even span greenhouses (Table 1).

Table 1. Cost analysis in dollars for foundations.

	Even Span			Quonset		
	720 ft.^{2}	1377 ft.^{2}	2652 ft.^{2}	720 ft.^{2}	1320 ft.^{2}	2640 ft.^{2}
Foundation Items						
Cubic yards concrete	3.11	4.44	6.67	1.11	1.33	2.55
Cost for concrete in dollars	51.93	74.15	111.39	18.53	22.21	42.59
Cost for reinforcement rod in dollars	15.68	22.12	36.12	5.50	6.66	11.93
Total cost for materials	67.61	96.27	147.51	24.03	28.87	54.52
Cost/sq. ft. of floor area	.0939	.0699	.0556	.0334	.0219	.0207

THE FRAME

The selection of a building material for the frame is an important consideration of greenhouse construction. In this study, wood is considered for the even span greenhouses and metal is considered for the quonset greenhouses.

The cost for Douglas fir frames are estimated at 26.5 cents per board foot of material and the cost for redwood frames are estimated at 30.5 cents per board foot of material. In this analysis, copper naphthanate (10%) is considered as a preservative for both species. Paint, which is not a preservative, is also included for beautification. An oil base paint should not be used because it has a tendancy to blister and peel. Exterior acrylic and latex paints should be used (7).

There are a number of ways to apply a preservative, however, the pressure method is the best. When the preservative is applied at the construction site, a cold soaking method is superior to a brush treatment. Soaking allows more penetration of the material into the wood although it is less effective than the pressure method (7).

The costs for redwood and Douglas fir frames including components are illustrated in Table 2. The total frame cost increases as the size of the greenhouse increases. However, the cost per square foot of floor area decreases with increasing greenhouse size. The cost for redwood remains consistently greater than the cost for Douglas fir, Fig. 1.

Table 2. Cost analysis in dollars for even span greenhouse frames.

	720 ft.^{2}		1377 ft.^{2}		2652 ft.^{2}	
	Quantity	Cost	Quantity	Cost	Quantity	Cost
Frame Materials						
16 d galvanized nails @ $.18/lb.	25 lb.	4.50	50 lb.	9.00	100 lb.	18.00
Greenhouse white paint @ $6.80/ gallon	3 gal.	20.40	4 gal.	27.40	6 gal.	40.80
Wood preservative @ $4.00/ gallon	11 gal.	44.00	16 gal.	64.00	22 gal.	88.00
3'X6'-8" aluminum door	1 door	37.95	1 door	37.95	1 door	37.95
½"X8"X3'6" exterior plywood @ $11/ sheet	1½ sheets	16.50	2 sheets	22.00	4 sheets	44.00
Accessories (total)		123.35		166.00		240.71
Douglas fir	532 bd.ft.	141.01	1082 bd.ft.	286.66	1900 bd.ft.	503.51
Douglas fir w/acc		264.36		452.66		743.82
Douglas fir w/acc/ft.^{2}		.3672		.3287		.2805
Redwood	532 bd.ft.	162.31	1082 bd.ft.	329.76	1900 bd.ft.	578.86
Redwood w/acc		285.66		495.76		816.57
Redwood w/acc/ft.^{2}		.3968		.3600		.3090

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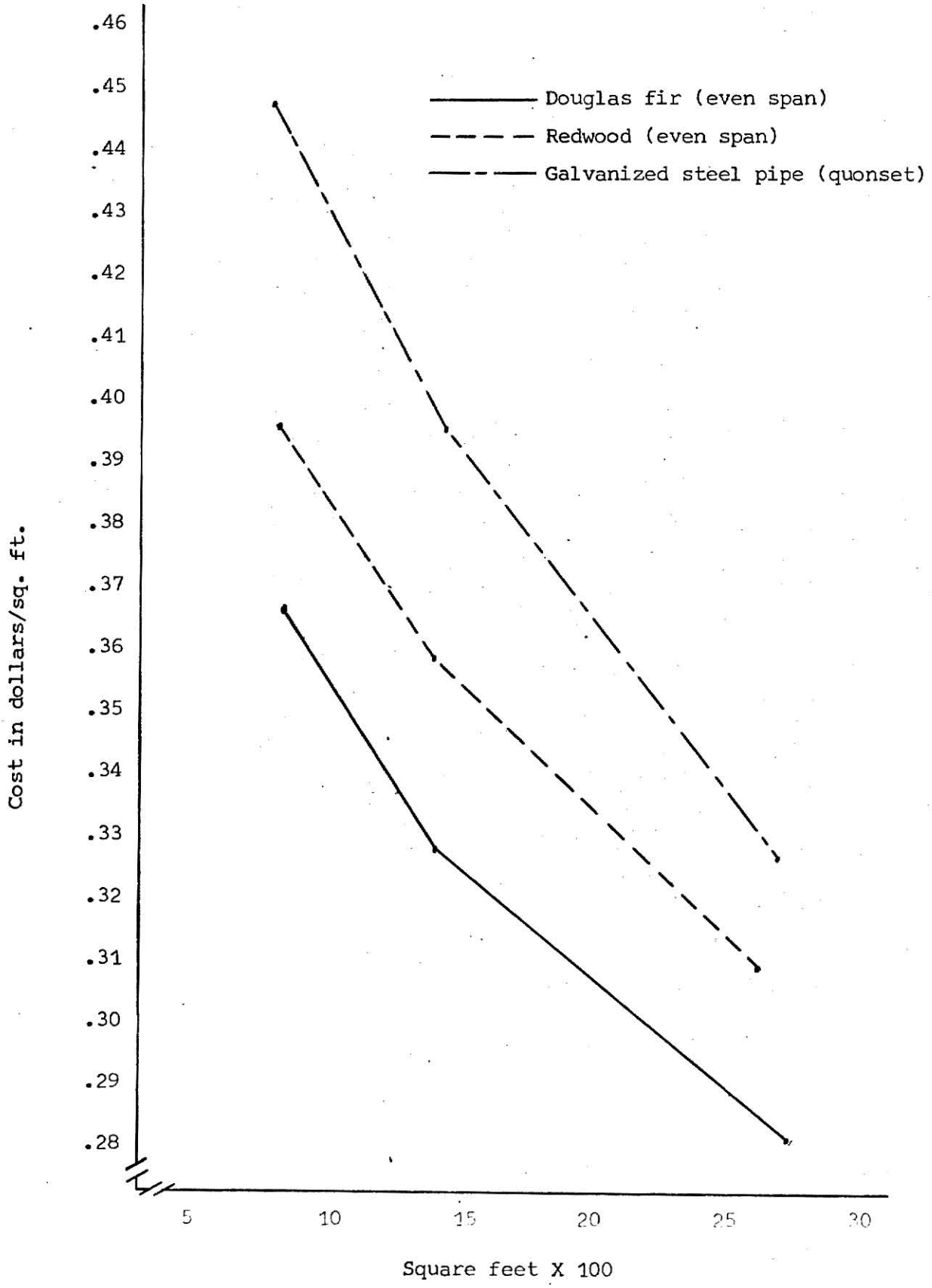
Figure 1. Cost per square foot of floor area for Douglas fir, redwood and galvanized steel pipe frames with components.



Materials other than wood are used for greenhouse construction. For this analysis, 1 inch galvanized steel pipe is used to estimate the framing costs for the quonset greenhouses. One-inch galvanized steel pipe is used for the sides and top to support the glazing materials, and Douglas fir is used for the end walls.

Electric conduit, which is often used for small quonset greenhouses was not considered in this analysis. Several 10 to 16 feet wide structures using 1/2 or 3/4 inch electric conduit have given satisfactory results (8). Conduit is not considered to be structurally sufficient for even the smallest 20 feet wide house. The next larger size of conduit is 1 1/2 inches at 43 cents per foot of material, which is greater than the 42.5 cents per foot for galvanized steel pipe. Therefore, the larger sizes of conduit would exceed the costs for galvanized steel pipe.

The cost per square foot of floor area for the quonset frame and components decreases as the floor area increases from 720 to 2640 square feet (Table 3 and Fig. 1). The costs for the quonset frames are consistently greater than the frames for even span greenhouses (Fig. 1). However, the cost for the quonset greenhouse frames becomes nearer the cost for the even span greenhouses as the floor area increases. The costs for the components and for the framing materials remain greater for the quonset greenhouses at all sizes (Tables 2 and 3). The cost for the materials increases at a progressively faster rate for the quonset greenhouses than for the even span greenhouses.

Table 3. Cost analysis in dollars for quonset greenhouse frames.

	720 ft.^{2}		1320 ft.^{2}		2640 ft.^{2}	
	Quantity	Cost	Quantity	Cost	Quantity	Cost
Frame Materials						
1" gal. steel pipe bows @ $.425/ft. w/ connectors	10 bows	131.70	12 bows	242.25	23 bows	476.10
1¼"X25" gal. pipe stakes @ $.5629/ft.	20 stakes	23.40	24 stakes	28.14	44 stakes	51.48
3/4" gal. pipe purlins @ $.2978/ft.	3 purlins	32.16	3 purlins	39.22	3 purlins	78.62
1¼" gal. pipe straps @ $.09 ea.	32 straps	2.88	38 straps	3.38	75 straps	6.75
3'X6'-8" aluminum door	1 door	37.95	1 door	37.95	1 door	37.95
2"X8"X10' Douglas fir @ $.265/ bd.ft.	53.4 bd.ft.	14.14	29.9 bd.ft.	21.18	79.9 bd.ft.	21.18
2"X8"X12' Douglas fir @ $.265/ bd.ft.	96 bd.ft.	25.44	116.8 bd.ft.	30.96	252.9 bd.ft.	67.03
2"X4"X8' Douglas fir @ $.265/ bd.ft.	166.2 bd.ft.	44.05	372.3 bd.ft.	98.63	372.3 bd.ft.	98.63
Wood pre-servative @ $4/gal.	2 gal.	8.00	5 gal.	20.00	6 gal.	24.00
Cost for frame and components		319.22		521.71		861.74
Cost for frame with components/ sq. ft.		.4441		.3957		.3264

GLAZING MATERIALS

The type of plastic chosen as a glazing material will depend upon the initial cost of the material and the use intended for the structure. Light transmission is an important consideration, however transmission through plastic films is adequate for most crops. The light transmission through plastic materials is approximately 80-90 percent and is 90 percent for glass (8).

