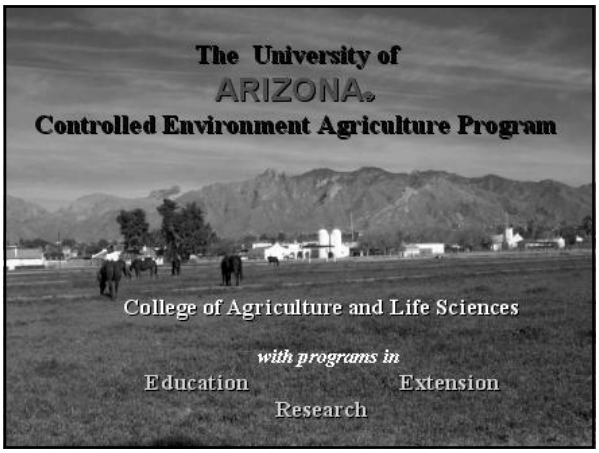
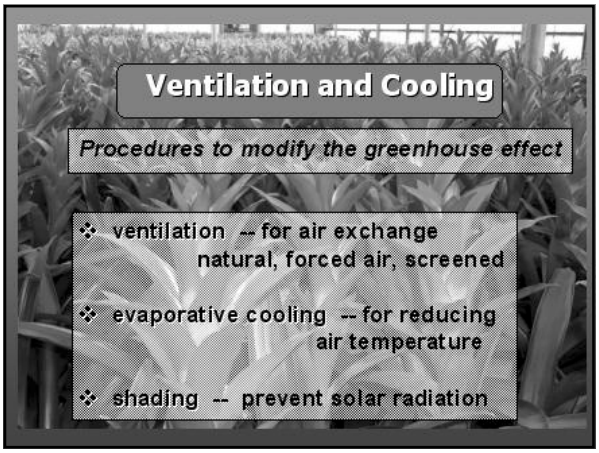




EXPECTATIONS

- Temperature Reduction
- Moisture Reduction
- Prevent Carbon Dioxide Depletion
- Air Movement for Oxygen & Carbon Dioxide Exchange
- Improved Labor Climate

Begin Cooling Difficulties Immediately!!

Ventilation and Cooling

Procedures to modify the greenhouse effect

forced air ventilation

BENEFITS

- Positive Displacement of Air
- Immediate Response to Controller
- Fan Staging
  - Small Air Exchange in Winter
  - Reduce over-Cooling
  - Save Electrical Energy
- Combine With Other Systems
  - Evaporative Cooling
  - De-Humidification

Active Ventilation and Cooling

- Capacity = Cubic feet per minute (CFM)
- Static Pressure = Air Flow Resistance (inches water)
- Power Requirement = Motor Horsepower

SIZING THE EXHAUST FANS

- Design For Maximum Cooling Load
  7-8 CFM per Ft^2 Floor Area
- Determine Floor Area
  Install 7 - 8 CFM Fan Capacity per Ft^2

Example: 24 Ft by 100 Ft = 2400 Ft^2
16,800 - 19,200 CFM

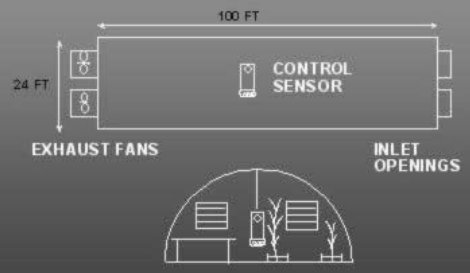
SIZING THE EXHAUST FANS

Example: 24 Ft by 100 Ft = 2400 Ft^2
16,800 - 19,200 CFM

One Fan or Two ??

	"A"	"B"
Capacity	18,000 CFM	9,000 CFM
Size	48 inch	36 inch
Power	3/4 HP	1/2 HP
Number of Fans	1	2

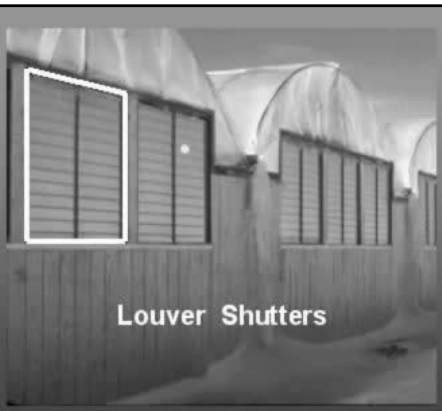
FLOOR PLAN OF 24 BY 100 GREENHOUSE



VENT INLET OPENINGS

Louver Shutters, Continuous Window, or Sidewall Opening

- **Louver Shutters**
  Square shape, "Point" Source
- **Motorized Window**
  Continuous Inlet, "Line" Source
- **Roll-up Sidewalls**



Louver Shutters

SIZING THE INLET OPENING

Desirable Air Velocity (jet)
700 Ft per Minute

1.4 Ft^2 Inlet per 1000 CFM

Example: 24 Ft by 100 Ft = 2400 Ft^2
16,800 - 19,200 CFM
(assume 18,000 CFM)

