SYSTEMS ENGINEERING FOR GREENHOUSE OPERATIONS 1/

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Abstract .--A brief definition of systems engineering and how it can be applied to a greenhouse design is given. Special emphasis is placed on complete definition of requirements at an early stage. A sample design is given to illustrate interaction of operations and equipment.

The production of containerized seedlings is expanding at a rapid rate. Along with this expansion, new techniques, both biological and mechanical are being developed. Seedlings are grown successfully in simple plastic greenhouses and in aluminum framed glass greenhouses. Watering may be done with automatic traveling overhead sprinklers or a simple handheld nozzle. There is a wide selection of greenhouse coverings, structures, lights, containers, heating and cooling equipment, controls, and other components. Also there is a need for new equipment such as materials handling and packaging equipment.

There is a temptation to look for a standard greenhouse system that is the optimum for growing containerized seedlings. Unfortunately, no single best system exists. Each species of plant has its own environmental requirement, each location has its own external environment and each manager has his own goals and cost constraints. Therefore it would be surprising if a loblolly greenhouse in Georgia was exactly like a spruce greenhouse in Washington. What the manager needs is a total system that matches his requirements as closely as possible.

During the late fifties and early sixties techniques for matching systems and requirements were developed and the term systems engineering was applied to them. This was used in procurement of weapons and space vehicles which involved highly complex systems and commitment of vast resources.

Many of the methods and tools of systems engineering are very specialized and refined. However, systems engineering has also been defined as "just good engineering only more so". This is the context in which I am using the term systems engineering today.

Figure one illustrates the relationship of the greenhouse system to various requirements. Performance includes maximum and minimum inside temperatures, quantity of nutrient, quantity and quality of light, relative humidity, airflow and composition and others. It is the performance desired of the system not the seedlings. Reliability includes avoidance of catastrophic failures, warning systems, and redundancy in controls. Under packaging and operability we define requirements for mixing soils, filling containers, seeding, thinning, transplanting, watering, fertilizing and preparing seedlings for transport to the planting site. Maintainability can be a tradeoff with reliability, the more reliable the systems the less maintenance required. All of these requirements are subject to cost limitations. Initial cost is important but annual fixed costs for depreciation, rent, insurance and taxes must be considered. Estimates of operating costs for fuel, electricity, fertilizer, growing media, containers and labor should be made. The manager may want to consider other less tangible costs such as cost of inflexibility, possible changing land values, or energy shortages. Once a location is selected many of the environmental factors become fixed; maximum summer temperatures, minimum winter temperatures, snow loads, windspeeds, degree days, solar angle, daylight hours, solar energy, etc. If there is an option of locations this should be considered as a method of changing environmental requirements.

In figure two we have a model of the systems engineering process. The process begins on

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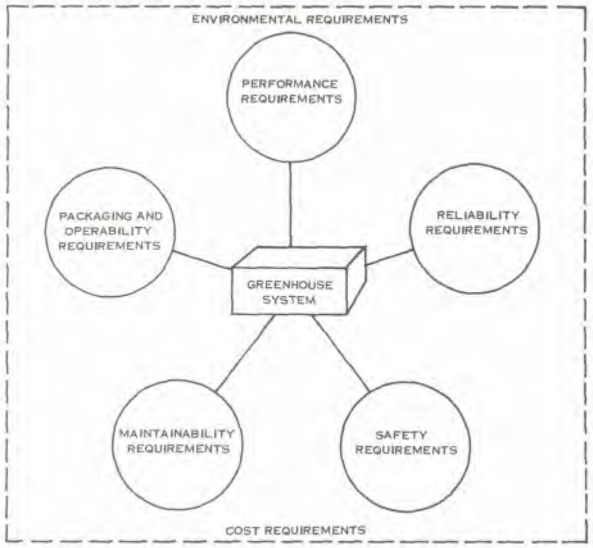

Figure One.--A framework of system design.

the left with information. In this case it may be from a manager who wants yearly production of a number of seedlings, of a certain size and species and in a certain biological condition at a specified time within cost limits. The next step is to establish the requirements as shown in figure one, that will meet these goals. After detail requirements are established we can look for solutions. This may be existing commercial equipment and components or it may require new designs. Concurrently we begin technical analysis and testing if required to determine whether the proposed designs meet the criteria which has been established.

