

NRAES-33 Greenhouse Engineering

By R. Aldrich and J. Bartok

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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.

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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 groundgrown 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.

Public Road North Side
Service Road
Customer Parking
Headhouse Sales Area
Production Area
Supplies In
Wind Break
Production Area
Supplies In
Service Road
Customer Sales Parking
Area
Headhouse
Public Road on East Side
Public Road on South Side
Customer Parking
Sales Area
Headhouse Supplies
Production In Area

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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.

Figure 1–2. Garden center layout.

Services
 Employee
 Parking
 Service
 Road
 Greenhouses
 Shade
 Structure
 Outdoor
 Display
 Customer
 Parking
 Retail
 Store
 Public Road
 Cash
 Register
 Locations

A. Individual greenhouses with separate headhouse.

PARKING
 BULK STORAGE
 12' ROADWAY
 50' x 120'
 HEADHOUSE
 10' min. between greenhouse
 12 @ 28' x 144' =
 48,384 sq.ft.

B. Gutter connected greenhouse with attached headhouse.

PARKING
 50' x 120' BULK STORAGE
 HEADHOUSE
 Service aisle
 144' x 336' =
 48,384 sq.ft.
 Each aisle
 serves 2 bays

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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.

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 gutterconnected 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.

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.

H and I

12' x 12'

A

10' X 12'

B

10' X 12'

C

12' X 12'

D

12' X 12'

E

20' X 20'

F

34' X 20'

G

To ghse.

From ghse.

Supplies in To market

6'

H

16' x 16'

E

20' x 16'

A

20' x 16'

F

20' x 28'

I

20' x 28'

G

To ghse.

From ghse.

To market

Supplies in

12' X 10'

6' D

12' X 10'

C

12' X 10'

B

KEY

A HEAT & SERVICE
 B MEN'S ROOM
 C WOMEN'S ROOM
 D LUNCH ROOM
 E OFFICE
 F GERMINATION
 G TRANSPLANT
 H ORDER ASSEMBLY
 I FLAT FILLING

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

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

Table 1–1. Sizing the electrical system.

^(a) Excluding plant lighting and heavy machinery

To Market
 Order
 Assembly
 Dry
 Storage
 Overhead
 Supplies In
 Expansion
 Area
 36' x 104' Headhouse
 10' min. space
 10' min. space
 6' Aisle
 6' Aisle
 6' Aisle
 28' x 144' 6' Aisle
 Greenhouse
 28' x 144'
 Greenhouse
 28' x 144'
 Greenhouse
 12' x 16'
 Office
 16' x 16'
 Heat
 &
 Service
 16' x 16'

Transplant
12' x 16'
Seed &
Germinate
Toilets
8' x 12'
12' x 24'
Flat
Filling
Media
Mixing
8' x 12'

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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.

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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.

f. Bag System

Drip Tube
Polyethylene bag
Rockwool, Foam, or
Peat-Vermiculite mix

d. Bed system with polystyrene flats

Polystyrene flat
PVC Liner
Nutrient Solution

b. Pipe System

Nutrient Supply Line
3" PVC pipe sloped to
drain nutrients
Chain Support and
Conveyor System

a. Sand/Stone Culture

Concrete Bed and Aisle
Sand or Stone Support Medium
Polyethylene or Polyvinyl Liner

c. Tray System

Direction
of Travel
Track
Shelf Nutrient Solution
Growth Tape
Slat
Air Duct

e. NFT System

Starter Block Nutrient
Polyethylene Channel

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.

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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.

Wheelchair Access

Ground Bed or
Container Areas

Sink

A. In-line Layout

Potting

Mixing

Storage

Warm Section Cool Section

4' x 12' Benches

2' Aisles

Work

Table

20' 32' 32'

30'

Chem.

Storage

Display

Cooler

Work

Table

B. T Layout

Potting Chemicals

24'

Classroom

Demonstration

Display

Cooler

Work

Tables

32'

32' 32'

70'

6'

Ground Bed or

Container Area Cool Section

Warm Section Sliding Doors

4' x 12' Benches

2' Aisles

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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.

CROSS SECTION

Perforated
PE Tube
General Lighting
Duplex Outlet
Sidewall
Vent
Finned Tube
Valved outlet
for root zone heating
Hose
Valve
Aspirated box
for Thermostat
Bench Top

PLAN

Sidewall vents full
length each section
Duplex
Outlet
Valved outlet
for root zone
heating
Container
Area
Hose
Valve
General
Motorized Lighting
Louver
Fan and
perforated
PE tube for
mild weather
cooling
Finned tube
space heating
Partition Wall
COOL SECTION
WARM SECTION
Exhaust fan
Aspirated
box for
Thermostats
Bench
Area
Valved
outlet
for root
zone
heating
Classroom

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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.

Figure 1–9. Suggested layouts for retirement center greenhouses.

B. Attached Gable Greenhouse

24'

32'

8'

Access to living unit

Access to outside

Service Area

Drain

Storage

3' Aisle for Wheelchair

2' Aisles

4' Benches

Fintube

Heater

A. Lean-to Greenhouse

10' 30'

16'

6'

Access

to

outside

Access to living unit

Service

Area

Drain

Work

Bench

Storage

3' Aisles

4' Benches

Fintube

Heater

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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.

Figure 1–10. Anthropometrics for wheelchair-bound men and women.

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.

Mean 5'¾"

Anthropometrics: Wheelchair-bound men

+ = maximum reach

– = minimum reach

+4'9¼"

mean 4'4½" head height

–3'11¾"

mean 3'5" shoulder

+3'9¼"

–3'¾"

mean 2'¾" elbow

+2'6"

–2'½"

Eye level mean 4'¼"

+4'4¾"

–3'7¼"

Mean forward reach

1'9¾" over high table

1'2" over low table

–1'5¾"

–8"

mean 1'11¾" knee level

+2'2½"

+8½"

Foot height

Thigh level at point

of obstruction

Anthropometrics: Wheelchair-bound women

+ = maximum reach

– = minimum reach

+4'6¼"

mean 4'1½" head height

–3'8¼"

mean 3'3" shoulder

+3'7½"

–2'10¾"

+2'6"

–2'½"

mean 2'¾" elbow

Eye level mean 3'7½"

+4'2"

–3'5"

1'7" over high table

1½" over low table

–1'3½"

–5½"

Thigh level at point

of obstruction

mean 1'11½"

+2'2¼"

+8¾"
Foot height
knee level
mean 6½"

Anthropometrics: Wheelchair-bound men

+ = maximum reach

- = minimum reach

mean 5'7½" vertical reach

-5'2¼"

Knuckle height

mean 1'3"

+1'4¼"

+8¾"

mean 7¼"

Front edge of chair 1'7"

mean 1'4½" +1'6½"

+2'4¾"

+2'1¾"

mean

1'11½"

2'2½"

Sitting

erect

Back

Toe

projection

vertical reach

Forward mean 4'7½"

-4'3½"

Oblique

vertical reach mean 5'2¾"

-4'10¼"

Anthropometrics: Wheelchair-bound women

+ = maximum reach

- = minimum reach

mean 5'2" vertical reach

-4'8¾" Oblique

vertical reach mean 4'9¾"

-4'5½"

vertical reach

Forward mean 4'3"

-3'11"

Toe

projection

+2'2"

+1'11"

mean

1'9"

2'0"

Sitting

erect

Back

mean 1'2½"

+1'4½"

Front edge of chair 1'7"

+7"

mean 5¾"

Knuckle height

mean 1'4½"

+1'5½"

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

Figure 1-12. Ramps for handicapped access.

B. 21' Greenhouse

58'

42' 16'

21' inside

5' x 5' Conc. Slab

8'

5'
8'
A. 30' Greenhouse
8'
8'
5'
5'
4'
4'6" 4'6"
4' x 8' Benches
4' x 12' 4' x 12'
4' Aisle
42' 16'
58'
5' x 5' Conc. Slab
30' inside
2'8"
2" O.D. Met. Railings
Slope not to exceed
1" vertical to
12" horizontal.
ELEVATION
PLAN
1/8" Met. Platform
2" x 4" Curb
2" x 4" slats 3/8" apart
or Broomed Concrete
Single run access ramp
2'5"
4"
4"
2" x 4"
Curb
ELEVATION
Slope not to exceed
1" vertical to
12" horizontal.
2'
12"
4"
PLAN
6'0" 12'0" 6'0"
5'10"
2'5"
Double run access ramp

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Special identification should be used for sightand 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 raisedletter 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. Leveraction 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.

Length to Fit

3 to 5 feet

2" x 4" on Edge

2" x 4" Flat for Pipe

Flange

1" Dia. Galv.

Steel Pipe

1" x 1" x 1"

Split Tee

1¼" Dia. Steel Pipe

1¼" Pipe Flange

1¼" x 1¼" x 1"

Split Tee

¼" Dia. x 2" Machine Bolt

5/6" Dia. Holes 1½"

on Center

1" Dia. Galv.

Steel Pipe

1" Pipe Flange

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

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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

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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.

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

4"x4" Pressure Treated Columns

12" O.C. Each Direction

12'-0"

9'-0"

3'-6"

Grade

2'-0"

2'-0"

CROSS SECTION

PLAN LAYOUT

12'-0"

12'-0"

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

4"x4" Pressure Treated Posts
12'-0" O.C. Each Dir.
2"x6"
Rafters
2'-0" O.C.
Shade
Fence

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

Figure 1–16. A-frame overwintering structure.

1" x 4" wind brace.
Fasten wind brace
and ridge board to
hoops with U-bolts.
Anchor timbers with
steel pins 4' O.C.
ELEVATION
1" x 4" Ridge board
Hoops spaced
4' O.C. set in
holes in timber
Length of
house to suit—
generally 96' or
144'
CROSS SECTION
12'0"
Film
Battens
Film
buried
6" x 6" Pressure
Treated Timber
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.
1" x 4" Ridge Boards
1" x 6" Collar Tie
2" x 4" x 10'
6" x 6" Pressure Treated
Timber Sill
4" x 4" Pressure
Treated Sill
Frame End View
3'0"
Secure 4"x4" to Doorway
6"x 6" with framing anchor
12'1"
13'0"
Frame Side View
1" x 4" Wind Brace
each side, each

end of the
building
Anchor sills with
3'0" steel stakes 6' O.C.
Framing anchor to
secure frame to sill
Cover frame
with 6 mil white
polyethylene.
Fasten to sill with
1" x 2" battens.
3'0" 3'0" Multiples of 3'

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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.

4'0" 4'0"

6'0"

Pipe Rail

Pipe can be used

for warm water

heat supply

Trays rolled into cold

frame from either end

Rafter

Top constructed

in 8" units

PLAN PIPE FRAME

4'0" 4'0"

6'0"

PLAN

Drop Front

Rafter

Pipe Rail

Pipe can be used

for warm water

heat supply

CONCRETE FRAME

Cross Section

a. Roll-up cover with drop front for fork lift loading

6'0"

6" Gravel

6" Sand Sill

2'0"

1'0"

Hinge for

drop front

PE film roller pipe

hand cranked

Film rolled part way

for ventilation

Batten for

film

6" Conc. or

Concrete

Masonry

Wall

12"

6"

3'0"

Tray

Flats

2" x 4" Rafter

4'0" O.C.

1½" x 3" Butt hinge 4' O.C.

2" x 4" Plate

Eye Bolt

18" O.C.