18 x 1.4 Ft^2 = 25.2 Ft^2

SIZING THE INLET OPENING

- Select Louver Shutters
  One, 5 Ft by 5 Ft = 25 Ft^2
  OR
  Four, 30 in by 30 in = 25 Ft^2
- Select Continuous Inlet Window
  25 Ft by 1 Ft = 25 Ft^2
  12 inch Opening

LOCATING FANS AND INLETS

- Location of Inlet More Critical Than Location of Fan
  - Suction by Fan on Greenhouse
- Distance From Inlet to Fan:
  - Freestanding - 100 Ft
  - Multi-span - 200 Ft
  - Long Distance Increases Air Temperature Rise From Inlet to Fan
- Put Inlets at Plant Height

LOCATING FANS AND INLETS

Inlet Opening (endwall side view)

Louver Shutters

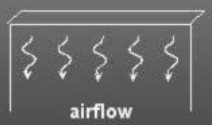
Continuous Window

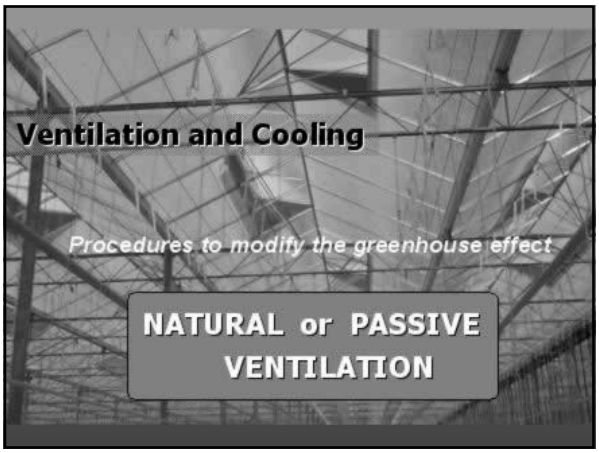
LOCATING FANS AND INLETS

Inlet Opening (endwall top view)

Louver Shutters

Continuous Window



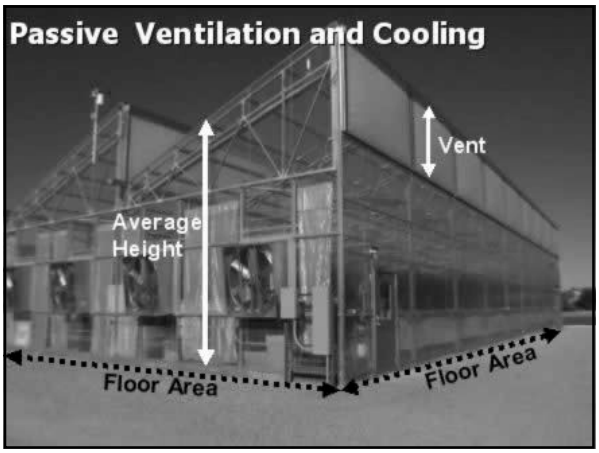


NATURAL VENTILATION

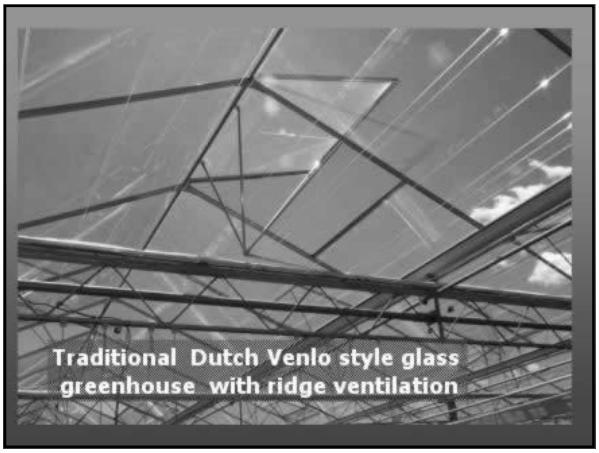
- Traditional for Glasshouses
- Cooling Dependent Upon:
  - Air Temperature Difference
  - Winds
- Least Cooling in Summer When Most Needed

NATURAL VENTILATION

- Ridge or Peak Openings
- Sidewall Openings
- Unglazed Roof Bays
- Screen Greenhouses


Passive Ventilation and Cooling
Vent
Average Height
Floor Area
Floor Area


Roof Vent in Partial Open Position
Vent Opening


Traditional Dutch Venlo style glass greenhouse with ridge ventilation

OPENING ROOF GREENHOUSE

- early design (1989 'MX')
- hinge at gutter
- one side open per bay

Roll-up Sidewalls and Opening Screened Roof

Fixed Screen Covered Greenhouse

insect exclusion

Ventilation and Cooling

Procedures to modify the greenhouse effect

EVAPORATIVE COOLING

OBJECTIVE OF EVAPORATIVE COOLING

- Cool Below Outside Air Temperature
- Humidify Inside Air
- Modify Leaf Temperature
- Propagation

