Presentation

at the

Universidad Autonoma Chapingo, Ingeniera Mecanica Agricola, Chapingo, Mexico

invitation of

Raquel Salazar Moreno, PhD,
Academic Coordinator Mechanical Engineering Department
Universidad Autonoma Chapingo

27 al 31 de Mayo 2002


The University of
ARIZONA®
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College of Agriculture and Life Sciences
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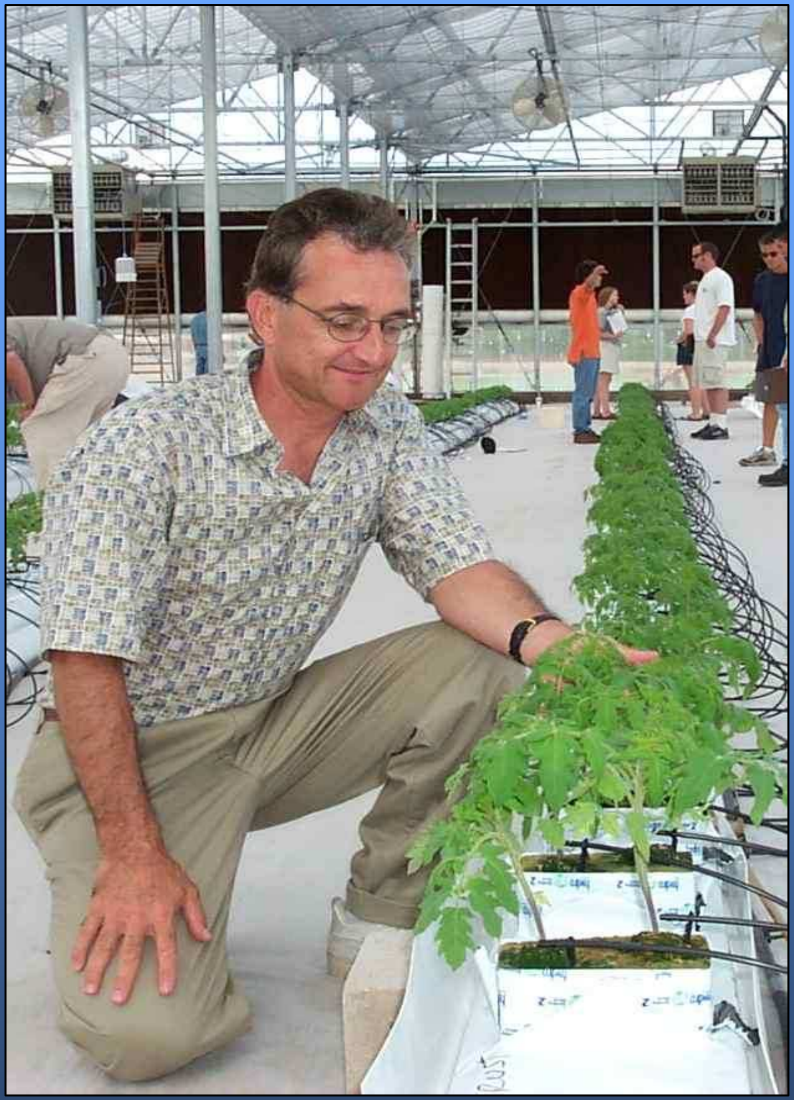


The University of
ARIZONA®
Controlled Environment
Agriculture Program

Dr. Gene Giacomelli,
Director, Agriculture & Biosystems Engineering

Greenhouse Structures and Glazing

Dr. Gene Giacomelli, PhD.

Professor of Agriculture & Biosystems Engineering
and
Director of the Controlled Environment Agriculture Center

The University of Arizona
Tucson, Arizona

Plant-Based Greenhouse System Design

Given that greenhouse is a system of many systems and processes.

Assume that the GH system consists of 3 fundamental aspects, each must be considered separately, then in combination, to assure effective design and successful operations

Three fundamental aspects:

1 Crop and Cultural Procedures
2 Nutrient Delivery System
3 Controlled Environment

3 Fundamental Aspects:

1. **Crop Cultural Procedures**

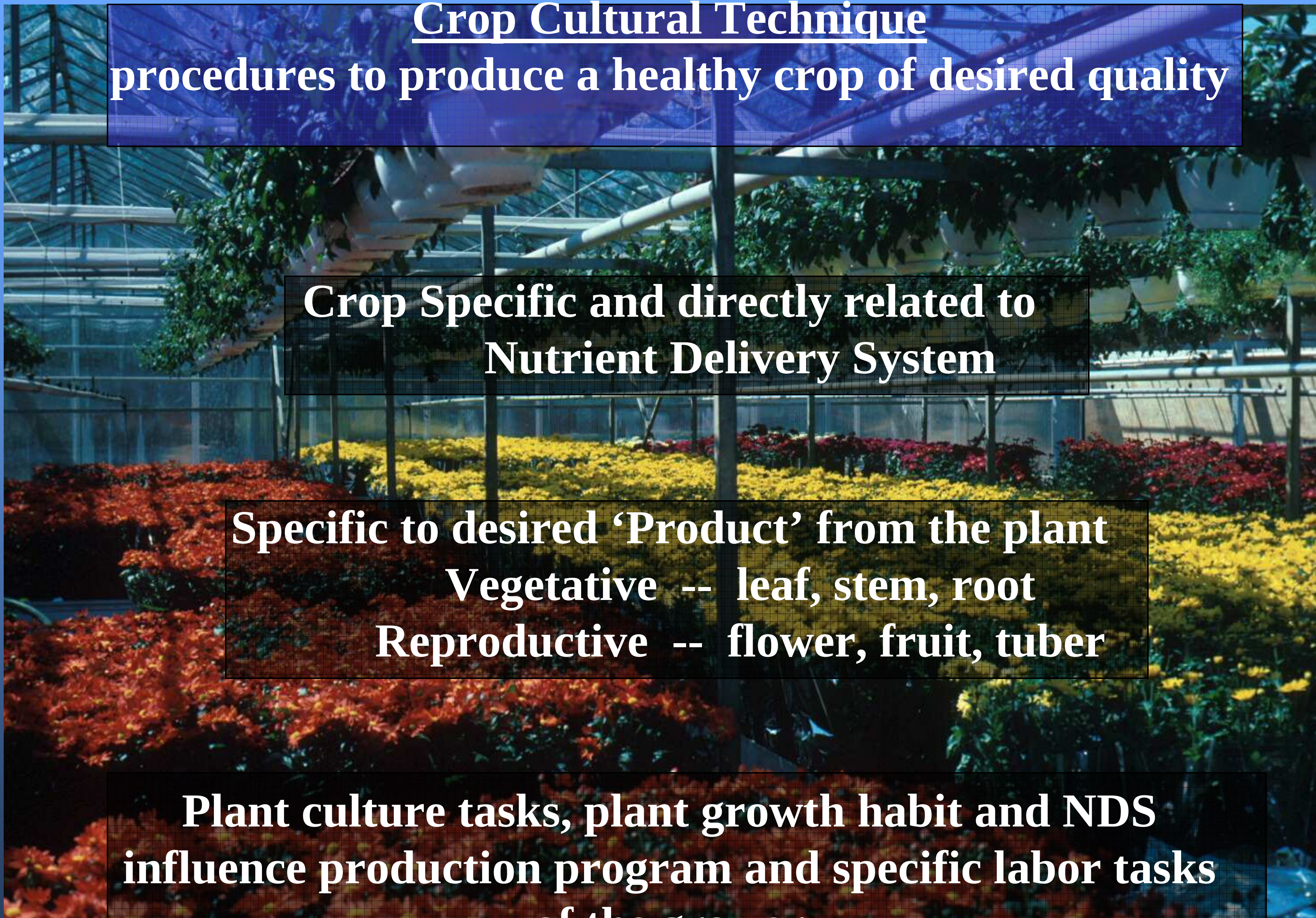
the plant needs; based on crop[s] to be grown

2. **Nutrient Delivery System**

procedures for delivery of primarily water and fertilizer to the crop, but also CO_2, light, etc

3. **Environmental Control**

means to provide the plant environment,
includes the structure and the environmental control systems [ventilation, cooling, heating, shading, lighting, computer, thermostats, etc]



Crop Cultural Technique

procedures to produce a healthy crop of desired quality

Crop Specific and directly related to Nutrient Delivery System

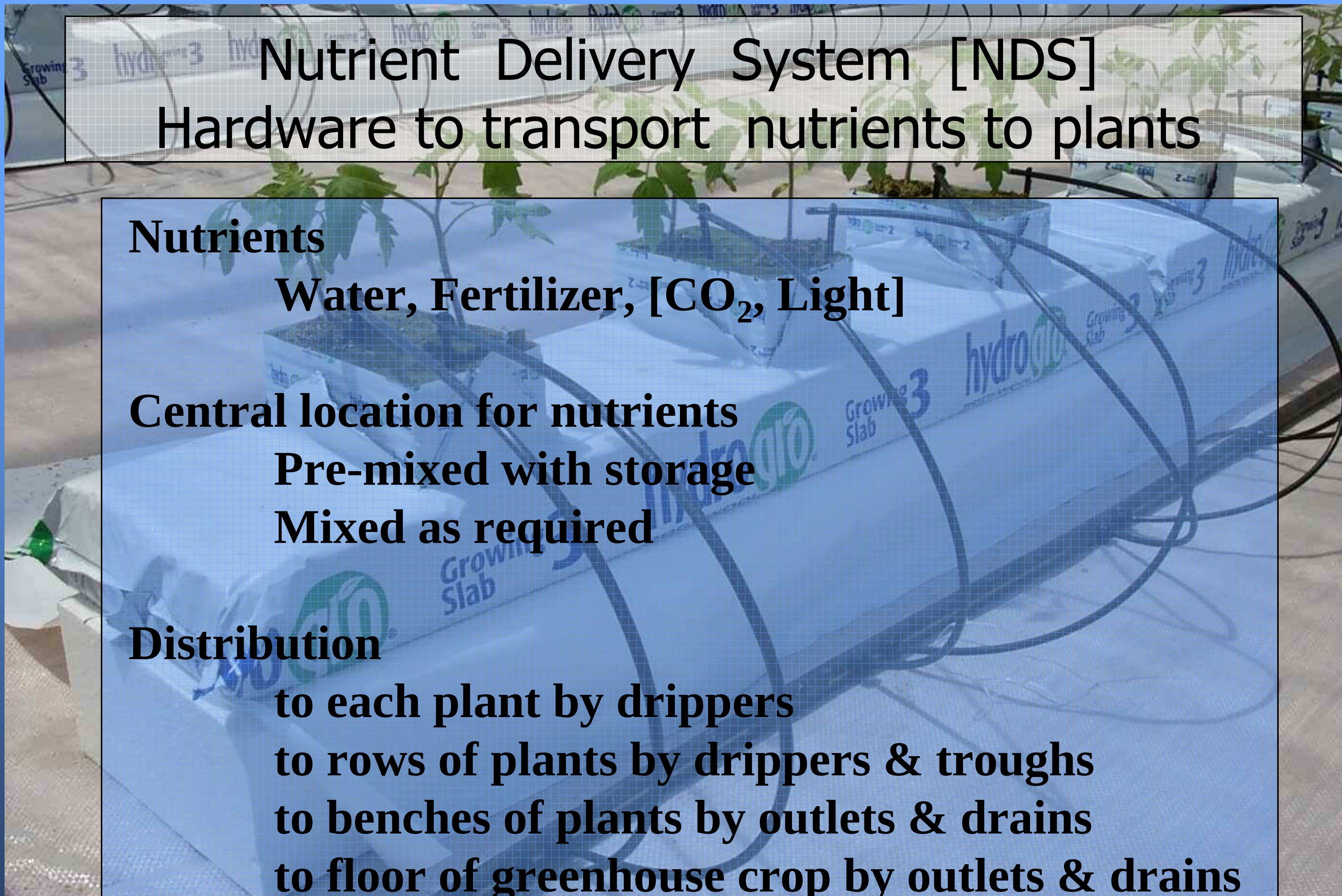
Specific to desired 'Product' from the plant

Vegetative -- leaf, stem, root

Reproductive -- flower, fruit, tuber

Plant culture tasks, plant growth habit and NDS influence production program and specific labor tasks of the grower

Nutrient Delivery System [NDS]
Hardware to transport nutrients to plants



Nutrients

Water, Fertilizer, [CO_2, Light]