I have been told that there is only one independent consulting engineer in the United States who specializes in greenhouse design. Unfortunately there is no single book that covers all phases of analysis and design in detail. However, there are many technical publications on greenhouse design, particularly from the American Society of Agricultural Engineers. Manufacturers and their representatives willingly supply information. Assistance is also available from engineers in state and federal government.

The next step is evaluation and decision making. The decision may be to propose new solutions and modify certain requirements. This is the optimization loop and may be repeated several times. To stress the importance of this step I have prepared a chart, figure three, which indicates important relationship between systems and requirements. Each system and requirement is connected at a common block. If the block is colored it indicates an especially important relationship. If the block is blank the relationship is unimportant or only of slight importance. The chart can be expanded to include more detail. This can be a useful tool to insure that all interactions between systems and requirements have been considered and evaluated.

In summary, the system design process should be an orderly, step by step process. In the case of a greenhouse system it is especially important that the team include an engineer and a biological expert and that each be willing to continuously evaluate and change their solutions and requirements to meet original goals.

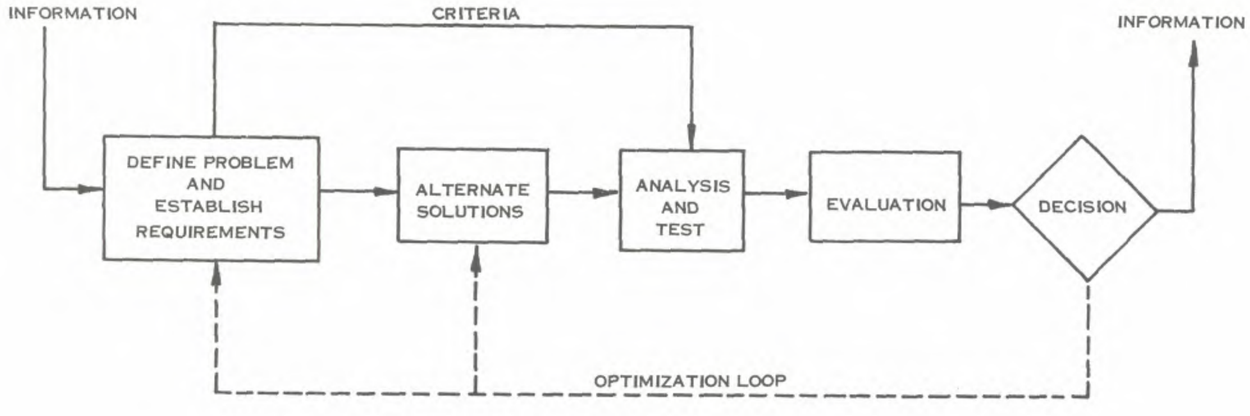

Figure Two.--Model of the system-design process.