THEORY OF EVAPORATIVE COOLING

- Water Evaporates
- Energy is Consumed and Air is Cooled and Humidified
- Evaporation Rate Depends on "Dryness" (Humidity) of Air, and Temperature of the Air
- Continued Evaporation Requires Exchange of Humid Air with Dry Air

TYPES OF EVAPORATIVE COOLING SYSTEMS

- Pad and Fan
- Misting
- Fogging

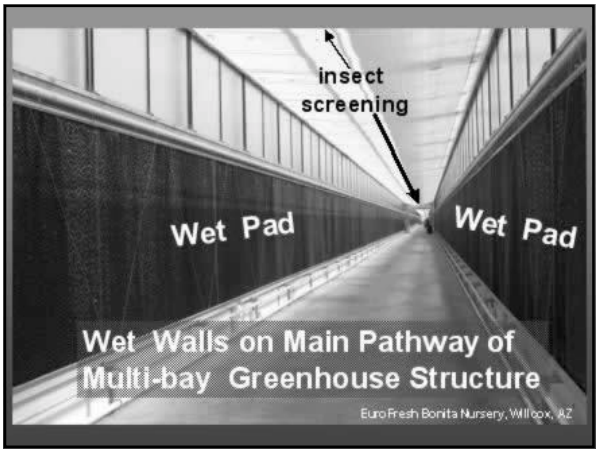
PAD AND FAN

- Components
  - Pad at Ventilation Inlet
  - Ventilation Fans
- Operation
  - Recirculate Water Through Wetted Matrix
  - Force Outside Air Through Matrix
  - Want 'Tight' Greenhouse (few leaks)

Wet Wall Pad at Inlet Window


Wet Wall Pad at Inlet Window
inside view


Wet Wall Pad on Quonset
Greenhouse Structure


insect
screening
Wet Pad
Wet Pad
Wet Walls on Main Pathway of
Multi-bay Greenhouse Structure
EuroFresh Bonita Nursery, Willcox, AZ

MISTING COMPONENTS

- Mist Nozzles
  - Low Pressure (40 - 60 psi)
  - High Volume (4 GPH)
  - One Nozzle per 25 - 50 FT^2
- Overhead Pipe Network
- Pump and Controls
- Fan Ventilation

MISTING COMPONENTS

- Mist Nozzles
  - Low Pressure (40 - 60 psi)
  - High Volume (4 GPH)
  - One Nozzle per 25 - 50 FT^2
- Overhead Pipe Network
- Pump and Controls
- Fan Ventilation

MISTING OPERATION

- "Large" Water Droplets
- Surface Wetting Occurs
- Contact Evaporation
- Intermittent Spraying
- Good Cooling Uniformity

Misting Nozzles for Propagation

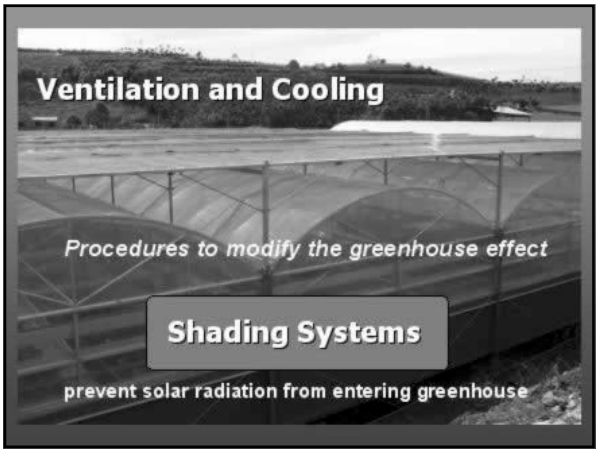
FOG COOLING COMPONENTS

- Fog Nozzles
  - High Pressure (1000+ psi)
  - Low Volume (1.2 GPH)
  - One Nozzle per 50 - 100 Ft^2
- Overhead Pipe Network
- Pump, Filters and Controls
- Water Quality
- Fan Ventilation

FOG COOLING OPERATIONS

- "Tiny" Water Droplets
- Instant Evaporation
- No Wetting
  - 3 to 12°F Cooling (humid climate)
  - 10 to 35°F Cooling (arid climate)
- Excellent Cooling Uniformity
- 1 GPM per 2000 Ft ^{2} Greenhouse

Fog Nozzle for Cooling



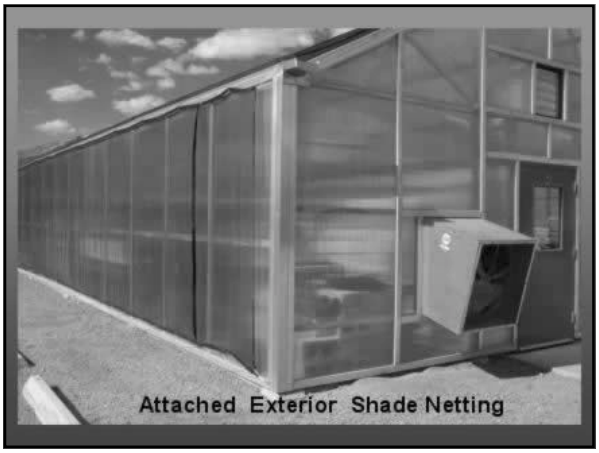
SHADING

REDUCES:

- Greenhouse Cooling Load
- Leaf Temperature
- PPF (PAR Needed for Growth)
- Plant Stress

SHADING SYSTEMS

- Paint Glazing
- Attached Exterior Netting
- Movable, Exterior Netting
- Movable, interior Shade Material



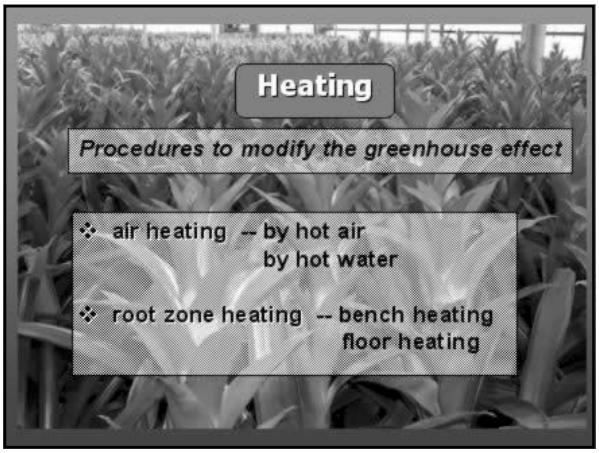
Attached Exterior Shade Netting

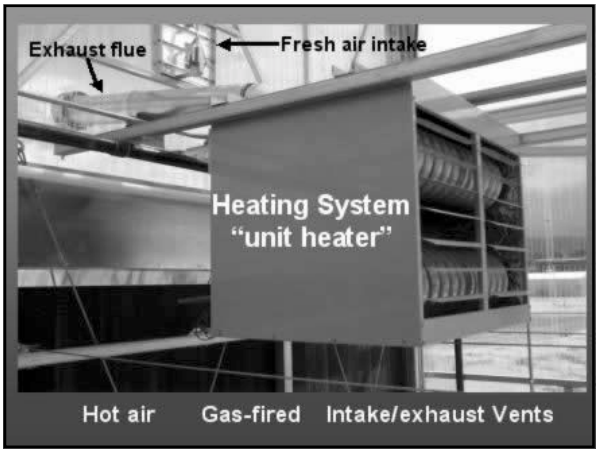

Movable, Exterior Shade Netting
Hines Nursery, Houston, TX

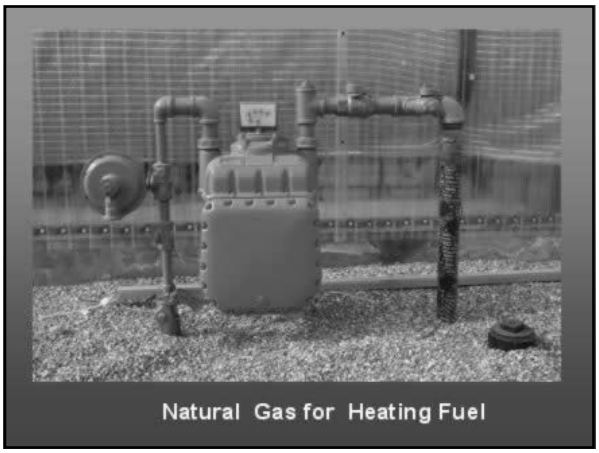

Retractable Roof
Shade Screen Greenhouse
Southwest Transplants, Yuma, AZ


Movable, Interior Shade Material


Retracted, Stowed
Movable, Interior
Shade Material
Deployed
Florida


Heating
Procedures to modify the greenhouse effect
air heating -- by hot air
by hot water
root zone heating -- bench heating
floor heating

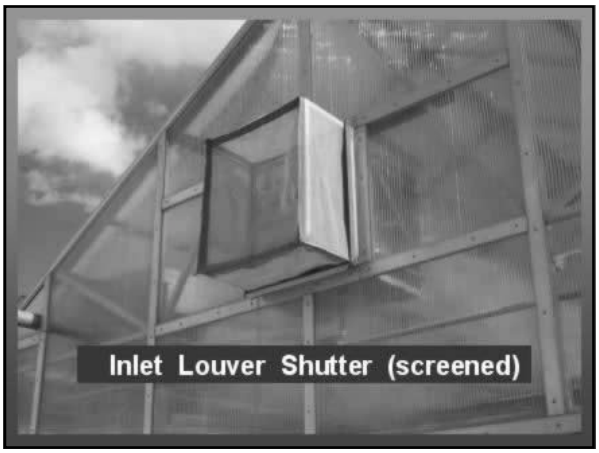

Exhaust flue
Fresh air intake
Heating System
"unit heater"
Hot air
Gas-fired
Intake/exhaust Vents