Central location for nutrients

Pre-mixed with storage

Mixed as required

Distribution

to each plant by drippers

to rows of plants by drippers & troughs

to benches of plants by outlets & drains

to floor of greenhouse crop by outlets & drains

Controlled Environment

Greenhouse or other structure with environmental control systems

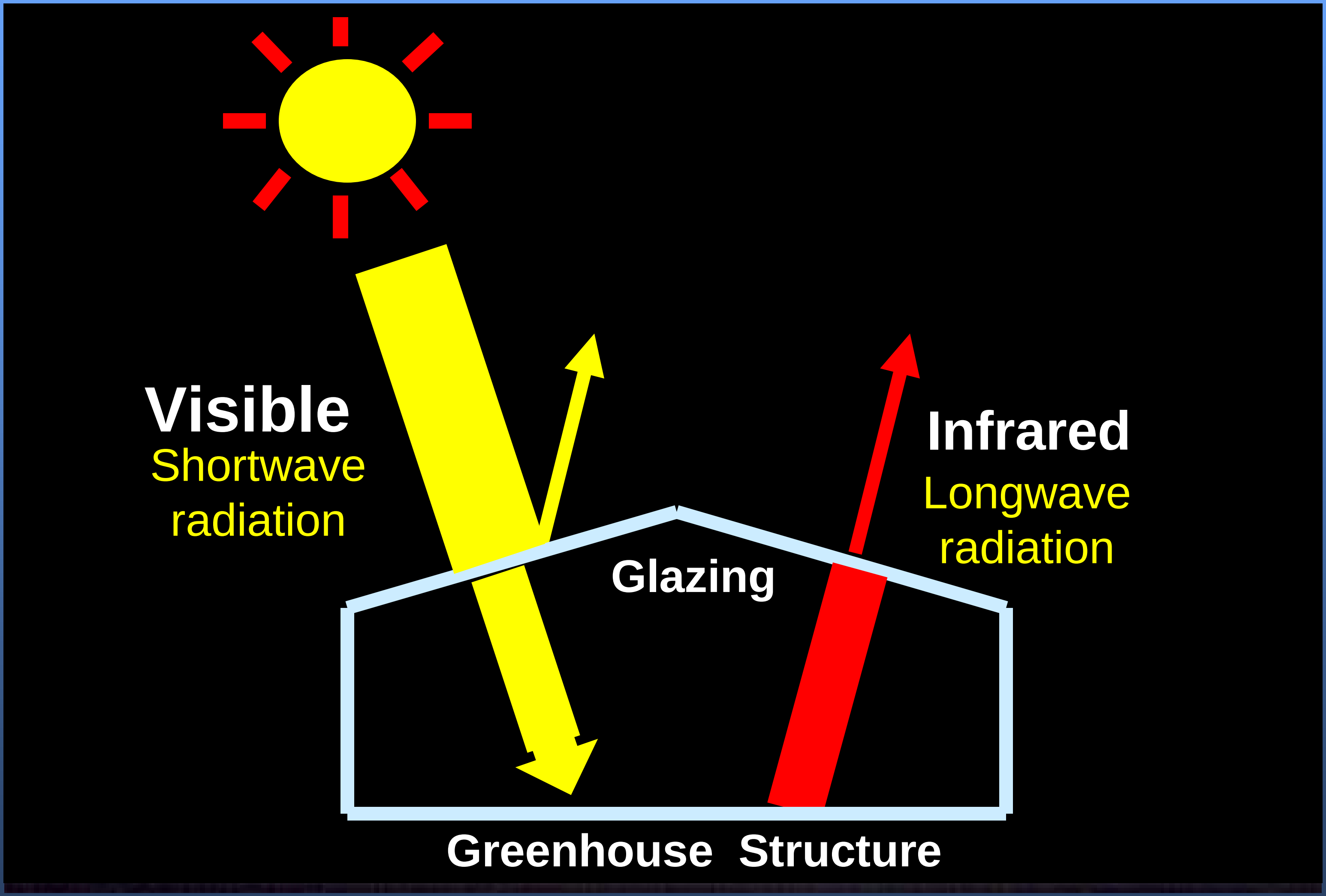
Maintain desired climate

Compatible with Nutrient Delivery System and Crop Culture Technique

Unobtrusive and dependable

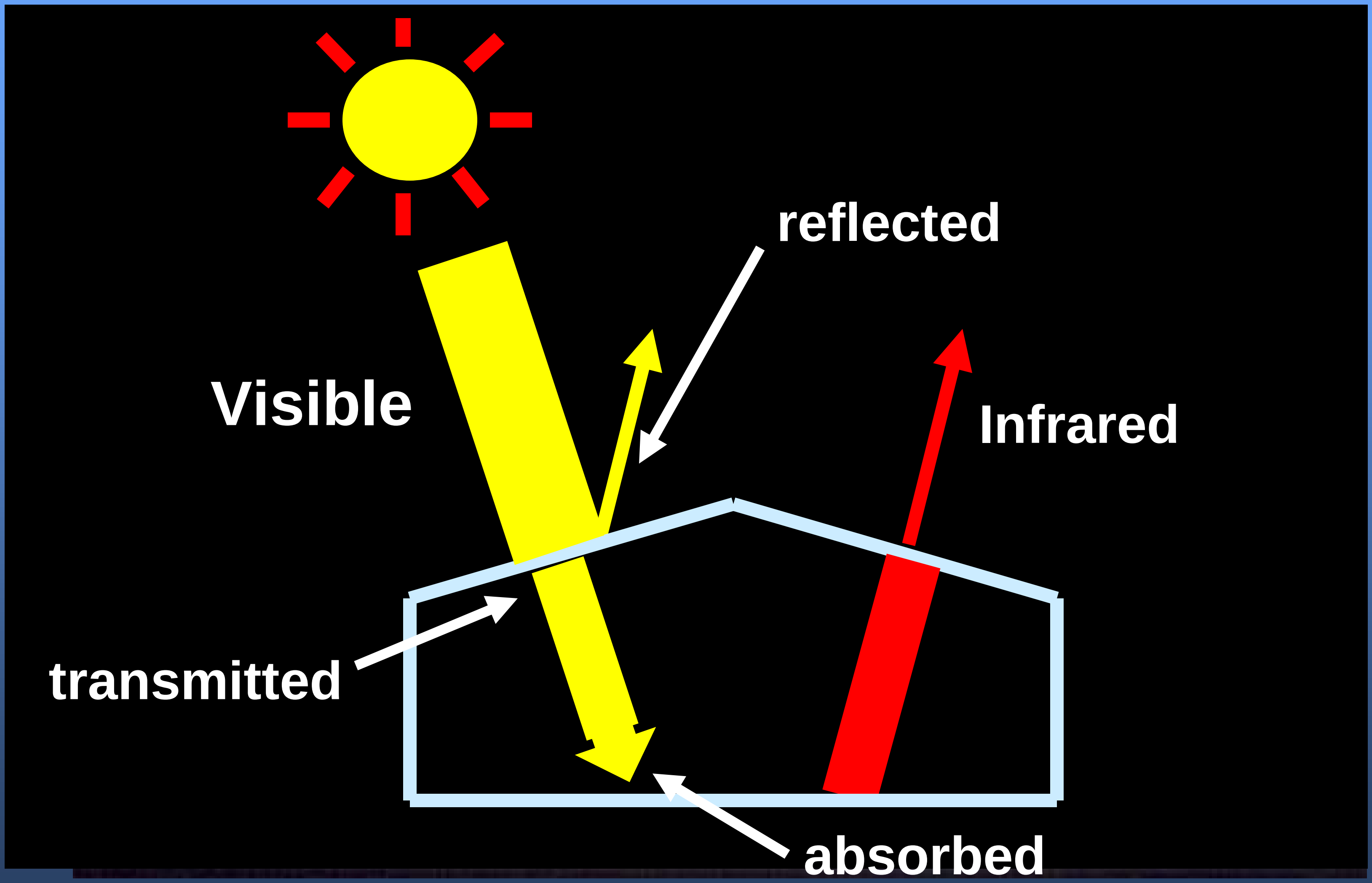
Greenhouse Effect

more energy enters, than leaves



Radiation

may be transmitted, reflected or absorbed



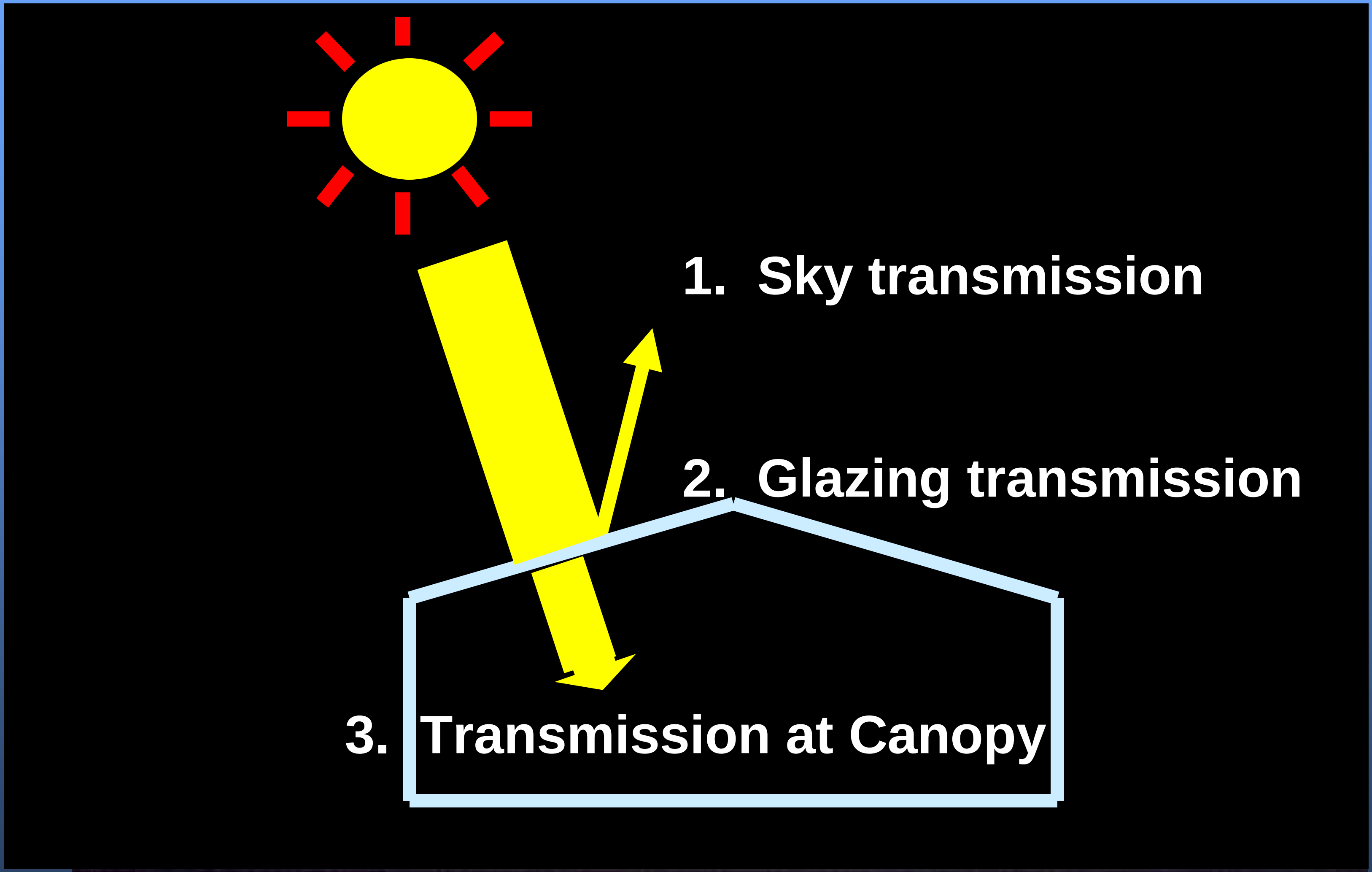
Transmission

comparison of the radiation intensity
below the atmosphere, or glazing
to that
above the atmosphere, or glazing

1. Sky Transmission
2. Glazing Transmission
3. Transmission at Canopy

Transmission

in the sky, at glazing, or at canopy



Which is most important for you?