Three types of plastics are used for this cost analysis. Polyethylene film is the least expensive per square foot of material, polyvinyl chloride is intermediate in cost, and fiberglass is the most expensive material considered per square foot of material.

Polyethylene is the least durable material considered, and has a tendancy to deteriorate in sunlight. Therefore, polyethylene film should be replaced annually when used as the outside glazing material (9). Ultraviolet resistant polyethylene film has been developed that is more durable in sunlight, although it is more expensive. The UV[1] polyethylene is more durable than standard polyethylene, but it will not remain durable for two summers in most locations in Kansas. However, it will remain durable for two winters and one summer. Polyethylene varies in costs from 0.5 cents to 2.5 cents per square foot of material (8).

The least expensive material is 4 mil polyethylene when compared on a cost per square foot of material basis. However 6 mil UV at a cost of 2.19 cents per square foot is used for comparisons of polyethylene with polyvinyl chloride and fiberglass.

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[1] Ultraviolet light resistant

Table 4. Cost analysis in dollars for flexible and rigid plastics.

	Even Span			Quonset		
	720 ft.^{2}	1377 ft.^{2}	2652 ft.^{2}	720 ft.^{2}	1320 ft.^{2}	2640 ft.^{2}
Glazing Materials						
Accessories for flexible plastics	71.93	132.48	225.51	63.40	92.20	130.60
Accessories for fiberglass	124.60	189.25	339.60	27.85	27.85	27.85
Polyethylene (cost for material)	32.83	57.36	101.16	31.63	56.50	96.76
Polyvinyl chloride (cost for material)	134.91	235.71	415.71	129.94	229.33	397.63
Fiberglass (cost for material)	601.72	942.49	1700.78	462.40	757.20	1496.40
Polyethylene (cost with accessories)	104.76	189.84	326.67	95.03	148.70	227.36
Polyvinyl chloride (cost with acc.)	206.84	368.19	641.22	193.39	321.53	528.23
Fiberglass (cost with accessories)	726.32	1131.74	2040.38	490.25	785.05	1524.25
Polyethylene w/acc (cost/sq,ft,)	.1455	.1378	.1232	.1319	.1127	.0861
Polyvinyl chloride w/acc (cost/sq.ft.)	.2873	.2674	.2418	.2686	.2436	.2001
Fiberglass w/acc (cost/sq.ft.)	1.0087	.8218	.7693	.6809	.5947	.5774

Polyvinyl chloride (PVC) is the most durable flexible plastic and remains durable for two or more years. Polyvinyl chloride film costs 3 to 9 cents per square foot of material, and is the most expensive flexible plastic. Polyvinyl chloride is available in 3 to 12 mil thicknesses (8). For this analysis 8 mil polyvinyl chloride film at 9 cents per square foot of material is considered.

There are accessories required for the installation of flexible plastic glazing materials. Accessories add appreciably to the cost for installation and vary in cost depending upon the options considered. For this analysis the minimum number of accessories were included. Accessories that are included in the cost for flexible plastic films installed on quonset greenhouses are galvanized quick ties, 3/4 inch staples, and 20 gauge galvanized wire. The accessories used for the installation of flexible plastic films on even span houses are not the same as those used on quonset houses. Accessories included for the installation of flexible plastics on even span greenhouses included 20 gauge wire, plastic pressure tape, and staples.

The most expensive material, on a cost per square foot of material basis, considered in this analysis is fiberglass. Fiberglass is available in thickness ranging from .030 inches to .090 inches (8).

Prices for fiberglass range from approximately 20 to 75 cents per square foot of material (8). Five ounce fiberglass is used for comparisons with polyethylene and polyvinyl chloride for this analysis.

The cost for installation of fiberglass includes other components which are necessary for its installation. The necessary components are different for even span greenhouses than for quonset greenhouses. Even span houses require more accessories than quonset greenhouses. The cost for accessories for even span greenhouses increases as the size of the house increases,

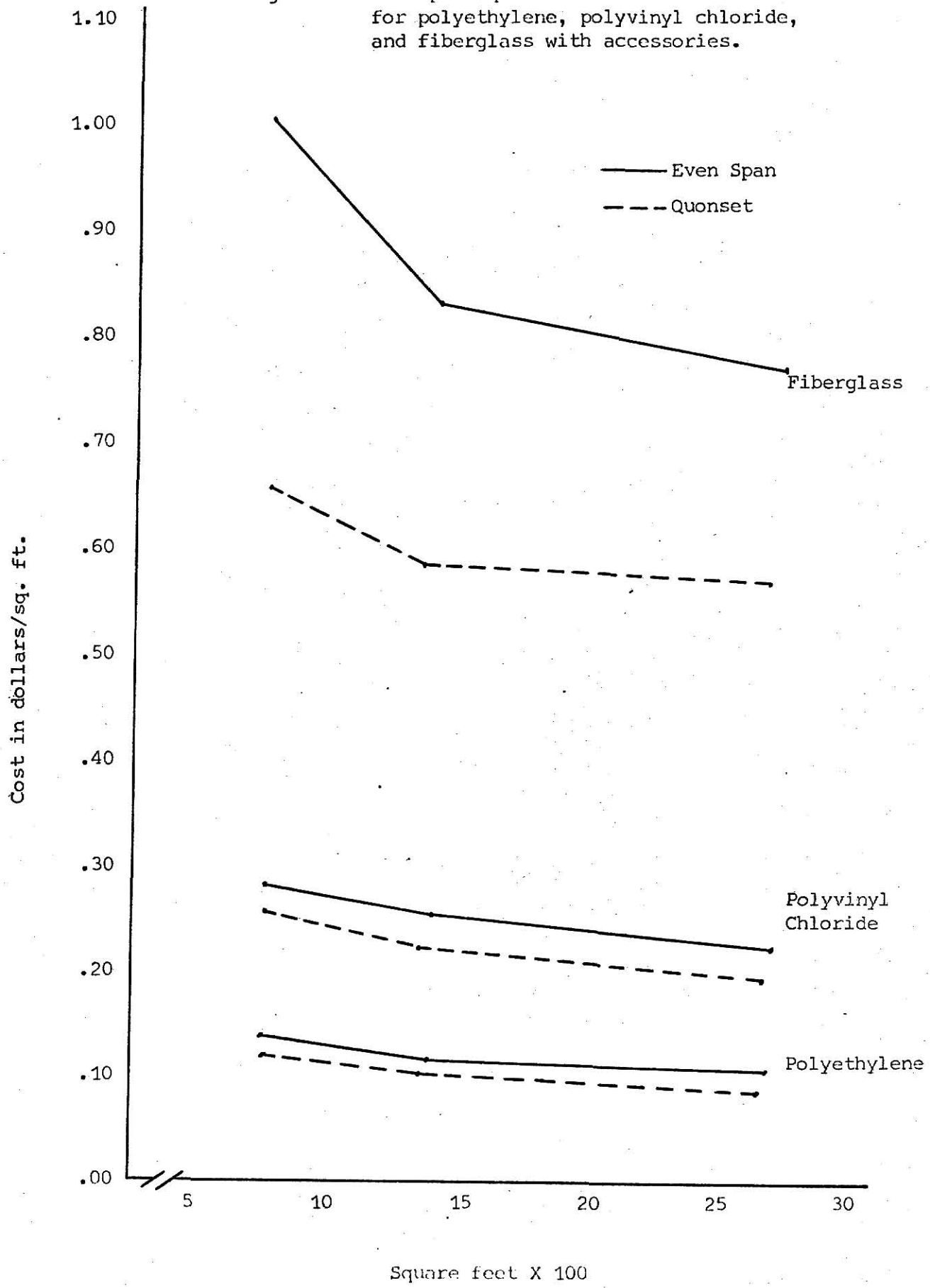
however, because of the quantity that materials are available in the cost of accessories for all quonset greenhouses remains constant.

The accessories included in the cost analysis for even span greenhouses glazed with fiberglass are: a standard ridge cap; diagonal white foam strips; horizontal rubber strips; vertical rubber strips; 2 inch aluminum screw nails; neoprene washers; and rivets. Accessories included in the cost analysis for quonset greenhouses glazed with fiberglass are: screws; polyethylene closures; 2 inch aluminum screw nails with washers; and 1½ inch aluminum screw nails with washers.

The costs for 6 mil UV polyethylene, 8 mil polyvinyl chloride, and 5 ounce fiberglass are compared in Table 4 and Fig. 2. The cost per square foot of floor area for the glazing materials installed on even span and quonset houses is also illustrated.

The cost to glaze a 720 square foot even span greenhouse with 6 mil UV polyethylene is $32.83 for material and $104.76 with accessories. The accessories for both polyethylene and polyvinyl chloride are the same. To cover the same house with polyvinyl chloride would cost $134.91 for glazing material and $206.84 with accessories. Under most circumstances the accessories could be reused, the most expensive being the galvanized wire. Initially it would cost $102.08 more to glaze the greenhouse with polyvinyl chloride. If the 6 mil UV polyethylene film would last for 1½ years and the polyvinyl chloride would last for 3 years, the polyethylene would have to be replaced twice for everytime the polyvinyl chloride was replaced. During a three year period, it would cost $65.66 to cover the greenhouse with 6 mil UV polyethylene and $104.76 for polyvinyl chloride. The cost for 6 mil UV polyethylene during a three year period is approximately 63 percent of the cost for polyvinyl chloride. However, this analysis does not consider labor. When labor is

Figure 2. Cost per square foot of floor area for polyethylene, polyvinyl chloride, and fiberglass with accessories.



a factor, the additional cost for labor may be sufficient enough to justify the use of polyvinyl chloride.

Fiberglass glazing materials for all size houses are more expensive for even span than quonset greenhouses. Costs per square foot of floor area for even span greenhouses are greater than for quonset greenhouses (Fig. 2). The primary reason is that the cost of accessories for even span greenhouses is initially greater than for quonset greenhouses (Table 4). The costs for accessories for even span greenhouses also increases with an increase in floor area, whereas the price is constant for the quonset greenhouses. The price for quonset greenhouse accessories remains constant because of the quantities in which they are available.