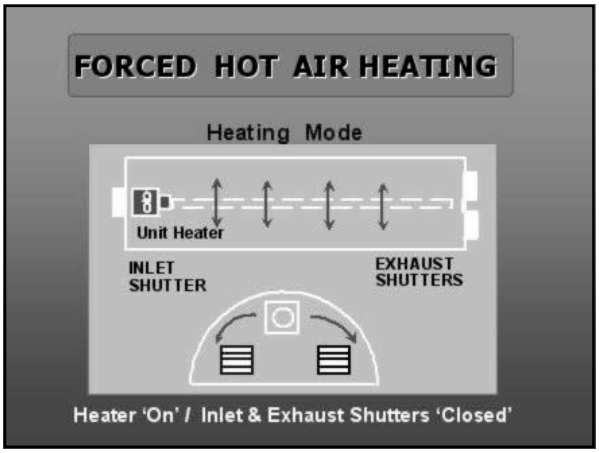
Natural Gas for Heating Fuel

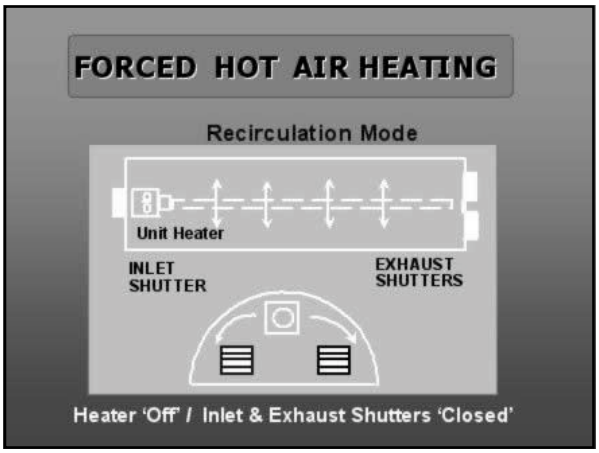
Location of the Unit Heater
Relative to the Crop

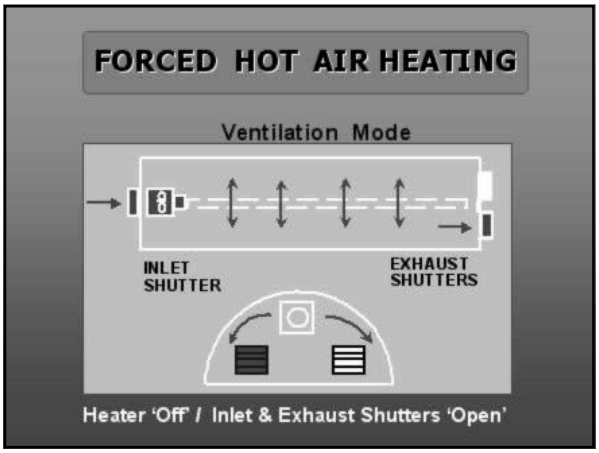
Ventilation Fan and Plastic Tube
Air Distribution Duct

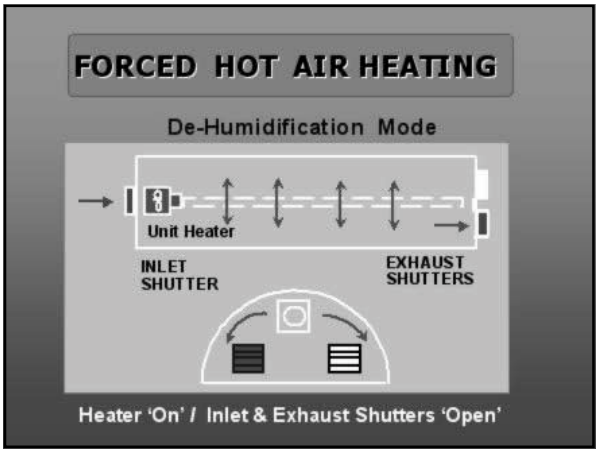

Inlet Louver Shutter (screened)

