GREENHOUSE OPERATION AND MANAGEMENT

Unit II: Growing Structures

Lesson 1: Greenhouse Parts, Structures, and Coverings

Objective/Competency:

Distinguish types of greenhouses by materials, structure, and layout.

Study Questions

1. **What are the primary considerations in selecting a site for a greenhouse operation?**
2. **What are different types of greenhouse structures?**
3. **What is the basic construction of a growing structure?**
4. **What are the interior parts of a greenhouse?**
5. **What other structures and areas are part of most commercial greenhouse operations?**
6. **What are some considerations for the interior layout of buildings and work areas?**

References/Supplies/Materials

1. *Greenhouse Operation and Management* (Student Reference). University of Missouri-Columbia: Instructional Materials Laboratory, 2002.

2. Transparency Masters

   TM 2.1 Frame Types
   TM 2.2 Ridge and Furrow Construction
   TM 2.3 Lean-To Greenhouse
   TM 2.4 Parts of a Greenhouse
   TM 2.5 Interior Layout of a Greenhouse
   TM 2.6 Other Outdoor Growing Structures

3. Activity Sheet

   AS 2.1 Plan Your Own: Part I

4. A current copy of Hummert's Horticultural Supply Catalog

5. Stuppy Greenhouse Manufacturing Inc. <http://www.stuppy.com/stuppy_site_map.html>

TEACHING PROCEDURES

A. Introduction

This unit involves the growing structure, environmental controls, and energy conservation and environmental protection. Lesson 1 describes the physical aspect of the greenhouse itself: what the building looks like, what materials are used, and what the floor plan is. The greenhouse owner must resolve how climate, topography, resources, zoning, and economics affect the growing structure before building can occur.

B. Motivation

Have the students discuss both the environmental and human factors that influence a greenhouse operation. How or why would the selection of the site be important? Why is the availability of resources such as roads, water, and labor a vital consideration?

C. Assignment of Study Questions

Encourage students to keep the activity sheets for Lessons1-3 as a reference for the Unit II Activity.

D. Supervised Study

Lead students in collecting the information needed to answer and discuss the study questions. The instructor may choose to work on one study question at a time or have students answer all the questions before the discussion. Another option is to have students work in cooperative learning environment and have groups work on different study questions.

E. Discussion

Lead students in a discussion of the study questions. Supplement students' responses and information with additional materials when needed.

1. What are the primary considerations in selecting a site for a greenhouse operation?

A profitable greenhouse operation does not just plop down on an empty spot of land. There are many environmental and human-related factors to consider: climate, topography, accessibility to resources, marketing, and zoning.

A. Climate
   1. Desirable locations
      a. High, natural light levels
      b. Moderate climate
   2. Locations that could increase energy and maintenance costs
      a. Very cold locations

   b. Locations with very high temperatures and humidity
   c. High elevations (wind)
   d. Valleys (frost)

B. Topography
   1. Location of the greenhouse
      a. Optimal site is where the greenhouse receives the most morning sunlight, thereby promoting the plant food production process (photosynthesis).
      b. Specific location depends on geography. For example, in Maryland, the best site for a greenhouse is toward the south or southeast; the next best option is toward the southwest.
      c. In Missouri, the ridge of the greenhouse should run north and south to permit the light to enter from a sidewall, not an endwall. Winter light is maximized and shadows are reduced.
      d. For states whose latitude is 40^{o} north or above, an east-west direction is best.
   2. Surface
      a. Level
      b. Able to provide good drainage
   3. Creation of windbreak to shelter structure from winter wind
   4. Prevention of obstacles in front of greenhouse
      a. Should be clear of large trees or structures
      b. May shade the greenhouse

C. Availability of resources
   1. Water
      a. Ample supply
      b. High quality
   2. Utilities (e.g., electricity, natural gas)
   3. Materials (e.g., soils, fertilizers, pesticides)
   4. Labor for regular operation and during harvest
   5. Services (e.g., waste removal services)

D. Land considerations
   1. Costs (e.g., purchase price, taxes)
   2. Proximity to roads and utilities
   3. Neighbors and how they may be affected by the operation
   4. Expansion potential

E. Marketing considerations
   1. Proximity to markets
   2. Competition

F. Legal considerations
   1. Permits and licenses
   2. Zoning regulations

2. What are different types of greenhouse structures?

The three styles of growing structures are freestanding, connected, and attached. Freestanding greenhouses come in five frame styles. Connected is a string of greenhouses sharing a roof. Attached greenhouses share a wall with another building.

A. Freestanding (detached) structures
   1. Frame styles (TM 2.1)
      a. Even span (gabled)
      b. Uneven span (placed on hillside/southern exposure)
      c. Gothic arch
      d. Quonset
      e. A-frame
   2. Advantages:
      a. Easy to maintain (e.g., snow removal from roof)
      b. Uniform light (minimal shadows)
   3. Disadvantages:
      a. More costly to construct (more sidewalls)
      b. Occupy more space (several freestanding structures vs. single connected structure)
      c. Less efficient (more surface exposed to elements)

B. Connected structures (TM 2.2)
   1. Framing styles similar to freestanding structures; connected by a common roof
   2. Advantages:
      a. Occupies less land
      b. Greater spans of interior space
      c. Less energy required to heat and cool
   3. Disadvantages:
      a. Gutters collect snow.
      b. Gutters create shadows.

C. Lean-to structures (attached) (TM 2.3)
   1. Attaches to common wall of an existing building (facing east or south)
   2. Advantages:
      a. Lower construction cost
      b. Heat from adjacent building
   3. Disadvantages:
      a. Limited space
      b. Less roof support

D. Innovative European energy-efficient growing structures
   1. "Venlo greenhouse" from the Netherlands - galvanized steel superstructure
      a. Gable roof
      b. Self-supporting glazing bar system
         i. Bars opposite each other - less materials needed, more available light
         ii. Rust free, no maintenance, lasts for years
         iii. Strong and stable
      c. Polycarbonate sidewalls and endwalls
         i. Provide thermal insulation
         ii. Regulate temperature
      d. High-light glass glazing
         i. Transmits light very well
         ii. Promotes high-quality growing environment for crops
      e. Roof vents

i. Controlled thermostatically or by computer
ii. Cut energy costs by using natural ventilation

2. "Rovero" greenhouse from the Netherlands
   a. Retractable roof
   b. Roof's positions
      i. Closed
      ii. Half closed
      iii. Open
   c. Roof covering - clear or diffused polyethylene
   d. Sidewall and endwall
      i. Motorized
      ii. 8-mm-polycarbonate roll-up curtain
   e. Greenhouse environment - fully computer controlled
3. Field-scale and conventional tunnel greenhouses; originally developed in France (single span) and Spain (multispan)
4. Cantilevered roof vent units (from "National Polytunnels," Lancashire, England)
   a. Positioned on top of each roof span
   b. Winch mechanism able to open five vents in a row
5. Folding roof - folds back into gutter
   a. "Max Air" model from National Polytunnels
   b. Model from Polybuild (Surrey, England, and Dutch company HCT)

3. What is the basic construction of a growing structure?

The greenhouse structure is composed of two basic parts: the frame and the covering. Construction options are limited and must be considered not only in terms of cost but also durability, reliability, frequency of repair or replacement, and adaptability to expansion.

A. Greenhouse framing
   1. Framing considerations
      a. Cost (construction and maintenance)
      b. Strength
      c. Choice of covering material
      d. Amount of light blocked
   2. Framing materials
      a. Wood
         i. Must be decay resistant (e.g., redwood or other wood treated with waterborne, salt-type preservatives that are safe for plants)
         ii. Must NOT be treated with chemicals that emit fumes toxic to plants (e.g., creosote)
         iii. Can be painted with light-reflecting, white, water-based paint for further protection
      b. Aluminum alloy
         i. Flexible
         ii. Durable
         iii. Affordable

c. Steel or iron

B. Greenhouse covering
1. Considerations
a. Style of greenhouse
b. Durability (ability to withstand snow, wind, and extreme temperatures)
c. Cost (construction and maintenance)
d. Type of framing required for support
e. Availability of materials
f. Interior environment created
i. Heat retention
ii. Light penetration
iii. Light diffusion
iv. Condensation potential
v. Static electricity charge
2. Types of covering materials
a. Glass
i. Usually heavy, tempered glass
ii. Advantages:
(a) Strong
(b) Inexpensive to maintain
(c) Excellent light transmission
(d) Long lasting
iii. Disadvantages: requires a heavier, more costly framing structure, breakable
b. Polyethylene (PE) film
i. Advantages:
(a) Lightweight
(b) Flexible
(c) Easy to install
(d) Can be supported by a lightweight frame
(e) Transmits light as well as glass
ii. Disadvantages:
(a) Susceptible to weather damage
(b) Needs repeated rinsing to get rid of dust
(c) Must be replaced every 2-4 years
c. Rigid panels
i. Common materials
(a) Polycarbonate - examples: Lexan, Verolite (double walled and similar to Lexan), Dyan-Glas, and Green-Lite
(b) Fiber-reinforced polyester (FRP) (fiberglass) - flammable (requires fire insurance)
(c) Polymethyl methacrylate (PMMA) acrylic
ii. Advantages:
(a) Lightweight
(b) Sturdier than film,
(c) Durable (replace 10-20 years)
iii. Disadvantage: can be damaged by elements over time

4. What are the interior parts of a greenhouse?

A key concern in the layout of a greenhouse is the type of market it serves. Is this operation wholesale or retail? This answer impacts the decision of bench layout, bench construction, and flooring. Encourage students to discuss why this is true.

