IPRO 336: Implementing the Plant

Architectural Greenhouse System

Structural Materials

There are several types of framing that can be used on a greenhouse. The frames are made of wood, galvanized steel, or aluminum. Build-it-yourself greenhouse plans are usually for structures with wood or metal pipe frames. Plastic pipe materials generally are inadequate to meet snow and wind load requirements. Frames can be covered with glass, rigid fiberglass, rigid double-wall plastics, or plastic film. All have advantages and disadvantages. Each of these materials should be considered--it pays to shop around for ideas.

➢ Frames

Greenhouse frames range from simple to complex, depending on the imagination of the designer and engineering requirements. This design employs a simple rigid-frame with a curved roof.

Rigid-frame

Figure 1 Cold Form Greenhouse Structure

The rigid-frame structure has vertical sidewalls and rafters for a clear-span construction. In this greenhouse the frame is going to have a curved roof.

➢ Covering

Triple-wall plastic

It was decided that the most efficient material to be used in this greenhouse would be a Triple-Wall Polycarbonate (16mm), as shown in the following picture:

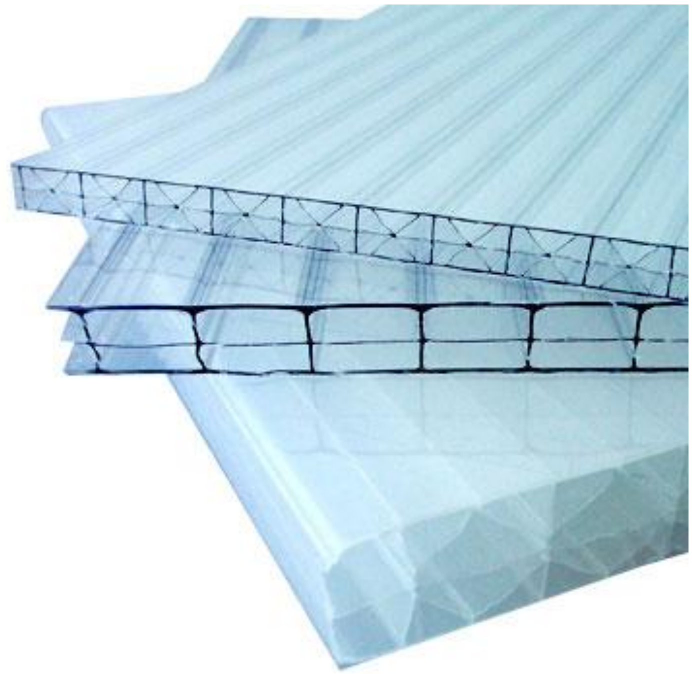

Figure 2. Triple Polycarbonate Wall

This material has a lot of advantages listed below:

16mm Triple-Wall Polycarbonate offers a 35% better insulation factor over twin-wall.

- Clear, UV-resistant sheets are lightweight, easy to handle and to install.
- Tough, practically shatterproof material maintains 76% light transmission, even after years of use.
- Diffused light transmission reduces sudden fluctuations in temperature that could be dangerous to your flowers or vegetables.
- Superior insulating qualities for better heat retention saves you money on energy consumption.
- 10 years of guaranteed light transmission.
- Flame retardant and virtually no condensation, providing manufacturer's recommendations are followed.

The only disadvantages for using such material are mostly aesthetic issues, suggesting that glass greenhouses are more pleasing.

➢ Foundations and Floors

Since this greenhouse is located on the roof, the existing roof foundation is 8’’ of concrete and 6.5’’ of polyiso insulation. One foot of concrete could be added in order level the existing roof floor. Roof drainage already exists and can be utilized to drain the excess water from the plant’s watering system, however with the addition on the one foot of concrete a new system can be devised to better suit the greenhouse design. The new system will be linked to the old system. A layout of this system is shown in the renderings. Also a floor heating system could be used and placed under that concrete bed in order to provide the heating requirement needed.