To cover a 720 square foot quonset greenhouse with 6 mil UV polyethylene it will cost $31.63 for the materials. It will cost $462.40 to cover the same house with 5 ounce fiberglass. If the useful life of the fiberglass were 12 years, and if the polyethylene were replaced every 1½ years, the polyethylene would be replaced eight times during the useful life of the fiberglass. It will cost $253.04 to cover the greenhouse with 6 mil UV polyethylene for a twelve year period and $462.40 to cover the same greenhouse with fiberglass. These costs do not include accessories. The cost for polyethylene is approximately 55 percent of the cost to glaze the same greenhouse with 5 ounce fiberglass. Labor is not included.

To glaze a 720 square foot quonset greenhouse with polyvinyl chloride will cost $129.99 for the glazing material, and $462.40 to glaze the same greenhouse with fiberglass. During twelve years the polyvinyl chloride, if replaced every 3 years, will cost $512.96. It will cost approximately 10 percent more to glaze the greenhouse with polyvinyl chloride over a 12 year

period. If labor were included the cost would be greater. Comparisons of costs for the glazing material used in this analysis can be made by using Table 4.

ENVIRONMENTAL CONTROL

Heating and Ventilation

The temperature of a small greenhouse may be adequately controlled by using a fan-jet system. The system is designed to distribute the air heated by horizontal type unit heaters, uniformly throughout the house. The system also provides ventilation during the spring and fall.

The heating requirements (BTUs/hr) for the greenhouses in this analysis are estimated for a temperature difference of 70°F and a wind velocity of 15 mph. The temperature difference is the difference between the outside design temperature and the temperature that is to be maintained within the greenhouse (5). The heat requirements for quonset and even span greenhouses are illustrated in Table 5.

All of the houses considered have a construction factor of 1.00 except the fiberglass covered wood house, which had a construction factor of .95. The construction factor is an indication of the relative ability of a material to conduct heat. Two layers of polyethylene have a construction factor of .70 and one layer of polyethylene has a factor of 1.00. This indicates that the use of two layers of polyethylene should reduce the heating requirements and heating costs by 30 percent (Tables 5 and 6). Cost for horizontal discharge gas fired unit heaters with sufficient capacity to supply the necessary heat when one layer of glazing material is used is compared to the cost for the same type heater needed when an inside layer of polyethylene is used is compared in Table 5.

The cost for an inside layer of polyethylene justifies its use. The costs for a layer of 6 mil polyethylene compared to the difference in costs that can be realized by its installation are illustrated in Table 5.

Table 5. Analysis of unit heater capacities and costs in dollars for greenhouses covered with single and double layers of polyethylene.

	Even Span			Quonset		
	720 ft.^{2}	1377 ft.^{2}	2652 ft.^{2}	720 ft.^{2}	1320 ft.^{2}	2640 ft.^{2}
Heating Items						
BTUs/hr. for a single layer of material (1.00)	70,000	140,000	255,000	65,500	130,000	257,000
BTUs/hr. with an inside layer of polyethylene (.70)	49,000	98,000	178,000	45,500	91,000	165,000
Cost for unit heater when one layer of glazing is used	241.00	386.00	673.00	241.00	386.00	561.00
Cost for unit heater when an inside film is used	202.00	299.00	426.00	202.00	299.00	426.00
Difference in price of unit heater (1 layer - 2 layers)	39.00	87.00	247.00	39.00	87.00	135.00
Cost for a single layer of polyethylene	18.89	32.99	58.19	18.89	35.01	52.22
Cost advantages of an inside layer of film	20.11	54.01	188.81	20.11	51.99	72.78

Table 6. Comparison of annual fuel costs in dollars for quonset and even span greenhouses using fuel oil, LP gas or natural gas.

	Even Span								
	720 ft.^{2}			1377 ft.^{2}			2652 ft.^{2}		
	1	2	3	1	2	3	1	2	3
Fuel									
Fuel oil	75.00	52.50	22.50	170.00	119.00	51.00	300.00	210.00	90.00
LP gas	95.00	66.50	28.50	190.00	133.00	57.00	340.00	238.00	102.00
Natural gas	29.00	20.30	8.70	63.00	44.10	18.90	110.00	77.00	33.00
	Quonset								
	720 ft.^{2}			1320 ft.^{2}			2640 ft.^{2}		
	1	2	3	1	2	3	1	2	3
Fuel									
Fuel oil	70.00	49.00	21.00	155.00	108.50	46.50	275.00	192.50	82.50
LP gas	81.00	56.70	24.30	180.00	126.00	54.00	305.00	213.50	91.50
Natural gas	27.00	18.90	8.10	66.00	46.20	19.80	100.00	70.00	30.00

1 - one layer of glazing material

2 - an inside layer of polyethylene

3 - difference in annual fuel costs

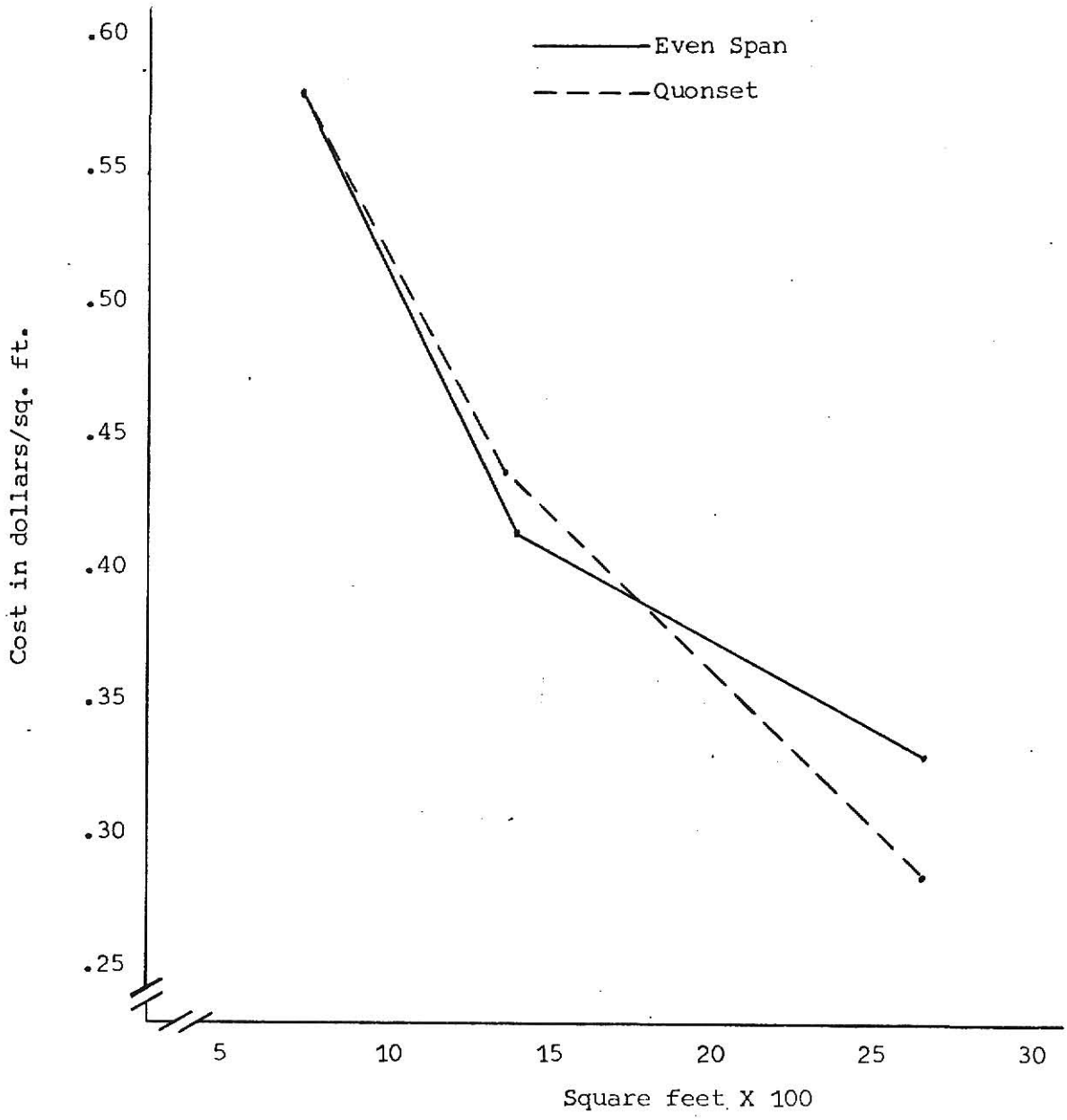
The cost for an inside layer of polyethylene is justified on the basis of initial cost for the heater. The inside layer of polyethylene should last more than one year because it will be exposed to fewer adverse conditions than the outside layer. The cost of a heater for a quonset greenhouse with 2690 square feet of floor area is reduced by $135.00 when an inside layer of polyethylene is used. The additional layer of polyethylene costs $53.22 which allows an initial cost difference of $72.78.

A gas fired horizontal discharge heater is the type used for this cost analysis. This type was selected because it is least expensive to operate when natural gas is available. The costs for heater units also includes other components which are necessary for the operation of the heating units (Table 7). The cost relationship for heating units in even span greenhouses is illustrated in Figure 3.

Three types of fuels are used for cost per year comparisons. The estimates are based on 17 cents per gallon for fuel oil, 15 cents per gallon for LP gas, and 55 cents per 1000 cubic feet for natural gas. Natural gas has the lowest cost annually, and LP gas has the highest. Costs for the fuels considered and a comparison of costs when an inside layer of polyethylene is used are illustrated in Table 6.

Considerable reductions in fuel costs are realized when an inner layer of polyethylene is used. A 2640 square foot quonset greenhouse required $110 annually to heat with natural gas. When an inside layer of polyethylene is used $33 can be saved annually. This annual savings will reduce the cost for the additional layer of polyethylene to $14.22 initially. This will allow an initial cost difference of $119.78 for the smaller unit heater. The inside layer of polyethylene could be replaced biannually for 14 years without adding an additional expense.

Figure 3. Cost per square foot of floor area for heating units with components for even span and quonset greenhouses.