2" x 2" x 6' cover

support bar

Gate Hook

Eye Bolt

Screw Eye

Eye Bolt

Rafter

b. Hinge cover with end loading of trays

Section & Details

2" x 4" Top rail

3'0"

1'0"

6" Gravel

6" Sand

Tray

Flats

2" x 4" Rafter
2" x 4" Rail
Pipe
1¼" Dia.
Pipe 4' O .C.
2" Pressure
Treated T&G Lumber

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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 **Figure 1–19.** Layout for storage and rooting rooms for 100,000 bulb capacity.

Figure 1–18. Packing room layout for cut flower operation. Example: 100,000 sq. ft. for rose house. 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, wirebottomed 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.

Office
12' x 16'
Cooler
16' x 16'
4' x 16'
Grading and Packaging
Personnel
Area
8' x 8'
M
8' x 8'
W
Sorting—3' x 16'
To Market
Deliveries
Dry Storage
48' Greenhouses
ROOTING
ROOM
20' x 24'
½ hp Refrigeration
4,320 cu. ft.
ROOTING
ROOM
20' x 24'
½ hp Refrigeration
4' Pallet
3' Aisle
6' Doorway
1' for air
circulation
3' Aisle
6"
for
air
circulation
TRAY
STORAGE
12' x 24'
1/3 hp Refrig.
2,592 cu. ft.
WORKROOM
16' X 52'
Media Storage
Receiving/Inspection
Dry Storage
to market
Order Assembly
tray filling, potting

to greenhouse

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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 MINIMUM RELATIVE HUMIDITY AT ACROSS EVAPORATOR STORAGE TEMPERATURES

(°F) 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

⁽¹⁾In many states, agricultural buildings are either exempt
from the code requirements or are treated as special use
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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Figure 2–1. Loads on greenhouse frames.

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

B. The length and direction of arrows

indicate relative size of wind loads and how they act on greenhouses.

GABLE GABLE

Wind

ARCH

Dead, live, snow

Dead, live

Dead, live, snow

Dead, live

HOOP

Dead, live, snow

Dead, live

ARCH

Wind

$\frac{1}{2}$

$\frac{1}{4}$ $\frac{1}{4}$

30'

HOOP

Wind

$\frac{1}{2}$

$\frac{1}{4}$ $\frac{1}{4}$

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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

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.

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.

5 lb. per sq. ft.

3 inches of wet snow

5 inches of dry snow

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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, twowheel 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.

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Figure 2–3. Typical foundations for greenhouses.

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

Below
frost
24" min
12"

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
Conc. footing

Below
frost
24" min
12"
8" min.

C. CONCRETE MASONRY WALL ON POURED CONCRETE FOOTING

Frame anchor
2" insulation board
Two coats of hot
bituminous material or
Portland cement plaster
Gravel backfill

Drain tile around footing
Greenhouse frame
Bolt sill to conc. block foundation
Top of block wall
12" above grade
Below frost
24" min
16"

Concrete
footing 8"

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
Drive to min.
depth of 30"

Post
Grade

Note: A driven post provides
limited resistance to uplift.

Post

anchor
Frame
anchor
Pressure
treated wood
post
Poured concrete or 2" x 4" x 8"
pressure treated lumber spiked
to post.
Board
insulation
Coupling
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

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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.

Arch Roof

Gable Roof

Hoop Gable Frame

Trussed Roof

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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.

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

20' length 1" dia. thick
wall conduit
2" x 4" x 6" long
hardwood blocks
secure to floor
7'0" radius
13'6"
6"

1'3"

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

B. ROLLER PIPE BENDER

36"

18"

1/2" 6" 3"

drill

Weld

7" x 12.25 lb/ft

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

steel strap

3/4" Machine bolt

1-5/8"

3-3/4"

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.

4" Dia. x 1-3/4" wide

steel caster wheel

3/4" bore

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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 ft². 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 ft²). 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.

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Figure 2–6. Sizing drain pipe for rainwater and snow melt removal. Flow rate (gpm)

10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,500
2,000
1,000
1,500
900
800
700
600
500
400
300
200
150
100
60
80
40
30
20
10
0.001
1.25
0.002
2.5
0.004
3.5
0.005
6
0.007
8
0.01
12
0.02
24
0.03
36
Slope (ft./ft.)
Slope (in./100 ft.)
Greenhouse ground area (sq.ft.)
Total
greenhouse
area
1/2
greenhouse
area
PVC
Corrugated PE
320,820

288,940
 256,655
 224,575
 192,495
 160,410
 128,330
 96,246
 80,250
 64,165
 32,080
 48,125
 28,875
 25,665
 22,460
 19,250
 16,040
 12,830
 9,625
 6,415
 4,810
 3,210
 1,925
 2,565
 1,280
 960

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Figure 2–8. Spectral transmittance of selected film greenhouse covering materials.

ULTRAVIOLET
 GLASS SUN'S RADIATION
 FIBERGLASS
 RIGID P.V.C.
 ACRYLIC
 POLYCARBONATE
 WAVELENGTH, NANOMETERS (NM)
 RELATIVE ENERGY
 VIOLET
 100
 90
 80
 70
 60
 50
 40
 30
 20
 10
 0
 300 350 400 450 500 550 600 650 700 750 800
 BLUE GREEN YEL. ORAN. RED

Figure 2–7. Spectral transmittance of selected rigid greenhouse covering materials.

100 POLYVINYL
 90
 80
 70
 60
 50
 40
 30
 20
 10
 0
 ULTRAVIOLET VIOLET BLUE GREEN YEL. ORAN. RED

POLYETHYLENE
POLYVINYL FLUORIDE
U.V.

POLYETHYLENE
RELATIVE ENERGY
WAVELENGTH, NANOMETERS (NM)

300 350 400 450 500 550 600 650 700 750 800

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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.

Bar Cap
Glass Pane
Caulk Sealant
Roof Bar
Roof Bar to
Purlin Bolt
Condensate
Gutter
Typical Glass Glazing on
Aluminum Roof Bar
Corrugated

Polycarbonate
Glazing
Spacer
Tek Screw or Ring Nail
Purlin
Fiberglass or Polycarbonate Glazing
on Wood Purlin
Top Film
(double sheet)
Lock ring
in place
Outside
of frame
Hex head
bolt & nut
Baseboard
Acrylic or Polycarbonate
Structured Sheet
Two Piece Aluminum
Extrusion Connector
Support Frame
Structured Sheet Glazing System

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Table 2–3. Transmittance of solar and thermal radiation through greenhouse glazing material. ^(a)

GENERAL TYPE COMMENTS

TYPICAL

TRADE

NAMES

LIGHT (PAR)

TRANSMITTANCE

(%)

THERMAL

TRANSMITTANCE

(%)

ESTIMATED

LIFETIME

(YEARS)

\$/FT.² (b)

GLASS Advantages

Excellent transmittance

Superior resistance to
heat, U.V., abrasion

Low thermal
expansioncontraction

Readily available

Transparent

Disadvantages

Low impact resistance
unless tempered

High cost

Heavy

Double strength

Insulated units

Solatex

88

75–80

91–94

3

< 3

< 3

25+

25+

25+

0.75–2.00

3.50–7.00

1.25–3.50

ACRYLIC Advantages

Excellent transmittance

Superior U.V. &

weather resistance

Will not yellow

Lightweight

Easy to fabricate on

site

Disadvantages

Easily scratched

High expansioncontraction

Slight embrittlement

with age

High cost

Relatively low service

temperatures

Flammability

Single wall

Plexiglass

Double wall

Exolite

93

87

< 5

< 3

20+

20+

1.50–2.00

2.00–3.50

POLYCARBONATE Advantages

Excellent service

temperatures

High impact resistance

Low flammability

Disadvantages

Scratches easily

High expansioncontraction

Single Wall

Dynaglas

Lexan

Corrugated

Macrolux

Corrugated

Double wall

Macrolux

PolyGal

Lexan Dripgard

91–94

83

< 3

23

10–15

10–15

1.25–1.50

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.

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GENERAL TYPE COMMENTS**TYPICAL****TRADE****NAMES****LIGHT (PAR)****TRANSMITTANCE**

(%)

THERMAL**TRANSMITTANCE**

(%)

ESTIMATED**LIFETIME**

(YEARS)

\$/FT.² (a)

FIBERGLASS

REINFORCED

POLYESTER

Advantages

Low cost

Strong

Easy to fabricate and

install

Disadvantages

Susceptible to U.V.,

dust, and pollution

degradation

High flammability

Lascolite

Excelite

Filon

Double wall roof

panels

90

60–80

< 3 10–15

7–12

0.85–1.25

5.00

POLYETHYLENE

FILM (PE)

Advantages

Inexpensive

Easy to install

Readily available in

large sheets

Disadvantages

Short life

Low service

temperature

Tufflite III 603

Standard UV

Tufflite Dripless

703 Fog Bloc

Sun Saver

Cloud 9 Tufflite

Infrared

Dura- Therm

< 85 50

50

< 20

3

3

3

0.06

0.07

0.09

POLYVINYL

CHLORIDE (PVC)

CORRUGATED

Advantages

Durable

Good fire rating

High impact strength

IR inhibitor

Disadvantages

Lower light

High expansion

Yellows with age

Only 4 ft. widths

Bio 2 84 < 25 10+ 1.00–1.25

(Table 2–3 continued)

* 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.

transmittance

available

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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.

Safety chain

Fork Mounting Wood bearing blocks

Length to fit polyethylene steel pipe

Welded steel channel frame

Bolt to bucket

Bucket Mounting

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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.

Figure 2–11. Details of an air-inflated polyethylene-covered greenhouse.

Polyethylene
Plastic
Flower Pot
Clothes Dryer
Duct
Fan Installation
Squirrel Cage
fan draws
in outside
Install adjustable air
damper to control
maximum air pressure
between film layers
Polyethylene
Fastening
Grade
Frame
Member
Post
Skirt Plank
Double Layer
Polyethylene
1 x 2
6d nails
every 12"

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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.

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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

Oil- or gas-fired steam or hot water

1.00–1.75

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

Motorized

0.50–1.00

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.

Table 2–4. Greenhouse construction costs. (a)

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Chapter 3:**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).

Transport
Operation
Relay

Inspection
Storage
Market flats
from storage
Seed flats from
germination
Move flats convenient
to transplanter
Transplanter sets flat
on transplant table
Level media in flat
Move seed flats to
transplant area
Transplanter takes seedlings
from seed flat
Inspect for size and quality
Transplant seedlings
Flats are set on conveyor
Waterer
Seed flats and waste removed
Flats by conveyor to stacker
Flats stacked on pallets
Pallets moved to greenhouse
Flats unloaded from pallet
Flats moved across greenhouse
Flats placed on ground
to growing
Operation Chart
Symbols

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"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.

SOIL
(bulk)
PEAT
(bags)
VERMICULITE
(bags)
Bucket loader
SHREDDING
Shredder w/ screen
PASTURIZATION
Chemical
Bucket loader
Bucket loader
BATCH MIXING
2 yd. Ribbon Mixer
STORAGE
(bulk)
POT FILLING
Belt Conveyor Conveyor & Feeder Bin
Scale
LIME
FERTILIZER
Bucket loader Bucket loader

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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

B. Support buildings layout showing work and storage areas and equipment.

Flat holding area is removed when marketing begins.

Germination Conditioning

Transplanting Room

Customer

Entrance

Flat Holding

Conveyor

Soil Mixer

Soil Mix

Storage DRY

Flat STORAGE

Filler

Flat Storage

Seeding

A. Plan Layout

GROWING HOUSES

Growing House

Perennials

Soil Pile

Customer

Entrance

Seeding

Transplanting

Germination

Soil Mixing,
Flat Filling,
Storage

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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 cleanup 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 repellent signs. Tags, seeds, hardware, and spare parts should be located in one area and clearly labeled. Racks or bins work

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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.