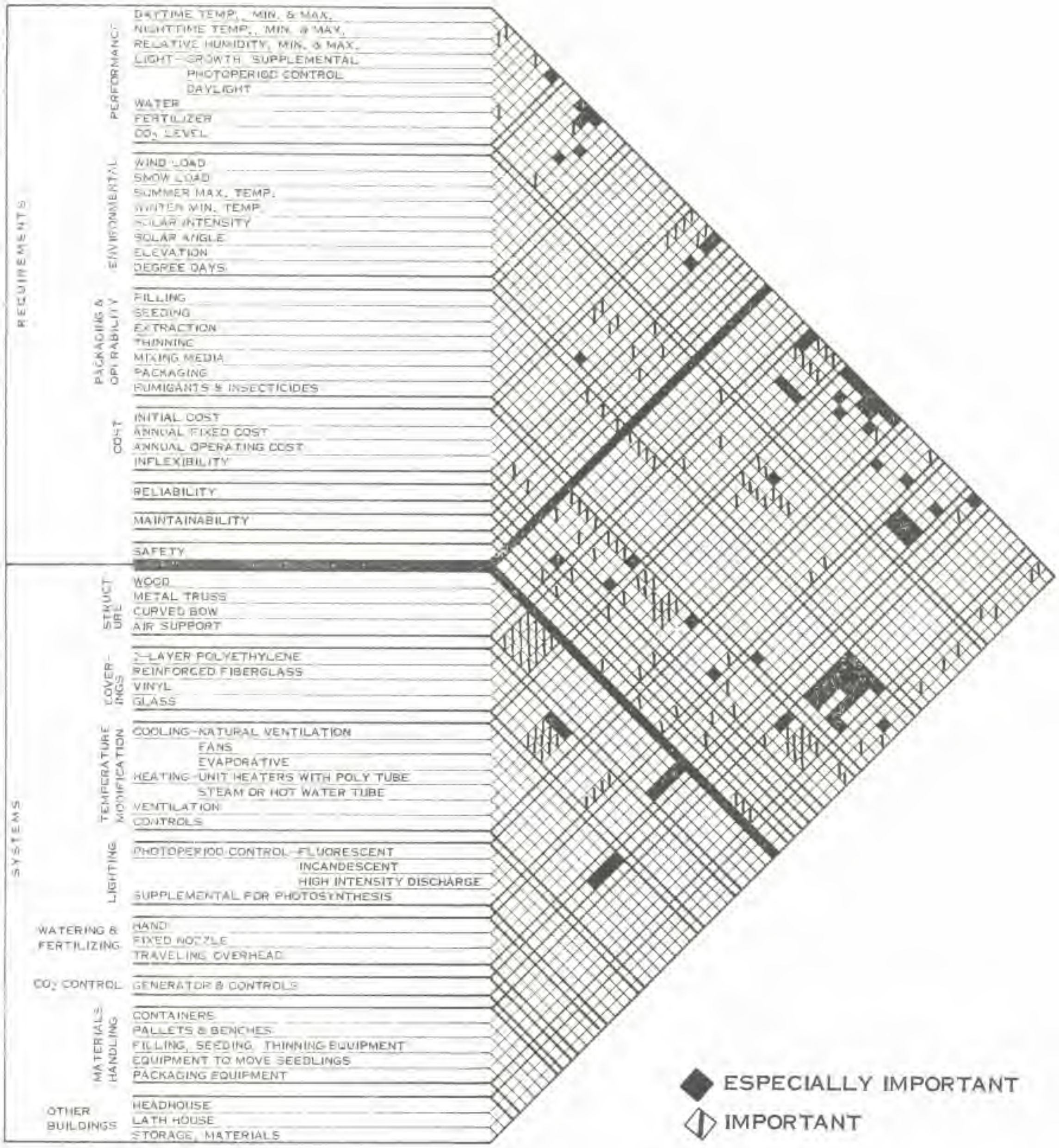

Figure Three.--Greenhouse systems and requirements relationships.

That is a brief outline of the systems engineering approach to the design of a greenhouse.

The next figures show an example of a greenhouse system that was designed with specific goals. Again, we would not expect that other systems with different goals would be exactly the same.

Figure four shows the general configuration of the system. It consists of four greenhouses, a rigid structure that connects the four, and contains some of the controls for heating equipment. This in turn is connected to the headhouse which provides the working area for mixing soil media, filling containers, and seeding. It also has an unheated area for storage of materials. Over in the right you see the lathhouse where the seedlings are maintained during part of their growing cycle. Figure five shows a layout of the general arrangement of the same facility. The greenhouses are 30 feet wide, and 96 feet