The reduction in annual fuel costs increases when fuel oil or LP gas is used. A quonset greenhouse with 2640 square feet of floor area, when heated with LP gas, will have an annual reduction of $102 when an inside layer of polyethylene is used. This reduction will more than cover the $52.22 required for the additional layer of polyethylene. Therefore, as the cost for fuel increases, an additional layer of polyethylene becomes more important.

All of the quonset greenhouses require less BTUs/hr than the even span greenhouses (Table 5). The costs for heating units (per sq. ft.) for the larger quonset greenhouses is also less than the costs for the larger even span greenhouses. The costs per square foot of floor area may be greater for quonset greenhouses in some instances.

Often the quonset greenhouses require considerably fewer BTUs/hr than the even span greenhouses, which is not indicated by the prices (Tables 5 and 7). This is because the capacity between unit heaters has a large range. The 1320 square foot quonset house requires 130,000 BTUs/hr and the 1377 square foot even span greenhouse requires 140,000 BTUs/hr. However, the next lower capacity heater has a capacity of 120,000 BTUs/ hr, which is not large enough for the quonset greenhouse. The 140,000 BTU heater is used for both greenhouses. There is a large increase in the cost per square foot of floor area between the large quonset and large even span greenhouses because the large even span greenhouse required a larger unit heater to obtain the required BTUs/hr.

Commercially, an inner layer of polyethylene is often not used on glass houses or other permanent houses because of the inconvenience of installation and the cost for labor. The additional layer is justified when labor is not a factor and when crop growth will not be impaired by reduced light transmission.

Table 7. Cost in dollars for horizontal gas unit heaters.

	Even Span			Quonset		
	720 ft.^{2}	1377 ft.^{2}	2652 ft.^{2}	720 ft.^{2}	1320 ft.^{2}	2640 ft.^{2}
Heating Items						
Heater	241.00	386.00	673.00	241.00	386.00	561.00
Fan jet	107.00	111.00	114.00	107.00	111.00	112.00
Motorized shutter	38.00	39.00	42.00	38.00	39.00	42.00
Heating accessories	15.00	22.00	26.00	15.00	22.00	26.00
Polyethylene tubing	12.00	12.00	12.00	12.00	12.00	12.00
Total cost	413.00	570.00	867.00	413.00	570.00	753.00
Cost/sq.ft.	.5736	.4139	.3269	.5736	.4318	.2852

Cooling

Cooling is accomplished by the fan and pad cooling system, which helps to maintain a desirable temperature and helps to avoid temperature extremes during the summer. The requirements for the cooling system are estimated for an elevation of 1500 feet, a light intensity of 5000 foot candles, and a temperature difference within the house of $7^{o}F$. At higher elevations there will be greater light intensities, which will cause greater temperatures in the greenhouse. These factors will cause the fan and pad requirements to increase. The volume of air (cubic feet per minute) required to cool the greenhouses under consideration is illustrated in Table 8.

Aspen pads are used with recirculated water to cool the incoming air. As the size of the house increases, the square feet of pad area increases (Table 8). Pad to fan distances of 100 to 200 feet are optimum and distances over 200 feet should be avoided (1). All of the houses considered have distances of less than 100 feet, except for the large even span greenhouse. Therefore, a factor was used to compensate for the short fan to pad distances.

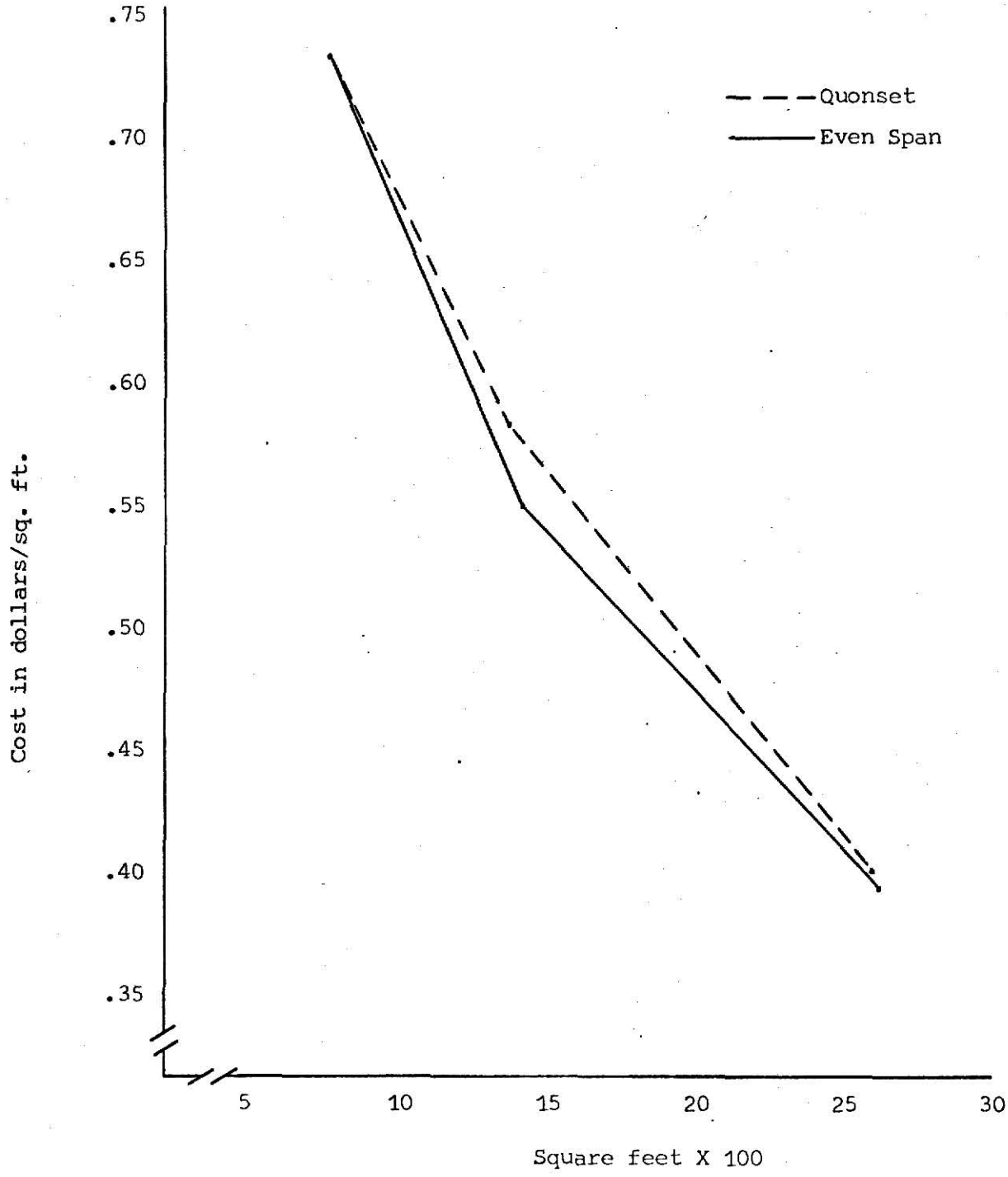
The cooling system is composed of a number of components, which are necessary for the system to function. The total cost for the cooling system decreases as the square feet of floor area increases (Table 8 and Fig. 4).

The costs for the cooling systems for even span and quonset houses are the same, because the shape of the house has little influence on cooling requirements. However, there are slight differences in the costs per square foot of floor area. This is because there are a few less square feet of floor area in the quonset greenhouses than in the even span greenhouses.

Table 8. Cooling system requirements (cfm), square feet of aspen pad, and costs in dollars for fan and pad cooling systems for even span and quonset greenhouses.

	Even Span			Quonset		
	720 ft.^{2}	1377 ft.^{2}	2652 ft.^{2}	720 ft.^{2}	1320 ft.^{2}	2640 ft.^{2}
Cooling Requirements and Costs						
Cubic feet/minute (cfm)	12,904	21,481	41,371	12,904	19,324	38,649
Sq. ft. of aspen pad	84	147	284	84	130	284
Exhaust fans (cost)	192.00	360.00	496.00	192.00	360.00	496.00
Pad frames (cost)	44.25	76.70	150.45	44.25	76.70	150.45
Pump and float (cost)	96.60	96.60	96.60	96.60	96.60	96.60
Aspen pads (cost)	13.50	23.40	45.90	13.50	23.40	45.90
Pipe distribution system (cost)	85.30	115.70	159.60	85.30	115.70	159.60
Humidistats (cost)	19.70	19.70	19.70	19.70	19.70	19.70
Thermostats (cost)	72.00	72.00	72.00	72.00	72.00	72.00
Total cost	523.35	764.10	1040.25	523.35	764.10	1040.25
Cost/sq. ft.	.7269	.5549	.3923	.7269	.5789	.3940

Figure 4. Cost per square foot of floor area for cooling systems for even span and quonset greenhouses.



BENCHES, AISLES, AND OTHER CONSIDERATIONS

Benches are an important consideration for a greenhouse and they should best facilitate the intended use of the structure. Four types of benches are considered in this analysis. Wooden benches with wire tops, wooden benches with wooden tops, and steel benches with wire tops can be used for pot flower production. Steel benches are more durable than wooden benches, however they cost nearly twice as much as wooden benches. Concrete benches are often used for cut flower production. It is recommended that the concrete ground bench has a V-botton with tile drainage (9).

Greenhouses that are to be used for commercial production will probably have larger benches and less aisle area than a high school greenhouse. The benches and aisles considered in this analysis are designed for high school greenhouses. Benches that are against a wall and accessible from only one side should be limited to approximately 30 inches in width, and should be 30 to 36 inches high (10). Benches that are accessible from both sides are four feet wide.

The total cost for benches will depend upon the type of bench used and the number of benches required. The amount of bench area available, in the greenhouses under consideration, with a four foot center aisle and 30 inch aisles between the benches with approximately 5-10 percent of the floor area for storage is illustrated in Table 9. The amount of area available for production can be changed to accommodate the use of the greenhouse.

The cost for benches may be a factor that will help determine the type of bench used. A galvanized steel pipe bench with a wire mesh top is the most expensive type at $.95 per square foot of bench area. A concrete ground bench costs $.39 per square foot of bench and was the least expensive type analyzed. A wooden bench with a wire mesh top costs $.52 per square foot of

Table 9. Bench and aisle area available and cost for concrete aisles.