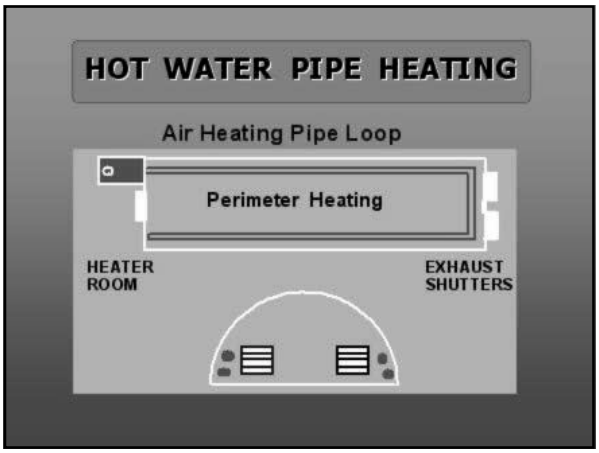

Ventilation Fan and Plastic
Tube Air Distribution Duct

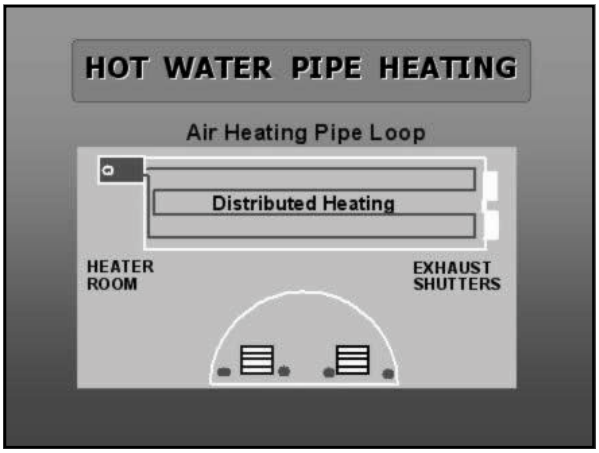

FORCED HOT AIR HEATING
Heating Mode
Unit Heater
INLET
SHUTTER
EXHAUST
SHUTTERS
Heater 'On' / Inlet & Exhaust Shutters 'Closed'


FORCED HOT AIR HEATING
Recirculation Mode
Unit Heater
INLET SHUTTER
EXHAUST SHUTTERS
Heater 'Off' / Inlet & Exhaust Shutters 'Closed'


FORCED HOT AIR HEATING
Ventilation Mode
INLET SHUTTER
EXHAUST SHUTTERS
Heater 'Off' / Inlet & Exhaust Shutters 'Open'

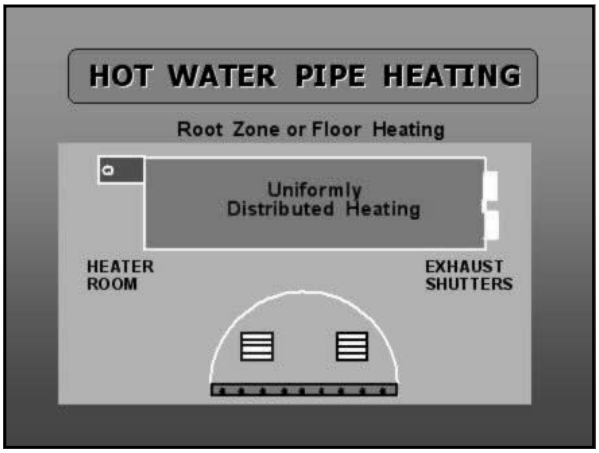

FORCED HOT AIR HEATING
De-Humidification Mode
Unit Heater
INLET SHUTTER
EXHAUST SHUTTERS
Heater 'On' / Inlet & Exhaust Shutters 'Open'


HOT WATER PIPE HEATING
Air Heating Pipe Loop
Perimeter Heating
HEATER ROOM
EXHAUST SHUTTERS


HOT WATER PIPE HEATING
Air Heating Pipe Loop
Distributed Heating
HEATER ROOM
EXHAUST SHUTTERS


Under Bench Air Heating
Hot Water Finned Tube


Pipe Rail Hot Water Heating
and Transport System


HOT WATER PIPE HEATING
Root Zone or Floor Heating
Uniformly
Distributed Heating
HEATER
ROOM
EXHAUST
SHUTTERS

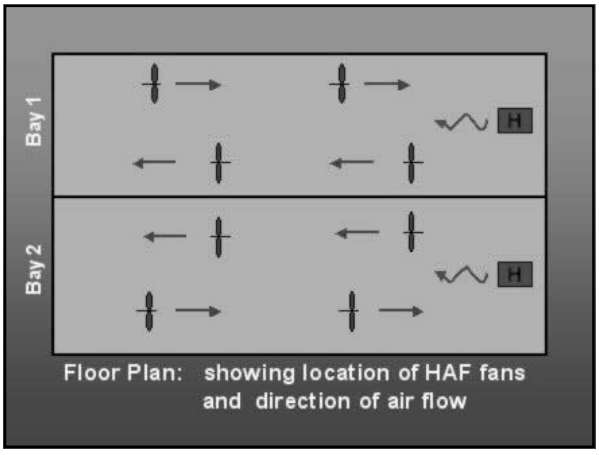

Concrete Floor Heating
System

HORIZONTAL AIR FLOW

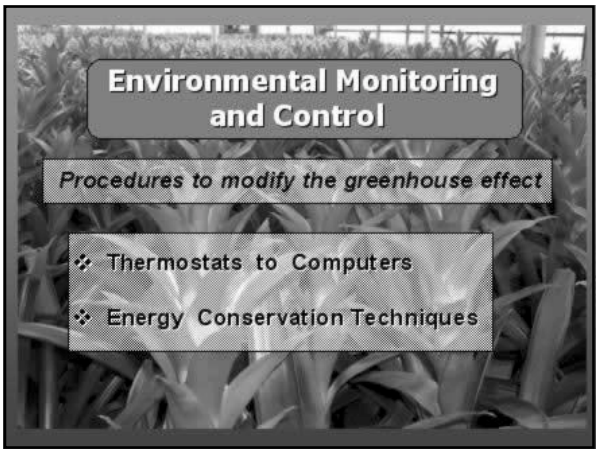
Internal Forced Air Movement
NOT Ventilation