Diffuse and Direct Radiation

Total Radiation = Direct + Diffuse

Diffuse Radiation -- radiation has been reflected by the atmosphere or glazing

Direct Radiation -- radiation received directly, without any reflection

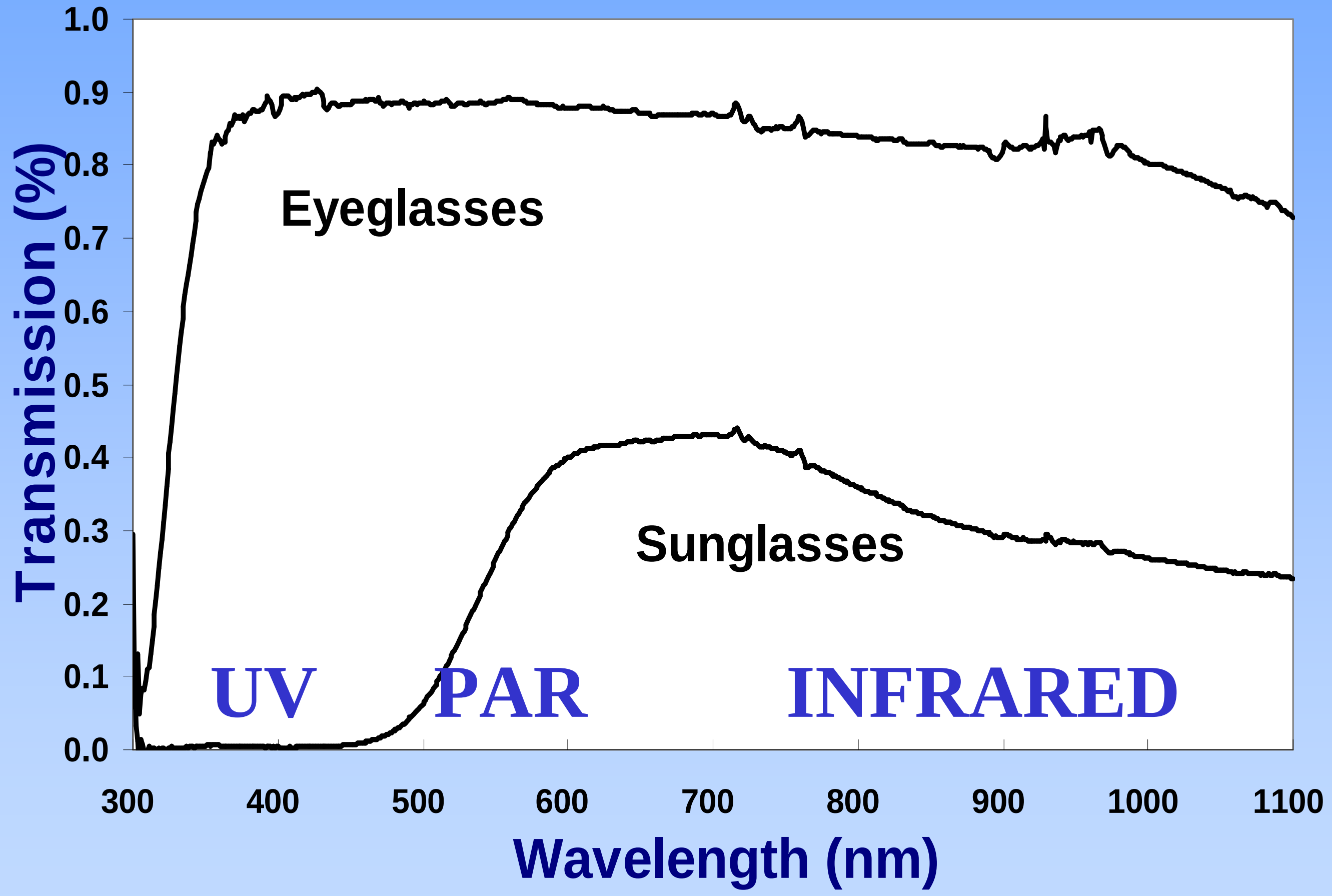
Clearness Index

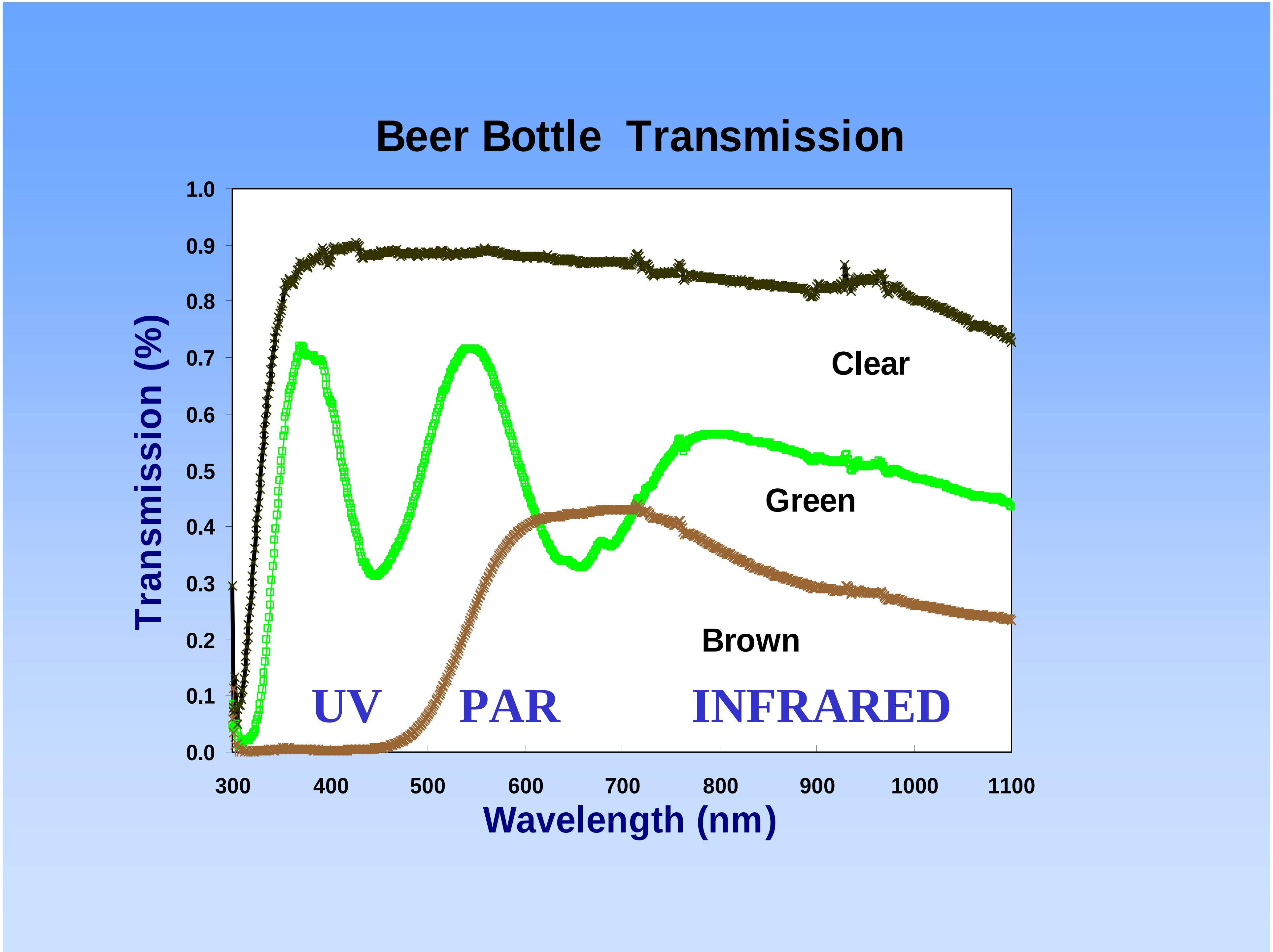
Transmittance of the Sky

Percentage of the solar radiation that passes through the atmosphere to the ground

CI = 0.75 is a clear day (mostly direct radiation)
CI = 0.25 is a cloudy day (mostly diffuse radiation)

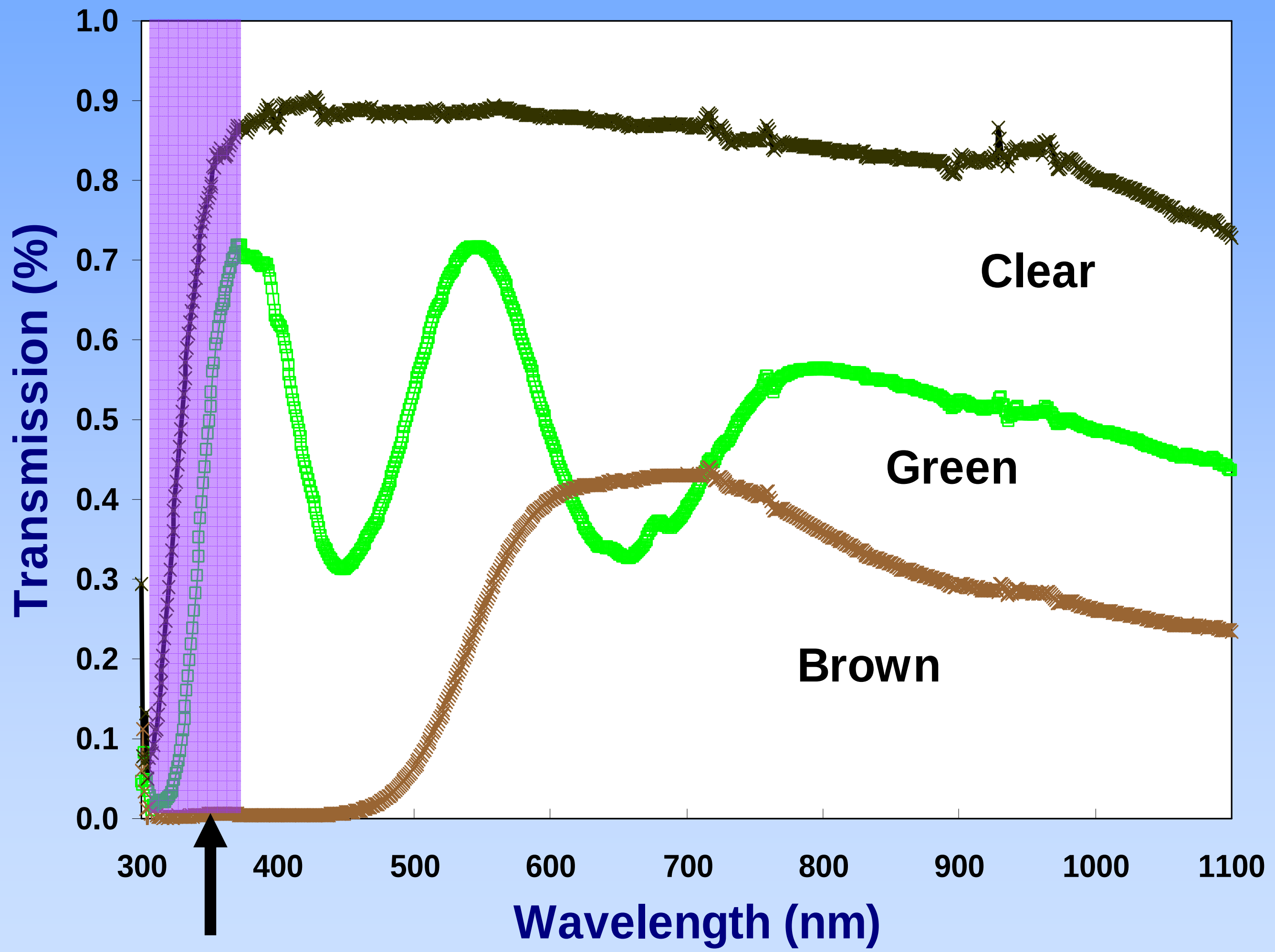
Transmission of Spectacles





Beer Bottle Transmission
Transmission (%)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
300
400
500
600
700
800
900
1000
1100
Wavelength (nm)
Clear
Green
Brown
UV
PAR
INFRARED

Beer Bottle Transmission



Ultra Violet transmission means 'skunky' beer!

Radiation

Quantity -- intensity or amount of energy within the waveband

Quality -- distribution and intensity of wavelengths within the waveband

Measured as Energy [$W\ m^{-2}$], or

Number of Photons [$\mu Mol\ m^{-2}\ s^{-1}$] within a waveband

Wavebands of Solar Radiation

waveband

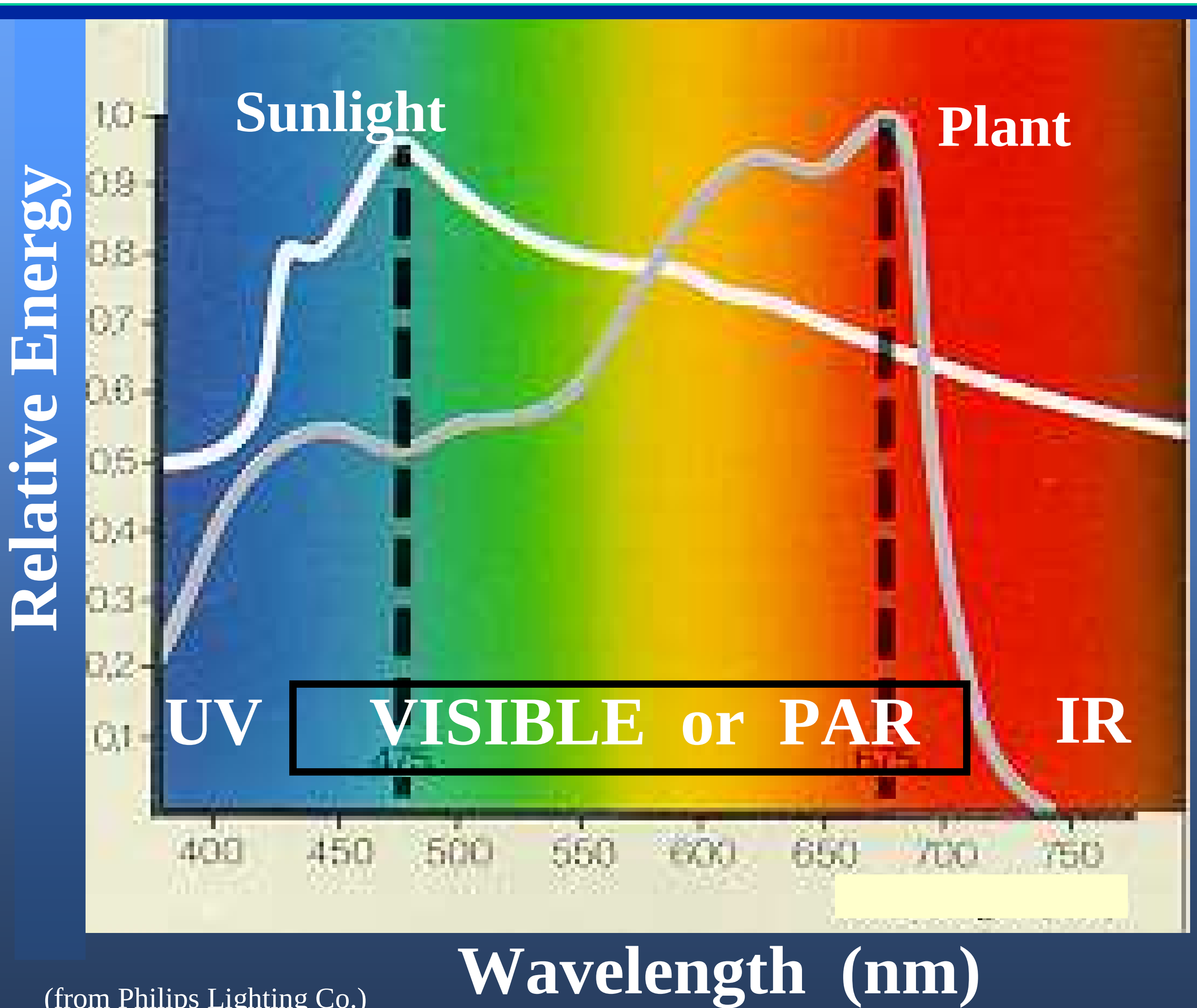
Ultra-Violet or UV => 100-400 nm

Visible or white “light” => 380-760 nm

PAR => 400-700 nm

Infrared or IR => 750 - 1,000,000 nm

Wavebands of Solar Radiation

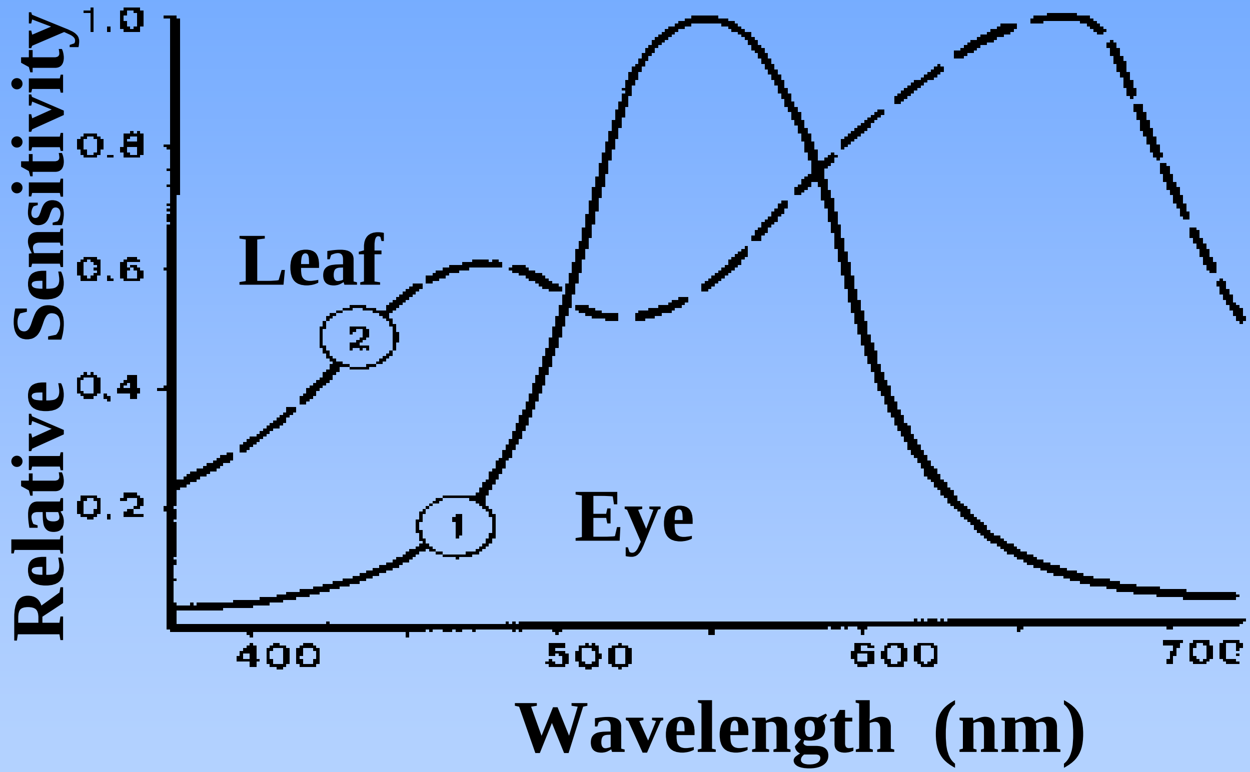


(from Philips Lighting Co.)