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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

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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'

A. Longitudinal bench layout–59 % growing area

50'

Bench

Aisle

Bench

30"

5'

43'

29"

B. Peninsula bench layout–69% growing area

50'

Bench

Aisle

3'

4'

5'

Aisle 18"

2'

C. Movable bench layout–81% growing area

50'

Aisle

Aisle

2'

30'

4'

13'

2' 5'

Fixed bench

Movable bench

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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.

C. Wood frame with wood

See 'A'

See 'A'

1/4" space

1" x 4"

1" Lumber sides

2" x 4"

3/8" CC Grade Exterior

Plywood Gusset both sides

A. Pipe frame with corrugated cement-mineral fiber board
 B. Concrete block, wood frame with pressure treated plywood
 3/8" Corrugated cement-mineral fiber board
 3/8" Cement-mineral fiber board
 11 Ga. Galv. Steel Corner
 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
 3/8" x 5" x 5" Galv. Steel angle 2' O.C.
 See 'A'
 2" x 4"
 Concrete Blocks
 Use Redwood or Pressure Treated Lumber
 3/4" Pressure treated plywood
 D. Wood frame with welded wire or expanded metal
 See 'A'
 See 'A'
 See 'C'
 1" x 4"
 2" x 4"
 1" x 4" x 14 Gauge or 2" x 4" x 12 Gauge Galv. Steel
 Welded Wire or Expanded Metal
 1" Lumber sides
 Use Redwood or Pressure Treated Lumber
 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
 See 'A'
 2" x 4"

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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.

Pallet System Movable Benches

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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.

1" Rough Lumber

(Wire mesh or expanded metal may be substituted)

1/8" x 1" Steel Strap

1-1/2" Steel Pipe

Length of Bench

1/8" x 1" x 3"

Steel Strap Stop Weld to Channel Ends

1-1/2" x 3'2-1/4"

Steel Pipe

6" Dia. x 12" Deep

Concrete Pier

3" x 4.1 lb/ft x 3'3"

2'10"

2'8"

2'2-1/4"

5'0"

Note: Place Support Frames

4' O.C. for Bench Crops &

5' O.C. for Pot Plants

6'0"

2'6"

2" x 4" x 5'10-1/4"

3'1-1/2"

1/8" x 1" Steel Strap

Fasten to 2" x 4"

with #8 x 3/4" FH

wood screws, 12" O.C.

Countersink all screws.

Stop, Welded to Channel

3" x 4.1 lb/ft x 3'8" lg.

Steel channel for 24" aisle.

3'6" long for 18" aisle

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16"

C. Wood A-frame pot rack

72"

16"

16"

16"

16"

1" x 6" x 10"

2" x 4" x 26"

2" x 4" x 39"

2" x 4" x 50"

2" x 4" x 62"

2" x 4" x 72"

2" x 6" x 18'

stagger joints

2" x 4" x 8"

Note:

Frame spacing—9' apart.

Use pressure treated lumber.

91"

D. S-type hanger rack support

48"

24"

24"

24"

6"

support

pipe

2" x 4" x 22 lg.

V-notch ends

5/8" dia. x 84" lg.

steel rod each side

1" dia. steel fence

or water pipe

5/8" dia. x 4" lg.

steel rod—welded

B. Pipe frame rack support

72"

30"

20"

20"

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.

U-bolt

1" dia. x 18' lg. steel

fence or water pipe

1" dia. steel

fence or water pipe

15" dia.

bend

A. Wood A-frame rack support

60"

28"

22"

22"

22"

Wire or rod to keep
frame from spreading

1" dia. steel water or

fence pipe. Drill holes
for a slip fit.
2" x 4" x 8' lg.
pressure treated lumber
Note:
Frame spacing–10' apart

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.

2"

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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.

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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

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.

Figure 3–9. Tying greenhouses together with a headhouse allows for better labor efficiency.

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.

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

GREENHOUSE

GREENHOUSE

GREENHOUSE

OFFICE

UTILITIES

FLAT/POT FILLING
TRANSPLANT
AREA
MEN WOMEN
SHIPPING
ORDER
ASSEMBLY
HEAD
HOUSE
SUPPLIES
EXPANSION
AREA

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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

Barrel Mixer

Continuous Mixer using Feeder Bins

and In-line Rotary Mixer

Hopper Mixer

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Figure 3–11. Flat and pot filling systems.

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.

Pot Filler

Flat Filler–Belt Feed

Flat Filler–Conveyor Feed

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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

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Figure 3–14. Carts and wagons.

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

Figure 3–13. Conveyors.

Double Wheel Cart
Four Wheel Cart
Tractor-Trailer Train
Roller Conveyor
Chain Conveyor
Belt Conveyor
Overhead Conveyor

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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.

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.

Figure 3–15. Pallet moving equipment. The location must have convenient access to the
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Figure 3–17. Flat handling.

Figure 3–16. Plant shipping container with two-way entry for a fork lift.

10" T-Hinge
57-1/2"
47"
89"
4" x 5.4 lb/ft
steel channel
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.

Shipping Cabinet Shipping Cart System

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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.
APRON SPACE TRUCK LENGTH
TRAFFIC CIRCULATION

LOADING

DOCK

Stall Width

Dock Width

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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.

Figure 3–19. Loading 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

2'6"

1'0" 1'6"

7'6"

4'0"

6"

4" Drain Tile

#4 Steel Reinforcing Bar

20" lg. 4' O.C.

Gravel or Stone

3" x 12" Oak Bumper

3/4" x 12" Bolts 6' O.C.

4" Reinforced Concrete

(alternative: 4" Asphalt)

#4 Steel Reinforcing Bar

Dock surface should be at least

16' wide for fork lift operation.

Slope surface 1–2% for water

drainage.

Concrete Retaining Wall–

Place Expansion Joint

every 30'. Use concrete

with 28-day Compressive
Strength of 3,000 psi.

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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

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.

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Table 3-3. Apron space required.

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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 (CO₂) and water (H₂O), 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 CO₂, H₂O, 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

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GAS

AIR POLLUTION INJURY HAS BEEN DETECTED AT LEVELS AS LOW AS:

Acetylene (C₂H₂) 1 ppm

Carbon Monoxide (CO) 50

Hydrogen Chloride (HCl) 0.1

Ethylene (C₂H₄) 0.05

Methane (CH₄) 1000

Nitrous Oxide (N₂O) 2

Ozone (O₃) 4

Peroxyacetyl nitrate (PAN–smog) 0.2

Propane (C₃H₈) 50

Sulfur Dioxide (SO₂) 1

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.

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Figure 4–1. Energy exchange between a greenhouse and the surroundings.

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.

Infra-Red Thermal
 Radiation from
 Atmosphere
 Infra-Red Thermal
 Radiation from
 Walls, Soil, etc.
 Transpiration
 Evaporation
 Infra-Red Thermal
 Radiation from Plants
 Reflected
 Sunlight
 Reflected
 Sunlight
 Sun
 Air
 Dust
 Particles
 Direct

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**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
 Painted white
 Painted black

0.32
 0.20
 0.96
 0.10
 0.91
 0.88
 Galvanized steel:
 Oxidized
 Painted white
 0.80
 0.34
 0.28
 0.90

Table 4–2. Transmissivity of glazing materials. ^(a)

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

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.

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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:

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

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.

hr (Furnace heat) = hc (Conduction heat) + hsa (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:

$$h_c = AU (t_i - t_o) \quad (4-1)$$

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:

$$h_{sa} = 0.02 M (t_i - t_o) \quad (4-2)$$

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.

$$h_r = h_c + h_{sa} = AU (t_i - t_o) + 0.02 M (t_i - t_o) \quad (4-3)$$

where h_r = 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:

$$h_s = T I_s A_F \quad (4-4)$$

Cold Sky Cold Outside Air
 Conduction into Ground
 Perimeter
 Conduction
 Infiltration
 (Cold Air)
 Radiation to
 Cool Sky
 Exfiltration
 (Warm Air)
 Convection
 Conduction
 to Air
 Convection

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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.

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

^(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 (ft³). Low wind speeds or protection from wind will reduce the rate to

a minimum value of 0.5 exchange per hour in some situations.

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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 onehalf the solar radiation received by the plant is used to evaporate water. In equation form:

$$h_{cv} = E F h_s \quad (4-5)$$

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:

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

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:

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

where t_o = temperature of air leaving the cooler, °F

t_{wb} = outside air wet bulb temperature, °F.

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

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.

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Figure 4-4. Evaporative cooling effect as a function of relative humidity of outside air.

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.

No shading on greenhouse

50% of solar energy reflected by shading

Temperature Rise, °F

Air changes per minute

0

0

1 2 3 4

9

18

104

Temperature of cooled air leaving pad, °F

86

95

77

Outside Average Temperature, °F

59 68 77 86 95

RH of outside air 30% RH 50% RH 70% RH

90% RH

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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 airwater 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.

CONSTRUCTION SYSTEMS

**Outside
Temperature**

(°F)

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.

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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 $96 \text{ ft.} \times 192 \text{ ft.} = 18,432 \text{ ft.}^2$; the installed fan capacity is $8 \text{ cfm/ft.}^2 \times 18,432 \text{ ft.}^2 = 147,456 \text{ cfm}$ (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.

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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 – 0.512"). 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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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"

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Chapter 5:

Equipment for Heating and Cooling

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).

Figure 5-1. Direct-fired floor-mounted warm air furnaces.

Ducts can be perforated PE tubes or galvanized steel.

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

Warm Air Discharge Flue

Circulating

Burner Fan

Assembly

Fire

Box

A. Top discharge only

Flue

Flue Gases

Heat Exchange

Burner

Assembly

Barometric

Damper

Warm Air

Discharge

B. Bottom discharge

Greenhouse 2

Ringline Supply

Ringline Return

Check Valve

Ringline

Circulators

Boiler Room

Return

Supply

4-Way

Valve "B"

4-Way

Valve "A"

Greenhouse

Circulators

Greenhouse Return

Greenhouse Supply

Greenhouse 1

Expansion Tank

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.

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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.

Fuel
 Supply
 Heating
 Element
 Pressure
 Relief Valve
 WATER
 HEATER
 or
 BOILER
 From Supply
 Pressure
 Reducing
 Valve
 Check
 Valve
 Thermometer
 Thermometer
 Mixing Valve
 Pressure Gauge
 Air Eliminator
 Air Purger
 Expansion
 Tank
 Gate Valve
 Pump From Floor
 or Bench
 To Floor
 or Bench

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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

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

(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.

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Figure 5-4. Typical pipe layout for floor or bench heating (reverse return).**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

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

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

Warm water
supply
Cold water
return
Pipe loops
Maximum length
3/4" pipe = 400'
1/2" pipe = 200'

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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.

Perforated PVC

supply pipe

Supply

Water flow

through rock fill

Perforated

return pipe

Return

4" porous concrete

12" crushed stone

3/4" average size

20 mil vinyl liner

1" foamed plastic board

6 mil polyethylene film

3"

Polyethylene pipe loop for supplemental heat 12" O.C.

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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.

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'.

No. of loops of maximum length indicated

Pump Capacity (GPM)

Supply Pipe Size (in.)

80

72

64

56

48

40

32

24
 16
 8
 0
 3
 2-1/2
 2
 1-1/2
 1-1/4
 1
 3/4" pipe
 1/2" pipe
 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
 20 Btu/sq.ft.-hr.
 Plants in soil or pots
 15 Btu/sq.ft.-hr.
 Surface covered with flats
 Heat output (1000 Btu/hr)
 Bed or bench area (sq.ft.)
 1000 2000 3000 4000 5000 6000
 40
 30
 20
 10
 60
 50
 80
 70
 100
 90
 0

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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_r = 540,650 Btu/hr. for each outer section

h_r = 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

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Figure 5–8. Fan layout for horizontal air flow systems to provide uniform temperature distribution.