A. Interior layout
   1. Type of layout depends primarily on greenhouse purpose
      a. Wholesale
      b. Retail
   2. Aisles - wide enough to accommodate equipment and people
   3. Common layout designs (TM 2.5)
      a. Lengthwise benching
      b. Crosswise benching
      c. Peninsular benching

B. Flooring
   1. Considerations
      a. Must be able to accommodate equipment and work flow
      b. Must include proper drainage
      c. Bare ground not acceptable
         i. Risk of pathogens
         ii. Difficult to provide proper drainage
   2. Materials
      a. Concrete
         i. Include drain basins
         ii. Slope toward drains
      b. Gravel
         i. Weed mat covered with gravel
         ii. Porous enough to allow water to drain

C. Benches
   1. Considerations
      a. Retail or wholesale
      b. Sturdy enough to hold plants
      c. Provide air movement and water drainage
   2. Types
      a. Fixed
      b. Moveable
         i. Can be moved outdoors
         ii. Used for double-crop production (one crop on floor, second bench moved outdoors)
      c. Rolling
         i. Maximizes use of floor space
         ii. Uses less aisle space
         iii. For wholesale use only
   3. Materials
      a. Wood

b. Concrete
c. Metal
d. Plastic

5. What other structures and areas are part of most commercial greenhouse operations?

A greenhouse does not exist alone as a growing environment. Coldframes, hotbeds, and lath houses are additional ways to grow crops in a managed setting. The three use a combination of structure and nature. Other areas that may be a part of a greenhouse operation include offices, rest rooms, and loading zones. If the operation is retail, there are parking lots and display areas.

A. Other growing structures
   1. Coldframes
      a. Outdoor growing structure with transparent covering
      b. Heated only by the sun
      c. Top opened during the day, closed at night
      d. Used to harden and protect plants from frost; winter storage of bulbs
   2. Hotbeds
      a. Outdoor growing structure with transparent covering
      b. Heated by steam, hot water, or electricity
      c. Used to start seedlings and cuttings
   3. Lath houses
      a. Outdoor growing structures covered with lath or shade fabric supported by vertical poles
      b. Reduce light intensity
      c. Used in summer in temperature climates or year-round in warm climates

B. Additional areas
   1. Work spaces (e.g., soil mixing and propagation areas)
   2. Storage areas
   3. Roadways
   4. Loading and shipping areas
   5. Parking areas
   6. Display areas
   7. Offices
   8. Break room/kitchen area
   9. Rest rooms

6. What are some considerations for the interior layout of buildings and work areas?

The orientation of the greenhouses and the other buildings is essential to an efficient greenhouse operation. AS 2.1 instructs students how to design a layout of a greenhouse operation using the information contained in this lesson.

A. Wholesale or retail operations have different types of work areas.
B. Generally, a good layout provides the following:
   1. Efficient work flow (does not interfere with customer visits)

2. Efficient labor practices
3. Maximum use of space
4. Minimal impact on the environment (e.g., water runoff, pollution)
5. Optimal orientation for greenhouses (e.g., south or southeast)
6. Expansion possibilities
7. Regulatory compliance

F. Other Activity and Strategy

Invite a commercial builder to discuss the practical details of building a greenhouse. Ask this individual to bring samples of exterior coverings. Ask how greenhouses are priced. What are the advantages of pre-engineered packages versus entirely new construction? Is it better to plan expansions and equipment upgrades before construction begins on the initial building?

G. Conclusion

A greenhouse is a complex system. Although it is a protected environment for growing plants, the greenhouse is influenced by the climate and topography around it. The shape, framing, and covering materials are dictated by cost, durability, and type of operation.

H. Answers to Activity Sheet

Instructor's discretion

I. Answers to Assessment

1. C
2. D
3. D
4. A. Must be able to accommodate equipment and work flow
   B. Must include proper drainage
   C. Bare ground not acceptable
5. A. Coldframes
   B. Hotbeds
   C. Lath houses
6. The student may list any one of the following advantages
   A. Excellent light transmission
   B. Long lasting
   The student may list any one of the following disadvantages
   A. Breakable
   B. Requires a heavier frame structure
7. The student may list any one of the following advantages
   A. Lightweight material
   B. Sturdier than film
   C. Durable
   The student may list any one of the following disadvantages

   A. Can be damaged by the elements
   B. Must be replaced frequently
8. D
9. B
10. C
11. E
12. A

UNIT II: GROWING STRUCTURES Name_____

Lesson 1: Greenhouse Parts, Structures, and Coverings Date_____

ASSESSMENT

Multiple Choice: Circle the letter of the best answer.

1. What are the basic parts of the greenhouse structure?

   A. Frame and layout
   B. Covering and ventilation
   C. Frame and covering
   D. Flooring and covering

2. What are three interior parts of a greenhouse?

   A. Display area, flooring, and layout
   B. Benches, layout, and loading area
   C. Flooring, Quonset, and benches
   D. Layout, benches, and flooring

3. What is the correct direction of the ridges in a greenhouse built in Missouri that allows light to enter from the sidewalls?

   A. East and west
   B. North northeast
   C. South and southwest
   D. North and south

Short-Answer Questions: Write the answers in the space provided.

4. What are three major considerations in determining the layout of flooring in a greenhouse?

   A.

   B.

   C.

5. What are three other types of growing structures?

   A.

   B.

   C.

6. What is an advantage and disadvantage of glass as a covering material?

   Advantage Disadvantage

7. What is one advantage and one disadvantage of polycarbonate as a covering material?

   Advantage Disadvantage

Matching. The terms on the left refer to freestanding frame styles, which are pictured on the right side. Write the correct letter in the space provided.