- 50 FPM Air Velocity
- 2.5 - 3.5 CFM per Ft^2 Floor
- 1/15 - 1/6 HP Motors
- Four, 1/15 Hp Fans (2400 Ft^2)

H.A.F. Fans - Horizontal Air Flow



Floor Plan: showing location of HAF fans and direction of air flow



ENVIRONMENTAL CONTROL SYSTEM

GOALS

- Enhance Plant Growth
- Assure Timing of Maturity
- Maintain Quality

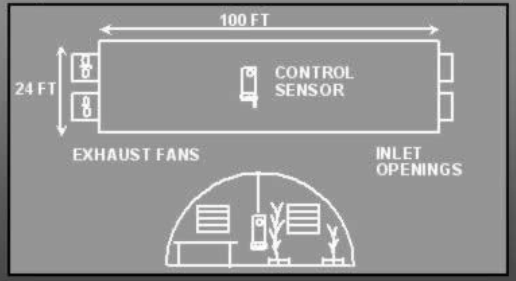
PROCEDURE

- Provide Spatial Uniformity
- Provide Control Strategy
- Minimize Energy Consumption

HEATING / COOLING CONTROL SENSOR

- Locate Near Plant Canopy
- Representative Greenhouse Location
- Shade From Direct Sun
- Protect From Moisture
- Aspirate With Fan

FLOOR PLAN OF 24 BY 100 GREENHOUSE

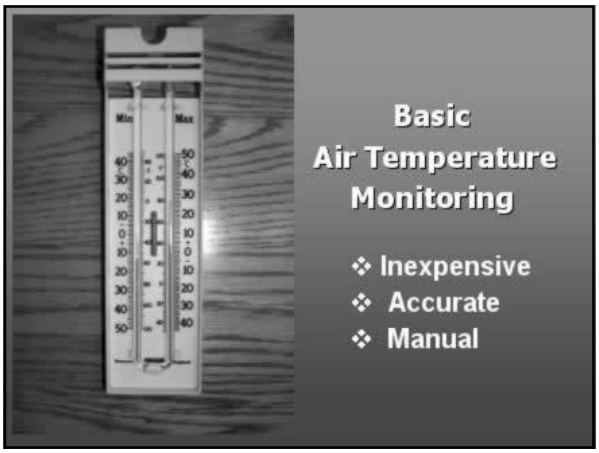


Manual Thermostats

Environmental Control and Plant Culture

Monitor Plant Parameters with Sensors

- Air Temperature
- Root Zone Temperature
- Humidity
- Light Intensity
- Nutrients (pH & E.C. & CO_2)
- Time



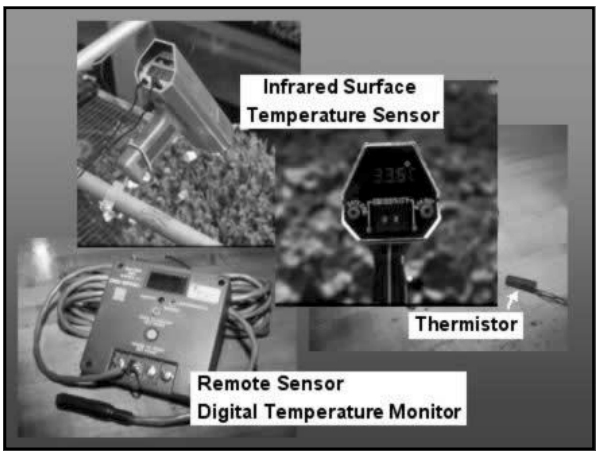
Basic Air Temperature Monitoring

- Inexpensive
- Accurate
- Manual

TEMPERATURE MEASUREMENT

Electronic
- Small Size
- More Accurate
- Requires Additional Hardware to Read

Examples
- Thermocouple
- Thermistor
- RTD (resistance Temperature Detector)
- Solid State Devices



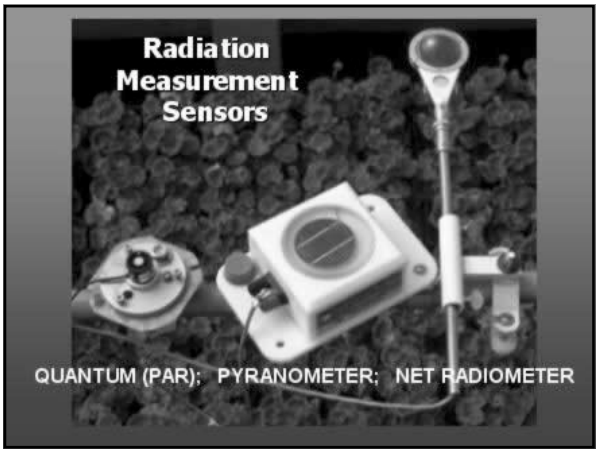
RADIATION MEASUREMENT

Radiometric (Total)