The “colors” of the radiation visible to humans can be divided into the following wavebands:

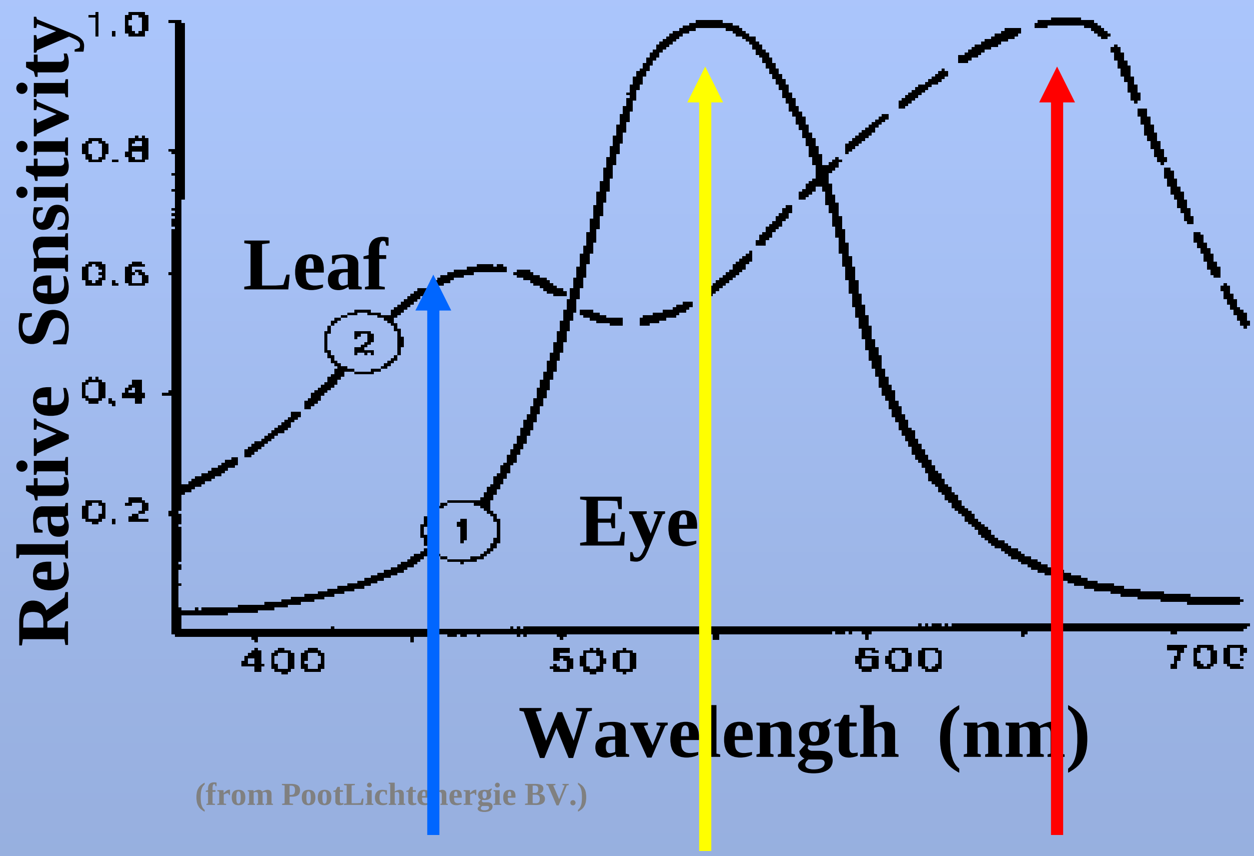
Waveband	Color	Function in the Plant
380-436 nm	violet	may support effect of blue light
436-495 nm	**blue**	**some need, prevents tall plants**
495-566 nm	green	contributes to photosynthesis
566-589 nm	yellow	contributes to photosynthesis
589-627 nm	**orange**	**maximum photosynthesis**
627-780 nm	**red**	**maximum photosynthesis; enhance flowering, stem length; Red/Far-red ratio is important**

Comparison of what the human eye "sees" relative to what the plant utilizes



(from PootLichtenergie BV.)

Comparison of what the human eye "sees" relative to what the plant utilizes



We see best in yellow
We don't see as well for plant needs which are blue and red

What's A Photon?

Photon is a unit of light

It has a <u>Wavelength</u>, Frequency, and <u>Energy</u>

Wavelength measured in nanometers (nm)
Frequency measured in cycles per second

$$\text{Energy} = \frac{h\ c}{\text{wavelength}}$$

Sensors

Pyranometer sensor measures solar radiation from 280-2800nm. 97% of the sun's spectral distribution "total solar" radiation. Units are W m^{-2}

Quantum sensor is PAR waveband (400-700nm) measured as μMol m^{-2} s^{-1} or W m^{-2}

Net Radiometer determines the difference of the radiation measured above to that being reflected from below a surface

Spectroradiometer splits incoming radiation into individual wavelengths or prescribed wavebands, then measures the irradiance (energy) of the photons.
spectral irradiance is μMol m^{-2} s^{-1} nm^{-1} or W m^{-2} nm^{-1}

GREENHOUSE DESIGN and CONSTRUCTION, SPACE UTILIZATION, FACILITIES MANAGEMENT

Decisions on design of greenhouse structure will affect:

- Labor Management
- Materials Flow
- Space Utilization
- Automation & Labor Savers
- Utilities Distribution
- Height of Greenhouse
- Energy Costs
- Total Light and Light Distribution

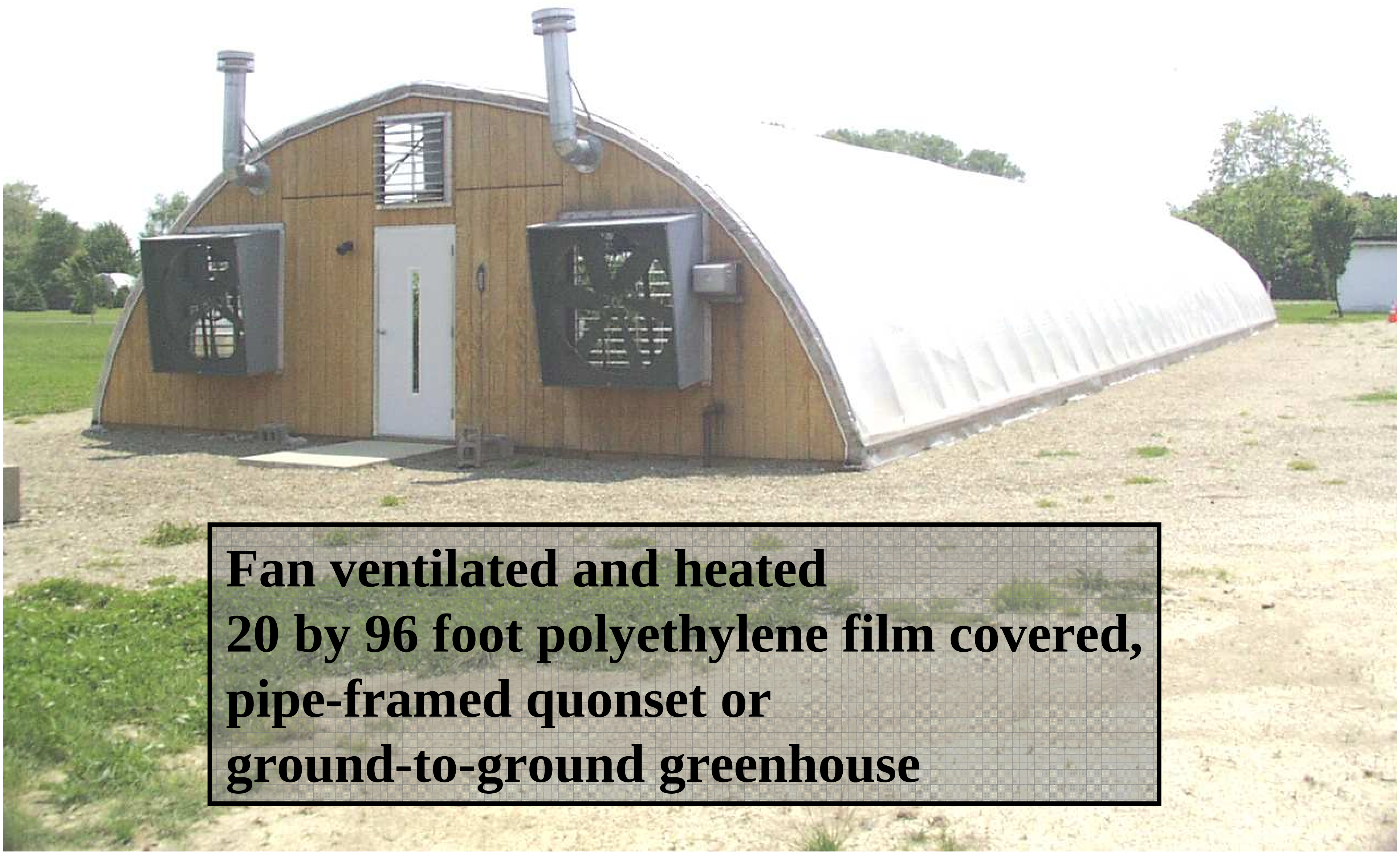
WOW!

- The Choice of Greenhouse should be the LAST Decision

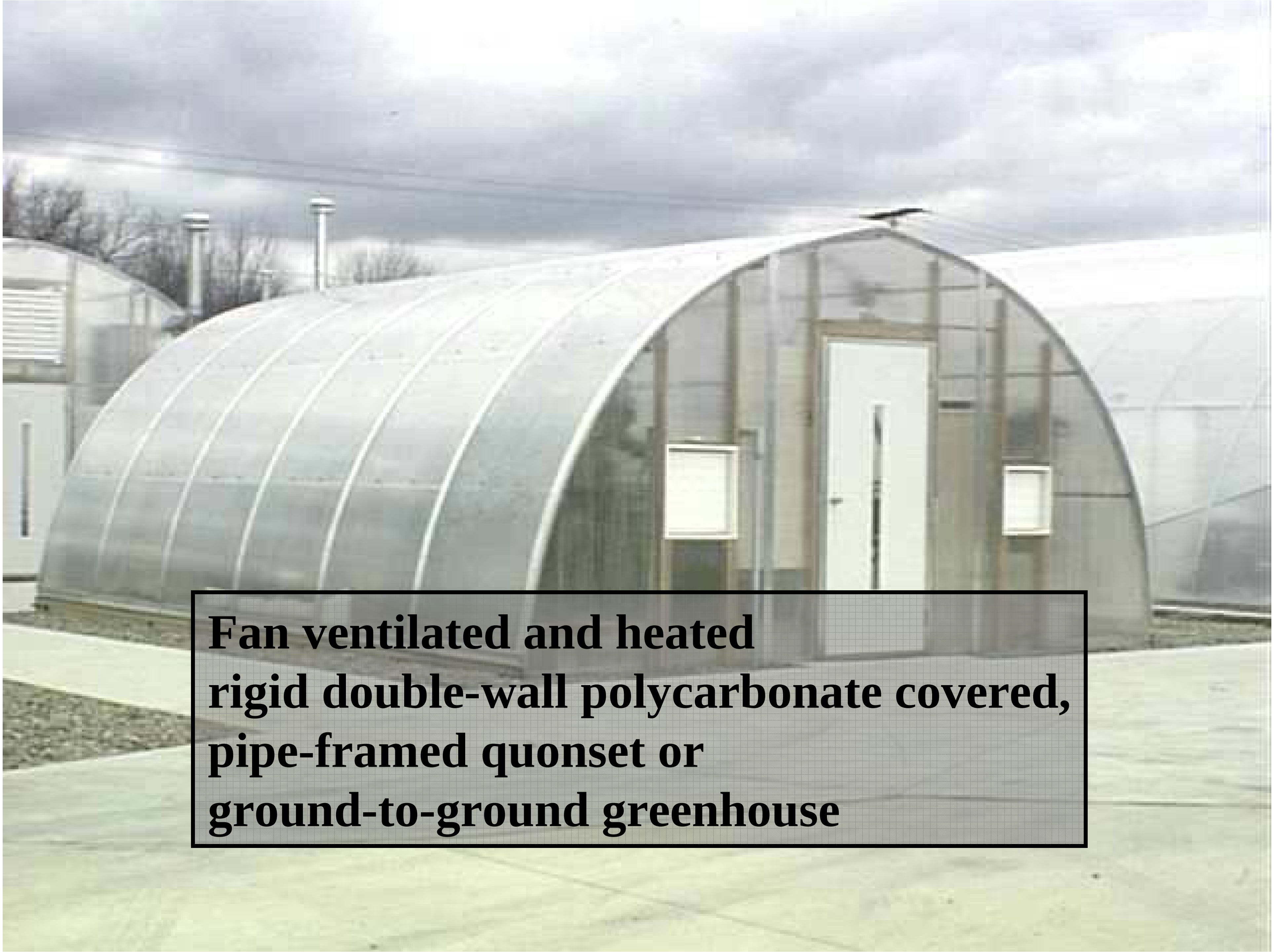
  Since the Structure seems to affect EVERYTHING

- YES! All crops, growing procedures, and management preferences should be decided first!


Polyethylene film covered,
pipe-framed quonset or
ground-to-ground greenhouse
Natural ventilated, with roll-up
sidewalls
Dr. Otho Wells, UNH.