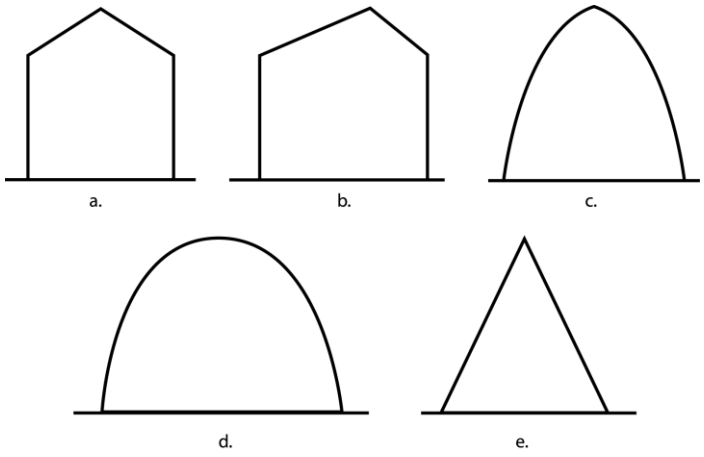
_____8. Quonset

_____9. Uneven span

_____10. Gothic arch

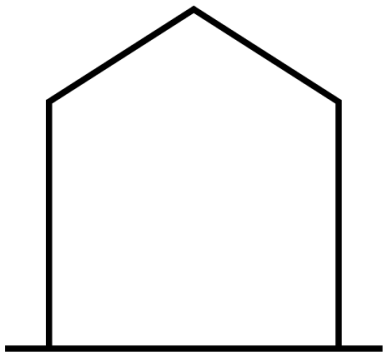
_____11. A-frame

_____12. Even span

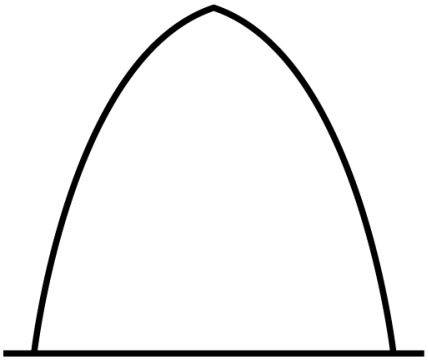


TM 2.1

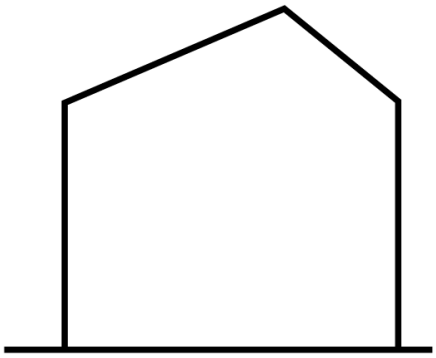
Frame Types



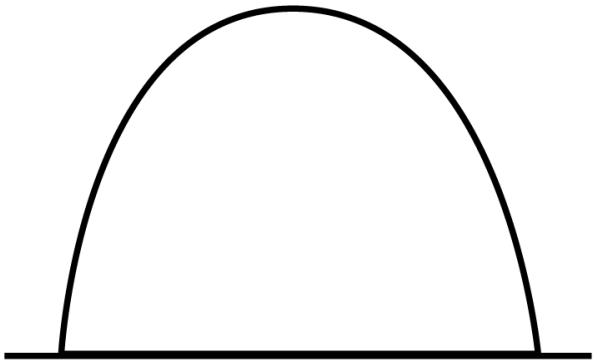
Even Span



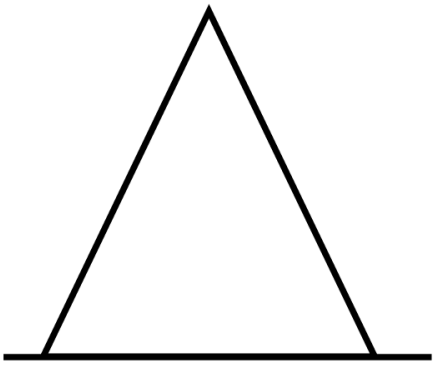
Gothic



Uneven Span



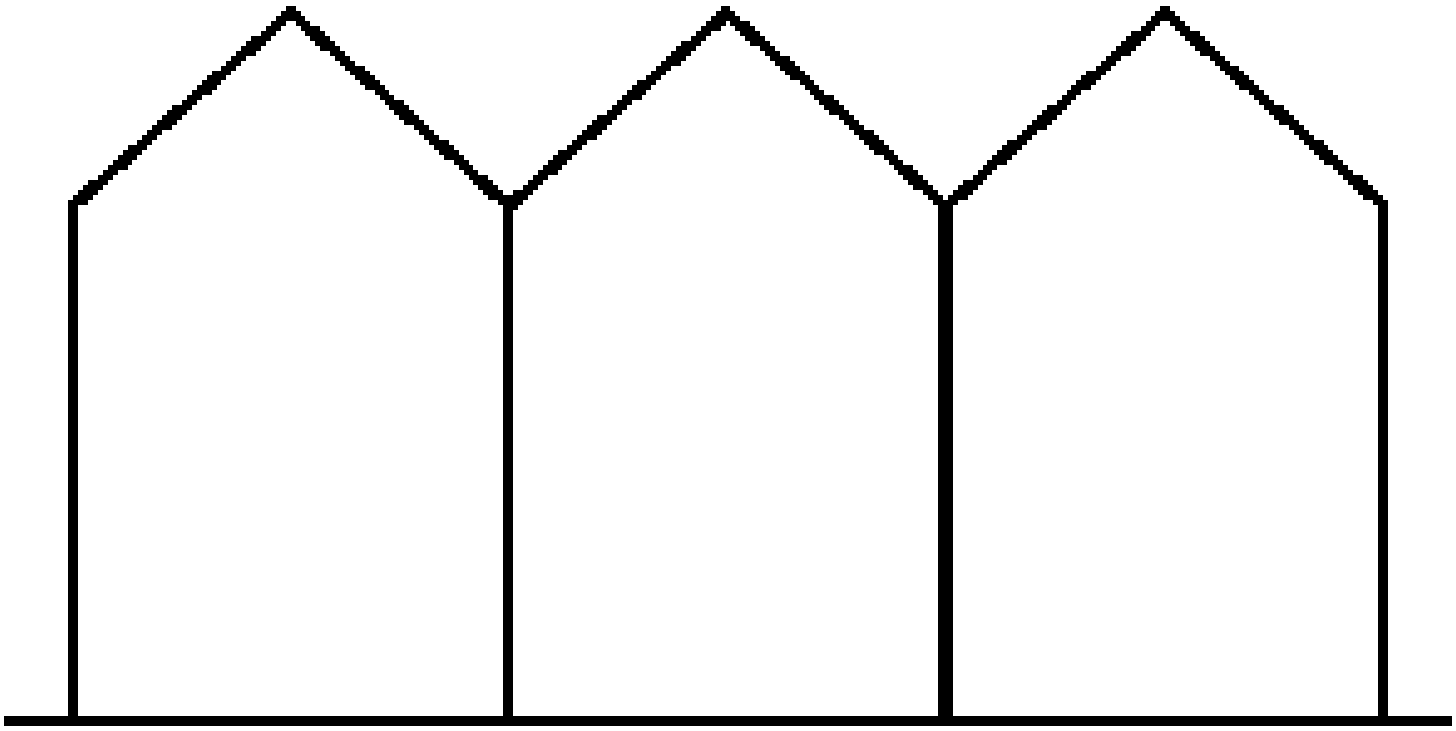
Quonset



A-Frame

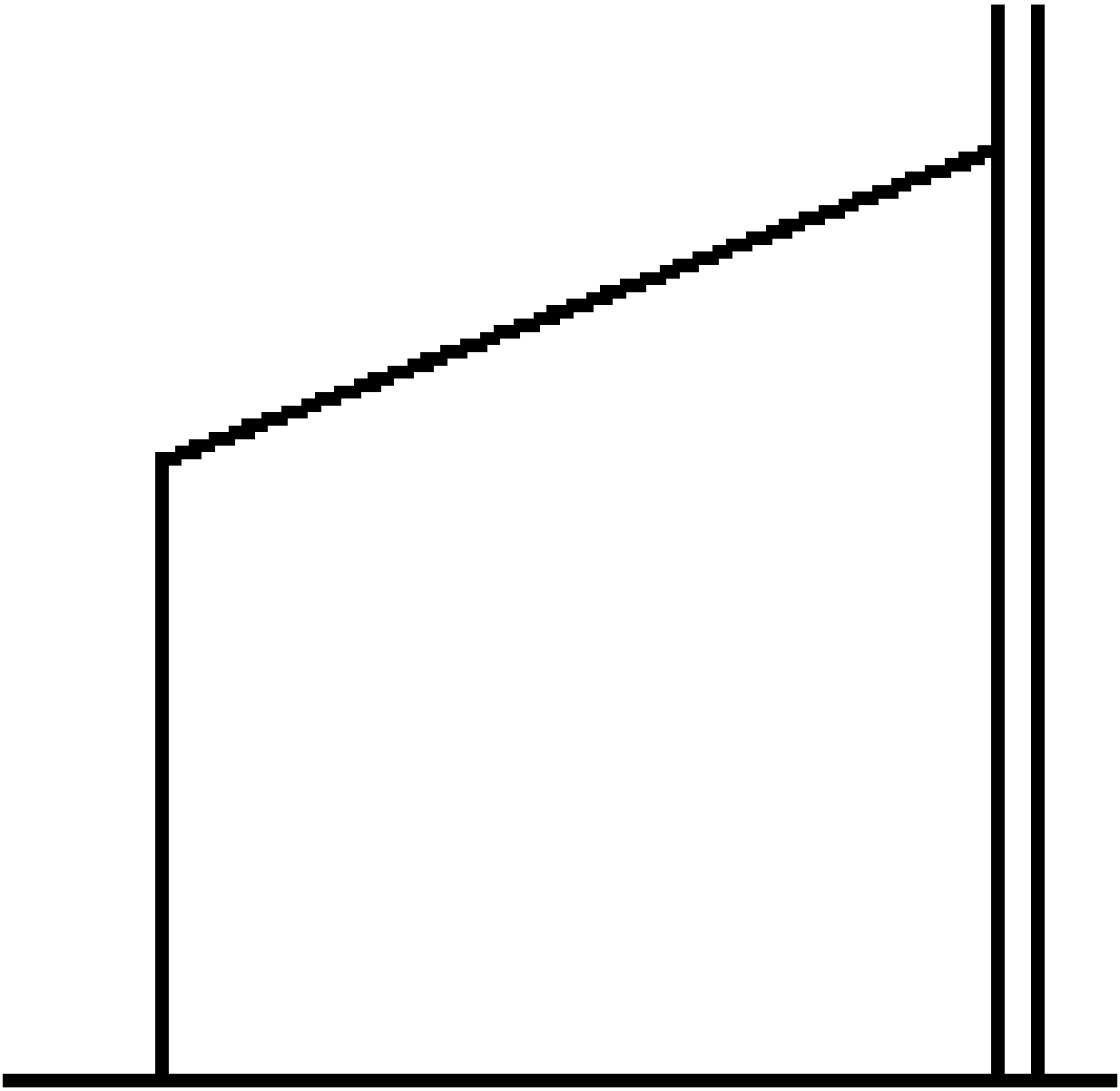
TM 2.2

Ridge and Furrow Construction



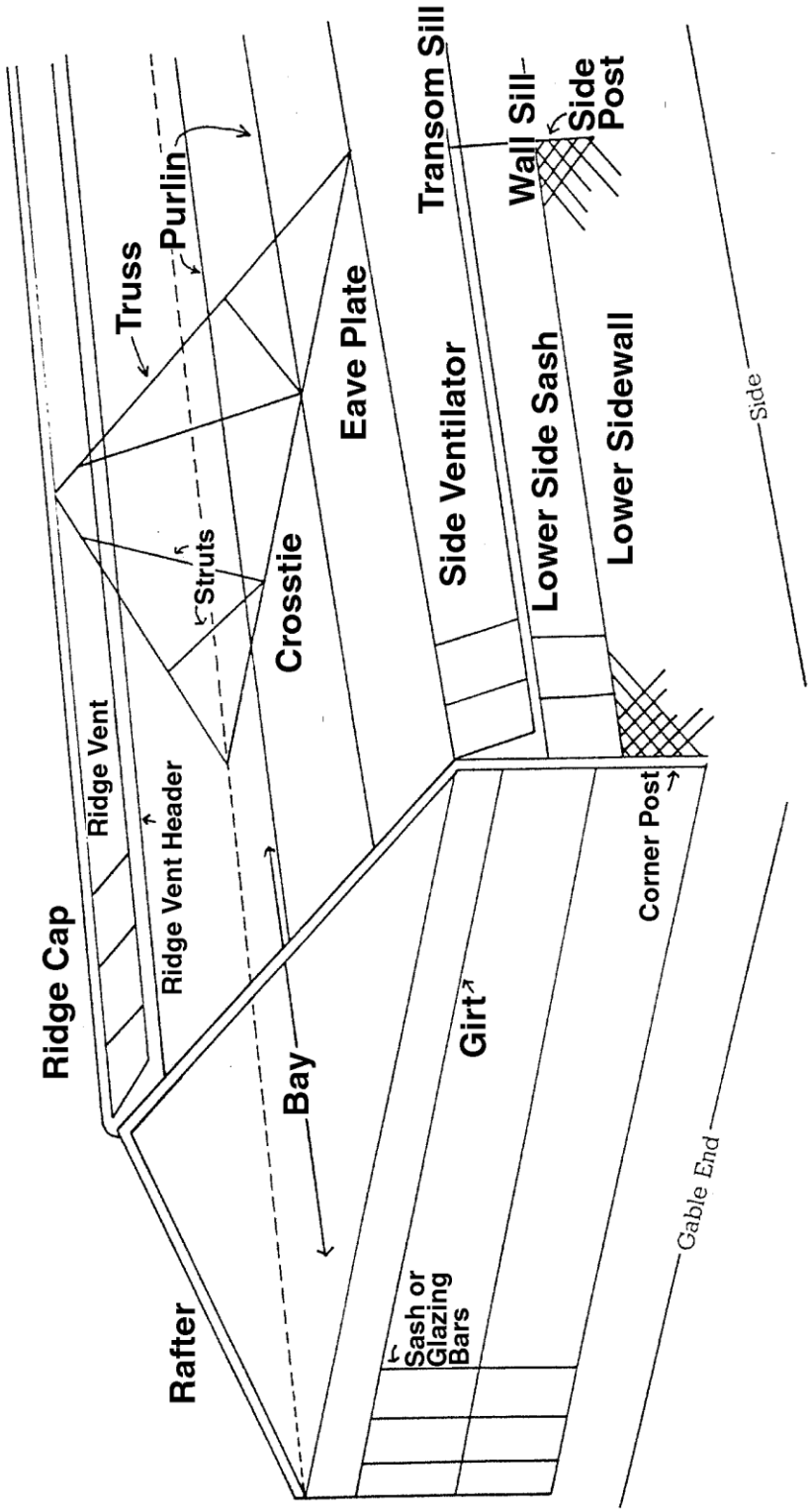
TM 2.3

Lean-To Greenhouse



TM 2.4

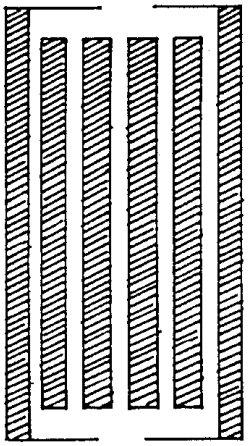
Parts of a Greenhouse



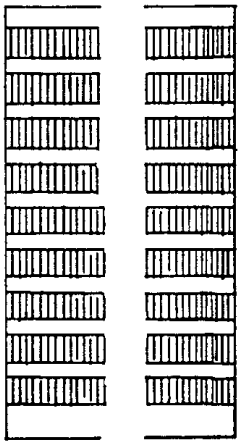
TM 2.5

Interior Layout of a Greenhouse

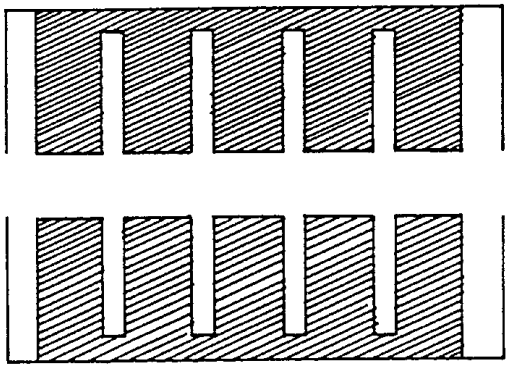
Lengthwise Benching (Longitudinal)



Crosswise Benching (Island)

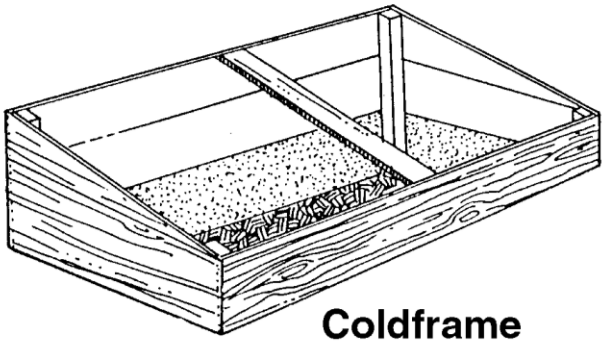


Peninsular Benching

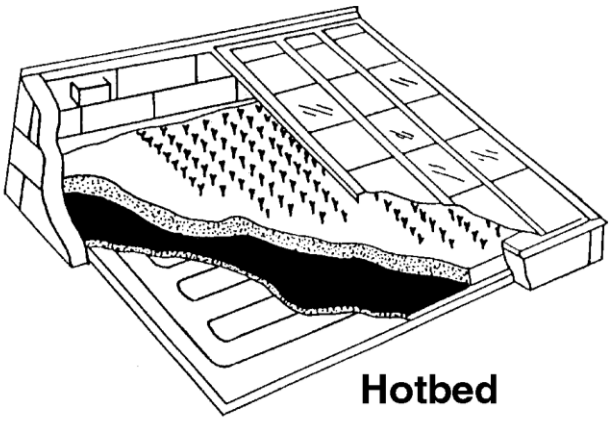


TM 2.6

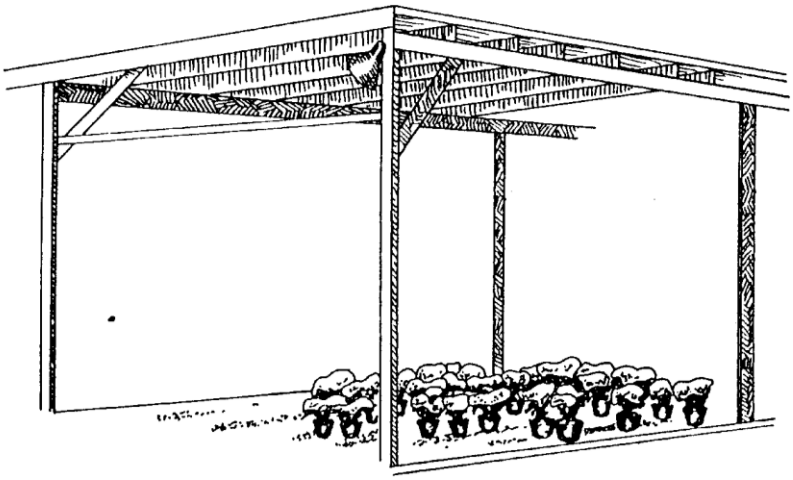
Other Outdoor Growing Structures



Coldframe



Hotbed



Lath House

UNIT II: GROWING STRUCTURES AS 2.1

Lesson 1: Greenhouse Parts, Structures, and Coverings Name_____

Plan Your Own: Part I

Objective: Develop a greenhouse structure.