	Even Span			Quonset		
	720 ft.^{2}	1377 ft.^{2}	2652 ft.^{2}	720 ft.^{2}	1320 ft.^{2}	2640 ft.^{2}
Items						
Bench area (sq. ft.)	296	656	1260	296	637	1209
Bench area (% of floor area)	41	47	47	41	48	45
Sq. ft. of aisles	395.5	641.0	1323.0	395.5	589.0	1322.0
Cu. ft. of concrete for aisles	3.05	7.0	12.5	3.05	5.5	12.5
Cost for concrete @ $16.70 per cu. yd.	50.94	116.70	208.75	50.94	91.85	208.75
Cost for 14 gauge wire	59.00	108.50	231.50	59.00	99.00	231.50
Total cost for aisle	104.94	225.40	440.25	104.94	190.85	440.20

bench area and a wooden bench with a wooden top costs $.57 per square foot of bench area. The costs are approximate and will change with size of the bench and modifications of their construction.

A four foot center aisle the length of the greenhouses accommodates maximum student movement. The aisles between the benches are 30 inches wide. Concrete at $16.70 per cubic yard and wire mesh is used to estimate the aisle costs. Concrete aisles are not necessary in a greenhouse and need not be included. Often crushed stone, gravel or the ground is used as an aisle. The cost analysis for aisle construction is illustrated in Table 9. All aisles are 3 inches thick.

Other utilities, such as plumbing and heating, are not included in this analysis. The cost for electrical facilities will depend upon the type of lighting required and the amount of electrical wiring needed. Some houses, such as those equipped with a mist system, will require more plumbing than houses not so equipped. Facilities such as these would best be installed by electrical and plumbing contractors. However, there are certain factors that should be considered. It will be best to locate the greenhouse as close to existing utilities as possible. This will reduce the costs of materials for installation of the electrical, plumbing, and heating systems. Also the soil type, drainage, and exposure must be considered. If these factors have undesirable characteristics, they should be corrected, or the greenhouse should be located at a different site.

Labor is not considered as a factor in this analysis. However, if labor were a factor, it would probably affect the selection of materials for construction and would also add appreciably to the construction costs.

TOTAL COST ANALYSIS

The total for a plastic greenhouse will vary depending upon the materials and method of construction. A cost analysis for plastic greenhouse construction is illustrated in Table 10. The most expensive house per square foot is the 720 sq. ft. fiberglass covered even span greenhouse and the least expensive is the 2640 sq. ft. polyethylene covered greenhouse.

By using Table 10 and other data analyzed in this manual, a plastic greenhouse can be selected to best facilitate individual needs.

Table 10. Cost analysis in dollars for plastic greenhouse construction.

	Even Span			Quonset		
	720 ft.^{2}	1377 ft.^{2}	2652 ft.^{2}	720 ft.^{2}	1320 ft.^{2}	2640 ft.^{2}
Item						
Foundation	51.93	74.15	111.39	18.53	22.21	42.59
Douglas fir frame (even span)	264.36	452.66	743.82	---	---	---
Galvanized steel frame (quonset)	---	---	---	319.22	521.71	861.74
Heating and ventilation	413.00	570.00	867.00	413.00	559.00	753.00
Cooling system	523.35	764.10	1040.25	523.35	764.10	1040.25
Concrete aisles	104.94	225.40	440.25	104.94	190.85	440.20
Total less glazing	1357.58	2086.31	3202.71	1379.04	2057.87	3137.78
Polyethylene	104.76	189.84	326.67	95.03	148.70	227.36
Polyvinyl chloride	206.84	368.19	641.22	193.39	321.53	528.23
Fiberglass	726.32	1131.74	2040.38	490.25	785.05	1524.25
Total with polyethylene	1462.34	2276.15	3529.38	1474.07	2206.57	3365.14
Cost/sq.ft. of floor area	2.03	1.65	1.33	2.05	1.67	1.27
Total with polyvinyl chloride	1564.42	2454.50	3843.93	1574.43	2379.40	3666.01
Cost/sq.ft. of floor area	2.17	1.78	1.45	2.18	1.80	1.39
Total with fiberglass	2083.90	3218.05	5243.09	1869.29	2842.92	4662.03
Cost/sq.ft. of floor area	2.89	2.34	1.98	2.60	2.15	1.77

LITERATURE CITED

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10. Duncan, G.A. and Roberts, D.R. A Greenhouse for Teaching Plant Science and Production. University of Kentucky, College of Agriculture, Cooperative Extension Service. Misc. 395. 1971.

ACKNOWLEDGEMENT

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Gratitude is also extended to Dr. Ronald Campbell, Head of the Department of Horticulture and Forestry; Dr. Charles Marr, Assistant Professor of Horticulture and Forestry; and Dr. James Albracht, Associate Professor of Education, who served as committee members.

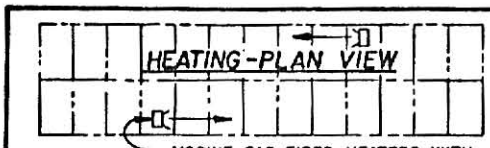
APPENDIX

ILLEGIBLE DOCUMENT

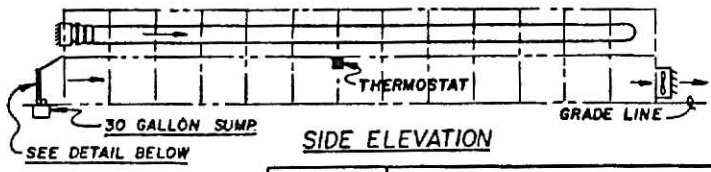
THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE

Stuppy's
120 EAST 12th AVE., NORTH KANSAS CITY, MO. 64116, 1-816-842-6696

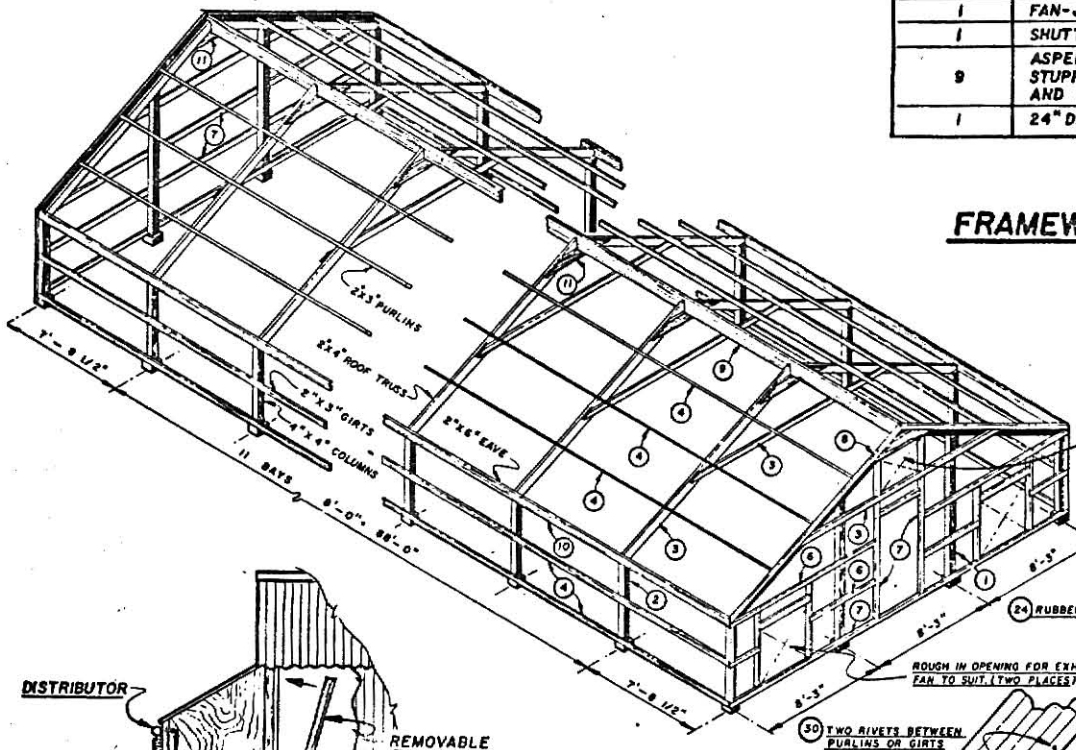


TEMP DIFF.	NO. HTRS	MODEL	BTU OUTPUT PER HEATER
50°	2	P175A	140,000
60°	2	P225A	180,000
70°	2	P300A	240,000

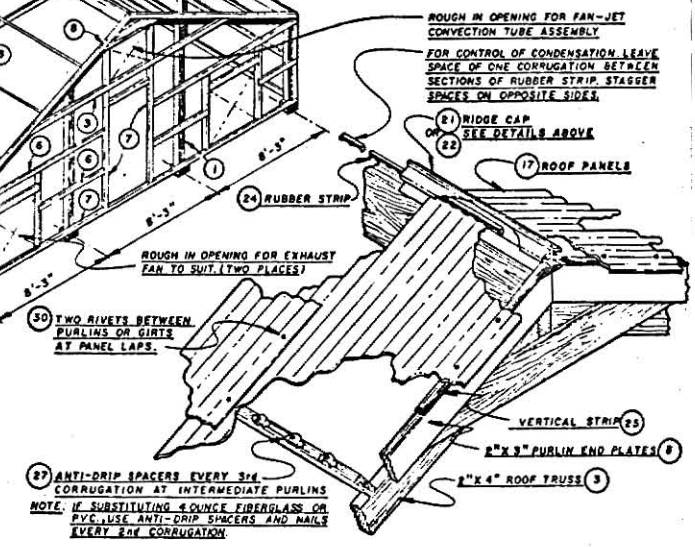


NUMBER REQUIRED	DESCRIPTION
2	FAN, ACME FLORAL BREEZE #DC42F
2	WALL BOX #WB42
2	AUTOMATIC SHUTTER #W4545
1	FAN-JET #R24F
1	SHUTTER #W3030MT
9	ASPEN PAD AND FRAMES - 66" CONSULT STUPPY FOR PIPE DISTRIBUTION SYSTEM AND ACCESSORIES.
1	24" DIAMETER POLY TUBE 105' LONG