**Fan ventilated and heated
20 by 96 foot polyethylene film covered,
pipe-framed quonset or
ground-to-ground greenhouse**



Fan ventilated and heated rigid double-wall polycarbonate covered, pipe-framed quonset or ground-to-ground greenhouse


Multi-span, gutter-connected saw-tooth design with
rigid single-layer polycarbonate covered,
truss-frame greenhouse
Natural ventilation and fan & pad evaporative cooling


Controlled Environment Plant Production System
Gutter-connected, multi-span,
or ridge & furrow greenhouse
with separated seedling, headhouse and production area
Burlington County Eco-Complex, NJ

2000 Survey by NGMA

U.S. National Greenhouse Manufacturers Association

- **50% of Growers Prefer Gutter-Connected Greenhouses**
- **Remaining Prefer Single Span, Ground to Ground Greenhouses**
- **60% of Growers Prefer Polyethylene Film Covered Greenhouses**

OBJECTIVES
of Facilities Planning

- Grow the maximum plants per unit area per unit time
- Improve crop quality
- Organize/Simplify operations
- Improve management
- Improve labor efficiency
- Improve equipment utilization
- Reduce energy costs (per plant)

In General,

- Capitalize on Expertise of Grower\Manager
- Consider Future Expectations
- Design for Basic Production Necessities
- Design for Future Expansion and Upgrades
- Do Not Block Future Moves
- Select Systems With Immediate Need
- Create “Workable”, Not “Optimal” System

GREENHOUSE PLAN

There are 3 general “locations” within all greenhouses.
They can be arranged in various ways.
They can exist in a number of forms.

- 1 Growing Area
- 2 Work Area
- 3 Connecting Pathways

Growing Area
(production area)

Location where crops are grown (aka Bay)

- **Design for optimal crop growth**
  microclimate
  irrigation

- **Design for labor efficiency**
  floor, benches, overhead, or combination

Work Area

Location where crops are prepared prior to entering the growing area, and prior to shipping.

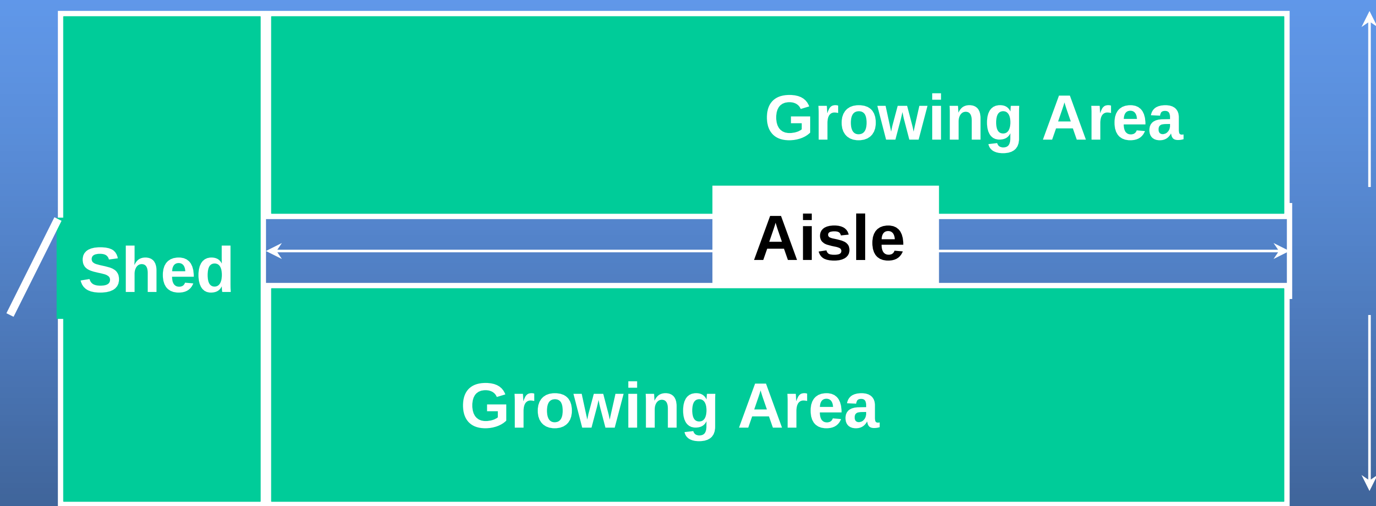
- **Input / Output area of facility. "Headhouse" or Shed**

- **Adjacent to storage / supplies area.**

Connecting Paths

Transportation pathways, walkways, or aisles

- Link work area (input/output) with growing area
- Just like roadways, these can delay transport, or promote efficient traffic movement

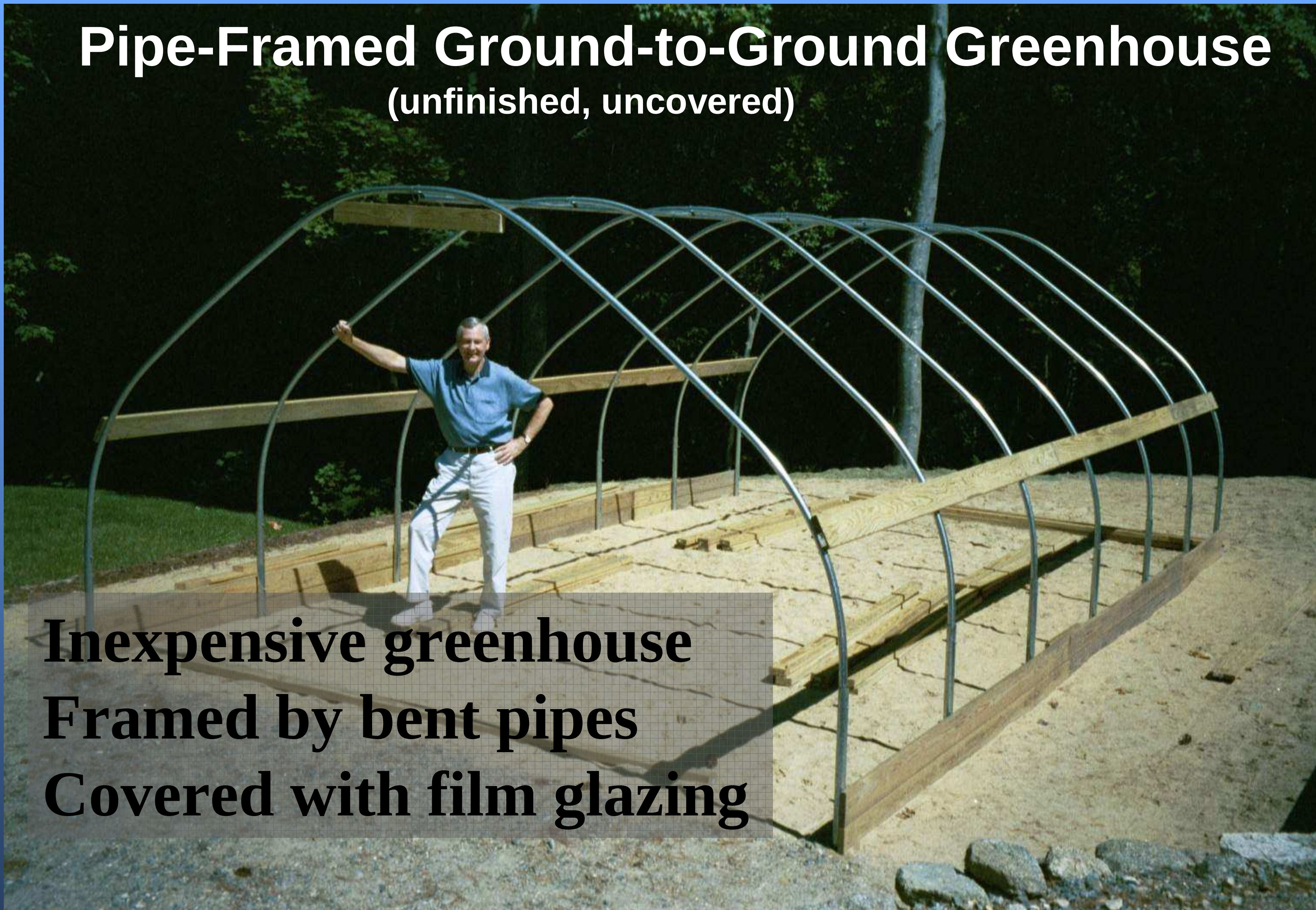


Locations in Greenhouse Plan

[single bay, ground-to-ground greenhouse]

Pipe-Framed Ground-to-Ground Greenhouse

(unfinished, uncovered)



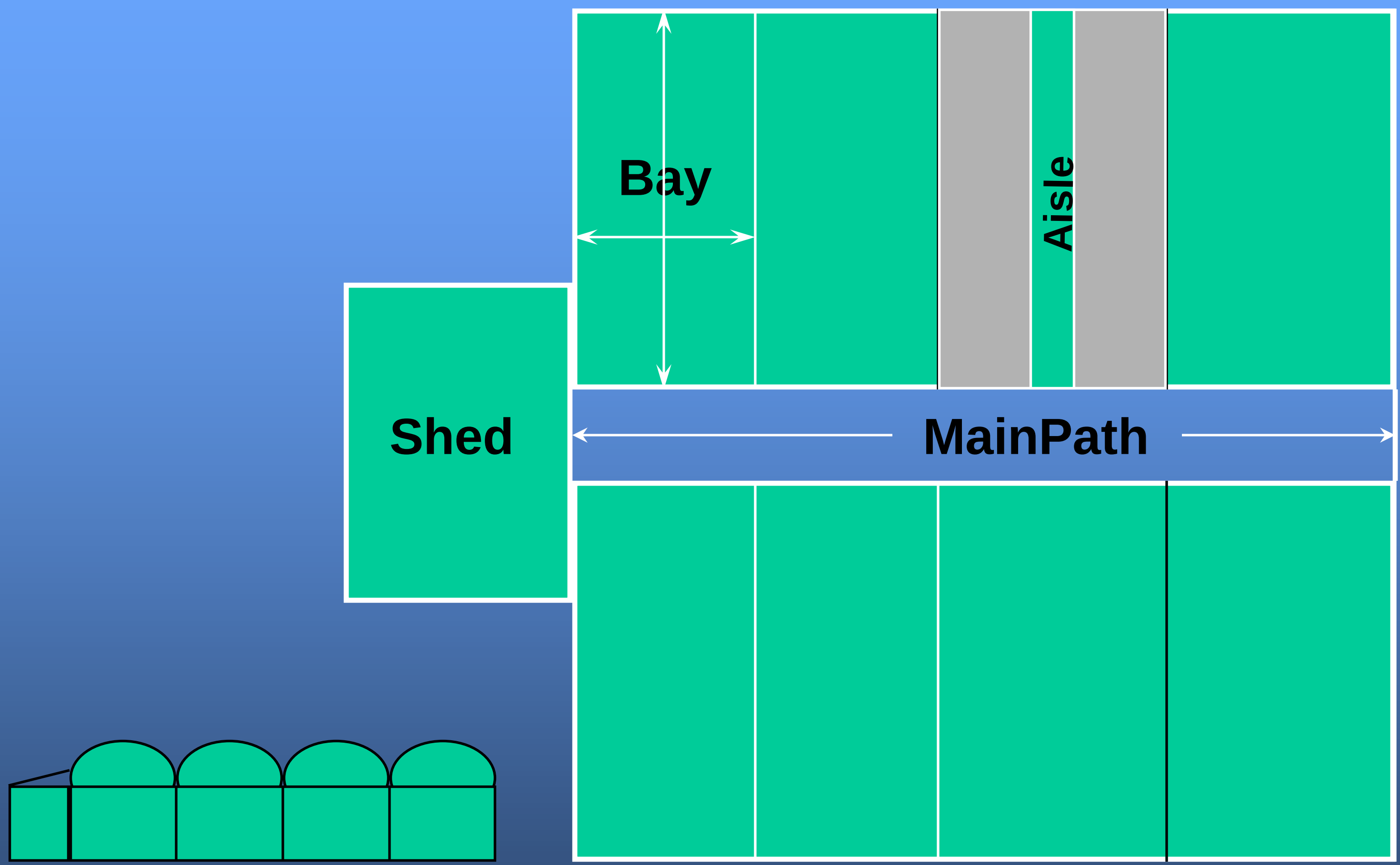
Inexpensive greenhouse
Framed by bent pipes
Covered with film glazing

Dr. Otho Wells, University of New Hampshire

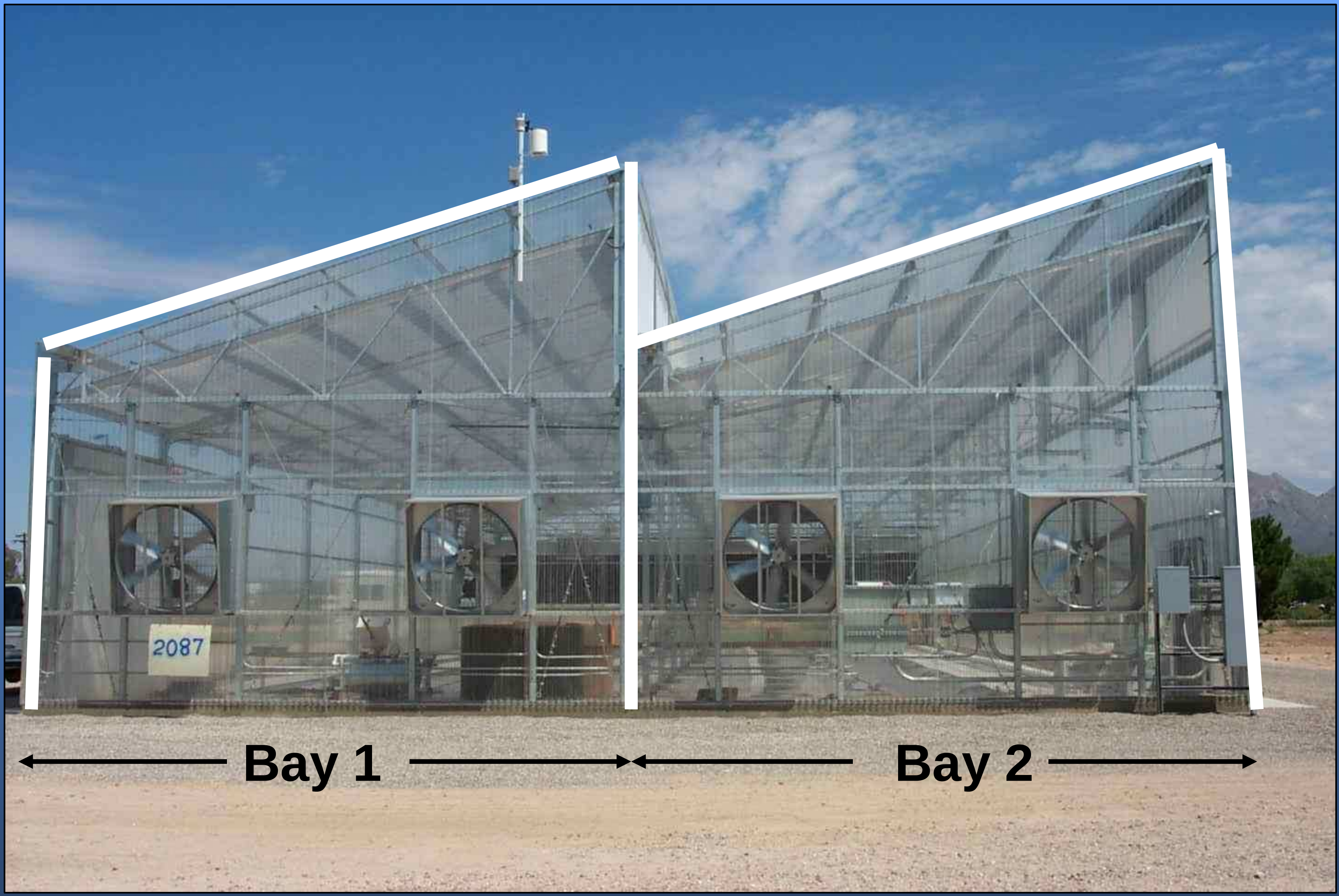
Labor Management, Materials Handling and Economy of Scale is better with Gutter-Connected than with Ground-to-Ground Greenhouses