Directions: Select one of the following topics. Work in a small cooperative group to answer the questions related to the selected topic. Use textbooks, the Internet, professional greenhouse magazines, and other resources to gather information, sketches, and pictures. Remember to discuss cost, complexity of setup, repair and upgrade. Keep this activity sheet; it will be helpful in Lessons 2 and 3 of this unit and in the unit activity.

Group One: Site Selection

1. Where are you building your greenhouse: on top of a hill, in a valley, etc.? Why?
2. What is the direction of the growing structure?
3. What types of energy costs are required with this site?
4. What sort of infrastructure is available at this site?
5. How accessible is this site for materials delivery?
6. Are utilities readily obtainable?

Group Two: Legal

1. How much does the land cost?
2. What is the expansion potential?
3. Are there any neighbors? How does the business affect them?
4. Is this a wholesale or retail operation?
5. How close is the competition? How close is your customer base?
6. What are the zoning regulations for your land?
7. What permits or licenses do you need to build the greenhouse?

Group Three: Design

1. What type of structure is this? Why?
2. How easy or complex is it to set up, repair, and upgrade?
3. What framing material are you going to use? Why?
7. 4. What type of covering material are you going to use? Why?
5. What are the initial costs and costs of repair? How often does the covering need to be repaired or replaced?
6. Is the material flammable?