70'–120'

6-row

9-row

Notes:

1. Add a row of fans for each additional 50 ft. of greenhouse length.
2. For greenhouses with three bays, air in the two outside bays should move in the same direction. For greenhouses with odd numbers of bays, air in the center three bays should flow in the same direction.
3. Total fan capacity in cubic feet per minute (cfm) should equal one-fourth the house volume. 16" dia. circulating fans with 1/15 hp motors will generally be sufficient.

Fan

Direction of air flow

8-row

7-row

Individual

2-row

3-row
4-row
5-row

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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.
SIZE, DIA.

(in.)

SPEED

(rpm)

CAPACITY

(cfm)

MOTOR

(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

Table 5–3. Typical fan performance data.

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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.

- A. Winch rolled, opens from bottom.
- B. Winch raised film, opens from top.
- C. Hand crank system to roll plastic film, opens from bottom.

Brackets to keep plastic in place
 Attach plastic film to PVC or aluminum pipe.
 Hand Crank
 Film battens
 Greenhouse frame
 Greenhouse frame
 7/32" dia. PVC wrapped steel cable
 Pulley
 1/8" dia. PVC wrapped
 1/2" dia. steel cable
 steel conduit
 Bracket
 3" dia. PVC or aluminum

pipe
Batten for film
Manually operated
worm gear winch
Manually operated
worm gear winch
Greenhouse frame
Film battens
1/3" dia. PVC wrapped
steel cable
3/4" dia. steel conduit
or 3/4" PVC pipe

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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 $147,456 \text{ ft.}^3/\text{min.} \div 250 \text{ ft./min.} = 590 \text{ ft.}^2$ and should extend the length of the wall. The maximum opening width should be $590 \text{ ft.}^2 \div 192 \text{ ft.} = 3.1 \text{ ft.}$ (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 5–11. Fog system for evaporative cooling.

Figure 5–10. A complete system for temperature control in a greenhouse.

Perspective
Intake louver for
mild weather cooling
Exhaust fans
PE tube
Unit heater
Powered side wall vent
for intermediate cooling
Aspirated Sensor
Box Wetted pad for
maximum cooling
Finned tube

Perimeter heat
Circulation and mild
weather cooling fan
Fog
nozzles
Intake louver
Pump control thermostat
Exhaust fan and inlet louver
High pressure pipe control thermostat
Pressure gauge
Pressure relief valve
Pump (2–300 psi)
Filter
Water supply Exhaust fans

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

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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.

Figure 5–12. Aspirated box for control sensors.

Box or muffin fan
40–60 cfm
Mounted to exhaust air
from box continuously
Mount box at plant height.
Make box large enough
for all sensors
Sensors
Air intake
Hasp
Hinged door

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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 gasfilled 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.

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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

Figure 5-13. An example of greenhouse temperature control with five cooling stages.

THERMOSTAT #1 Hot THERMOSTAT #2 THERMOSTAT #3

Neutral

115 v.

1 2 3 4 5

Relay Relay Relay Relay Relay

SPST SPST SPDT SPDT SPST

1 1

1

2 2

Neutral

Hot

115 v.

Circ. Fans Louver Ex. F. Ex. F. Ex. F. Vent Ex. F. Pump

1 - L 2 - L 1 - H 2 - H

Stage

Normal

1

2

3

4

5

Circ. fan

on

on

on

off

off

off

Louver

closed

open

open

closed

closed

closed

closed

Vent

closed

closed

closed

open

open
open
Exh. Fan 1
off
low
low
high
high
high
Exh. Fan 2
off
off
low
low
high
high
Pump
off
off
off
off
on

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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-todawn

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

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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.

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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.

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
Other sensors
Power failure relay
Thermostat
Bell, buzzer or
light
Switch
Battery

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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 hookup 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

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

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

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Figure 5–15. System transfer switch.

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.

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Bul. 85-14. Coop. Ext. Service, University of

Connecticut, Storrs, CT 06268.

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Bench Heating for Greenhouses. Publ. E-047. Coop.

Ext. Service, Rutgers University, New

Brunswick, NJ 08903.

To power company service

Meter box

Transfer switch

Polarized 220 volt

Plug and outlet

To generator

Main

disconnect

switch and

fuse box

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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.

Frequency (cycles per second)
Wavelength (meters)
Hertzian waves
Wavelength in nanometers Power
Transmission
Broadcast
Short wave
Television
Directional
Radio (Radar)
FM
Infrared
Near Far
Ultraviolet
Vacuum U.V.
X-rays
Hard Soft
Gamma rays
Cosmic rays
Light
Violet Blue Green Yellow Red
380 400 500 600 700 760
10⁻¹⁴ 10⁻¹² 10⁻¹⁰ 10⁻⁸ 10⁻⁶ 10⁻⁴ 10⁻² 1 10² 10⁴ 10⁶ 10⁸
10²⁴ 10²² 10²⁰ 10¹⁸ 10¹⁶ 10¹⁴ 10¹² 10¹⁰ 10⁸ 10⁶ 10⁴ 10²
1 X-unit
1 angstrom
1 nanometer
1 micron
1 cm
1 meter
1 kilometer

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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/m^2) or milliwatts per square meter (mW/m^2) or in watts or milliwatts per square foot (W/ft^2 , mW/ft^2).

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/m^2 , mW/ft^2). It is a measure of the quantity of energy in wavelength band 400 - 700 nanometers (nm) received by the plants. Since footcandle meters are readily available, it is easier to evaluate lighting levels in foot-candles and convert the reading to mW/ft^2 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

400 500 600 700 800
NANOMETERS
RELATIVE RESPONSE
Standard Luminous
Efficiency Curve
(CIE)
Photosynthesis Action
Spectrum I
Photosynthesis Action
Spectrum II

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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

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

Table 6-1. Energy values and conversion factors for four types of lighting units.*

* Poot, J. 1984. *Application of Growlight in Greenhouses*. Poot Lichtenergie 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.

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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,

$$N = \text{light level} \times \text{surface area} = 800 \times 9 \times 128 = 24 \text{ fixtures}$$

effective flux 38,400

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

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

Therefore, H (the height above the table) =

$$L = 1.55 \times H = 1.55 \times 3.38 = 5.24 \text{ feet}$$

$$B = 2.7 \times H = 2.7 \times 3.38 = 9.13 \text{ feet}$$

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

A F

4.2 x E

38,400

4.2 x 800

3.8 feet

4 2 .

= = =

E

F

A

and, therefore, A =

F

E

=

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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 nonuniform 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 lowcost 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

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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 eye, 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 ($\mu\text{E}/\text{m}^2\text{s}$). 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/m^2). 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.

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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.

Figure 6–3. Comparison of lamp efficiencies.

* Includes

Ballast

Incandescent

Tungsten-Halogen

Mercury

Fluorescent

Metal Halide

High Pressure Sodium

Low Pressure Sodium

LAMP EFFICIENCY—Lumens/Watt*

150

140

130

120

110

100

90

80

70

60

50

40

30

20

10

0

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Table 6-4. Comparison of light sources.

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 yelloworange 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

**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-

Halogen

75 — — 2,000 1,400 — 19

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

Sodium

400 25 425 24,000 50,000 45,000 117

1,000 60 1,060 24,000 140,000 126,000 132

Low Pressure

Sodium

180 50 230 18,000 33,000 — 143

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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 nonproduction areas.

Figure 6–4. Greenhouse supplemental lighting: a) individual bench lighting; b) area lighting.

A. Individual Bench Lighting B. Area Lighting

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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 luminaires 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. Luminaires 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, multilevels are installed, one above the other, to maximize

Figure 6-5. Germination/starting unit.

PLANT TRAY

1/2" x 4' x 8' Ext. CC Plywood

1" x 2" Furring Strip

CROSS BRACE

LIGHT FIXTURE SPACING

4'

4" 10"

3' 0"

8' 9"

2' 10-1/2"

4' 3"

Cross Brace

2" x 4"

2" x 4"

18"

6' 6"

Corner Post

4" x 4"

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.

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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.

Figure 6–6. Germination cart.

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

GERMINATION CART

10"

10"

10"

4' - 8"

2' - 0"

Seedling

Flats

4' - 2" tube

Fluorescent Strip Fixtures
with cool white tubes
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.

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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 CO₂ 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

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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.

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

Table 6–5. Estimated maximum daily water requirements.

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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.

$0.5 \times 25 \times 100 = 1,250$ gallons per day

add 10% for leaching, $0.10 \times 1,250 = 125$ 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:

$1,375 \text{ gal./day} = 687.5 \text{ gal./hr.}$

2 hrs./day

This is the peak use rate.

$687.5 \text{ gal./hr.} = 11.46 \text{ gal./min.}$

60 min./hr.

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

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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

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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.

pump hp = flow (gpm) x total head required (ft.)

3,960 x pump efficiency

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

motor hp = pump horse power

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 1) 15 ft. of 1-1/4 in. steel
(from pipe, 1.9 psi/100 ft.—
Tables 3 & 4, 0.019 psi/ft. x 15 ft. x
Appendix 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

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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:

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

For the example:

$hp = 164.5 \text{ ft.} \times 12 \text{ gpm} \approx 1.00 \text{ hp}$

3,960 (0.50)

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.

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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

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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

A. Backflow preventer valve B. Air gap preventing backflow

Normal Flow Condition Backflow Condition

Water

Supply

Gate Valve

Mixing

Tank

Air Gap

Gate Valve

To

Distribution

6–8'

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Figure 6–8. Typical pump-type fertilizer injector installation.

Figure 6–9. Low pressure greenhouse watering system for groundbeds, benches, or troughs.

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1. Fertilizer Injector

2. Isolation Gate Valves

3. Bypass Gate Valves

4. Concentrate Tank

5. Blending Tank

6. Universal Injector

7. System On-Off Valve

8. Check Valve

9. Wye Strainer

10. Waste Line to Drain

Line Strainer

Gate Valve

Air Gap

1" Pipe or Larger

Supply Line

Gate Valve &

Backflow Preventor

Strainer

Alternate Supply

Pressure Reducer

or Flow Meter

Gate Valve

300 Gal. Mixing Tank

1" Pipe

X

Distribution

X PRESSURE

2' 0.9 PSI

4' 1.7 PSI
6' 2.6 PSI
8' 3.5 PSI
10' 4.3 PSI

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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?

$H = 3 \text{ psi} \approx 7 \text{ ft.}$

0.43 psi/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.

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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).

Distribution

1" Pipe—Plastic or Galvanized

Pressure Reducer

or Flow Meter

Faucet

Faucet

Solenoid Valve

Time Clock

or Controller

Pressure

Tank

Gate Valve

Fertilizer

Injector

Check Valve

or Backflow

Preventor

Strainer Gate Valve

1" Pipe or

Larger

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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 Spacing of dia. of water (mph) 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.

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Figure 6-11. Examples of movable watering systems.

PORTABLE WATERING ROOM
GREENHOUSE WATERING CART
Hose Reel on Cart
1" dia. Hose w/ Strainer
Harness
Ball Valves
Swivel
1" dia. Aluminum
Pipe Boom
Boom Height
Adjustment
Energy Blanket Track
Full Cone Spray Nozzle
12" spacing-12" above plants
0.6-0.8 gpm = 30 psi
80 deg. spray angle
Manifold with connections for supply
line and four hose connections to
booms
Swivel for pipe
Wide angle spray nozzles
40" spacing-13" height

0.6–0.8 gpm = 30 psi
120 deg. spray angle
3/4" Garden
Hose w/ Strainer
1/2" Galvanized
Water Pipe
Flat Spray Nozzle
20" spacing
18" height–0.15 = 0.20 gpm = 30 psi
80 deg. spray angle
12-volt switch
10 ft/min
1/4 ton capacity
Limit Switch
Steel Guide Pipe
Deadman

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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 480 gal. = 6-2/3 min.