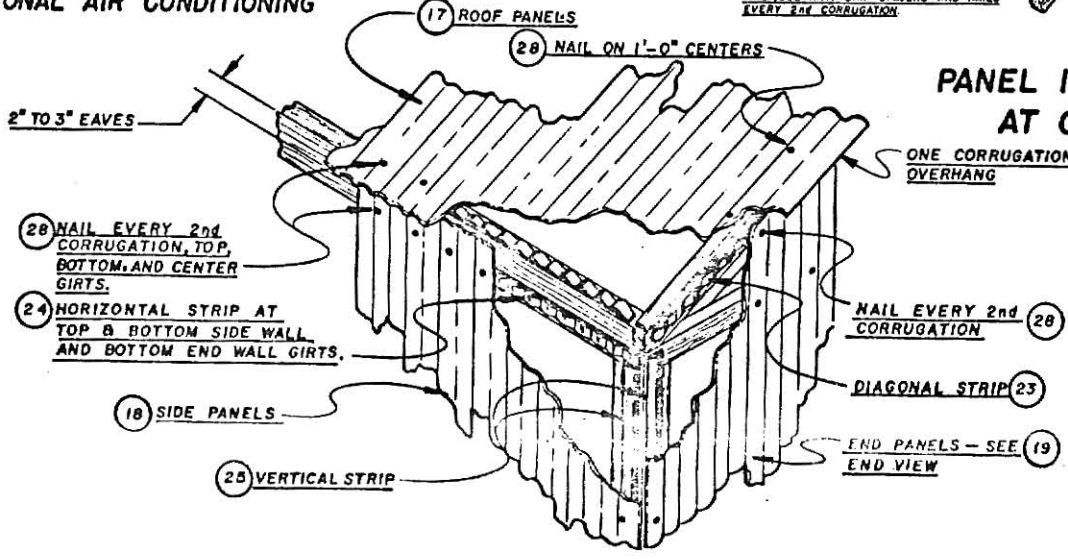
FRAMEWORK ERECTION PLAN

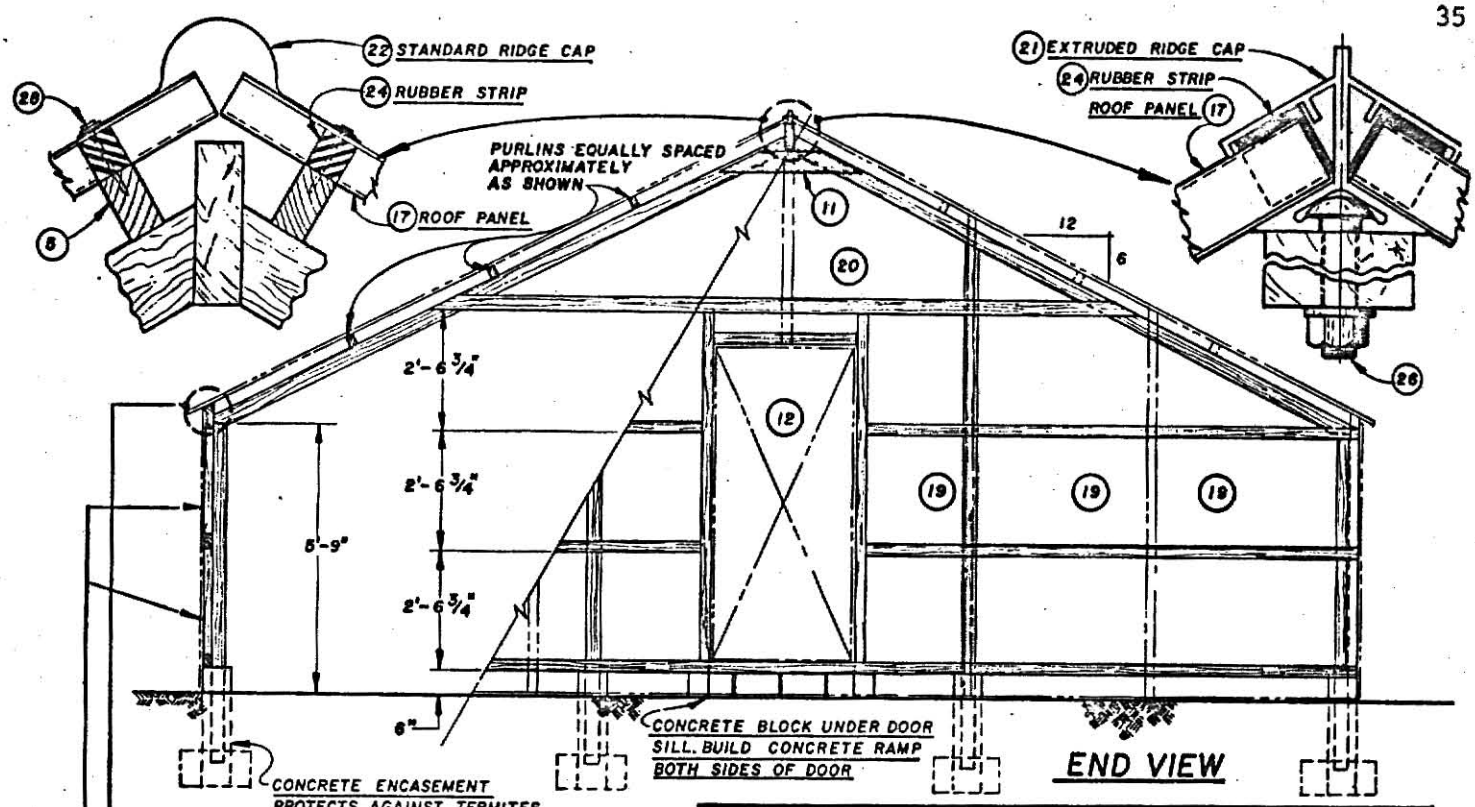


OPTIONAL AIR CONDITIONING



PANEL INSTALLATION AT CORNERS





END VIEW

BILL OF MATERIAL

ITEM	QUANTITY	DESCRIPTION
1	4	4"x 4"x 12' #1 FIR OR CONSTRUCTION HEART REDWOOD (DOORS)
2	26	4"x 4"x 8' #1 FIR OR CONSTRUCTION HEART REDWOOD (SIDES)
3	39	2"x 4"x 14' #1 FIR OR CONSTRUCTION HEART REDWOOD (ROOF)
4	78	2"x 3"x 16' #1 FIR OR CONSTRUCTION HEART REDWOOD (ROOF & 3 PCS)
5	14	2"x 3"x 16' #1 FIR OR CONSTRUCTION HEART REDWOOD (ROOF)
6	4	2"x 3"x 12' #1 FIR OR CONSTRUCTION HEART REDWOOD (ENDS)
7	14	2"x 3"x 10' #1 FIR OR CONSTRUCTION HEART REDWOOD (ENDS)
8	4	2"x 3"x 14' #1 FIR OR CONSTRUCTION HEART REDWOOD (ENDS)
9	7	2"x 6"x 16' #1 FIR OR CONSTRUCTION HEART REDWOOD (RIDGE)
10	14	2"x 6"x 16' #1 FIR OR CONSTRUCTION HEART REDWOOD (EAVES)
11	14	1/2"x 8"x 3'-6" MARINE PLYWOOD
12	1	3'x 6'-6" ALUMINUM DOOR
13	100 POUNDS	#16d BOX NAILS – GALVANIZED
14	———	CONCRETE (AS REQUIRED PER JOB)
* 15	6 GALLONS	GREENHOUSE WHITE
* 16	22 GALLONS	WOOD PRESERVATIVE (CUPRINOL)
* 17	50	52 5/8"x 14'-4" FIBERGLASS (ROOF)
* 18	25	52 5/8"x 12'-0" FIBERGLASS (SIDEWALL)
* 19	6	52 5/8"x 12'-0" FIBERGLASS (ENDS)
* 20	3	52 5/8"x 12'-0" FIBERGLASS (GABEL)
* 21	11	STUPCO #1224 ALUMINUM, EXTRUDED RIDGE SECTION
* 22	11	STANDARD RIDGE CAP
* 23	60'	DIAGONAL STRIP, GREY FOAM
* 24	700'	HORIZONTAL STRIP, RUBBER
* 25	75'	VERTICAL STRIP, RUBBER
* 26	32	3/8"-16 x 7 1/2" CARRIAGE BOLT, NUT AND WASHER
* 27	1250	ALUMINUM ANTI-DRIP SPACERS
* 28	4000	2" ALUMINUM SCREW NAILS WITH NEOPRENE WASHERS
* 29	1	RIVET GUN (RENTALS AVAILABLE)
* 30	1100	3/16" ALUMINUM, HI-CLINCH RIVETS WITH WASHERS

NOTE: THE QUANTITIES LISTED IN THE BILL OF MATERIAL ARE EXACT, IT IS ADVISABLE TO ORDER ONE EXTRA 14'-4" PANEL (ITEM 17) IN CASE OF TRANSIT OR JOB DAMAGE.....

THIS GREENHOUSE DESIGN IS SUPPLIED AS A COURTESY BY STUPPY SUPPLY COMPANY. THERE IS NO CHARGE FOR ITS ACCEPTANCE AND USE..... FULL RESPONSIBILITY FOR ITS USE MUST THEREFORE BE ASSUMED BY THE USER.