Environmental Systems

Greenhouses provide a shelter in which a suitable environment is maintained for plants. The sun is our best source for heat; however more systems need to be used in order to maintain the best environment and to obtain the best possible results from a greenhouse. This is done by using heaters, fans, thermostats, and other equipment. Several options were suggested to be implemented in this greenhouse. The chosen results are what thought to be the most efficient, and reliable.

➢ Heating

The heating requirements of a greenhouse depend on the desired temperature for the plants grown, the location and construction of the greenhouse, and the total outside exposed area of the structure. As much as 25 percent of the daily heat requirement may come from the sun, but a lightly insulated greenhouse structure will need a great deal of heat on a cold winter night. The heating system must be adequate to maintain the desired day or night temperature.

Heating systems can be fueled by electricity, gas, oil, or wood. The heat can be distributed by forced hot air, radiant heat, hot water, or steam. The choice of a heating system and fuel depends on what is available, the production requirements of the plants, cost, and individual choice.

Calculating Heating System Capacity

The formula used for finding the overall heat loss in the greenhouse, Q is:

$$\left[\frac{A1}{R1}+\frac{A2}{R2}\right](ti-to)(f_w)(f_c)(f_s)$$

Q - Heat loss used to determine the minimum size of heater or boiler required to maintain the inside design temperature, (kW);

A1, A2 - Surface Areas, (m^2)

R1, R2 - Thermal Resistance of Each Component, (˚C/W), Table 1

R1 (Thermal resistance of glazing material) = 0.472 is used for triple polycarbonate material.

R2 (Thermal resistance of construction material) = 7.55 (0.4 for 8'' thick concrete and 7.15 for 7.15'' polyiso foam).

ti-to - Inside / temperature, outside temperature, (˚C);

The temperature difference measured for inside temperature is **ti** = 15˚C, and outside temperature ranging from -14˚C to -20˚C. Also, inside temperatures of 10˚C and 18˚C were compared to an outside temperature of – 20. Tables with the acquired data are provided below.

Fc - Construction Factor = 0.7, for triple polycarbonate wall

Fs - System Description, (°C/W) = 1, radiation or convection near ground or below benches.

Fw - Wind factor

This value was provided by comparing the temperature differences calculated at a steady wind velocity of 25 mph.

Zone A&B

A1	A2
25.14	25.106
11.148	
88.57	
124.858	

R1	R2	Ti	to	ti-to	fw	fc	fs	Q
0.472	7.55	15	-14	29	1	0.7	1	5437.456
0.472	7.55	15	-16	31	1.02	0.7	1	5928.702
0.472	7.55	15	-18	33	1.04	0.7	1	6434.948
0.472	7.55	**15**	**-20**	**35**	1.06	0.7	1	**6956.193**
0.472	*7.55*	*10*	*-20*	*30*	*1.02*	*0.7*	*1*	*5737.453*
0.472	*7.55*	*18*	*-20*	*38*	*1.08*	*0.7*	*1*	*7694.937*

Zone C

A1	A2
30.19	30.22
11.148	
113.96	
155.298	

R1	R2	ti	to	ti-to	fw	fc	fs	Q
0.472	7.55	15	-14	29	1	0.7	1	6760.384
0.472	7.55	15	-16	31	1.02	0.7	1	7371.15
0.472	7.55	15	-18	33	1.04	0.7	1	8000.565
0.472	**7.55**	**15**	**-20**	**35**	1.06	0.7	1	**8648.629**
0.472	*7.55*	*10*	*-20*	*30*	*1.02*	0.7	1	*7133.371*
0.472	*7.55*	*18*	*-20*	*38*	*1.08*	0.7	1	*9567.109*

Zone D&E

A1	A2
35.86	35.892
11.148	
142.432	

189.44

R1	R2	ti	to	ti-to	fw	fc	fs	Q
0.472	7.55	15	-14	29	1	0.7	1	8244.03
0.472	7.55	15	-16	31	1.02	0.7	1	8988.835
0.472	7.55	15	-18	33	1.04	0.7	1	9756.383
0.472	**7.55**	**15**	**-20**	**35**	1.06	0.7	1	**10546.67**
0.472	7.55	10	-20	30	*1.02*	0.7	1	8698.873
0.472	7.55	17	-20	37	*1.08*	0.7	1	11359.7