72 gpm

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 120 gal. = 7-3/4 min. per lateral

15.5 gpm

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.

AISLE

96'

Supply Pipe—2-1/2"

Nozzle Spacing Lateral—1-1/4"

5' O.C.

10'

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Figure 6–13. Example layout of a watering system using 0.5 gpm nozzles.

Figure 6–14. Samples of typical watering systems.

96'

AISLE 25'

Nozzle Spacing—40" O.C. Lateral Spacing—5' O.C.

Lateral Pipe—1-1/4"

Supply

Pipe

DRIP TUBES SPRAY STAKES

CAPILLARY MAT WATERING

Drip Hose

Capillary Mat

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MIST SYSTEM LAYOUT

MIST SYSTEM PLUMBING & CONTROLS

24-hr. timer Program Repeating

Timer

Automatic Brass

Drain Valve

Female Adapter

Male Adapter Saddles

Brass Coupler

Solenoid

Valve

PVC Pipe

Nozzles

Strainer

Bell Wire

Appliance Wire

Transformer

Gravel and drain necessary

on outdoor beds

Rooting medium

(approx. 6' deep)

Wind screen or deflector

for outdoor beds only

Nozzle orifice

12–18 inches

above surface of

rooting medium

Electrical Power

Line Strainer

Water Line

Solenoid Valve

Timer

n

1 load c nc no 2

Figure 6–15. Mist system layout.

Carbon Dioxide Enrichment

Carbon dioxide (CO₂) is essential for the growth of all green plants. The normal atmosphere contains about 0.03% CO₂ or about 300 ppm. Research over the years on many crops has confirmed that higher levels of CO₂ 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 CO₂

Manufactured CO₂—Available in cylinders or bulk.

Cylinder capacities: 5, 10, 15, 20, and 50 lbs. of CO₂

Bulk: Special storage tank required

Minimum purity: 99.5%

More expensive than CO₂ obtained from

combustion

Combustion—Natural gas, propane, or kerosene

Advantages:

Less expensive than manufactured CO₂ 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. 4' apart (approx.)

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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 CO₂ EQUIPMENT

During the night, CO₂ is given off by the plants and may reach levels of 400–450 ppm. When photosynthesis begins after sunrise, CO₂ 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 CO₂ used by the plants and for the amount lost to infiltration air through the greenhouse surface.

Make-up CO₂ = Plant Use + Infiltration Loss

Figure 6–17. CO₂ levels in a greenhouse during a sunny day in winter compared to outside air.

Insert Elbow

Space 180° nozzles 30" apart on narrow benches (up to 42" wide—48" wide for roses).

Polyethylene Pipe

Coupling

Second solenoid valve required for benches 100–200' long.

Space alternating 180° and 45° nozzles 20" apart on wide benches (42" or wider).

Use 2 solenoid valves for benches wider than 42" and up to 150' long.

Use 4 solenoid valves for benches 150–200' long.

Insert

Tee

Water Supply

Line

180°

Nozzle

45°

Nozzle

Polyethylene

Pipe

Solenoid Valve

GREENHOUSE

OUTSIDE

PERCENT CARBON DIOXIDE

A.M. P.M.

TIME OF DAY

A.M.

0.05

0.04

0.02

0.03

0.01

6 9 12 3 6 9 12 3 6

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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 CO₂/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 CO₂ 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 CO₂ level – 300)

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 CO₂.

Plant usage rate is assumed to be 0.003 ft.³/hr.-ft.².

Calculate the size of the CO₂ generator, how much kerosene or LP gas will be used per hour, and the heat output per hour.

1) Size of the CO₂ generator:

Make-up CO₂ = Plant Use + Infiltration Loss:

Plant Use

= Greenhouse Floor Area x Plant Usage Rate

$$= (96 \text{ ft.} \times 192 \text{ ft.}) \times 0.003 \text{ ft.}^3/\text{hr.}-\text{ft.}^2$$

$$= 55.3 \text{ ft.}^3 \text{ CO}_2/\text{hr.}$$

Infiltration Loss

$$= \text{Greenhouse Volume} \times \text{Air Changes per Hour}$$

$$\times 0.000001 \times (\text{Desired CO}_2 \text{ level} - 300)$$

$$= (96 \text{ ft.} \times 192 \text{ ft.} \times 9\text{ft.}) \times 0.5 \text{ changes/hr.}$$

$$\times 0.000001 (1300 - 300)$$

$$= 165,888 \text{ ft.}^3 \times 0.5 \text{ changes/hr.} \times 0.001$$

$$= 82.9 \text{ ft.}^3 \text{ CO}_2/\text{hr.}$$

Make-up CO₂

$$= 55.3 \text{ ft.}^3/\text{hr.} + 82.9 \text{ ft.}^3/\text{hr.} = 138.2 \text{ ft.}^3/\text{hr.}$$

2) Amount of fuel needed per hour:

From Table 6–7 on the opposite page, kerosene yields 187 ft.³ CO₂/gal. and LP gas yields 108 ft.³/gal.

Fuel Needed = CO₂ required

fuel yield

Kerosene:

$$\text{Fuel Needed} = 138.2 \text{ ft.}^3/\text{hr.} = 0.74 \text{ gal./hr.}$$

187 ft.³/gal.

LP gas:

$$\text{Fuel Needed} = 138.2 \text{ ft.}^3/\text{hr.} = 1.28 \text{ gal./hr.}$$

108 ft.³/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.

Heat

$$\text{output/hr.} = \text{Gal. fuel/hr.}$$

Heat output of fuel

Kerosene:

$$\text{Heat output} = 0.74 \text{ gal./hr.} \times 134,000 \text{ Btu/gal.}$$

$$= 99,160 \text{ Btu/hr.}$$

LP gas:

$$\text{Heat output} = 1.28 \text{ gal./hr.} \times 91,600 \text{ Btu/gal.}$$

$$= 119,040 \text{ Btu/hr.}$$

Figure 6–18. Rate of photosynthesis in relation to light

intensity with increase in CO₂ levels.

RELATIVE LIGHT INTENSITY
RELATIVE PHOTOSYNTHETIC RATE

18

14

10

6

2

2 4 6 8

0.08% CO₂

0.03% CO₂

0.01% CO₂

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EQUIPMENT

A typical control system for a compressed gas installation is shown in Figure 6–19 on the next page.

The CO₂ 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 CO₂, 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ used) can be obtained with a controller. The most common type operates on the principle of selective absorption of infrared radiation by CO₂. Greenhouse air is sampled and the measured concentration of CO₂ is converted to an electrical signal. When CO₂ 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

Table 6-7. Carbon dioxide (CO₂) yields from fuels. ^(a)

FUEL

(lb./gal.)

YIELD

(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.

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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.

Figure 6–19. Equipment for using compressed CO₂ gas.

Figure 6–20. LP or natural gas burner for CO₂ production.

DISTRIBUTION SYSTEM IN GREENHOUSES

Limit switch located on ventilator turns off CO₂ when vents are opened.

24-Hour

Time Clock

Perforated

poly tubing

Solenoid Valve

Flow Meter

Cylinder

Regulator

Line

Regulator

From storage

tank

CO₂ burner

Thermostat

Pressure Gauge

24-Hour

Time Clock

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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

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.

(a) Dry air at 70°F, dry saturated steam at 230°F.

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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 troublefree 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

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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.

Soil

Peat

Perlite

Supplements

Mixer

MIXING

TREATING

COOLING

RAW MATERIALS

Belt

Conveyor
Media
Chamber
Belt
Conveyor
Belt Conveyor
Media
Chamber
Exhaust
Piernum
Steam
Heating Supply
Fan
Aerated Steam
Supply Piernum
To End Use
Belt Conveyor
Cooling Fan

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Figure 6–22. Components of hydraulic sprayer systems.

Figure 6–23. Types of hydraulic sprayers.

TYPICAL CENTRIFUGAL PUMP HOOK-UP TYPICAL PISTON PUMP HOOK-UP

Positive Vent
Line
Jet Agitator
Agitation
Line
Line
Strainer
Control Valve
Control Valve
Boom Shut-off
or Selector
to boom nozzles
Pressure
Gauge
Centrifugal
Pump
Tank Shut-off
Jet Agitator
Agitation
Line
Control
Valve
Pressure gauge
w/ damper Boom Shut-off
or Selector
to boom nozzles
Pressure Relief
Valve
Piston Pump
Surge Tank
Line
Strainer
Tank Shut-off
By-pass Line
COMPRESSED AIR SPRAYER PORTABLE SPRAYER
KNAPSACK SPRAYER TRAILER-MOUNTED BOOM SPRAYER
Valve
Carrying Strap
Hose
Pump Handle
Filler Cap
Pump Flunger

Extension Tube

Nozzle

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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

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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 Calibration distance band width (inches) (feet)

10	408
12	340
14	292
16	255
18	227
20	204
24	170
28	146
32	127
36	113
40	102

Figure 6–24. Types of nozzles.

EVEN
FLAT-FAN
REGULAR

FLAT-FAN
SOLID CONE
HOLLOW CONE
SPRAY PATTERN
SPRAY PATTERN
SPRAY PATTERN
SPRAY PATTERN

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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:

gal./A = 43,560 ft.²/A x gal. to refill

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.

gal./A = 43,560 ft.²/A x gal. to refill

660 ft. x boom width (ft.)

= 66 ft./A x gal. to refill

boom width

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:

$\text{gal./A} = \text{nozzle output (oz. per minute)} \times 46.4$

$\text{boom width (ft.)} \times \text{speed (mph)}$

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,

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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 cartmounted 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

Figure 6–25. Misting and fogging applicators.

BACKPACK MIST SPRAYERS
FOR GREENHOUSE OR NURSERY
PULSE-JET FOGGER

AIR BLAST SPRAYERS FOR USE ON FIELD-GROWN NURSERY STOCK OR TREES

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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 highpressure 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 containergrown 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.

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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.

Figure 6–26. Equipment for distributing granular pesticides.

TRACTOR-MOUNTED AND TRAILER-MOUNTED BROADCASTERS

HAND PUSH SPREADER FOR LAWN & BED APPLICATION CHEMICAL DISPENSER FOR INDIVIDUAL POTS

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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 $960 \text{ ft.}^3 / 6 \text{ min} = 160 \text{ cfm}$ is needed. The high speed should have a capacity of $960 \text{ ft.}^3 / 3 \text{ min.} = 320 \text{ cfm}$.

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.

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Figure 6–27. Pesticide storage room within a building. Adapted from Connecticut Plan No. 254.

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

10" Dia. 2-speed kitchen exhaust fan
wired so that low speed is always on,
except when room is occupied. High
speed is activated by light switch.

Four tube 4' fluorescent light fixtures

Fire Extinguisher

2A 10 BC

Floor to Ceiling Shelves

10"

Screened

Louver

Bag

Storage

Floor Drain

Barrel

Storage

Equipment

Storage

Sink

5' long

counter

with

storage

under &

overhead

10'

10'

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.

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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 buildup 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.

PLAN

12' 20'

12' 8"

3'

11' 4" x 13'

5' 0" x 11' 4"

Bulk Storage

Counter &

Cabinets

Mixing and

cleanup room

Concrete slab for

cleaning equipment

Provide outside

house bibb

Ridge ventilator

End Elevation Side Elevation

Exhaust Fans

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

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.