For "Large" Greenhouse Business, Select a Gutter Connected Structure

Bonita Nursery, Willcox, AZ

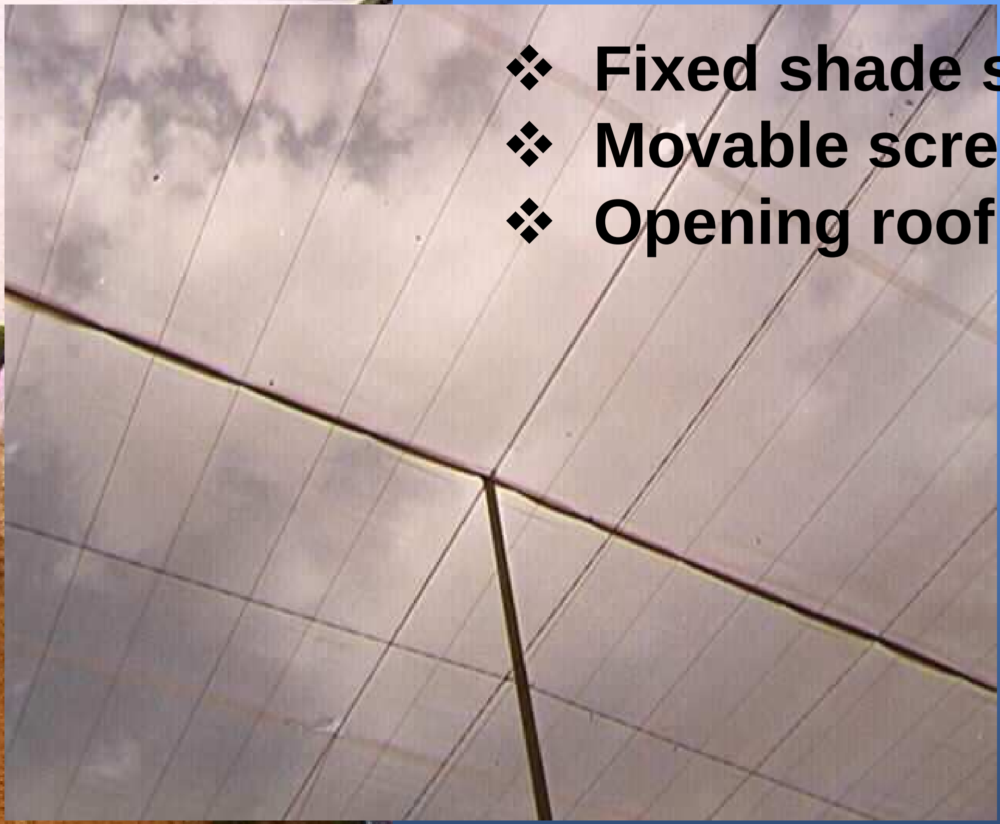


Locations in Greenhouse Plan
[gutter-connected greenhouse]



Multi-Bay, Gutter-Connected

Other structures



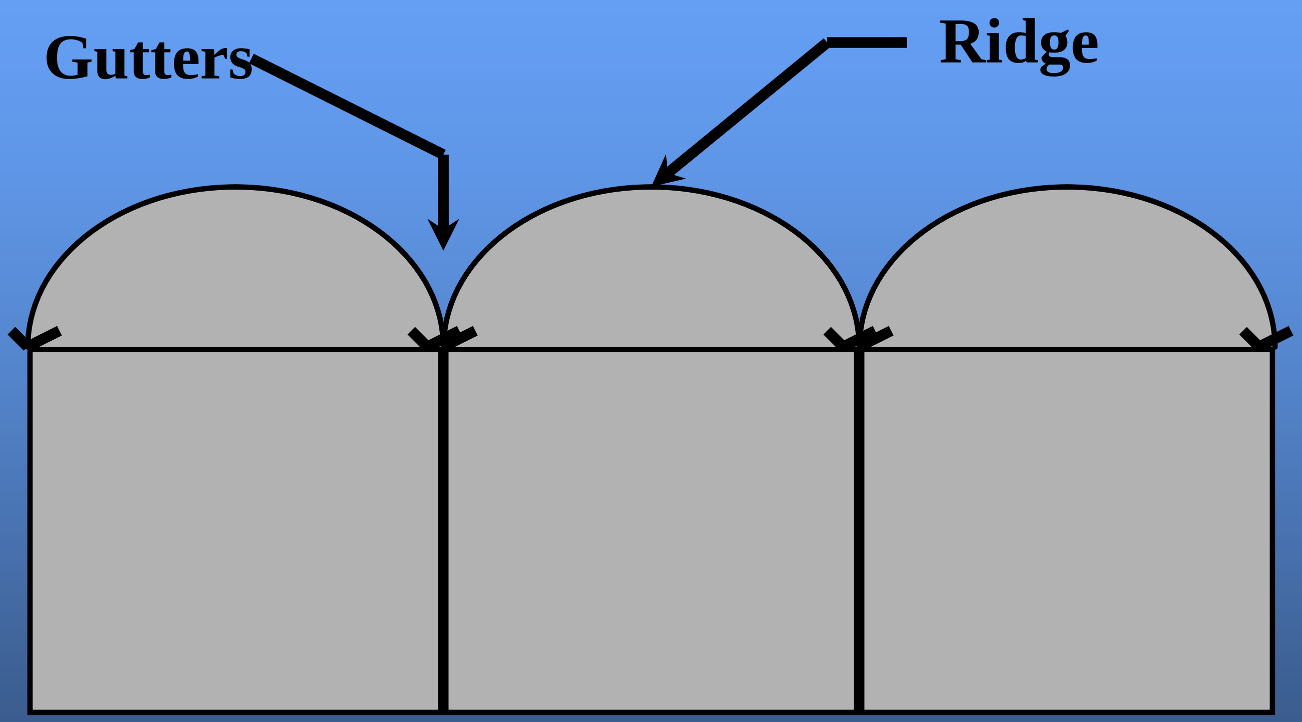
- Fixed shade structure
- Movable screen structure
- Opening roof structure

Tenerife, Canary Islands

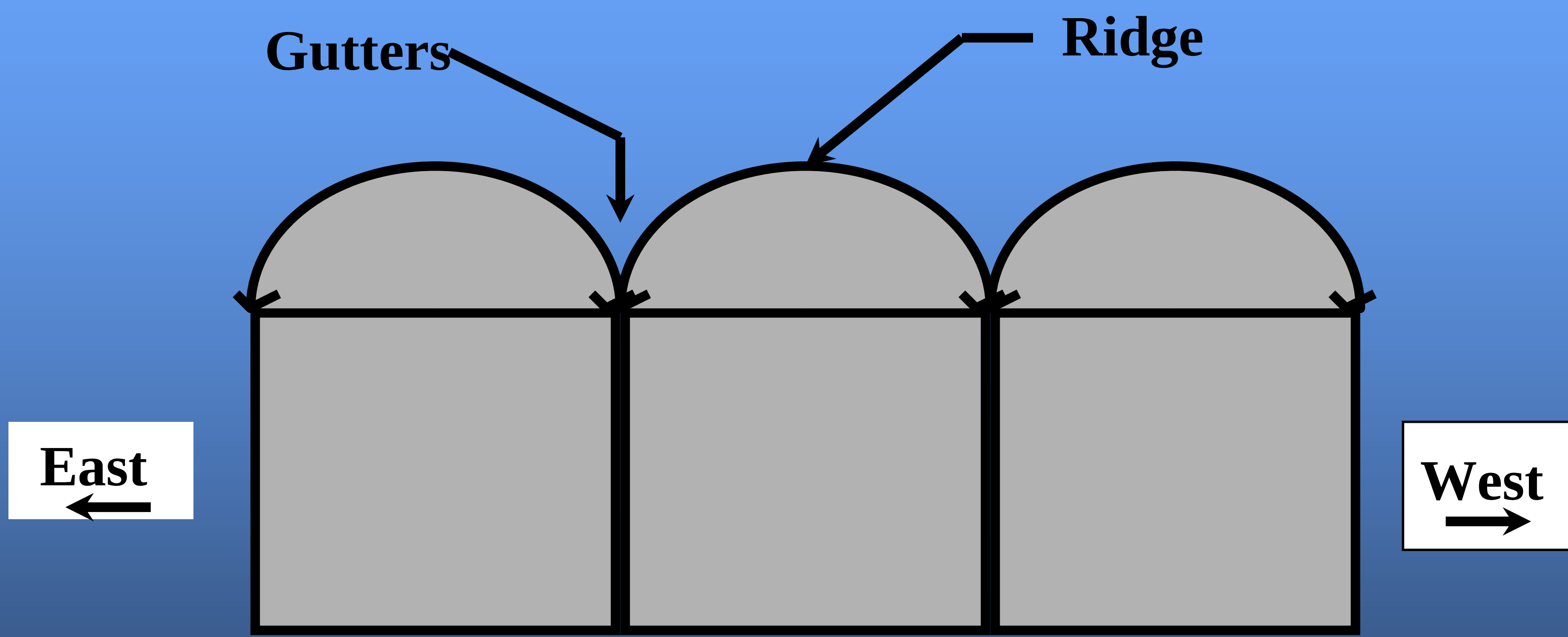
Light Availability to Plants

- Greenhouse Orientation
  Compass Direction of Gutters/ Ridge
  (East-West) or (North-South)

  – Most Total Light per Year N-S
  – Most "Winter" Light E-W
  – Most Uniform Light Distribution N-S