Group Four: Layout

1. What is the interior layout?
2. What material is used on the flooring? Why?
3. What material is used for the benches? Why?
4. What type of bench is used? Why?
5. Are there any other types of growing structures? If yes, what kind and why?
6. What other work areas are needed?
7. Do these choices reflect a good layout for a commercial greenhouse operation?

GREENHOUSE OPERATION AND MANAGEMENT

Unit II: Growing Structures

Lesson 2: Environmental Control

Objective/Competency:

Describe how environmental factors in a greenhouse are controlled.

Study Questions

1. **What types of environmental controls may be found in a greenhouse?**
2. **How is the temperature in a greenhouse monitored and controlled?**
3. **How can a greenhouse be kept warm during cold weather?**
4. **Why must a greenhouse be ventilated?**
5. **How is a greenhouse kept cool during warm weather?**
6. **How is greenhouse humidity controlled?**
7. **What equipment is used to irrigate plants in a greenhouse?**
8. **How are carbon dioxide and light levels controlled in a greenhouse?**

References/Supplies/Materials

1. *Greenhouse Operation and Management* (Student Reference). University of Missouri-Columbia: Instructional Materials Laboratory, 2002.

2. Transparency Masters

   TM 2.7 Devices to Monitor Temperature
   TM 2.8 Methods of Ventilation

3. Activity Sheet

   AS 2.2 Plan Your Own: Part II

4. Ball, Vic, Editor. *Ball Red Book Greenhouse Growing*, 14th ed., Reston, VA: Reston Publishing, Inc., 1985.

5. A current copy of Hummert's Helpful Hints

TEACHING PROCEDURES

A. Review

Students are starting to look beyond the obvious and consider unseen aspects in the design of a greenhouse. Lesson 2 explores elements of the environment that personnel should control to produce optimal crops.

B. Motivation

1. Once the greenhouse owner assesses the land, climate, and resources, the actual structure is built. But it is just a shell to be converted into a controlled environment to raise crops. Ask the students what environmental elements have to be manipulated to raise the best crops in the shortest amount of time.

2. To demonstrate elements of a greenhouse environment on a reduced scale, have students work in small cooperative groups to create terrariums. Encourage each group to select a different type: desert, tropical forest, etc. Use small glass fish tanks or wide-mouth glass containers. Other materials needed are gravel, charcoal chips, small rocks, and a selection of small plants and ground cover, such as moss. As students develop their terrariums, discuss how light, water, and temperature affect the growth of plants.

C. Assignment of Study Questions

D. Supervised Study

Lead students in collecting the information needed to answer and discuss the study questions. The instructor may choose to work on one study question at a time or have students answer all the questions before the discussion. Another option is to have students work in cooperative learning environment and have groups work on different study questions.

E. Discussion

Lead students in a discussion of the study questions. Supplement students' responses and information with additional materials when needed.

1. What types of environmental controls may be found in a greenhouse?

There are seven environmental factors to adjust inside the greenhouse. The methods of control are discussed here. Subsequent units detail why these factors need monitoring.

A. Natural elements to control in a greenhouse
   1. Temperature

2. Humidity
3. Water
4. Light
5. Carbon dioxide
6. Pests
7. Disease

B. Basic methods of control
   1. Manual
   2. Automated
   3. Integrated control system
      a. Analog and integrated control systems
      b. Multiple sensors throughout greenhouse
      c. Sense and control elements such as air and soil temperature, light intensity, relative humidity, and carbon dioxide levels
      d. Record data for evaluation and troubleshooting
      e. Provide data for planning future crops

2. How is the temperature in a greenhouse monitored and controlled?

Have students anticipate how plant development is influenced by temperature. What would result if the temperature becomes too cold or too warm?

A. Primary considerations in selecting temperature control systems
   1. Cost of equipment
      a. Installation
      b. Maintenance
   2. Ability to provide uniform control
      a. Minimize hot and cold spots throughout greenhouse
      b. Can be enhanced with horizontal airflow
   3. Capacity
      a. Ability to handle temperature extremes
      b. Ability to meet needs of the entire operation
   4. Reliability
      a. Power failure alarm that alerts a power outage
      b. Emergency generator in case of power failure
   5. Fuel
      a. Cost
      b. Availability
      c. Type of storage required
      d. Type of transportation required

B. Monitoring and control methods (TM 2.7)
   1. Thermometers (measure air temperature)
   2. High/low thermometers (measure day and night air temperatures)
   3. Thermostats
      a. On-off control of air temperature
      b. Step control (stages) of air temperature

4. Aspirated thermostats
    a. Read temperature of air blown across thermostat
    b. More accurate control than standard thermostat
5. Thermistors
    a. Electronic semiconductora used in computerized greenhouses
    b. Sense even subtle temperature changes; signal controller

C. Proper placement of monitoring devices
1. At level of the plants throughout the greenhouse
2. In an area shaded from direct sunlight and cooled fans

3. How can a greenhouse be kept warm during cold weather?

Discuss with students why heat is important to greenhouse-grown crops. What are desired qualities in sources of heat? Are some sources more conducive to specific crops?

A. Heating considerations
1. Heat loss occurs in three ways.
    a. Conduction
    b. Infiltration
    c. Radiation
2. Lost heat must be replenished to protect plants.
3. There are several desirable heat source features.
    a. Energy efficiency
    b. Reliable
    c. Safety
4. Heat is measured in Btu.

B. Solar energy
1. Solar energy provides only some heat.
    a. Greenhouse collects and stores the heat energy from the sun that passes through the covering during the day.
    b. This heat warms the plants and other objects inside the greenhouse.
    c. The heat that is radiated back does not have enough energy to pass back through the covering (greenhouse effect).
    d. Heat is retained at night. (The amount retained varies with the type of covering.)
2. Solar heat alone is not sufficient heat for greenhouses in most northern climates.
3. An additional source of heat must be provided.

C. Heating equipment
1. Unit heaters
2. Central heaters
3. Radiant (infrared) heat
    a. Infrared lights heat surfaces (plants, soil, benches, etc.) not the air.
    b. Air is warmed only by heat radiated from surfaces.
4. Emergency generators
    a. Powered by gas or fuel
    b. Necessary if there is a power outage that cuts power to the electric fans, which are essential parts of most heating systems

c. Necessary to keep cooling in greenhouse operation

D. Heat distribution
   1. Forced hot air
      a. Hot air - from burning several fuels, such as natural gas
         i. Distributed throughout the greenhouse
         ii. Ventilated to the outside to prevent buildup of air pollutants
      b. Horizontal discharge unit heaters
         i. Mounted on the ground or overhead
         ii. Push air through perforated polyethylene tubing that hangs above plants
      c. Vertical discharge unit heaters fans
         i. Mounted overhead
         ii. Move air downward
      d. Unit heaters - use HAF (horizontal airflow) fans to distribute heat evenly
      e. Fans at the peak of the greenhouse pushing down the hot air that rises
   2. Hot water
      a. Water is piped through greenhouse by metal piping that is placed along walls and under benches.
      b. Temperature is variable.
      c. A circulating pump moves the water.
   3. Steam
      a. Piped through greenhouse by metal pipes
      b. Temperature not as variable as hot water
      c. Carries more heat and moves farther

E. Fuel options
   1. Coal
   2. Kerosene oil
   3. Propane/natural gas
   4. Wood
   5. Electric (not an efficient fuel for most commercial greenhouse operations)

F. Venting
   1. Any heating system that burns fuel can be lethal to humans.
      a. Oxygen is depleted from the air.
      b. Oxygen shortage creates carbon monoxide - a gas that is fatal to humans.
   2. Impurities in fuel and incomplete combustion can create other toxic fumes.
      a. Ethylene gas
      b. Sulfur dioxide gas
   3. Safety measures are needed.
      a. Fuel-burning heat sources must be vented to the outdoors through a chimney.
      b. Ventilation system must be installed to bring fresh air into the greenhouse.

G. Circulation
   1. Circular air movement is an essential part of heating process.
   2. Air-mixing fans push the hot air that rises back down to plants.

4. Why must a greenhouse be ventilated?

Have students discuss why ventilation is important in a greenhouse. Have the students contemplate the lack of fresh air. What effect would it have on the plants?

A. Purpose of greenhouse ventilation
   1. Brings fresh air into greenhouse
   2. Reduces temperature
   3. Reduces relative humidity
      a. Excessive humidity causes condensation on plants.
      b. Condensation left on plants increases risk of disease.
   4. Replenishes carbon dioxide (CO_2)
      a. CO_2 is necessary for plant growth.
      b. Plants consume CO_2 during photosynthesis process.

B. Types of ventilation (TM 2.8)
   1. Ridge and side vents
      a. Chimney effect
      b. May be automated or manually operated
   2. Exhaust fans on sidewalls and endwalls
      a. Draws in fresh air
      b. Most beneficial in late spring, summer, and early autumn
   3. Perforated convection tube heater/fan system
      a. Motorized louvers let in fresh air.
      b. Fans mix air with inside air then distribute air through a convection tube.
      c. Convection tube running the length of the greenhouse overhead distributes air through the perforated openings.

5. How is a greenhouse kept cool during warm weather?

Ask students why cool air and reduced light are important in maintaining the greenhouse environment. Which factors from Lesson 1 of this unit also apply?