Expansion
Area
Movable
Benches
Movable
Benches
Access Road
Aisle Aisle
72' 144'
160'
Right
of Way
Proposed
Gutter-
Connected
Range
Gas Line
Aisle
50'
40'
Parking
Head
House
Receiving & Shipping
Existing greenhouses
to be removed
These glass greenhouses
in poor condition to be
replaced by new range
Present
greenhouse
range
South End Road

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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, fiberglassreinforced 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.

A. Original frame with wood sash bars and glass
B. Truss fabricated in place to permit column removal. Wood sash bars and glass remained in place during remodeling.

40'
9' 22' 9'
7' 1"
5' 6" 5' 6"
12
6
1
2
3
4

5

1/2" dia.

steel rod 3/4" dia. steel pipe

5/8" x 3" steel

strap rafter,

8'6" O.C.

2'6" conc.

wall

2" dia. steel pipe columns

8'6" O.C.

2" dia. steel pipe

3/4" x 3"

steel strap

post, 8'6" O.C.

5/16" x 2" x 1-1/2"

steel angle purlins

4' 0" O.C.

Cast steel gusset

at joints 1, 2, 3, 4, 5

Lateral bracing for

upper chord 2'0" O.C.

in lower panel only

7'1"

40'

Lower chord 5/8" x 1-1/2" steel strap

welded to 5/8" x 3" steel strap rafter

2" dia. steel

post cut and

welded to strap

1/2" dia. steel

rod welded top

and bottom

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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 system 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 CO₂ 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.

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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.

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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

Average

(°F)

GREENHOUSE AIR TEMPERATURE

°F lowered from A to B

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.

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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).

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

Figure 8–1. A lap seal reduces infiltration in a lapped glass glazed greenhouse.

Glass

Lap Seal

Glass

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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 gutterconnected 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 polystyrene 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 8-2. One method for covering a glass glazed greenhouse with a single layer of polyethylene film.

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.

Cutaway View

Hold tube in place with cord or plastic band every 20' to 30'

Air Inflated

Polyethylene Tubing

to create air space

Single layer of

Polyethylene, fastened at

all edges

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Figure 8-3. A track-supported thermal blanket stores against one endwall and works well for a free-standing greenhouse.

- Blanket clip
- Blanket
- Trolley
- Track
- Support wire
- End support
- Support wire or strapping
- Thermal blanket
- Track
- Heat seal
- Heat pipes
- Wall insulation

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Figure 8-4. Curtain system for gutter-connected greenhouse.

- Support Truss for plants and equipment
- Drive Cable
- Curtain Drive System
- Intermediate Support Cables
- INTERMEDIATE SUPPORT CABLES
- Polypropylene Monofilament Line
- Cable Tightener Bracket
- DETAILS
- Double Pulley Bracket
- Continuous Rectangular Tubing
- U-bolted to each post
- Pipe
- Curtain Drive
- Polyethylene Pipe slit to fit over steel pipe
- Cable Tightener
- Curtain Pipe
- Drive Holder
- Drive Shaft
- Bracket
- Bracket
- CURTAIN DRIVE SYSTEM
- Curtain
- 3/8" Pipe
- Nylon Pipe
- Holder
- Curtain
- Anchor
- Guide
- Cable Guide
- 2" Drive Shaft
- Pipe
- Drive Shaft

Mounting Bracket
bolted to posts
Drive Cable
Double Pulley
Bracket
12'–20' Bays typical

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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.

Table 8–3. Effect of energy conservation practices on fuel use and economics for a 40,000 ft.² greenhouse in the Northeast. ^(a)

Table 8–4. Overall heat transmission values for thin thermal blanket installed in three glass greenhouses.

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.

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.

**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.

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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.

Track is supported by
wires attached to the ceiling
Insulating blanket
Hinged board
Insulated
sidewall
Insulating
blanket
Insulation
board
Insulated
sidewall
Insulating
blanket
Insulated
bench
Uninsulated
sidewall

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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,

Table 8-5. Heating values and heating plant efficiencies for commonly used greenhouse fuels. 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.

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/ft ³	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

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30 40 50 60 70 80 90

Table 8–6. Fuel cost comparison.

Figure 8–6. Layout of a typical commercial woodchip/sawdust-fired boiler.

Heating Equivalent Cost, Dollars per Million Btu's
(\$/MBtu)

4 6 8 10 12 14 16 18

60 70 80 90 100 110 120 130 140 150

0.40 0.50 0.60 0.70 0.80 0.90 1.00 1.10 1.20

0.80 0.90 1.00 1.10 1.20 1.30 1.40 1.50 1.60

0.50 0.60 0.70 0.80 0.90 1.00

100

4 6 8 10 12 14 16 18

Heating Equivalent Cost, Dollars per Million Btu's

Coal: \$/Ton

Natural Gas: \$/therm

Fuel Oil: \$/gal

Propane: \$/gal

Green wood chips,

45% moisture: \$/Ton

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

Cool

Return

Water

Boiler

Aquastat

Hot Water Supply

Exhaust

Stack

Forced Draft

Fan

Stack Temp

Switch

Firebox

Igniter

Feed

Conveyor

Fuel Storage Bin

Conveyor

Drive

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Operation and maintenance costs are considerably greater for wood-fired units than comparable oilfired 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.

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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:

$$FR = (EN - Eo) 100$$

E_N

where FR = 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:

$$F_R = (80 - 70) / 100 = 12.5\%$$

80

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:

$$F = \frac{HDD (24) (h_t)}{C \times E \times t}$$

C x E x 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:

$$\begin{aligned} \text{HDD} &= 6,235 (0.80) (55^\circ\text{F}/65^\circ\text{F}) + 6,235 (0.2) \\ &= 4,221 + 1,247 \\ &= 5,468 \text{ HDD} \end{aligned}$$

The fuel requirement would be:

$$\begin{aligned} 5,468 \text{ HDD} (43,433 \text{ gal./yr.}) &= 38,090 \text{ gal./yr.} \\ 6,235 \text{ HDD} \end{aligned}$$

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:

$$\begin{aligned} h_t &= 0.5 (1,643,664) + 0.5 (243,302) + 66,528 \text{ Btu/hr.} \\ &1.1 \\ &= 547,888 + 121,651 + 66,528 \\ &= 736,067 \text{ Btu/hr.} \end{aligned}$$

(See Worksheet No. 4, Appendix XII, for detailed calculations of heat loss.)

Heat loss during the day would be

$$\begin{aligned} &\approx 1,950,000 \text{ Btu/hr. for a } 60^\circ\text{F} \text{ difference in} \\ &\text{temperature. The fuel requirement would then be:} \\ F &= 4,221 (24) (736,000) + 1,247 (24) (1,950,000) \\ &140,000 (0.80) (50^\circ\text{F}) 140,000 (0.80) (60^\circ\text{F}) \\ &= 13,314 + 8,864 \\ &= 21,998 \text{ gal./yr., a 49% percent reduction.} \end{aligned}$$

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.

Concrete Footing

Pipe

B lowers to

Inflate Tubes

Brace

2" x 4"

Framing

Members

Inner

Tube

Scaffold Plank

Cat Walk

Black film

between tubes

Outer Tube

Gutter

Pipe

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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 filmcovered, 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.

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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 (CO₂) 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 CO₂ 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 CO₂ 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.

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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.

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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 “waterlogged” 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.

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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

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Table 8-7. Heat required to warm one cubic yard of 1:1:1 soil:peat:perlite mix from 60°F.

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Appendix I REFERENCES

This list is not intended to be all-inclusive. Consult your Extension Specialist for additional titles.

GENERAL REFERENCES

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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.

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Appendix II

GREENHOUSE CONSTRUCTION AND SUPPLY COMPANIES

M ————— Manufacturer or supplier of commercial 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.
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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.
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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.
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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.

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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

2" x 2" end
frame only
Frame for Fan
or Louvers
2" x 4" ridge
2" x 8" rafter
4" x 4" x 14"
2" x 3"
2" x 4" eave
26'-3/8"
8'0"
4'0"
7'0"

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Plan No. SP 498

Plan No. 6185

10' 0"
20' 0"
2" x 4" Frame endwalls to suit individual needs
1" galv. pipe—1-1/2 lengths approx. 31 ft.
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"
6
12
4'-0"
TYP.
ROOF TRUSS 6'-0" O.C.
FASTEN FILM HERE.
(SEE DETAIL)
EXHAUST

FAN
 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. BLOWER TO KEEP
 LAYERS SEPARATED.
 FASTEN FILM HERE—SEE DETAIL
 2x3 SIDEWALL GIRTS
 1½" POLYURETHANE CEMENT
 ASBESTOS COVERED PANEL
 1'-6" VENT OPENING. HINGE
 AT TOP—COVER 2"x2" FRAME
 W/ FILM ON EACH SIDE
 ACME TUBE MODEL DA
 18" DIA. W/ RC 18 E 6 FAN
 JET 3120 C.F.M. 120,000
 BTU. HEATER
 BENCH TOP 3" B—GRADE
 CRUSHED STONE
 6" COARSE GRAVEL
 EARTH
 28'-0"
 4"x4" POST 6'-0" O.C. ¾"x¾" STOP FOR VENT
 2"x3"x4" BRACE, NAIL TO POST & UPPER CHORD W/ GALV. NAILS
 IF FIBERGLASS PANELS ARE USED INSTEAD OF FILM,
 FASTEN TO PURLINS W/ RING SHANK ALUM. NAILS WITH
 NEOPRENE WASHERS.
 NOTE:
 12"x12"x6" CONC.
 FOOTING
 3'-0"
 2'-6" 3'-0"
 7'-0"
 NOTE:
 CARRY FOOTINGS
 BELOW FROST LINE
CROSS SECTION
 SCALE: ¼" = 1'-0"
CROSS SECTION
 STEEL FRAME
 SCALE: ¼" = 1'-0"
 GRADE LINE
 6"x6" CONC. PIER
 3/8" DIA. RE—BAR
 2" GALV. STEEL PIPE 6'-0" O.C.
 WIND BRACE 3/16"x1" STRAP EACH SIDE OF
 COL. & TRUSS (FIELD WELD IN PLACE)
 28'-0"
 EXHAUST
 FAN METAL ROOF
 TRUSS
 12"x12"x6" THICK CONC. FOOTING
 1/8"x1½"x1½" STEEL
 ANGLE PURLINS
 STEEL ANGLE CLIP AT
 EACH PURLIN
 1'-6" VENT OPENING. HINGE
 AT TOP—COVER W/ FILM ON
 EACH SIDE OF 2"x2" FRAME
 2'-0"
 1'-0"
 6" 2'-0" 1'-0" 6'-0"

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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

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Table 2. Average yearly heating degree days for selected locations.^(a)

LOCATION HEATING DEGREE DAYS (HDD)

day (b) + **night** (c) = **total day** (d) + **night** (e) = **total**
65°F 65°F 65°F 55°F

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 Length (ft)

50 100 150 200 250

House Tube Fan Tube Fan Tube Fan Tube Fan Tube Fan
Width Des. Cap. Des. Cap. Des. Cap. Des. Cap. Des. Cap. Des. Cap.

(ft.) (cfm) (cfm) (cfm) (cfm) (cfm) (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.

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Appendix V

CONTAINER CAPACITIES

Table 1. Number of containers filled per unit of rooting media.