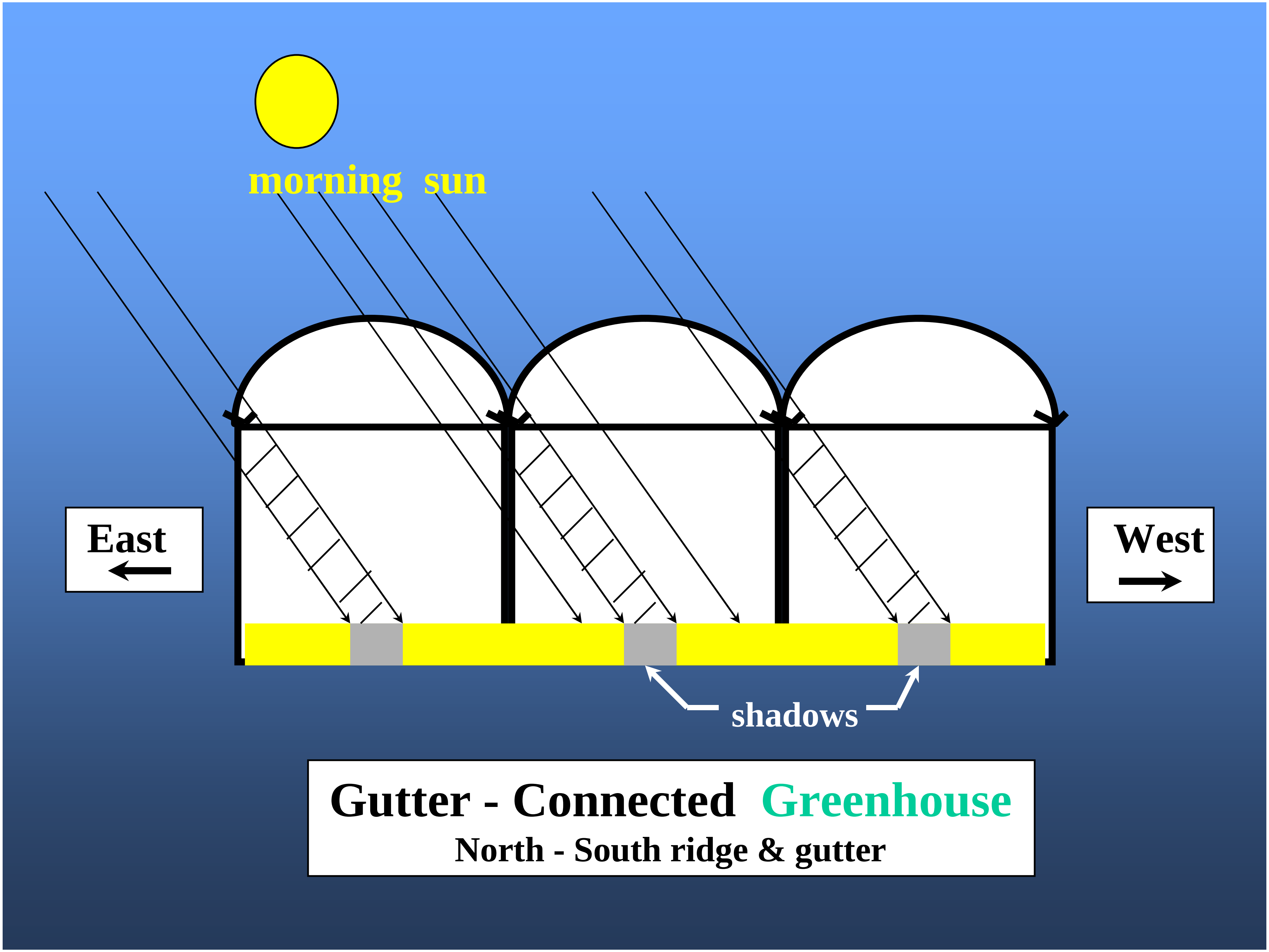


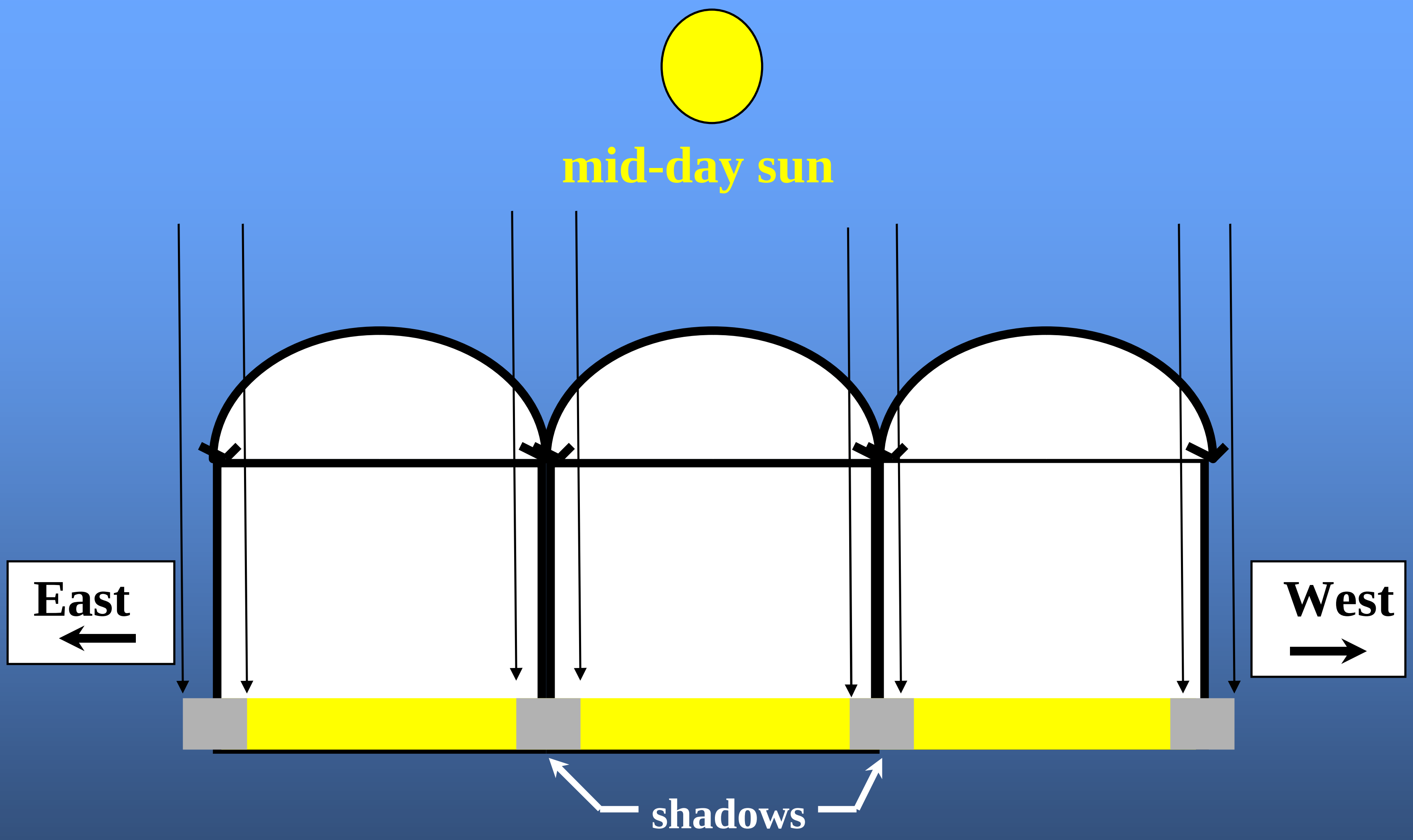
Gutter - Connected Greenhouse



Gutter - Connected Greenhouse

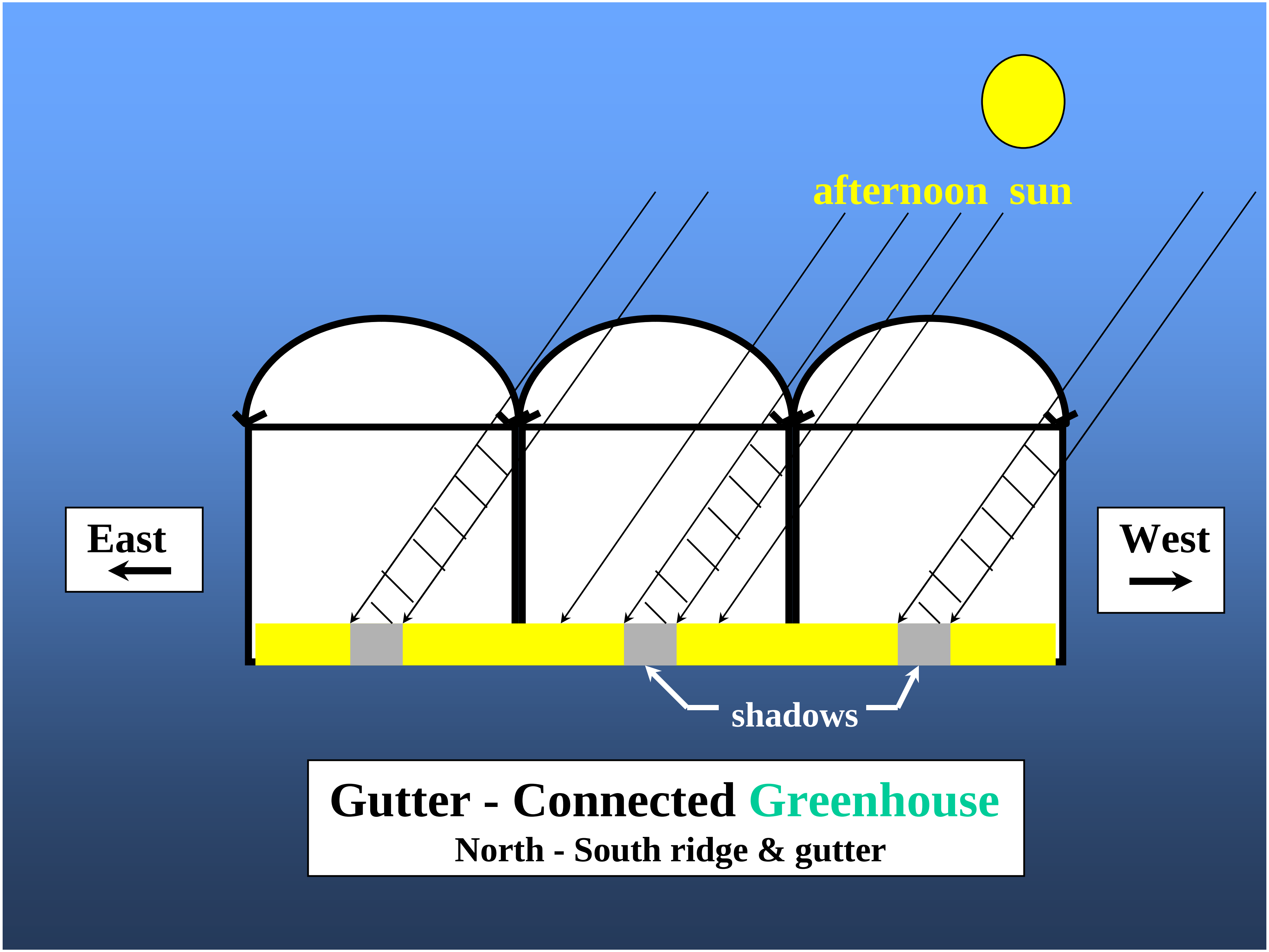
North–South ridge & gutter

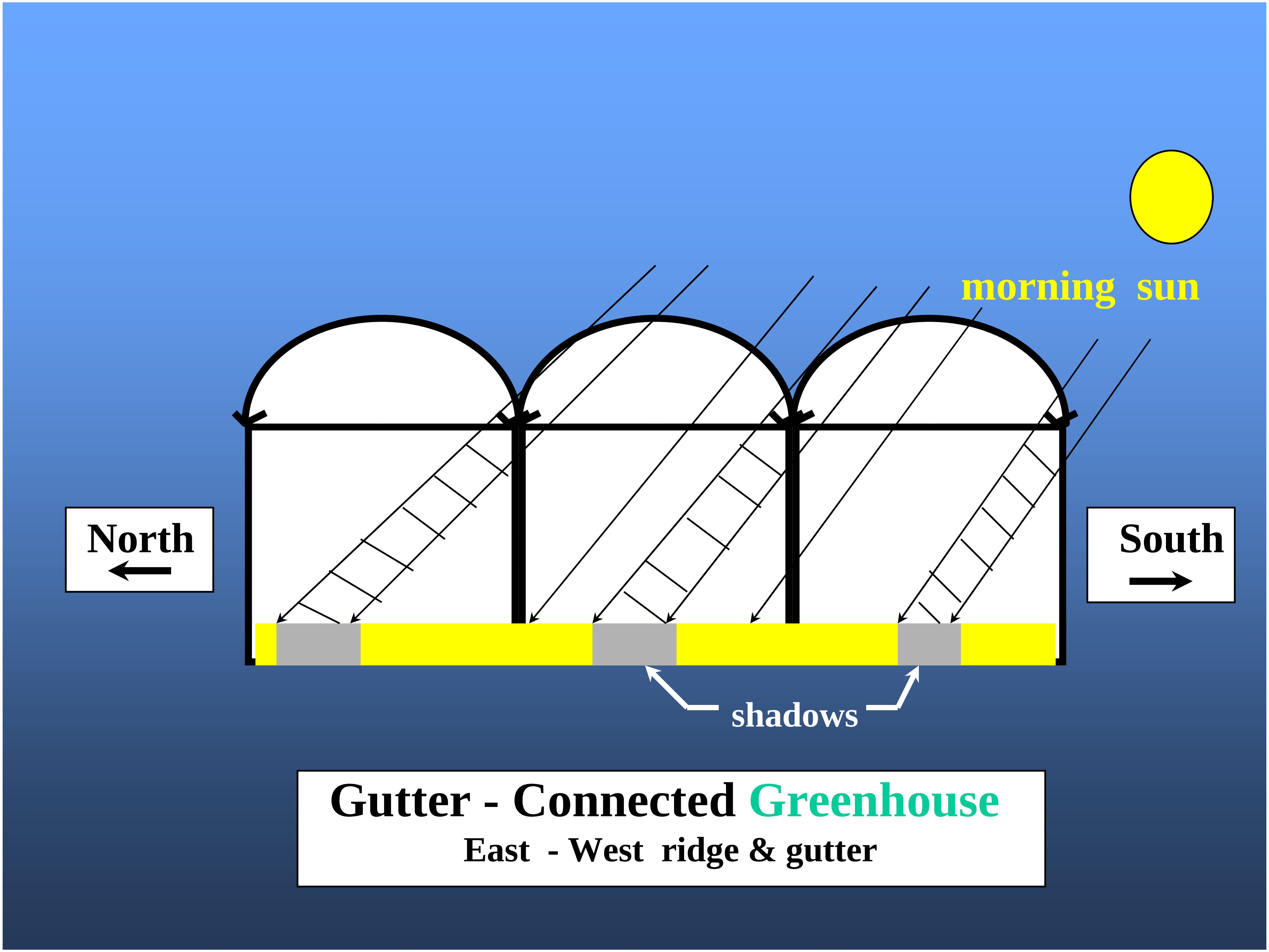

morning sun
East
West
shadows
Gutter - Connected Greenhouse
North - South ridge & gutter