A. Basic measures
   1. Provide even flow of cool air
   2. Reduce light intensity

B. Methods of providing cool air
   1. Ventilators, vents
   2. Forced air ventilation
   3. Fan and pad systems
   4. Fog system
      a. Water is forced through tiny nozzles to create fine mist.
      b. Evaporating water cools the air.
   5. Mechanical A/C system - inefficient cooling method for most commercial greenhouse operations

C. Methods of reducing light intensity
   1. Shade fabric
      a. Fabric is available in various types of fabrics.
         i. Woven polyethylene cloth from greenhouse supplier
         ii. "Aluminet" - knitted polyaluminum
      b. Weave density of fabric determines the amount of light that is shaded out.
         i. Fabric is selected according to its percent of density.
         ii. Weave densities range from 20 to 90%.
         iii. The percent approximates how much the light intensity is decreased. For example, a 55% shade fabric blocks about 55% of the ambient (surrounding) light.
      c. The best way to reduce heat is to drape the cloth on the outside of the greenhouse. Be sure to maintain ventilation.
   2. Shade paint
      a. Diluted, weak-binding latex paint
      b. Sprayed on outside of glazing, usually twice yearly
      c. Should wear off gradually over the summer and fall
      d. Wash off with soap and water to prevent light reduction in winter
   3. Blinds
      a. Wooden, plastic, or plastic-coated aluminum slats
      b. Mounted outside greenhouse like shade fabric
      c. Mounted inside blinds - adjustable
   4. Thermal screens - installed on ceilings and walls

6. How is greenhouse humidity controlled?

Specific plants thrive at specific ranges of humidity. Ask students to describe how humidity influences plants they cultivated at home.

A. Relative humidity (RH)
   1. How much water is dissolved in the air at a specific temperature
   2. Measured as a percentage
B. Range
   1. Ideal RH for most plants is 45-85% - examples:
      a. Greenhouse peppers - 75% RH
      b. African orchids - 40-60% RH
      c. Roses - 80% RH
   2. Too high
      a. Above 85% RH (However, cut tulips and cut daffodils are best stored at over 90% RH.)
      b. Water condensing on plants and increasing risk of fungal pathogens and disease
   3. Too low
      a. Below 45% RH (Note: For succulents and cacti, 5-15% RH is the ideal range.)
      b. May stunt plant growth or cause leaf burn
      c. Requires more watering
C. Methods of maintaining proper RH
   1. Use shading to reduce temperature and light.

2. Use cooling pads (evaporative cooling).
3. Keep greenhouse filled with plants. (They generate RH.)
4. Do not water plants late in the day. Ensure that floor of greenhouse drains well.
5. Hook up a fan in the greenhouse and set it to start running at 9:00 p.m. or 10:00 p.m. for 30-60 minutes.
    a. Exchanges moist, warm, inside air with moist, cool, outside air
    b. Enables heating system to warm air to its set point, which reduces level of water in the greenhouse
6. Open the roof ventilators to let hot air escape. Maximize exchange of air by having wide roof ventilators and a double row of sidewall ventilators.
    a. Prevents a buildup of moisture
    b. Prevents water vapor from condensing on plants, which can cause spread of disease
7. Install fans for ventilation.
    a. Introduce cooler outside air into the greenhouse during late spring, summer, or early fall.
    b. During late autumn, winter, and early spring, air is introduced into greenhouse through perforated polyethylene tubes.
        i. This prevents harsh, extremely cold outside air from harming plants.
        ii. When cold air leaves tubes, it mixes with warm greenhouse air and this prevents plants from suddenly getting chilled.
    c. Exhaust fans exchange greenhouse air with outside air.

7. What equipment is used to irrigate plants in a greenhouse?

Ask students to describe equipment they have used to water their own plants. Unit IV, Lesson 3, details how equipment and systems are used to irrigate greenhouse crops and it describes different irrigation systems.

A. Manual method
    1. Handheld hose
    2. Wand
B. Automated method
    1. Delivery through mist systems
    2. Spaghetti tubes, which are controlled by timers
    3. Drip emitters
    4. Ooze tubes
    5. Water loop
    6. Capillary mat system
    7. Ebb and flood system
    8. Boom system
    9. Spray stake/nozzle system
    10. Fertigators

8. How are carbon dioxide and light levels controlled in a greenhouse?

Carbon dioxide is vital for plants. Plants use CO_2 to produce energy during photosynthesis. The greenhouse owner can manipulate the amount of CO_2 to control a crop's growth cycle. Light must also be controlled carefully. More details are provided in Units III and IV.

A. Carbon dioxide
   1. Essential for plant survival
   2. Consumed by plants during photosynthesis
   3. Deficiency of CO_2 - if greenhouse is tightly closed, allowing no exchange of air
   4. Lost CO_2 to be replenished by a CO_2 generator
      a. Generators provide a maximum amount of CO_2 with a minimum of heat as a by-product.
      b. A timer regulates when to introduce CO_2 into the greenhouse.
         i. Add CO_2 when photoperiod begins or at sunrise.
         ii. Discontinue CO_2 enrichment during dark hours.
         iii. Average recommended level of CO_2 is 1,000-2,000 ppm (parts per million).
      c. Generator operates by burning propane or natural gas.
      d. A thermocouple monitors the pilot light.
      e. If pilot flame goes out, a safety valve closes to prevent unburned fuel from releasing into greenhouse.
      f. Larger generators allow the greenhouse owner to set a shorter cycle time. A shorter cycle time adds CO_2 into the greenhouse more efficiently.

B. Light
   1. Required light intensity depends on plant.
   2. Intensity of available light is measured in foot-candles, ranging from 500 f.c. on an overcast winter day to 10,000 f.c. on a clear summer day.
   3. Light intensity can be affected by several environmental factors.
      a. Geographic location
      b. Season
      c. Time of day
      d. Pollution
      e. Cloud cover
   4. Light intensity can be read in two ways.
      a. Light meter
      b. Computerized photocell
   5. Light intensity can be increased or decreased to meet plant's requirements.
      a. Light intensity/day length can be increased with supplemental lights.
         i. Fluorescent lights
         ii. High-intensity discharge (HID) lights
      b. Light intensity/day length can be decreased by several means.
         i. Blocking plants from light with black material
         ii. Putting plant under a bench to reduce exposure to light
         iii. Spraying a shading compound on growing structure
         iv. Placing a shade cloth above plants or over the growing structure

F. Other Activity and Strategy

Have students go through greenhouse supply catalogs to find examples of environmental control systems. Which are appropriate for your area? Which systems would be appropriate for someone specializing in olericulture in Florida or floriculture in North Dakota?

G. Conclusion

The interior of a greenhouse is a blank slate. Although the size and shape affect the interior, so do environmental factors such as temperature, light intensity, humidity, and carbon dioxide. These considerations affect the design of a growing environment.

H. Answers to Activity Sheet

Instructor's discretion

I. Answers to Assessment

1. D
2 C
3. C
4. D
5. D
6. C
7. B
8. D
9. The student may list any three of the following:
   A. Geographical location
   B. Season
   C. Time of day
   D. Pollution
   E. Cloud cover
10. The student may list any four of the following:
   A. Temperature
   B. Humidity
   C. Carbon dioxide
   D. Pests
   E. Diseases
11. Increases chances of fungi attacking plant
12. Between 45 and 85%
13. A. Ridge and side vents
   B. Exhaust fans
   C. Perforated convection tube heater/fan

UNIT II: GROWING STRUCTURES

Name_____

Lesson 2: Environmental Controls

Date_____

ASSESSMENT

Multiple Choice: Circle the letter of the best answer.

1. What are four considerations in selecting a temperature control system?

   A. Humidity level, installation, uniformity, and conduction
   B. Cost analysis, fuel, reliability, and light intensity
   C. Uniformity, storage requirements, location, and cost of equipment
   D. Capacity, reliability, uniformity, and fuel

2. How can light intensity be reduced?

   A. Horizontal airflow
   B. Ooze tube
   C. Thermal screen
   D. Thermistors

3. What methods can distribute heat?

   A. Hot air/steam, thermal screens, and infrared heat
   B. Radiant heat, fire tube, and fog system
   C. Forced hot air, hot air, and steam
   D. Thermal screens, fire tube, and solar energy

4. What is one purpose of ventilation?

   A. Deplete oxygen
   B. Collect dust
   C. Replenish carbon monoxide
   D. Replenish carbon dioxide

5. What does a high/low thermometer measure?

   A. Seasonal temperature inside the greenhouse
   B. Indoor/outdoor temperature
   C. Air blown across the thermostat
   D. Day and night temperature

6. When does a CO_2 generator introduce carbon dioxide in the greenhouse?

   A. During dark hours
   B. At noon
   C. Sunrise
   D. At midday

7. What are three types of equipment used to irrigate plants using the automatic method?

   A. Ebb and flood, handheld wand, and capillary mat
   B. Ooze tube, drip emitters, and water loop
   C. Tube system, subirrigation, and overhead
   D. Spray stake, boom system, and tube system

8. What is a fan and pad system used for?

   A. Heating
   B. Catching insects
   C. Increasing carbon dioxide
   D. Cooling

Short-Answer Questions: Write the answers in the space provided.