- Irradiance (Watt per square meter)
- Pyranometer (250 – 2300 nm)

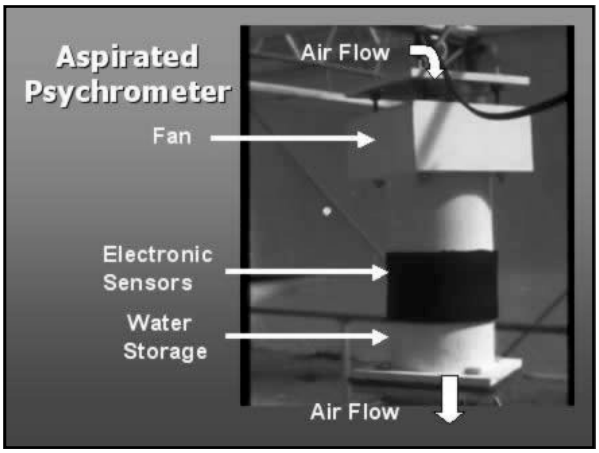
Photosynthetic (PAR)

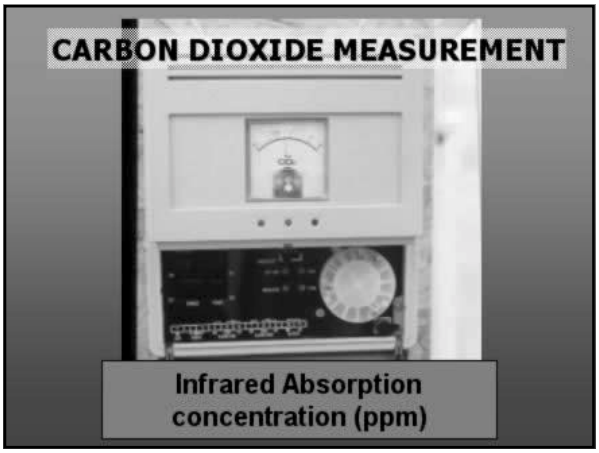
- PPF (micromole per square meter per second)
- Quantum Sensor (400 – 700 nm)



HUMIDITY MEASUREMENT

- Psychrometer
  Dry Bulb and Wet Bulb Air Temperature
- Solid State Device
  Capacitance or Inductance


Aspirated Psychrometer
Air Flow
Fan
Electronic Sensors
Water Storage
Air Flow


CARBON DIOXIDE MEASUREMENT
Infrared Absorption concentration (ppm)


NUTRITION
FREQUENCY
TIMING DEVICE (HOUR)
SOLAR INTEGRATOR (MJ/m2)
SALINITY
CONDUCTIVITY (mMHOS/cm2)
ACIDITY - ALKALINITY
pH (0 - 14)

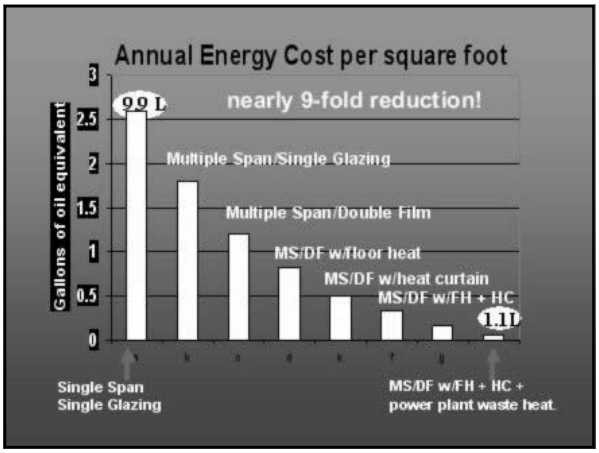
Computer-based Controller

- Multiple Zones
- Multiple Sensors, Multiple Types
- View, Process and Store Data
- Control Software
- Highly Flexible

Plastic Greenhouse Energy Conservation

- Double-layered P.E. Covering
- Multi-bay, Gutter-connected Greenhouses
- Internal insulation curtain
- Concrete Floor Heating
- Solar & Reject Heat Utilization

Mears, 1977



Horticultural Engineering Research Programs
Impact on Industry

90% reduction of greenhouse [GH]
energy-use over past 30 years

60% of all US GH's are covered with
double-layer, air-inflated polyethylene film

Internal GH energy blanket system
ubiquitous in industry
evolution into shading, cooling and insect screening

100% of field transplant crops grown
in economical GH's

Horticultural Engineering Research Programs
Impact on Industry

Floor heating technology applications
necessary for ebb & flood irrigation system

Transportable bench system US industry standard
for highly mechanized potted plant growing systems

GH Controlled Environment Agriculture technology
applied to plant growth chambers,
plant micro-propagation facilities,
plant biotechnology systems,
NASA bioregenerative life-support in space,
phytoremediation, plants are the processors.