1. * INDICATES MATERIAL AVAILABLE FROM STUPPY.
2. DRILL 5/32" HOLE THRU PANELS AND REDWOOD STRIPS BEFORE NAILING.
3. TAR-COAT THE PORTIONS OF 4"X 4" COLUMNS TO BE EMBEDED IN CONCRETE.
4. ENTIRE FRAMEWORK SHOULD BE PAINTED BEFORE ATTACHING FIBERGLASS PANELS. USE A GOOD WEATHERPROOF PAINT. (CONTINENTAL #71-100 GREENHOUSE WHITE)

104'-2" x 25'-6" GREENHOUSE SUGGESTED CONSTRUCTION

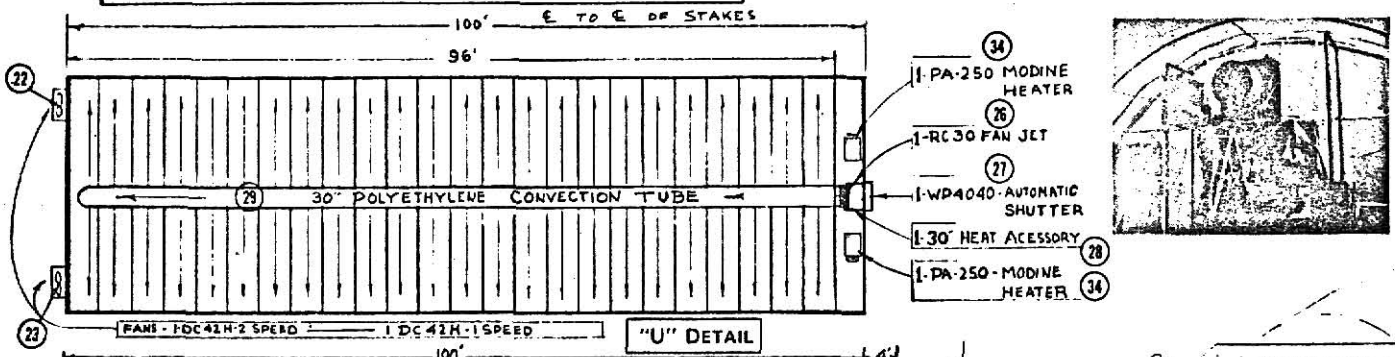
STUPPY SUPPLY CO.
120 E. 12TH AVE. KANSAS CITY, MISSOURI 64116 816-842-6697

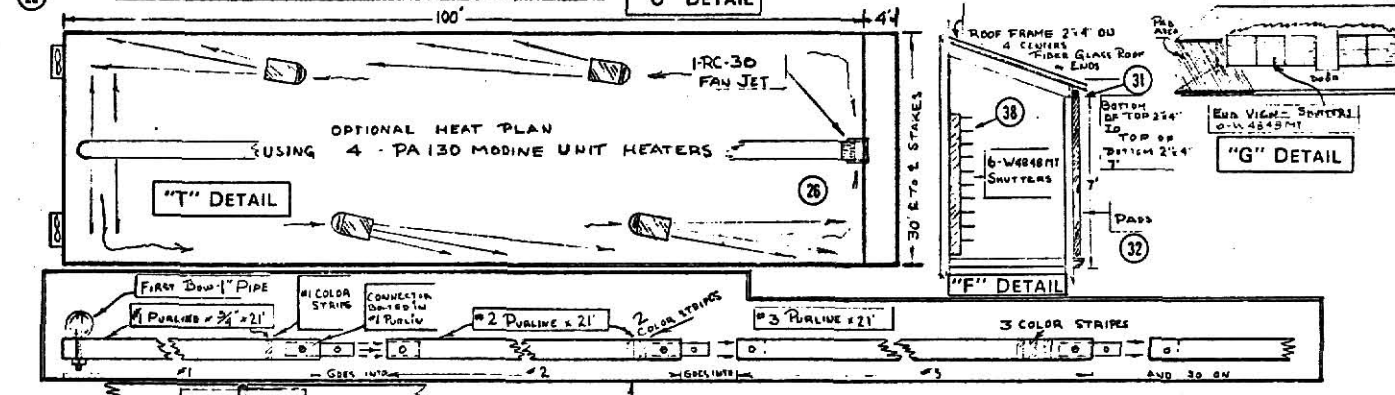
REVISED FEB., 1972 JECO 30-F-1018

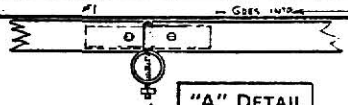
THE FOLLOWING DOCUMENT HAS PRINTING THAT EXTENDS INTO THE BINDING.

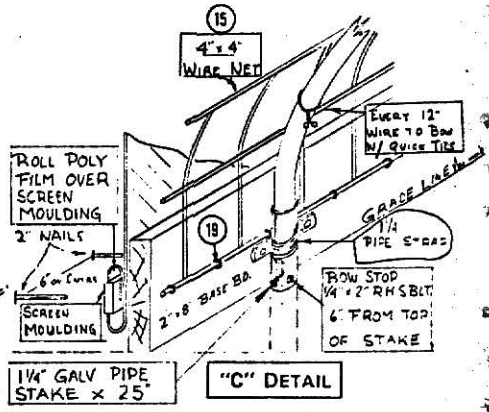
THIS IS AS RECEIVED FROM CUSTOMER.