**Container Containers Containers Container Containers Containers
Size per bushel per yd.3 Size per bushel 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.**

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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 "

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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 125% 125% Motor 125%

Horse- Full Full Full Full Horse- Full Full

power Load Load Load Load power Load Load

(amps) (amps) (amps) (amps) (amps) (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

(a) To obtain full load currents for 208-volt motors, 60 154.0 192.0

increase corresponding 230-volt motor load by 10%. 75 192.0 240.0

100 248.0 310.0

125 312.0 390.0

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Table 2. Starting and running requirements for commonly used 60-cycle, single-phase motors.

Approximate Watts required (a) Watts required

Motor amps to start to run

Horse- (full load) Split Cap. (full load)

power 120 V 240V phase start (b)

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)

Min. Wire Size Length of wire to motor in ft.

Load (Wire in cable 20 30 40 50 60 80 100 120 160 200 250 300 400 500

conduit or earth)

Types Types Bare or **Wire size (AWG or MCM)** (c)

R, T, RH, RHW, covered, (Note: Compare the size shown below with the size shown in the

TW THW overhead in column to the left and use the larger size.)

air (b)

5	12	12	10	12	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	12	10	10	8	8	6	4	
7	12	12	10	12	12	12	12	12	12	12	12	12	10	10	8	8	6	4	
9	12	12	10	12	12	12	12	12	12	12	12	10	10	8	8	6	4	4	
10	12	12	10	12	12	12	12	12	12	12	12	10	10	8	8	6	4	3	
12	12	12	10	12	12	12	12	12	12	12	12	10	10	8	8	6	4	3	2
14	12	12	10	12	12	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	0		
30	10	10	10	12	10	8	8	8	6	4	4	3	2	1	1	0	0	0	0
35	8	8	10	12	10	8	8	6	6	4	4	3	2	1	0	0	0	0	0
40	8	8	10	10	8	8	6	6	4	4	3	2	1	0	0	0	0	0	0
50	6	6	10	10	8	6	6	4	4	3	2	1	0	0	0	0	0	0	250
60	4	6	8	8	6	4	4	3	2	2	0	0	0	0	0	0	0	250	300
70	4	4	8	8	6	4	4	3	2	1	0	0	0	0	0	0	0	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.

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Table 4. Sizes of copper wire for single-phase, 230–240-volt motors and a 2% voltage drop. (a)

Min. Wire Size Length of wire to motor in ft.

Load (Wire in cable 20 30 40 50 60 80 100 120 160 200 250 300 400 500

(amps) conduit or earth)

Types Types Bare or **Wire size (AWG or MCM)** (c)

R, T, RH, RHW, covered, (Note: Compare the size shown below with the size shown in the

TW THW overhead in column to the left and use the larger size.)

air (b)

2	12	12	10	12	12	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	12	10
4	12	12	10	12	12	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 10 10 8 8 6
 10 12 12 10 12 12 12 12 12 12 12 10 10 8 8 6 6
 12 12 12 10 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 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.

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Table 5. Sizes of copper wire for three-phase, 230–240-volt motors and a 2% voltage drop. (a)

Min. Wire Size Length of wire to motor in ft.

Load (Wire in cable 20 30 40 50 60 80 100 120 160 200 250 300 400 500

(amps) conduit or earth)

Types Types Bare or **Wire size (AWG or MCM)** (c)

R, T, RH, RHW, covered, (Note: Compare the size shown below with the size shown in the

TW THW overhead in column to the left and use the larger size.)

air (b)

2 12 12 10 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
 4 12 12 10 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 10
 6 12 12 10 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 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 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 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 6 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 Fuse Wire Size Motor Fuse Length of Run
Size Size 50 100 150 200 Size Size 50 100 150 200
 (HP) (amps) (ft.) (HP) (amps) (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.

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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"

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Appendix IX

LIGHTING CONVERSION DATA

Table 1. Conversion from foot-candles to W/m²

(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.

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Table 2. Recommendations for supplemental greenhouse plant lighting.*

MINIMUM

LIGHTING LEVEL DAYLENGTH

PLANT SPECIES CROP STAGE 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
Cactaeae 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.

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Table 3. Lighting systems and cost comparison worksheet. (a)

**LIGHTING LIGHTING LIGHTING
SYSTEM 1 SYSTEM 2 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 LIGHTING LIGHTING
SYSTEM 1 SYSTEM 2 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 For every foot of elevation change, there will be a pressure due to Elevation change of ± 0.433 psi.

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Pounds/Sq. In. (PSI) per 100 Ft. of Pipe C = 100

Flow

GPM 1/2" 3/4"

PIPE SIZE Flow

1" 1-1/4" 1-1/2" 2" 2-1/2" 3" 4" 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							220

Note: Values below horizontal lines are at velocities over 5 ft./sec. and should be selected with caution.

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

Table 3. Friction loss in standard iron or steel pipe.

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Table 4. Friction loss in plastic pipe having standard I.D.

Pounds/Sq. In. (PSI) per 100 Ft. of Pipe C = 140

Flow

GPM 1/2" 3/4"

PIPE SIZE Flow

1" 1-1/4" 1-1/2" 2" 2-1/2" 3" 4" 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

Note: Values below horizontal lines are at velocities over 5 ft./sec. and should be selected with caution.

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**

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Table 5. Friction loss in ordinary rubber hose.

Table 6. Quantity of water available from a city service line (for a 50-ft. long service line). ^(a)

Pounds/Sq. In. (PSI) per 100 Ft. of Hose

Flow

GPM 1/2" 5/8"

HOSE SIZE Flow

3/4" 1" 1-1/4" 1-1/2" 2" 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

Size of Size of Gallons per

Service Line Meter Minute Available

(in. diameter) (in.) (gpm)

3/4 5/8 10

3/4 3/4 12 ^(a) This information is intended only as

1 3/4 18 a guide in determining the approximate

1 1/2 22 water supply available. The information is

1-1/4 1 30 based on a pressure drop of approximately
1-1/2 1 35 10 psi from the city main through the
1-1/2 1-1/2 45 service line and meter. For example, if the
2 1-1/2 60 static pressure in the city main is 60 psi,
2 2 75 then a 50-ft. service line with a 1-in. dia.
3 3 160 and a 3/4-in. meter should be capable of
delivering 18 gpm at 50 psi.

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Appendix XI

CROP STORAGE AND NIGHT TEMPERATURES

Table 1. Storage conditions for selected cut flowers, greens, and nursery stocks.^(a)

COMMODITY STORAGE TEMPERATURE APPROXIMATE METHOD OF (°F) STORAGE LIFE 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
 Tuberosa 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.

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COMMODITY STORAGE TEMPERATURE APPROXIMATE METHOD OF

(°F) STORAGE LIFE HOLDING

Cuttings

Azalea, unrooted 31–40 4–10 wks.
 Carnation, 31–33 5–6 mos.
 rooted & unrooted
 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

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Table 2. Standard night temperatures at which greenhouse crops are grown.

CROP SPECIES NIGHT TEMPERATURES REMARKS

(°F)

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 Vegetative growth,
50 flower initiation and
development; initiation also
occurs with long days and
high temperatures if radiant
flux is high

Calendula

C. officinalis 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) Temperatures during flower
initiation especially
62–63 (pot plants) critical; uniform initiation
very important for pot mums;
cultivars classified on basis
of temperature development

Cineraria

Senecio cruentus 60 Vegetative growth
48–50 Flower initiation and
development; plant
quality best at low
temperatures

Crossandra

C. infundibuliformis 75–80 Germination
65 Growth and flowering

Cyclamen

C. indicum 60–65 Germination
55 Seedlings

50–52 Growth and flowering

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CROP SPECIES NIGHT TEMPERATURES REMARKS

(°F)

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

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CROP SPECIES NIGHT TEMPERATURES REMARKS

(°F)

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.

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Appendix XII—Worksheets

WORKSHEET NO. 1—GREENHOUSE FACILITY PLANNING

General Specifications

Cropping System:

Bedding plants

Pot plants

Cut flowers

Woody ornamentals

Vegetables

Other

Production Unit:

Pots

Flats

Blooms

Other

Growing Media:

Soil, site mixed

Soil, purchased

Hydroponic

Marketing Period:

All year

Seasonal From to .

Growing Period:

All year
Part year

Growing System:

Floor
Fixed benches
Moving benches
Other

Annual Production:

Pots
Flats
Blooms
Other

Marketing System:

Wholesale only
Wholesale/retail
Retail only
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

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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 Ancillary Areas:

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SAMPLE WORKSHEET NO. 1—GREENHOUSE FACILITY PLANNING

General specifications

Cropping System:

Bedding plants X

Pot plants

Cut flowers

Woody ornamentals

Vegetables

Other

Production Unit:

Pots

Flats X

Blooms

Other

Growing Media:

Soil, site mixed X

Soil, purchased

Hydroponic

Marketing Period:

All year

Seasonal From to .

Growing Period:

All year

Part year X

Growing System

Floor X

Fixed benches

Moving benches

Other

Annual Production:

Pots

Flats 40,000

Blooms

Other

Marketing System:

Wholesale only

Wholesale/retail X

Retail only

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

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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 Ancillary Areas: 6,620

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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 = $A \div B$ containers/day

E. Hourly output required = $D \div C$ containers/hours

F. Volume of media required = $A \div$ containers filled/cu. yd.

(see Appendix V and VI) yd.³

G. Storage floor area required for media = $(F \times 27) \div$ depth of media (ft.)

ft.²

H. Volume of media required/day = $F \div B$ yd.³/day

I. Labor hours required to fill containers = $A \div$ containers/labor hour

(see Appendix VI) hours

J. Hours per day filling containers = $I \div B$ hours/day

K. Volume of media handled/hour = $H \div J$ yd.³/hour

L. No. of tractor-trailer units required

Equipment Required₁ Work Crew₂

¹ Does not include seeders, transplanters, waterers.

² Work crew to operate equipment listed.

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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 = $A \div B$ (10,000 \div 40) 250 flats/day containers/day

E. Hourly output required = $D \div C$ (25 \div 7) 36 flats/hr containers/hours

F. Volume of media required = $A \div$ containers filled/cu. yd.

(10,000 \div 95) 105 yd.³

(see Appendix V and VI, 13" x 15" flat, 95 filled/yd.³)

G. Storage floor area required for media = $(F \times 27) \div$ depth of media (ft.)

(105 x 27) \div 6 [assume media depth is 6ft.] 473 ft.²

H. Volume of media required/day = $F \div B$

(105 \div 40) 2.6 yd.³/day

I. Labor hours required to fill containers = $A \div$ containers/labor hour

(10,000 \div 60) 167 hours

(see Appendix VI, hand filling \approx 60 flats/hour)

J. Hours per day filling containers = $I \div B$ (167 \div 40) 4.2 hours/day

K. Volume of media handled/hour = $H \div J$ (2.6 \div 4.2) 0.62 yd.³/hour

L. No. of tractor-trailer units required none

Equipment Required¹ Work Crew²

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.

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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 500,000 (1 gal. cans) containers/season

B. Length of production season 50 days/season

C. Work hours/day 7 hours/day

D. Daily output required = $A \div B$ (500,000 \div 50) 10,000 cans containers/day

E. Hourly output required = $D \div C$ (10,000 \div 7) 1,429 containers/hours

F. Volume of media required = $A \div$ containers filled/cu. yd.

(500,000 \div 252) 1,985 yd.³

(see Appendix V, 252 one gal cans/yd.³)

G. Storage floor area required for media = $(F \times 27) \div$ depth of media (ft.)

(1,985 \times 27) \div 6 [assume media depth is 6ft.] 8,932 ft.²

H. Volume of media required/day = $F \div B$ (1,985 \div 50) 40 yd.³/day

I. Labor hours required to fill containers = $A \div$ containers/labor hour

(500,000 \div 1,429) 350 hours

J. Hours per day filling containers = $I \div B$ (350 \div 50) 7 hours/day

K. Volume of media handled/hour = $H \div J$ (40 \div 7) 5.7 yd.³/hour

L. No. of tractor-trailer units required 2

Equipment Required¹ Work Crew²

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.