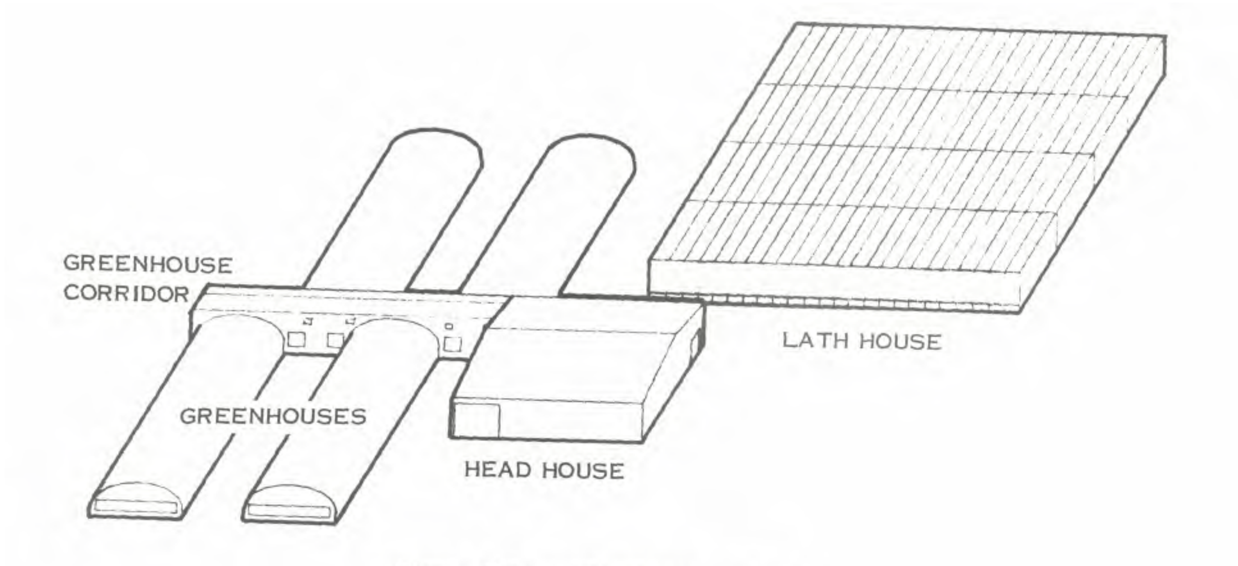

Figure Four.--Greenhouse system.

long, and there are four of them. They are staggered for two reasons. They are oriented with their long axis in the East-West direction and the staggering prevents shadowing of one greenhouse by the other. It also allows a free flow of exhaust air between the houses.

Also, there is sufficient room between the houses for mechanized snow removal. Conveyors are used throughout the greenhouses with a transfer track directly to the headhouse or from the headhouse into the greenhouse. From the lathhouse, or to the lathhouse, containers are moved on pallets with a forklift truck. Figure six is a layout of the headhouse itself showing in the lower part the standby power generator and the watering equipment which includes the ratio feeders for adding nutrients. It includes a small amount of storage for the mixing material, which in this case is the peat and vermiculite, a filling station where the containers are filled and seeded and a small area for loading and unloading pallets. The upper part is unheated and it contains the larger storage area for the pallets and containers. I've mentioned pallets and containers. The pallets are 5-1/2 feet wide and 13 feet long. They are very simple and made from angle iron welded with wheels mounted on each of the four corners. Each one will contain 33 styroblock containers. This leaves the narrow aisle down the center. There is one more space for pallets in each side of the greenhouse than is actually used. This enables the person doing cultural work to step between two pallets, do his cultural work, and then move one pallet forward so that he can get between the next two. At the end of the greenhouse there will be a transfer mechanism where the pallets can be made to move in a direction 90 degrees from the axis of the greenhouse to move them to the lathhouse or the headhouse. The labor require ments for this type of operation are quite minimized.

The greenhouses are covered with two layers of polyethylene plastic, the outer layer is six mil UV inhibited and the inner layer is four mil, not UV inhibited. The ends of the structure are covered with flat fiberglass.

The main structure is a commercially available pipe bow frame. The patented tiedown provided by the manufacturer is used which holds the plastic only on the sides and ends. A small centrifugal blower pressurizes the air between the two layers for separation. This type of system has been used quite successfully and has overcome many of the objections that people have experienced who have tried to nail plastic onto wooden structures which causes stress concentrations and tearing. The pipe bows are fitted into pipes that are driven into the ground. There is no permanent foundation, although a Styrofoam block is buried around the entire perimeter of the greenhouse to provide cold insulation. The flooring material is asphalt which is laid before the greenhouses are erected. The cooling system is evaporative pads along one end of each greenhouse with two exhaust fans--one of which is two-speed--at the opposite end of the greenhouse. Heating and air circulation is done with two polyethylene tubes that run parallel down the sides of the greenhouse. Hot air is supplied to these polyethylene tubes from individual heaters which are gas-fired unit heaters. The air intake is through a hooded duct which reaches down to the floor. This encourages the natural circulation of cold air along the