9. What are three environmental elements that affect light intensity?

   A.

   B.

   C.

10. What are four environmental factors that a greenhouse owner should monitor?

    A.

    B.

    C.

    D.

11. What damage can high humidity inflict on plants?

12. What is the ideal range of relative humidity for most plants?

13. What are the three types of ventilation systems?

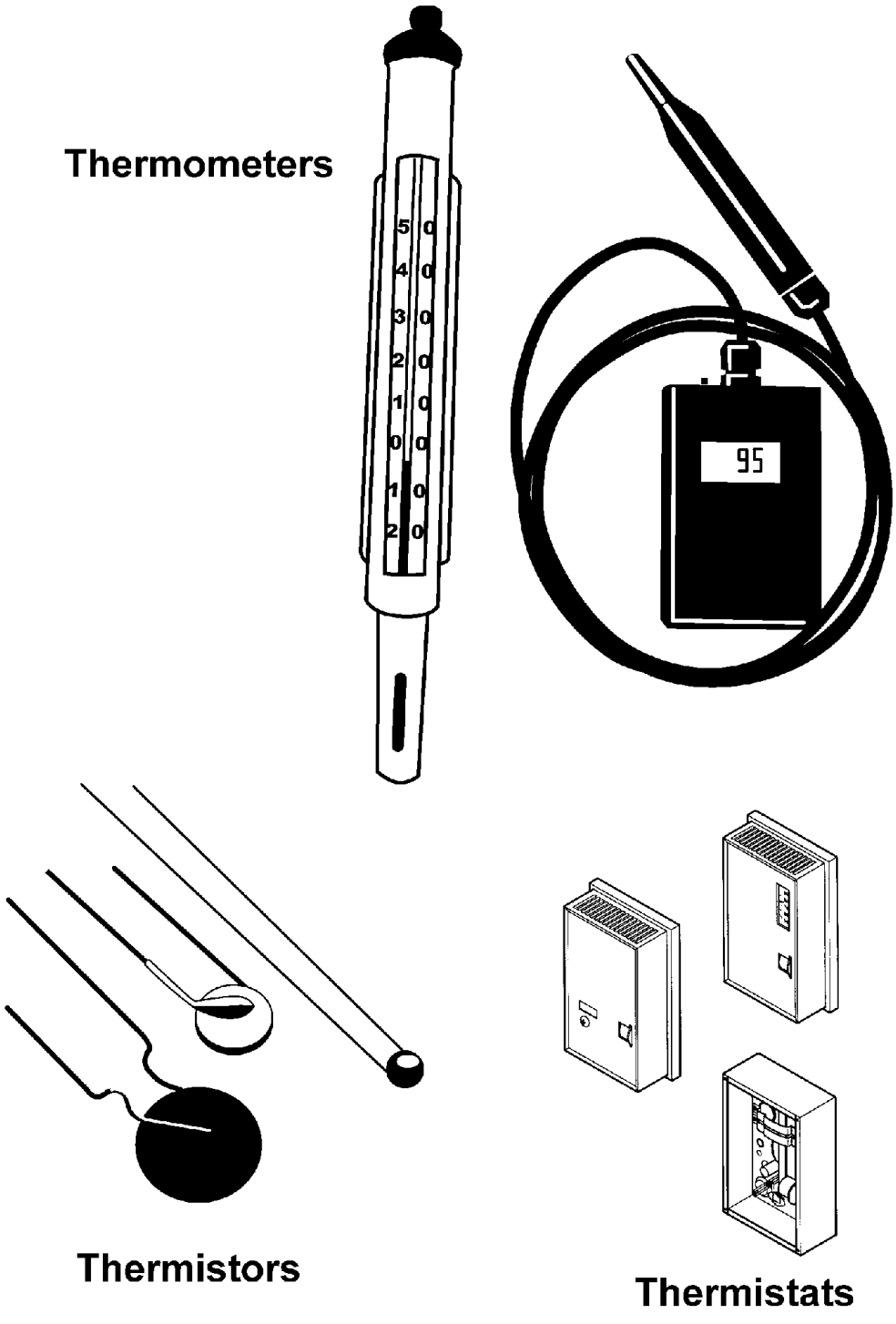
    A.

    B.

    C.

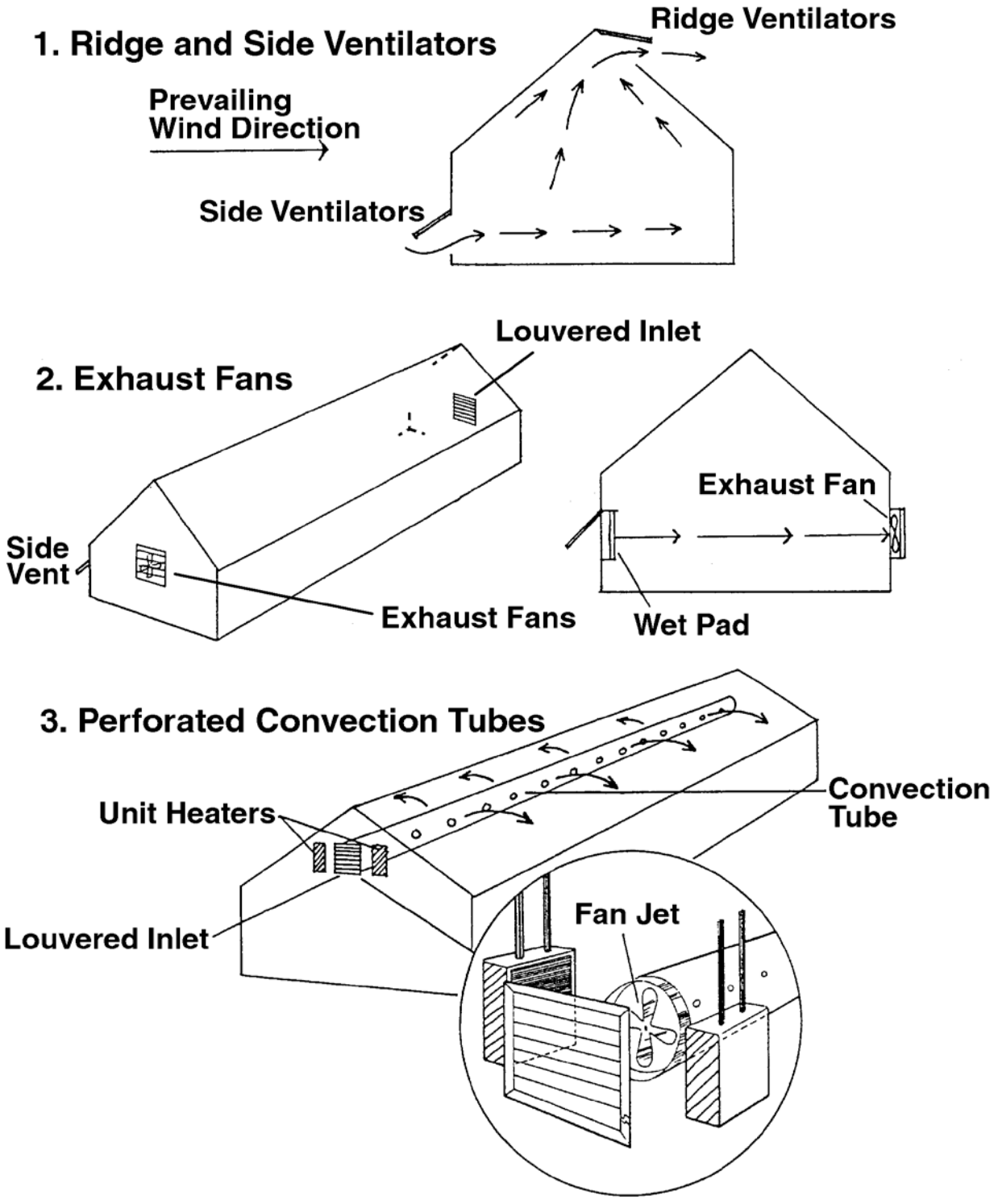
TM 2.7

Devices to Monitor Temperature



TM 2.8

Methods of Ventilation



UNIT II: GROWING STRUCTURES

AS 2.2

Lesson 2: Environmental Controls

Name_____

Plan Your Own: Part II

Objective: Integrate environmental controls into a strategic plan of a greenhouse.

Directions: Select <u>one</u> of the following topics. Work in a small cooperative group to answer the questions related to the selected topic. Build upon information from AS 2.1 to answer how you would control the greenhouse environment. Remember to discuss cost, complexity of setup, repair, and upgrade. Share your answers with the rest of the class.

Group One: Heat

1. How do you plan to monitor the temperature in your greenhouse? Why?
2. How do you intend to keep the greenhouse at the optimal temperature during the cold months?
3. What type of distribution system are you using?

Group Two: Cooling

1. How do you plan to monitor the temperature in your greenhouse? Why?
2. What method of cooling are you using: one or more than one means to control temperature?
3. How are you ventilating the greenhouse? Why this method?

Group Three: Humidity

1. How do you plan to monitor the relative humidity in your greenhouse?
2. How do you plan on regulating the humidity?
3. Does this system have more than one function?