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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 Original cost – Salvage value \$

Estimated life (years)

Interest on Original cost + Salvage value x Interest Rate \$

Investment 2

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 Estimated total lifetime cost \$

(parts & labor) 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

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SAMPLE WORKSHEET NO. 3—CALCULATING MACHINERY COSTS

Machine Flat/pot filling machine w/ supply hopper and belt conveyor. A bucket loader is already owned.

Original cost \$12,000

Estimated useful life 10 years

Estimated hours of use per year 15 flats/minute x 60 minutes/hour = 900 flats/hour

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) \$2,000

Fixed Cost Annual Cost

Depreciation $12,000 - 2,000 \div 10 = \$1,000.00$

10

Interest on $12,000 + 2,000 \times .08 = \560.00

Investment 2

Taxes $12,000 \times 0.03 = \$360.00$

Insurance \$ 30.00

Shelter \$ 20.00

Total Fixed Cost \$ 1,970.00

Variable Cost Annual Cost

Electricity $3.5 \text{ KW} (\$0.10) \times 28 \text{ hours} = \10.00

Repair cost 5.5% of 12,000 \$ 660.00

(parts & labor)

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

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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 Investment 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

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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 = Inside night temperature – minimum

outside temperature

Lower wall area $\times U_1 \times \Delta T =$

Upper wall area $\times U_2 \times \Delta T =$

Single wall area $\times U_3 \times \Delta T =$

Gable or curved end area \times

$U_4 \times \Delta T =$

Roof area $\times U_5 \times \Delta T =$

Perimeter length $\times U_6 \times \Delta T =$

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 .

$h_t = h_c + h_{inf} =$

H

B

C

D

H

A

B

C

D

A

B

C

D

E

F

G

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WORKSHEET NO. 4—EXAMPLE

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:

$$2N(E \times B) + (E \times 2C) = (2)(4) [(1.5)(24) + (1.5)(2)(192)] \\ = 864 \text{ ft.}^2$$

Upper wall area:

$$2N(F \times B) + (F \times 2C) = (2)(4) [(6.5)(24) + (6.5)(2)(192)] \\ = 3,744 \text{ ft.}^2$$

Single material wall:

$$2N(A \times B) + (A \times 2C) =$$

Gable area:

$$N \times B \times G = (4)(24)(6) = 576 \text{ ft.}^2$$

Curved end area:

$$1.3N \times B \times H =$$

Gable roof area:

$$2N \times D \times C = (2)(4)(13.4)(192) = 20,582 \text{ ft.}^2$$

Curved roof area:

$$N \times D \times C =$$

Perimeter:

$$2 [(N \times B) + C] = 2 [(4)(24) + 192] = 576 \text{ ft.}$$

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 .

$$h_c = \text{Area} \times U \times \Delta T$$

$\Delta T =$ Inside night temperature – minimum
outside temperature

$$\text{Lower wall area} \times U_1 \times \Delta T = 864(0.75)(60) = 38,880$$

$$\text{Upper wall area} \times U_2 \times \Delta T = 3,744(1.1)(60) = 247,104$$

$$\text{Single wall area} \times U_3 \times \Delta T =$$

$$\text{Gable or curved end area} \times$$

$$U_4 \times \Delta T = 576(1.1)(60) = 38,016$$

$$\text{Roof area} \times U_5 \times \Delta T = 20,582(1.1)(60) = 1,358,412$$

$$\text{Perimeter length} \times U_6 \times \Delta T = 576(0.8)(60) = 27,648$$

$$\text{Total } h_c = 1,710,060 \text{ Btu/hr.}$$

Step 5. Calculate greenhouse volume.

Gable house volume:

$$N [(A \times B \times C) + (B \times G \times C/2)] =$$

$$4 [(8)(24)(192) + 24(6)(192)(\frac{1}{2})] = 202,752 \text{ cu.ft.}$$

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} .

$$h_{inf} = 0.02 \times \Delta T \times \text{Volume} \times \text{Air changes/hour}$$

(Table 4–5, page 66)

$$= 0.02(60)(202,752)(1) = 243,300 \text{ Btu/hr.}$$

Step 7. Calculate total heat loss, h_t .

$$h_t = h_c + h_{inf} = 1,710,060 + 243,300$$

$$= 1,953,360 \text{ Btu/hr.}$$

A

B

C

D

E

F

G

$$N = 4$$

$$\Delta T = 60^\circ\text{F}$$

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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:

$$A \times B = \text{ft.}^2$$

Step 3. Calculate air flow required for each house:

(Use 8 cfm/ft.² of ground area)

$$A \times B \times 8 \text{ cfm/ft.}^2 = \text{cfm of installed capacity}$$

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 \approx 250 fpm through vents.

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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:

$A \times B = 18,432 \text{ ft.}^2$

Step 3. Calculate air flow required for each house:

(Use 8 cfm/ft.² of ground area)

$A \times B \times 8 \text{ cfm/ft.}^2 = 147,456 \text{ cfm}$ 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 \approx 250 fpm through vents.

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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.

$$\text{cfm}/250 = \text{ft.}^2$$

$$\text{cfm}/150 = \text{ft.}^2$$

Step 2. Calculate pad height to extend full length of one wall:

$$\text{ft.}^2 / \text{ft.} = \text{ft. of pad height}$$

Step 3. Calculate water flow rate and pump size:

$$\text{ft.} \times 0.5 \text{ gpm/linear ft. of pad} = \text{gpm}$$

Step 4. Calculate pump size:

$$\text{ft.}^2 \text{ of pad} \times 0.75 \text{ gal./ft.}^2 = \text{gal.}$$

For a system in which pad-to-fan distance is less than 100 ft., increase installed fan capacity

by the factor $F = 10 / D$, where D is the pad-to-fan distance.

D

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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.

$$151,200 \text{ cfm}/250 = 605 \text{ ft.}^2$$

$$\text{cfm}/150 = \text{ft.}^2$$

Step 2. Calculate pad height to extend full length of one wall:

$$605 \text{ ft.}^2 / 192 \text{ ft.} = 3.2 \text{ ft. of pad height}$$

(use 3.0 ft.)

Step 3. Calculate water flow rate and pump size:

$$192 \text{ ft.} \times 0.5 \text{ gpm/linear ft. of pad} = 96 \text{ gpm}$$

Step 4. Calculate pump size:

$$576 \text{ ft.}^2 \text{ of pad} \times 0.75 \text{ gal./ft.}^2 = 432 \text{ gal.}$$

For a system in which pad-to-fan distance is less than 100 ft., increase installed fan capacity

by the factor $F = 10 \sqrt{\frac{D}{100}}$, where D is the pad-to-fan distance.

D

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WORKSHEET NO. 7—AERATED STEAM HEATING SYSTEM

Type of container: No. filled/ft.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

$\Delta t^{\circ}\text{F}$ = Btu

Heat required for moisture = lbs. water x $\Delta t^{\circ}\text{F}$ = 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:

$h = \text{Btu} = \text{Btu/min}$

30 min x % eff

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Air flow required to supply the heat:

$M = \text{Btu/min} = \text{ft.}^3 \text{ of air/min}$

Btu/ft.³ of air

Steam required to heat and saturate the air:

$w = \text{ft.}^3/\text{min} \times \text{lb. of steam/ft.}^3 \text{ or air}$

= lbs. of steam/min.

Boiler capacity to supply the steam:

$N = \text{lb. of steam/min} = \text{lb./min, lb./hr.}$

% efficiency

Heat bin area for 24 in. maximum depth:

$A = \text{ft.}^2/\text{hr} = \text{ft.}^2$

2 ft.

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)

3

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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: $\text{ft.}^3/\text{hr}$ 81 $\text{ft.}^3/\text{day}$ 648

Media Specifications

Dry weight: 33 $\text{lb.}/\text{ft.}^3$

Moisture content: 40 %, dry weight basis

Specific heat: 0.27 $\text{Btu}/\text{lb.}\cdot^\circ\text{F}$

Media depth in heating chamber: 24 inches

Media depth in cooling chamber: 24 inches

System Specifications

Heating temperature: 160 $^\circ\text{F}$

Media temperature at start 60 $^\circ\text{F}$

Air temperature, average 60 $^\circ\text{F}$

Boiler to blower efficiency 90 %

Blower to media efficiency 50 %

Heat available from saturated air 25.7 $\text{Btu}/\text{ft.}^3$ air (See Table 6–9, p.123)

Steam required to heat and saturate 70 $^\circ\text{F}$ air 0.0225 $\text{lb.}/\text{ft.}^3$ air (See Table 6–9)

System Calculations

Wt. of dry media = 81 $\text{ft.}^3 \times 33 \text{ lb.}/\text{ft.}^3 = 2,673 \text{ lbs. media}$

Wt. of water in media = 2,673 lbs. media \times 0.4 % moisture content =
1,069 lbs. water

Heat required for dry media = 2,673 lbs. media \times 0.27 $\text{Btu}/\text{lb.}\cdot^\circ\text{F} \times$
100 $\Delta t^\circ\text{F} = 72,171 \text{ Btu}$

Heat required for moisture = 1,069 lbs. water \times 100 $\Delta t^\circ\text{F} = 106,900 \text{ Btu}$

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:

$h = 179,071 \text{ Btu} = 11,938 \text{ Btu}/\text{min}$

30 min \times .5 blower eff

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Air flow required to supply the heat:

$M = 11,938 \text{ Btu}/\text{min} = 464 \text{ ft.}^3 \text{ of air}/\text{min}$

25.7 Btu/ft.³ of air

Steam required to heat and saturate the air:

$$w = 464 \text{ ft.}^3/\text{min} \times 0.0225 \text{ lb. of steam/ft.}^3 \text{ of air} \\ = 10.44 \text{ lbs. of steam/min.}$$

Boiler capacity to supply the steam:

$$N = 10.44 \text{ lb. of steam/min} = 11.6 \text{ lb./min, } 696 \text{ lb./hr.}$$

0.9 boiler efficiency

Heat bin area for 24 in. maximum depth:

$$A = 81 \text{ ft.}^2/\text{hr} = 40.5 \text{ ft.}^2$$

2 ft.

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)

3

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Appendix XIII

USEFUL CONVERSIONS

Type of

Measurement To convert: Into: Multiply by:

feet inches 12

Length yards inches 36

rods feet 16.5

miles feet 5,280

miles yards 1,760

millimeters inches 0.04

microns millimeters 0.001

square feet square inches 144

Area 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

ounces grams 28.3495

Mass Weight 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

cubic feet cubic inches 1,728

Volume 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

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[Useful Conversions continued]

Type of

Measurement To convert: Into: Multiply by:

ounces milliliters 29.59

Liquid Volume (cubic centimeters)

pints liters 0.4732

quarts liters 0.9463

gallons liters 3.785

milliliters ounces 0.0338

(cubic centimeters)

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:

$$(68^{\circ}\text{F} - 32) \times .55 = 20^{\circ}\text{C}.$$

To convert Celcius to Fahrenheit: Multiply by 1.8 ($\approx 9/5$) and add 32, thus:

$$(60^{\circ}\text{C} \times 1.8) + 32 = 140^{\circ}\text{F}.$$

$$\text{Formulas: } (^{\circ}\text{F} - 32) \times (5/9) = ^{\circ}\text{C}$$

$$(^{\circ}\text{C} \times (9/5)) + 32 = ^{\circ}\text{F}$$

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