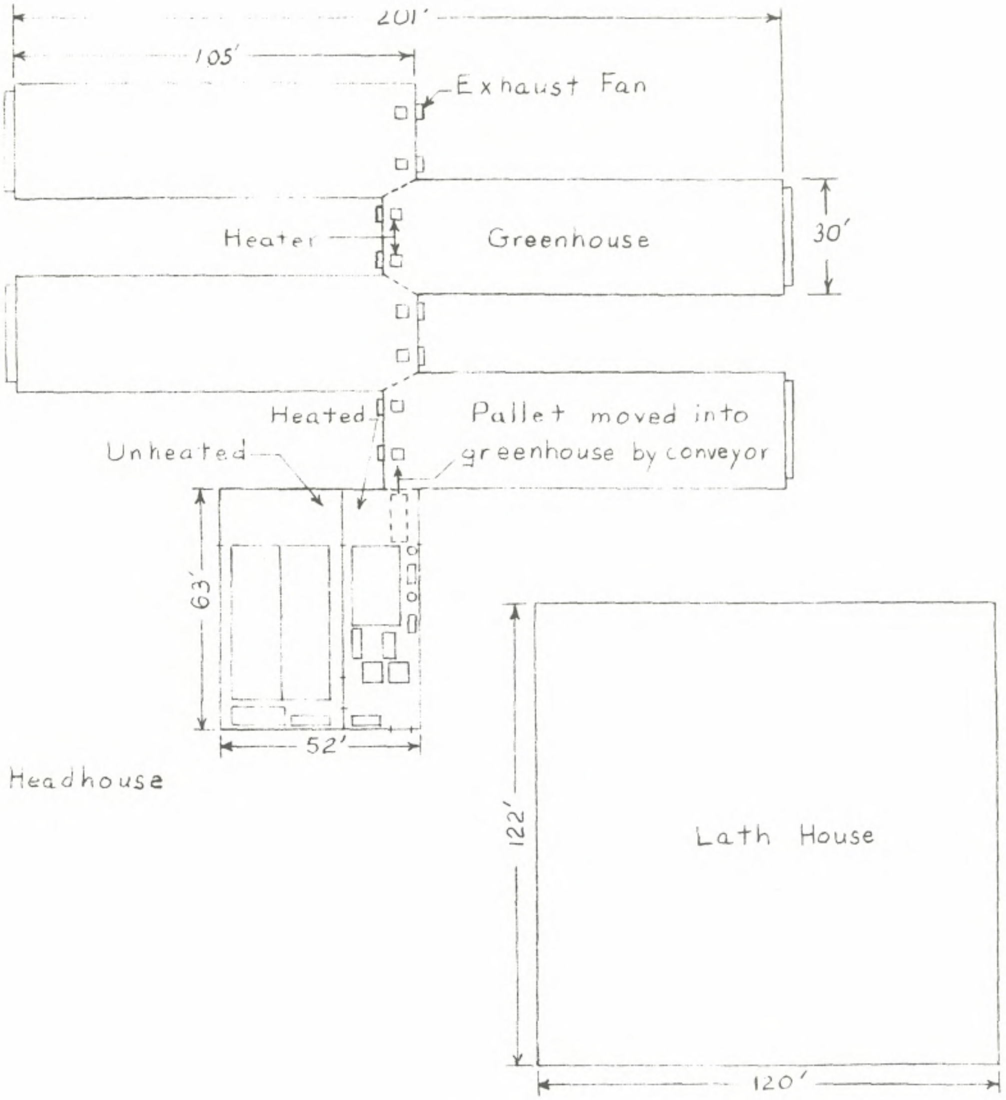

Figure Five.--Greenhouse system layout.

floor. This device plus the double poly tubes are necessary because of the extremely cold winter environment. The scheme has apparently been used in some areas in Canada with a double layer of plastic and a maximum variation within the house of about 4 degrees according to the manufacturer. A commercial carbon dioxide unit which is also gas-fired is supplied and this will be used during the early morning hours and during the day when the ventilation fans are not exhausting to the outside. It provides a significant amount of heat during some periods of operation. An integrated package for automatic control is used which controls the exhausting of air, the operation of the cooling pads, the heating cycle, and so on. This minimizes the requirement of having an operator involved in continuously changing controls. Also incorporated is a telephone connected warning system in case of any types of failure in the system. We have selected the 2-1/2 cubic inch styroblock containers. The growing media is a combination of peat and vermiculite with a thin layer of perlite added to the top after seeding. The watering and nutrient system are combined. It is an overhead moving track system. Lighting for photo-period control is provided with 250 watt PS 30 lamps. These are half silvered incandescent lamps which were originally made for poultry brooders. It will require three rows of lamps--one row down the center, and one along each side--and this should pro-