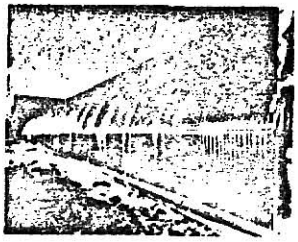
Stuppy's 30' RAINBOW GREENHOUSE

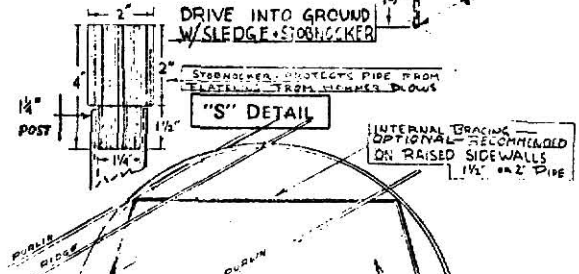


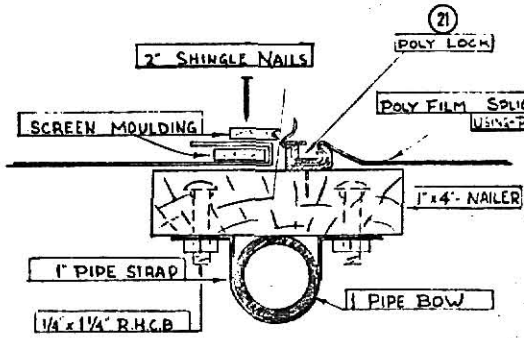


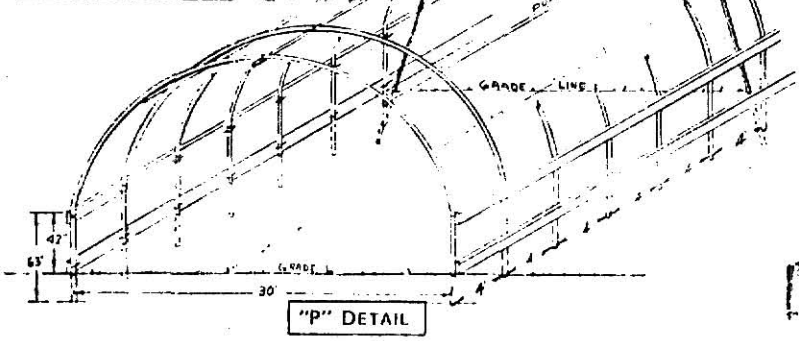


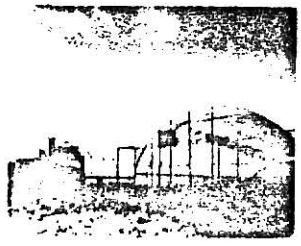


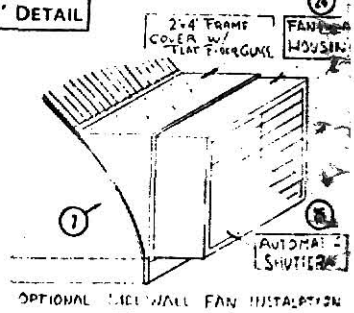


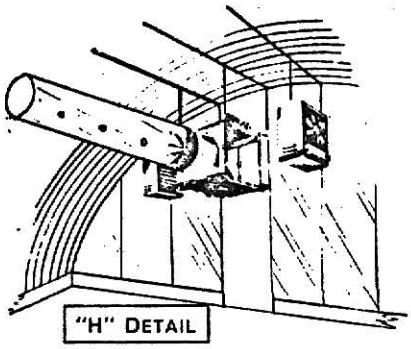




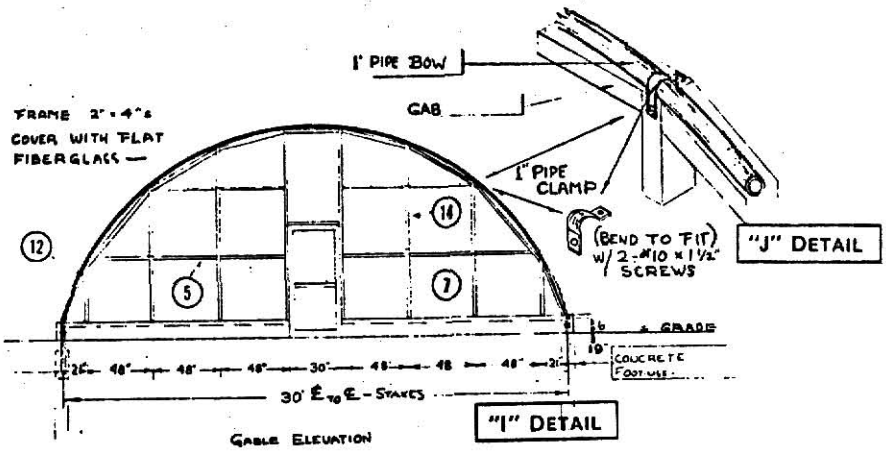


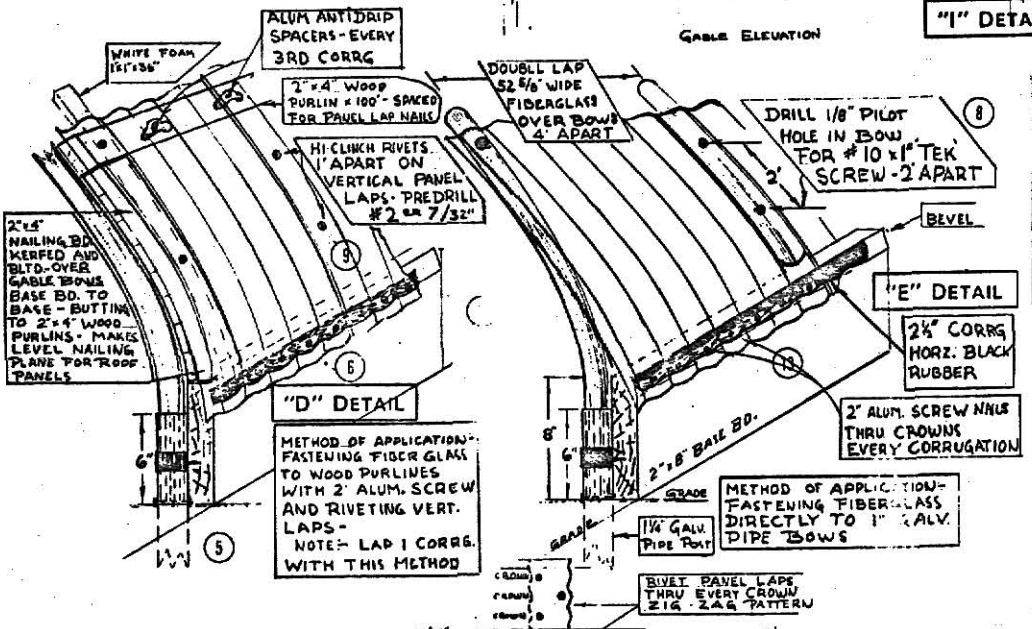


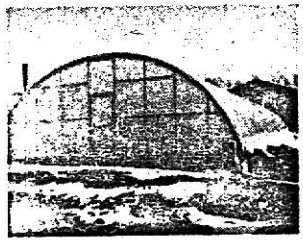


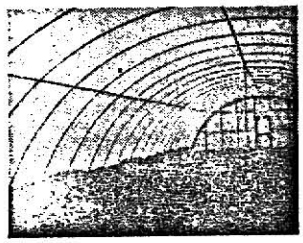


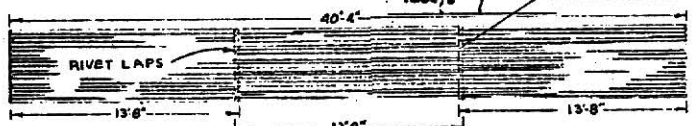
"H" DETAIL



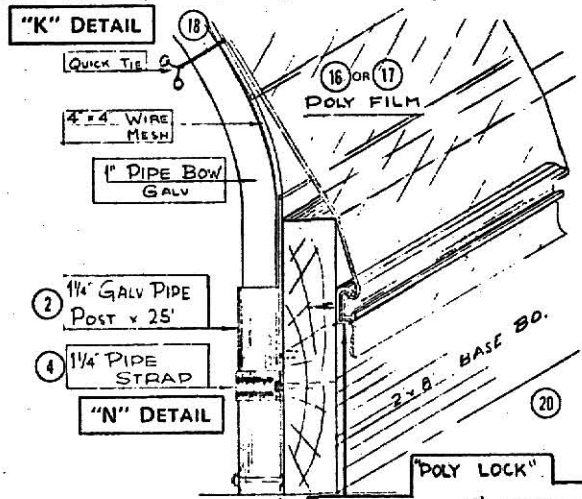


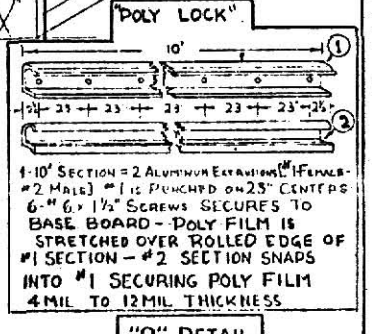






ROOF PANEL MAKE-UP - USING 3 PANELS FIBERGLASS 52 5/8" x 13'8" (164") EACH

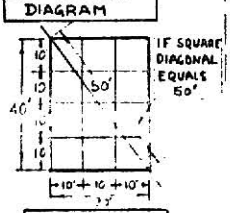




1-10' SECTION = 2 ALUMINUM EXTRUSIONS (1 FEMALE - #2 MALE) #1 IS PUNCHED ON 23" CENTERS
6-#6 x 1½" SCREWS SECURES TO BASE BOARD - POLY FILM IS STRETCHED OVER ROLLED EDGE OF #1 SECTION - #2 SECTION SNAPS INTO #1 SECURING POLY FILM 4 MIL TO 12 MIL THICKNESS

"O" DETAIL

PLOT SQUARING DIAGRAM



"R" DETAIL

NEW - IMPROVED - GALVANIZED PIPE STRUCTURE - SCHEDULE 40 - GRADE A120

BILL OF MATERIALS AND PRICE LIST

ITEM #	QUANTITY	STOCK #	DESCRIPTION
1	26	G2452	1" Galvanized Pipe bows with connectors
2	52	G2454	1¼" x 25' Galvanized Pipe Stakes
3	3	G2453	¾" Galvanized Pipe Purlins x 100' lengths
4	75	G2434	1¼" Pipe Straps
5	None		All wood members and nails furnished by others
RIGID FIBERGLASS COVERING, 2½" CORRUGATED GREENHOUSE CLEAR (TOTAL SQUARE FEET) 4,674.54			
OPTIONAL ON PANELS			
6	78		Panels 52 62" x 13'8", 5 Oz. Weight (3 extra)
7		G2688	1 Roll 4' x 50' Clear Fiberglass Type 550
		G2689	1 Roll 4' x 100' Clear Fiberglass Type 550
8	1000	G2073	Tek Screws #10 x 1"
9	1500	G213	Hy Clinch Aluminum Rivets with washers 3/16"
10	1	G215	Rivet Gun
11	100	G230	Horizontal Rubber Closures 36" x 1"
12	40	G229	Polyurethane Closures 36" x 1"
13	1000	G207	2" Aluminum Screw Nails with Washers
14	600	G205	1½" Aluminum Screw Nails with Washers
POLYETHYLENE COVERING			
15	5	G2424	4' x 4" Galvanized Wire Fabric 6' x 150'
16	1	G28915	Roll 40 x 100' 602 Monsanto 6 Mil Film UVL
17	1	G286	Roll 40' x 100' Polyethylene 4 or 6 Mil Plain
18	1000	G2425	Galvanized Quick Ties with Crank (G2426)
19	750	G2435	¾" Staples
20	20	G2041	Aluminum Poly Lock Extrusion x 10' (Base Board Seal)
21	8	G2041	Aluminum Poly Lock Extrusion x 10' (Gable Top Seal)
AUTOMATIC SUMMER/WINTER CLIMATE CONTROL			
22	1		DC42H Two Speed Exhaust Fan
23	1		DC42H Exhaust Fan
24	2		WB42DC Wall Housings
25	2		W4545 Automatic Shutters
26	1		RC30G Jet Fan
27	1		WP4040MT Motorized Shutter
28	1		Heating Accessory for RC30G Jet Fan
29	1	G3030	Polyethylene Convection Tube Model HS 100
30	1	G3160	Two Stage Line Voltage Thermostat (Ventilation)
31	30'		Pipe Distribution System
32	11		Aspen Pads & Frames 34" x 72"
33	1	G3100	No. 30 Pump (115 Volt)
34	2	G5071	No. PA 250 Modine Gas Fired Unit Heater (65° Temp. Diff.)
35	2		10" Metalbestos Stacks & Cap
36	3	G3150	1 Line Voltage Thermostat (Heater - Pump)
37	1	G3130	Relay (Pump)
38	6		W4848MT Motorized Shutters (Pad End)

NOTES

STANDARD 30' x 100' Rainbow Greenhouse

ALL STRUCTURAL MATERIAL PRE FORMED AND PRE DRILLED, COLOR CODED AND IN 4' MODULES. NUTS, BOLTS, AND WASHERS INCLUDED

ALL PRICES SUBJECT TO CHANGE WITHOUT NOTICE

Stuppy's

Feb. 1 1972
Montague

STUPCO RO30

GUIDELINES FOR PLASTIC GREENHOUSE CONSTRUCTION

by

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B. S., Kansas State University, 1971

AN ABSTRACT OF A MASTER'S THESIS

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Two types of greenhouse construction are considered for this analysis. The three even span greenhouses considered are 20 ft. X 36 ft., 25.5 ft. X 54 ft., and 25.5 ft. X 104 ft. The three quonset greenhouses considered are 20 ft. X 36 ft., 30 ft. X 44 ft., and 30 ft. X 88 ft. The results included in this abstract are for the materials and methods considered.

There was considerable difference in the costs for foundations for even span and quonset greenhouses. The quonset houses required less concrete for all sizes. The foundation for the 720 sq. ft. greenhouse cost $.04 per square foot of floor area and the 2640 sq. ft. greenhouse foundation cost $.02 per square foot.

In all cases, the least expensive frame was constructed of Douglas fir. Galvanized steel pipe remained the most expensive framing material for all size greenhouses. Costs for greenhouse frames varied from $.28 per square foot of floor area for Douglas fir for the 2652 sq. ft. even span house to $.44 per square foot of floor area for the 720 sq. ft. quonset greenhouse.

The most expensive glazing material analyzed is fiberglass and polyethylene is the least expensive. The costs to glaze the greenhouse ranged from $1.01 per square foot of floor with fiberglass to $.58 to glaze the 2640 sq. ft. quonset greenhouse with polyethylene.

Heating costs were substantially greater for LP gas than for fuel oil or natural gas. Natural gas is the least expensive fuel. By adding an inside layer of polyethylene film, the annual fuel costs could be decreased by 30 percent. The additional layer of film also decreased the BTUs/hr required and subsequently the initial cost for the heaters. The most expensive heater is for the 2652 square foot even span greenhouse and the least expensive is for both 720 square foot greenhouses. Costs per square foot of floor area for cooling systems was the same for both even span and quonset greenhouses.

Costs of benches varied considerably. The least expensive bench was the concrete ground bench at $.39 per square foot of bench area and the most expensive was the galvanized steel pipe bench with a wire mesh top at $.95 per square foot of bench area. Wooden benches are approximately $.55 per square foot of bench area.

Total costs per square foot of floor area decrease considerably as the floor area of the greenhouse increases. Of the greenhouses examined, the most expensive was the 720 sq. ft. even span greenhouse covered with fiberglass at $2.89 per square foot and the least expensive was the 2640 sq. ft. quonset greenhouse covered with polyethylene at $1.27 per square foot.