Group Four: Light

1. How do you plan to monitor light intensity? Why this approach?
2. How do you plan to control the light intensity: one approach or multiple methods?
3. What is the cost of your solution?

Group Five: Carbon Dioxide

1. How do you plan to monitor carbon dioxide in the greenhouse?
2. How will you control, augment, and release the amount of carbon dioxide?
3. Why is it important to control CO_2?

Group Six: Irrigation

1. Which method of irrigation will work best?
2. How will you integrate fertilizer injections?
3. What happens to the runoff water?

GREENHOUSE OPERATION AND MANAGEMENT

Unit II: Growing Structures

Lesson 3: Energy Conservation and Environmental Protection

Objective/Competency:

Identify energy- and cost-saving factors in greenhouse structures.

Study Questions

1. **What greenhouse modifications and procedures can be used to conserve energy?**

2. **What modifications and procedures can be used in a greenhouse to protect the environment?**

References/Supplies/Materials

1. *Greenhouse Operation and Management* (Student Reference). University of Missouri-Columbia: Instructional Materials Laboratory, 2002.

2. Activity Sheet

   AS 2.3 Windbreak

3. Scott, S. V., Master Gardener. "Evergreens in the Landscape." <http://outreach.missouri.edu/jasper/hort/mg/globe/069.htm>

4. Slusher, John P. "Planning Tree Windbreaks in Missouri." School of Natural Resources, University of Missouri-Columbia. <http://muextension.missouri.edu/xplor/agguides/forestry/g05900.htm>

5. Starbuck, Christopher J. "Landscape Plantings for Energy Savings." Department of Horticulture, University of Missouri-Columbia. <http://muextension.missouri.edu/xplor/agguides/hort/g06910.htm>

TEACHING PROCEDURES

A. Review

   Building on Lessons 1 and 2 regarding greenhouse structures and the mechanical workings, Lesson 3 explores both energy conservation and environmental protection and their relationship to greenhouse operations.

B. Motivation

Why are energy conservation and environmental protection important to the greenhouse owner? Ask students to explain the pros and cons of both topics. Ask for specific examples of how a greenhouse owner can conserve energy and protect the environment.

C. Assignment of Study Questions

Encourage students to keep and update the portfolio they are creating for Unit II Activity.

D. Supervised Study

Lead students in collecting the information needed to answer and discuss the study questions. The instructor may choose to work on one study question at a time or have students answer all the questions before the discussion. Another option is to have students work in cooperative learning environment and have groups work on different study questions.

E. Discussion

Lead students in a discussion of the study questions. Supplement students' responses and information with additional materials when needed.

1. What greenhouse modifications and procedures can be used to conserve energy?

If not planned properly, a greenhouse can consume a lot of resources and cut into the greenhouse owner's profits. Proactive steps can be taken.

A. Optimize natural light intensity.
   1. Minimize need for supplemental electric lighting.
   2. Ensure large trees, buildings, etc., do not shadow growing structures.
   3. Paint inside surfaces (benches, frames, etc.) with white latex paint. Do not use oil-based paint.

B. Optimize heating and cooling efficiency.
   1. Invest in quality heating, cooling, and ventilation systems.
      a. Energy efficient
      b. Using economical and available fuel
   2. Routinely maintain for optimal efficiency.

C. Create energy-saving structures.
   1. Check structure for air leaks.
      a. Make sure vents and fan louvers seal tightly.
      b. Seal holes or cracks in greenhouse covering.
      c. Install weather stripping around doors, etc.
   2. Protect from extremes in the elements.
      a. Insulate north-facing side during winter.
      b. Create windbreaks to protect plants from harsh weather.
      c. When needed, provide shade if there is high-intensity light and high temperature.

d. Install thermal blankets inside walls and roof.

3. Consider direction and intensity of natural elements (wind, sun, snow, frost) when selecting a site.

2. What modifications and procedures can be used in a greenhouse to protect the environment?

These solutions are particular to a greenhouse operation, but some of the ramifications are global. The misuse of chemicals can injure the person applying them and can also affect the environment. Care must be taken when draining fertilizer because those compounds can leach into the water table and contaminate it. Humidity and pests affect the crops directly.

A. Minimize the use of hazardous chemicals.
   1. Know and follow federal, state, and local regulations governing the use of chemicals in a greenhouse.
   2. Use the least toxic method of controlling pests.

B. Minimize risk for plant disease.
   1. Maintain the proper level of humidity.
   2. Use appropriate watering method.

C. Minimize risk of infestation.
   1. Place screens over vents.
   2. Construct screened entry.
   3. Inspect all new material upon arrival before placing them in the greenhouse.

D Minimize runoff pollution.
   1. Have good drainage to avoid contaminating the water table.
   2. Have an irrigation system that can be recycled.

F. Other Activity and Strategy

Invite a speaker from the Department of Natural Resources to talk about the interactions between a greenhouse operation and the natural environment.

G. Conclusion

Energy conservation and environmental protection are important concepts to a greenhouse grower. The implications extend beyond a greenhouse operation and can adversely affect many individuals.

H. Answers to Activity Sheet

Instructor's discretion

I. Answers to Assessment

1. Risk of pests entering the greenhouse
2. Optimizes natural light intensity
3. The student may list any two of the following:

A. Insulate north-facing side during winter
B. Install thermal blankets inside walls and roof
C. Screen high-intensity light bursts in spring

4. The student may list any three of the following:
   A. Minimize chemical usage
   B. Minimize risk of pest infestation
   C. Keep humidity at the appropriate level for the crop
   D. Drain waste liquids properly to avoid runoff pollution
5. A. Optimize natural light intensity
   B. Optimize heating and cooling efficiency
   C. Create energy-saving structures

UNIT II: GROWING STRUCTURES

Name_____

Lesson 3: Energy Conservation and Environmental Protections

Date_____

ASSESSMENT

Short-Answer Questions: Write the answers in the space provided.

1. When placed over ventilation openings, what do tight-fitting covers help reduce?

2. What is the benefit of painting interior structures with white latex paint?

3. What are two methods to protect a greenhouse from extremes in the elements?

   A.

   B.

4. What are three procedures used in a greenhouse that protect the environment?

   A.

   B.

   C.

5. What are three modifications that help conserve energy in the greenhouse?

   A.

   B.

   C.

UNIT II: GROWING STRUCTURES

AS 2.3

Lesson 3: Energy Conservation and Environmental Protections

Name_____

Windbreak

Objective: Justify how a windbreak helps conserve energy.

Directions: Use information from AS 2.1 and AS 2.2 in which you designed the structure and environmental controls for a model greenhouse. Now devise a windbreak that helps conserve energy. Use textbooks, magazines, catalogs, university Extension publications, and the Internet to find information. Three suggested web sites are listed below. Answer the following questions. (You may work with another student.)

- Scott, S. V., Master Gardener. "Evergreens in the Landscape <http://outreach.missouri.edu/jasper/hort/mg/globe/069.htm>
- Slusher, John P. "Planning Tree Windbreaks in Missouri." School of Natural Resources, University of Missouri-Columbia. <http://muextension.missouri.edu/xplor/agguides/forestry/g05900.htm>
- Starbuck, Christopher J. "Landscape Plantings for Energy Savings." Department of Horticulture, University of Missouri-Columbia. <http://muextension.missouri.edu/xplor/agguides/hort/g06910.htm>

1. Where is the windbreak placed?

2. Why? Be specific and name sources that justify your choice.

3. What is the windbreak made of?

4. Why?

5. How much energy can be saved? Estimate but cite reference.

UNIT II ACTIVITY

Growing Structures

Name_____

Greenhouse Portfolio

Objective: Generate a portfolio that incorporates information from the three lessons in Unit II.

Directions: In groups, use information from completed activity sheets, photographs, sketches, and other references including the Internet to create a greenhouse portfolio. Include information about all the structural and internal mechanisms needed to build a new commercial greenhouse. Because this is a group project, the work is based on consensus. Be sure you and your coworkers agree on the contents of your portfolio. Include all of the information listed below. Once completed, give the portfolio to the instructor who will give your group another group's portfolio for Phase II of this activity.

Phase I: The Portfolio

- Wholesale or retail operation
- Type of crop: floriculture, olericulture, or ornamental
- Site selection
- Climate
- Topography
- Availability of resources: water, utilities, materials, labor
- Land considerations
- Marketing concerns
- Legal considerations
- Type of structure
- Framing and covering material
- Interior layout
- Flooring
- Benches
- Temperature monitoring system
- Heating and cooling systems
- Ventilation
- Irrigation method
- Control of light intensity
- Monitor and control of carbon dioxide
- Energy conservation ideas
- Attention to environmental protection

Phase II: The Critique

Objective: Appraise another group's portfolio.

Directions: Evaluate how thoroughly each topic was discussed in the other group's portfolio. Answer the following questions and prepare a professional-looking critique. Give your answers and the critique to the instructor upon completion.

1. How complete is this plan? Are all of the questions answered? (Blueprints are not necessary.)

2. Are there any areas insufficiently addressed or forgotten altogether?

3. Is this plan practical or unrealistic? Why?

4. What energy conservation measures are indicated?

5. What environmental considerations are indicated?

6. Are the costs of materials discussed?

7. Is the cost and ease of upgrade discussed?