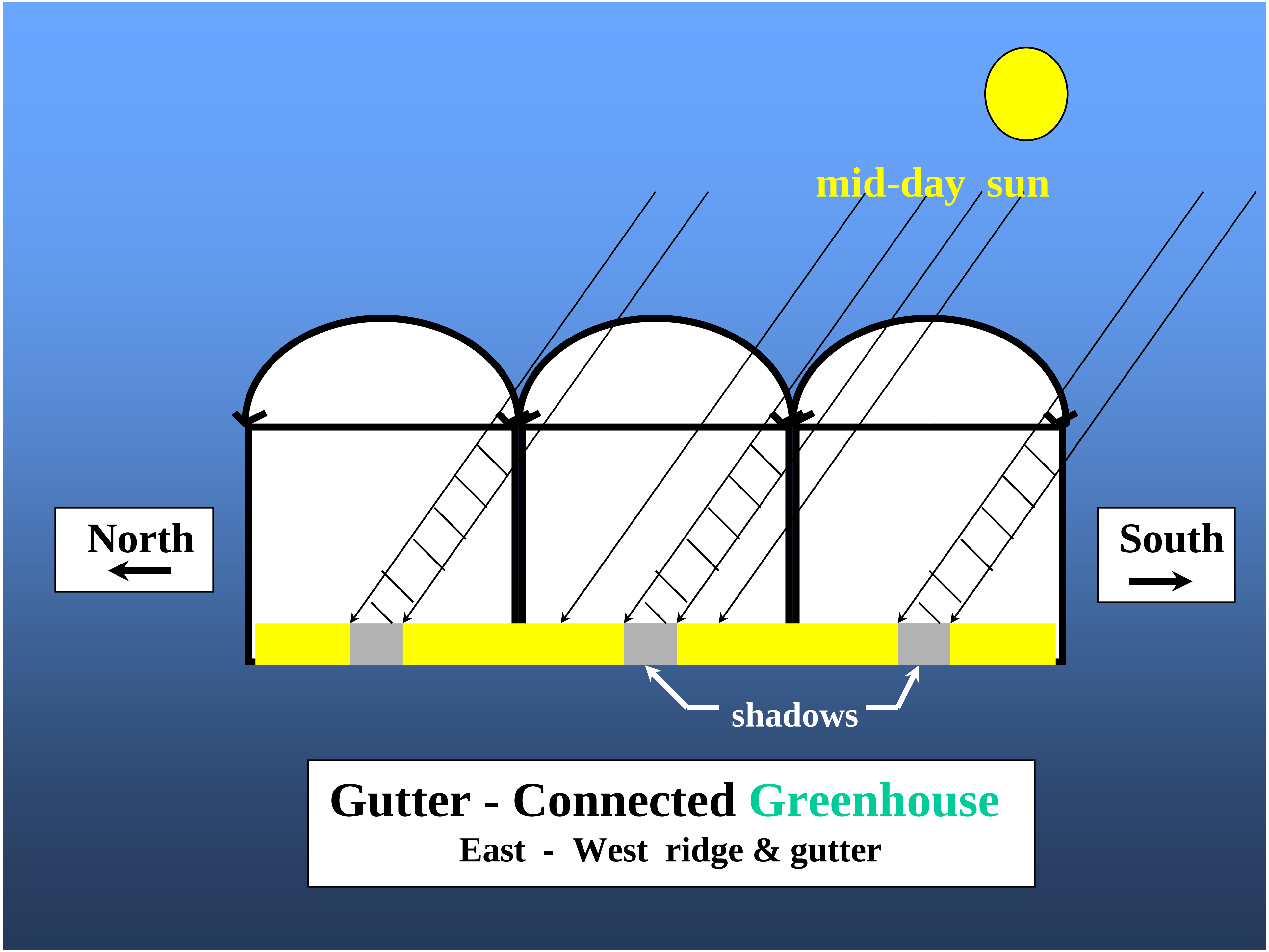


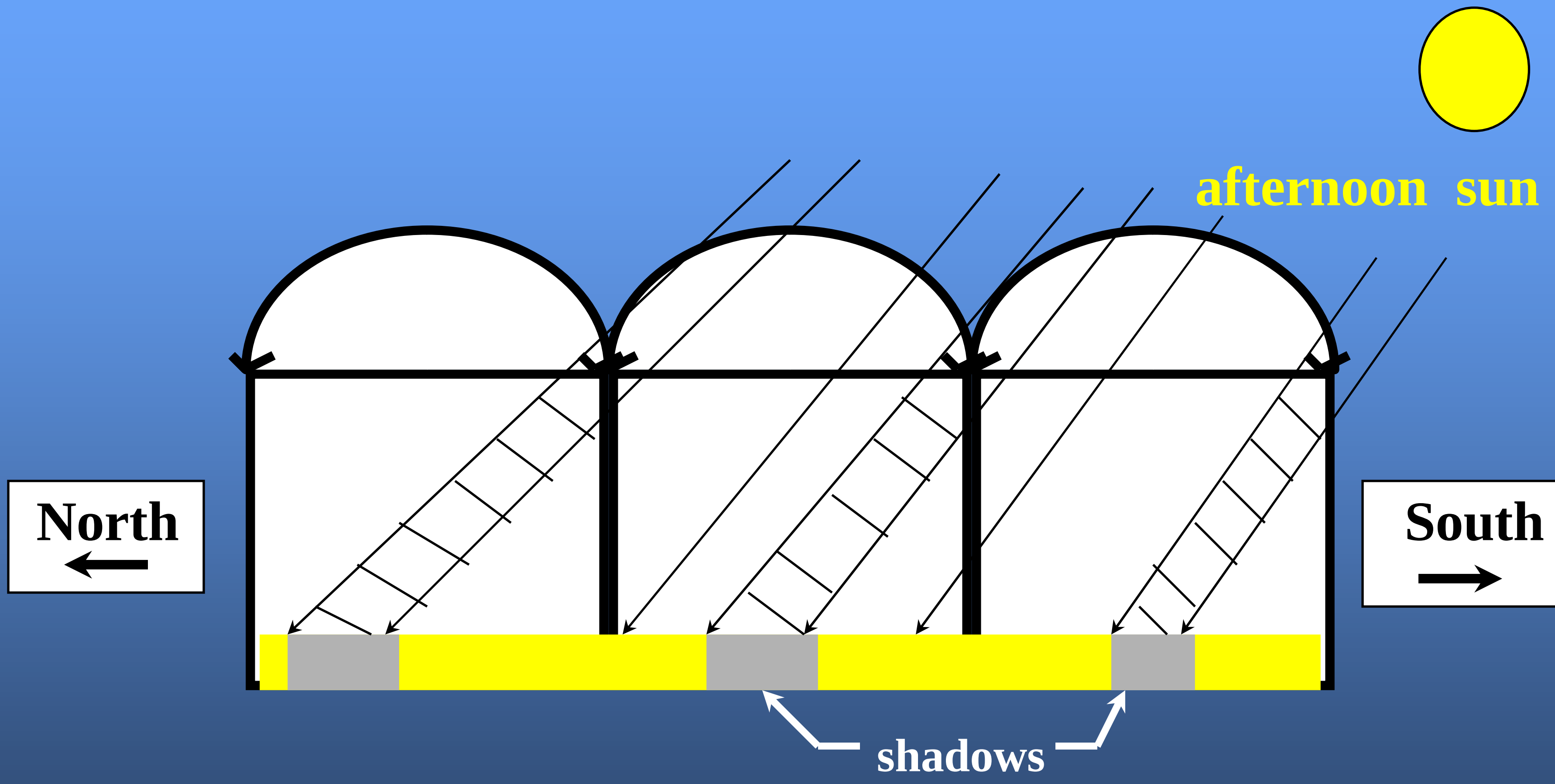
Gutter - Connected Greenhouse

North - South ridge & gutter


afternoon sun
East
West
shadows
Gutter - Connected Greenhouse
North - South ridge & gutter


morning sun
North
South
shadows
Gutter - Connected Greenhouse
East - West ridge & gutter


mid-day sun
North
South
shadows
Gutter - Connected Greenhouse
East - West ridge & gutter



Gutter - Connected Greenhouse

East - West ridge & gutter

Pathway of solar radiation to the plant

1. pass through atmosphere,
2. reach the greenhouse,
3. pass through glazing,
4. around structural framework and overhead equipment,
5. then to the plant canopy

Therefore it is important to consider

- southerly exposure
- free from nearby buildings, groves of trees and
- other obstructions
- obstruction-free northern exposure
  [on cloudy, diffuse days, much light enters from the north]
- greenhouse structure

freestanding, single-bay greenhouse [ground to ground, or Quonset-style] provides more light than a gutter-connected, multi-bay greenhouse

Why?

less overhead structure,

relatively narrow span

gives more glazing area for light reception

Greenhouse compass orientation

affects total light and distribution within the greenhouse

<u>east-west oriented ridge</u>

[large south-facing wall and roof area]

- ❖ good for low sun angle winter sunlight
- ❖ provides most total daily light during the winter season

however,

- ❖ distribution not uniform within greenhouse
- ❖ causes variable plant growth especially for tall crops, if rows aligned with east-west ridge

For best winter light

- freestanding east-west greenhouse
- long, narrow [less than 25 feet wide]
- for short crops like bedding and potted plants, or hydroponic lettuce

Greenhouse compass orientation

affects total light and distribution within the greenhouse

North - South Oriented Ridge

- ❖ For tall crop, grown in gutter-connected, multi-bay greenhouse, orient gutters [or ridges] in north-south direction.

- ❖ The reduction in total light entering the greenhouse in the winter is offset by improved daily light uniformity throughout the growing area.

- ❖ The "movement" of the shadows from the overhead structures as the day progresses from an eastern to western sun location, increases daily light uniformity.

GLAZING

Greenhouse coverings dominated by plastics!

from traditional glass to the polymer plastics
thin films or multi-layer rigid plastic panels

Enhancements include:

- ultra-violet radiation (UV) inhibitors,
- infrared radiation (IR) absorbency,
- anti-condensation drip surfaces
- selective radiation transmission properties.

Decision is influenced by
greenhouse structure and crop production system.

Three categories of coverings used for commercial greenhouses

1. glass
2. plastic films
3. rigid plastic panels

Traditional Glass

Glass is inert, long-lasting, non-combustible, resistant to UV radiation and air pollutant degradation, and provides consistent radiation transmission.

Drawback is vulnerability to hail. Tempered glass has increase strength and size, but costly.

Traditionally small size, but new glass pane dimensions up to 6 ft by 12 ft.

Maintenance is cleaning for radiation transmission and sealing edges for reducing energy losses.

Modern Plastics Alternatives

Rigid plastic structured panels

- fiberglass reinforced polyester (FRP),
  polycarbonate (PC),
- acrylic (PMMA, polymethylmethacrylate)
- polyvinyl chloride (PVC)

Thin films

- low-density polyethylene (LDPE)
- polyvinylchloride (PVC),
- ethylene vinyl acetate copolymer (EVA).

Manufactured in single, double and triple layers

Rigid Plastic Structured Panels

Initially more expensive than polyethylene film
Less maintenance and provide a longer useful life

New construction or glasshouse renovations or
end walls

Acrylic and polycarbonate panels use fewer,
stronger supports spaced wider for reduced shading

Strength from double-walled cross section
and depths up to1.6 cm (0.63 inch).

Plastic panels require more elaborate aluminum
extrusions for attachment to greenhouse

Rigid Plastic Structured Panels

FRP (fiberglass)

- resistance to hail damage,
- degrade on surface, exposes fibers, becomes dirty
- treatment with Tedlar coating

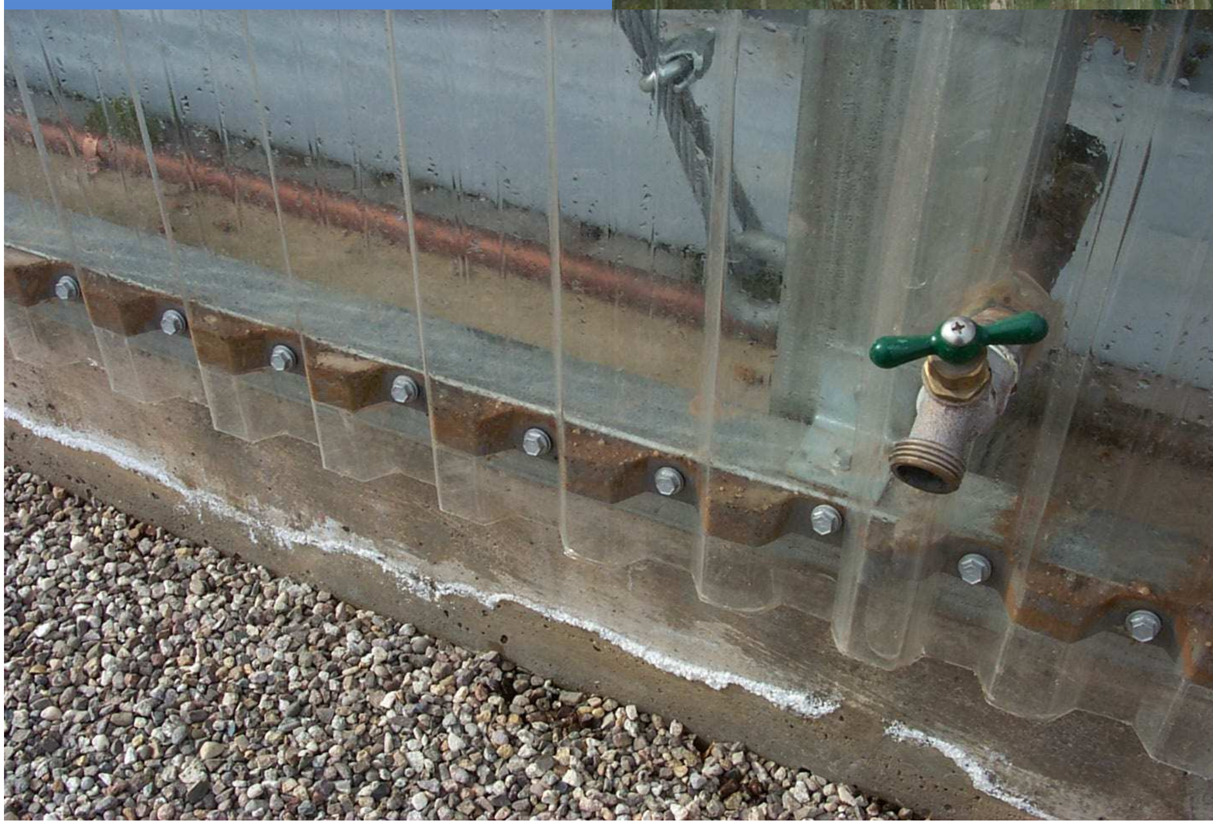
Acrylic and Polycarbonate

- double-walled channel cross section
- light weight, structural strength, and heat savings
- widths 1.2 m (4 ft), lengths 5 m (16 ft) [Acrylic], or 10 m [PC]
- PC thinner cross sections bend into arch roof shape

- UV radiation will discolor PC, if not protected
- co-extrude with acrylic or acrylic coated for UV protection
- corrugated, single-layer cross section
- condensation and algae inside double-walls
- acrylic and FRP will burn, PC will self-extinguish

Double wall, acrylic-coated polycarbonate

Single wall, corrugated polycarbonate sheets



Plastic Thin Films

minimum useful life of 24 months
three and four year films available

Manufacturing

co-extruding and multi-layering

Additives

- ❖ **ethyl vinyl acetate [EVA]**
- ❖ **cracking resistance in cold temperatures**
- ❖ **tear strength (at folds)**
- ❖ **ultra-violet radiation [UV] inhibitors**
- ❖ **infrared [IR] barrier**
- ❖ **condensate control**
- ❖ **wavelength selective transmission [“filter”]**

Plastic Thin Films

Polyethylene film most common

Reliable, low initial cost

Low air-infiltration rates

continuous film offers energy savings

High greenhouse air humidity

Moisture condensation/dripping

avoid -- flattened arch-shaped roofs

Traditionally,

Fan ventilation for cooling, no ridge vent openings

Currently,

Natural ventilated film-covered structures and opening roof greenhouse

Potential Film Problems

- Ultra violet radiation promotes degradation
- Temperature extremes and their duration
- Film contact on greenhouse structure
- Air pollutants reduce radiation transmission
- Chemicals for pest control
- Over-inflation

End

Greenhouse Structures and Glazings

Outline

Introduction

- who’s this guy? What’s he jawing about?

Greenhouse Effect

- Sunlight in---Heat out
- Structure influence – way to introduce GH designs, bench systems
  - ground to ground, multi-span, opening roof
- Glazing influence – introduce alternative types, pros/cons

Ventilation and Cooling

- procedures to offset the greenhouse effect
- ventilation -- for air exchange, etc
  - natural, forced air, screened
- evaporative cooling -- for reducing air temperature, etc
- shading -- prevent solar radiation

Heating

- air heating -- by hot air, by hot water
- root zone heating -- bench or floor systems

Environmental Monitoring and Control

- from thermostats to computers

Nutrient Delivery Systems

- Benches & Floors -- irrrigation, space utilization
- Supplemental Lighting, CO2 Enrichment

What's A Photon?

As Wavelength increases, the Energy decreases

As Wavelength decreases, the Energy increases

Therefore,
the longwave [Red] has _ _ _ _ energy than
the shortwave [Blue]?

$$\text{Energy} = \frac{h\ c}{\text{wavelength}}$$

What's A Photon?

As Wavelength <u>increases</u>, the Energy <u>decreases</u>

As Wavelength decreases, the Energy increases

Therefore,
the longwave [Red] has <u>L</u> <u>E</u> <u>S</u> <u>S</u> energy
than
the shortwave [Blue]?

$$\text{Energy} = \frac{h\ c}{\text{wavelength}}$$