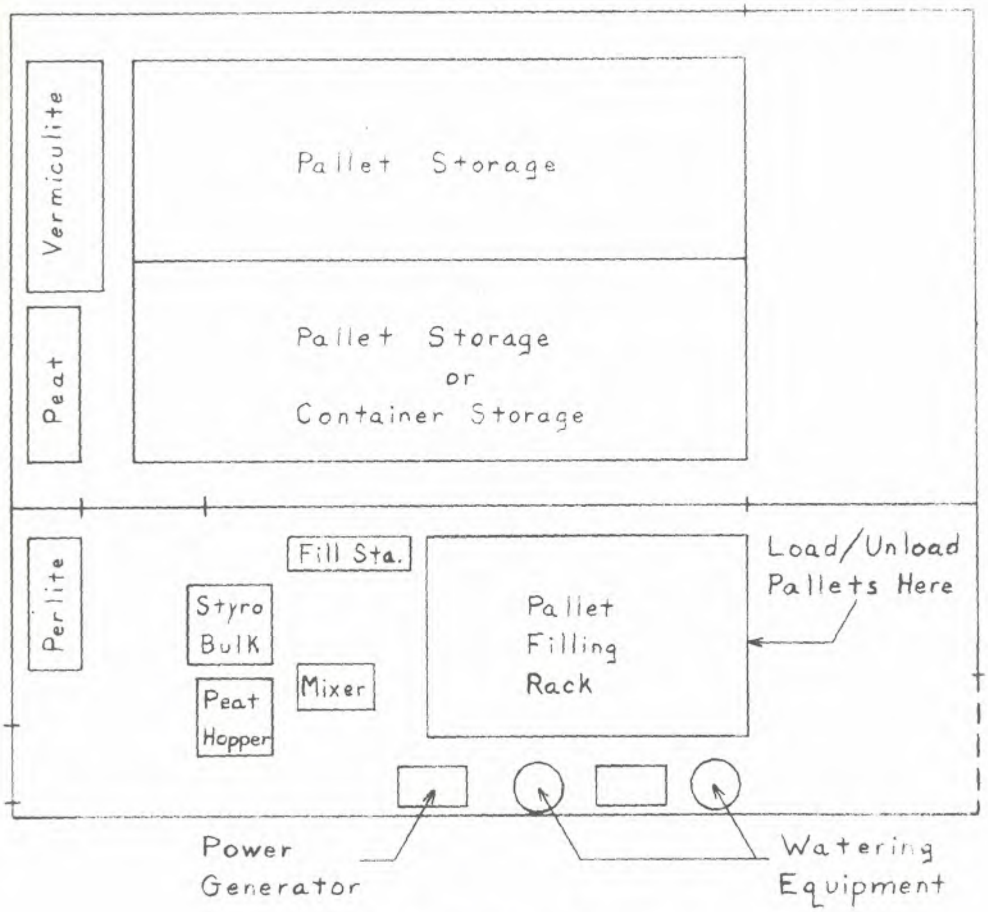

Figure Six.--Headhouse layout.

vide a light level of about 40-foot candles. They are wired in separate circuits to reduce the demand load. The lathhouse which is primarily intended to provide against direct sunlight and to provide wind protection originally was to have the roof made up of 12-inch boards which were standing on edge. These could be spaced so that at no time would the sun angle be such that any of the plants would be subject to direct sunlight, and at the same time that diffused sunlight from the sky is provided. At the present cost of lumber, this became quite expensive. So we have settled upon an alternate design which is strips of shade fabric which are strung on cables. The strips are about 12 inches deep and are strung from cables with intermediate supports on poles. These strips would normally be in a vertical position--this prevents any accumulation of snow on the shade fabric in the wintertime which would greatly increase the structural requirements. In order to reduce the spacing, during the spring and summer months the lower end of the shade fabric could be tilted over, somewhat in the same way as a venetian blind. This gives us a rather simple and fairly inexpensive structure for the shade house. The watering system in the shade house which in turn is also used for supplying nutrients is simply a series of overlapping rainbird sprinklers. Most of them would be half circle sprinklers to avoid splashing of water from the intermediate support poles.

Construction of a greenhouse system requires a large initial investment and substantial recurring annual costs. A good initial design with critical review of both solutions and requirements should give future benefits in both cost and quality of seedlings.