Total heat loss:

@ ti=15˚C and an outside temperature of -20˚C

Q=2*(Zone A&B)+(Zone B)+2*(Zone C&D)=2*6956.193+8468.629+2*10546.67

=43,474.355 Watts=148,439.965 Btu/hr

<u>Since this is a rooftop greenhouse, under floor heating seems like a good heating system. Multilayered pipes manufactured with cross – linked polyethylene can be used.</u>

Figure 3. a)Cross – Linked polyethylene pipes. b) Floor Heating/Hydronic Thermostat

➢ Air Circulation

Installing circulating fans in a greenhouse is a good way to allow the air to change and keep the temperature and humidity stable, especially during the winter when heat is almost always needed. Without air-mixing fans, the warm air rises to the top and cool air settles around the plants on the floor.

Small fans with a cubic-foot-per-minute (ft^3/min) air-moving capacity equal to one quarter of the air volume of the greenhouse are sufficient. For small greenhouses (less than 60 feet long), place the fans in diagonally opposite corners but out from the ends and sides. The goal is to develop a circular (oval) pattern of air movement. Operate the fans continuously during the winter. Turn these fans off during the summer when the greenhouse will need to be ventilated.

The fan in a forced-air heating system can sometimes be used to provide continuous air circulation. The fan must be wired to an on/off switch so it can run continuously, separate from the thermostatically controlled burner.

The total air volume of the greenhouse is about : V = 72,000 ft^3.

¼ of that volume is about: v = 18,000 ft^3

The total number of fans needed to keep this greenhouse properly ventilated is fourteen circulating fans that swill produce 1300 CFM, and four cooling fans (42") .

Figure 4. Circulating Fans – 24"

➢ Ventilation and Cooling

Ventilation is the exchange of inside air for outside air to control temperature, remove moisture, or replenish carbon dioxide (CO_2). Several ventilation systems can be used.

Natural ventilation uses roof vents on the ridge line with side inlet vents (louvers). Warm air rises on convective currents to escape through the top, drawing cool air in through the sides. This is a good system for spring and fall seasons when the outside temperature is not low.

The system that will be employed in this design is mechanical ventilation, which uses an exhaust fan to move air out one end of the greenhouse while outside air enters the other end through motorized inlet louvers. Exhaust fans should be sized to exchange the total volume of air in the greenhouse each minute.

The total volume of air in a medium to large greenhouse can be estimated by multiplying the floor area times 8.0 (the average height of a greenhouse). A small greenhouse (less than 5,000 ft^3 in air volume) should have an exhaust-fan capacity estimated by multiplying the floor area by 12.

The capacity of the exhaust fan should be selected at one-eighth of an inch static water pressure. The static pressure rating accounts for air resistance through the louvers, fans, and greenhouse and is usually shown in the fan selection chart.

Ventilation requirements vary with the weather and season. One must decide how much the greenhouse will be used. In summer, one to one air volume change per minute is needed. Small greenhouses need the larger amount. However, in winter, 20 to 30 percent of one air volume exchange per minute is sufficient for mixing in cool air without chilling the plants.

One single-speed fan cannot meet this criterion. Two single-speed fans are better. A combination of a single-speed fan and a two-speed fan allows three ventilation rates that best satisfy year round needs. A single-stage and a two-stage thermostat are needed to control the operation.

A two-speed motor on low speed delivers about 70 percent of its full capacity. If the two fans have the same capacity rating, then the low-speed fan supplies about 35 percent of the combined total. This rate of ventilation is reasonable for the winter. In spring, the fan operates on high speed. In summer, both fans operate on high speed.

Air movement by ventilation alone may not be adequate in the middle of the summer; the air temperature may need to be lowered with evaporative cooling. Also, the light intensity may be too great for the plants. During the summer, evaporative cooling, shade cloth, or paint may be necessary. Shade materials include roll-up screens of wood or aluminum, vinyl netting, and paint.

Small package evaporative coolers have a fan and evaporative pad in one box to evaporate water, which cools air and increases humidity. Heat is removed from the air to change water from liquid to a vapor. Moist, cooler air enters the greenhouse while heated air passes out through roof vents or exhaust louvers. The evaporative cooler works best when the humidity of the outside air is low. The system can be used without water evaporation to provide the ventilation of the greenhouse. Size the evaporative cooler capacity at 1.0 to 1.5 times the volume of the greenhouse. An alternative system, used in commercial greenhouses, places the pads on the air inlets at one end of the greenhouse and uses the exhaust fans at the other end of the greenhouse to pull the air through the house.

Figure 5. Polycarbonate Vent Window

Controllers/Automation

Automatic control is essential to maintain a reasonable environment in the greenhouse. On a winter day with varying amounts of sunlight and clouds, the temperature can fluctuate greatly; close supervision would be required if a manual ventilation system were in use. Therefore, unless close monitoring is possible, both hobbyists and commercial operators should have automated systems with thermostats or other sensors.

Thermostats can be used to control individual units, or a central controller with one temperature sensor can be used. In either case, the sensor or sensors should be shaded from the sun, located about plant height away from the sidewalls, and have constant airflow over them. An aspirated box is suggested; the box houses each sensor and has a small fan that moves greenhouse air through the box and over the sensor (Figure 5). The box should be painted white so it will reflect solar heat and allow accurate readings of the air temperature.

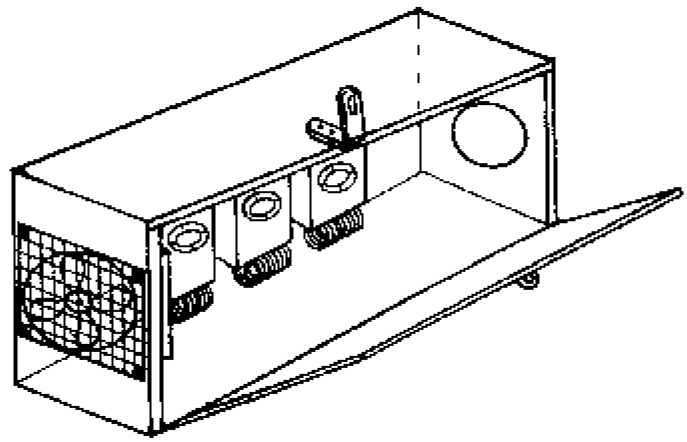

Figure 5. Thermostats in the middle of the greenhouse in a shaded, white, and aspirated box.

- **Watering Systems**

A water supply is essential. Hand watering is acceptable for most greenhouse crops if someone is available when the task needs to be done; however, many hobbyists work away from home during the day. A variety of automatic watering systems is available to help to do the task over short periods of time. Bear in mind, the small greenhouse is likely to have a variety of plant materials, containers, and soil mixes that need different amounts of water.

Time clocks or mechanical evaporation sensors can be used to control automatic watering systems. Mist sprays can be used to create humidity or to moisten seedlings. Watering kits can be obtained to water plants in flats, benches, or pots.

Figure 6. 3 - Zone Sprinkling System

CO_2 and Light

Carbon dioxide (CO_2) and light are essential for plant growth. As the sun rises in the morning to provide light, the plants begin to produce food energy (photosynthesis). The level of CO_2 drops in the greenhouse as it is used by the plants. Ventilation replenishes the CO_2 in the greenhouse. Because CO_2 and light complement each other, electric lighting combined with CO_2 injection are used to increase yields of vegetable and flowering crops. Bottled CO_2, dry ice, and combustion of sulfur-free fuels can be used as CO_2 sources. Commercial greenhouses use such methods.

Figure 7. 48” High Output Energy High Bay Fixtures