Greenhouse Structures

Steven E. Newman, Ph.D.
Colorado State University Cooperative Extension
Horticulture and Landscape Architecture
Glass Greenhouses

• Glass was the only choice until the 1950s
• Advantages
  – Greater light intensity over plastic panels and film plastic
  – More air exchanges with glass
    • Lower relative humidity
    • Less disease
    • Greater evapotranspiration
Glass Greenhouses

• Disadvantages
  – More “leaks” – greater heat input
  – Higher initial cost compared to plastic
    • Initial cost vs. long-term
    • Maintenance
    • Plastics require recovering
Glass Greenhouses

- **Lean-to**
  - Placed against an existing wall
  - Typically facing south
  - Common for institutional or hobby greenhouses
Glass Greenhouses

• Even-span
  – Two slopes of equal pitch and width
  – Most common configuration
Glass Greenhouses

• Uneven-span
  – Roofs of unequal width and pitch
  – Adaptable to slopes
  – Good for high latitude sites
Glass Greenhouses

- Ridge and Furrow
  - Multiple A-frame spans connected along the eaves
  - Gutters placed at junction of eaves
  - Also termed gutter connect
Glass Greenhouses

• Frame types
  – Wood frames
    • < 20 ft. wide
  – Pipe Frames
    • Up to 40 ft. wide
    • Side posts, columns, cross ties, and purlins from pipe
Pipe Frame Greenhouses

A

Purlin (Pipe)
Glass
Sash Bar (Wood)
Rafter (Pipe)

B

Purlin (Steel)
Glass
Sash Bar (Wood or Aluminum)
Rafter (Steel)
Glass Greenhouses

• Truss frames
  – Flat steel, tubular steel, or angle iron used to form truss
  – Most glass houses use truss frames
Glass Greenhouses

- Glass attachment
  - Placed upon sash bars with putty
  - Most sash bars are aluminum
    - Stronger = less superstructure per unit of glass
    - Reflective = more light than painted wood
    - Less maintenance than wood
Sash Bars

Diagram showing the components and labeling of sash bars with details like '27 down (31)', '56 screen (26)', '4 screen (53)', '33 down (55)', '5 down (35)', '23 down (53)', '14 down (25)', '27 down (31)', '10 screen (37)', and '4 screen (53)'.
Glass Greenhouses

• Glass types
  – 16-inch up to 39-inch pane widths
    • Wider panes = more light
    • Mainly double strength
  – Float glass is mainly used in U.S.
    • 88% light transmission
  – Low iron glass
    • 90-92% light transmission
    • More expensive
Glass Greenhouses
Glass Greenhouses

- Tempered glass allows wider panes
  - Up to 6 by 13 feet
  - Bent to a curve
  - Fewer seals between eaves and ridges
  - Can be bent to a curve
Glass Greenhouses
Tempered Glass
Glass Greenhouses

- Roof styles
  - Low profile roof
  - Venlo
  - Single panes from eaves to ridge
  - Smaller pitch angle
  - Less roof area
  - Less heating cost
Glass Greenhouses

• Roof styles
  – High profile
  – Large pitch angle
    • 6 x 12
  – Large roof area
  – Greater heating costs
Hail Damage
Snow Damage
Film Plastic Greenhouses
Film Plastic Greenhouses

*Polyethylene*

- Major film used in U.S.
- 6-mil exterior
  - 4-mil interior
  - Double layer for insulation
- UV inhibitors to increase life span
  - 3-5 year life
  - Anti-fog materials to prevent condensation
  - IR blockers = less heat loss
Film Plastic Greenhouses

- IR blockers to prevent heat loss
  - Short wave energy into greenhouse
  - Surfaces radiate IR radiation
  - Films block re-radiation
Film Plastic Greenhouses

*Polyester*
- Mylar
- Too expensive for glazing, but is used for shade cloth materials
- Retractable roof material
Film Plastic Greenhouses

Frame Types

- A-frame not the best (hard to cover)
Film Plastic Greenhouses

Frame Types
• Quonset
  – Bent bows using steel pipe or square steel tubing
  – 20-30 ft. width
  – Ground to ground
Film Plastic Greenhouses

Frame Types

- Gutter-connected
- Sidewalls of 8-14 feet
- Can be roll-up
- Usually rigid plastic
- Quonset-arch
- Gutters
  - 6-inch/100-ft slope
Film Plastic Greenhouses

Frame Types
- Gutter-connected venting
Film Plastic Greenhouses

Frame Types
• Saw tooth venting
Film Plastic Greenhouses

*Double-layer Covering*
- Two layers with air pocket in between
- Attached with clamping channel or batten strips
Polylock
Film Plastic Greenhouses

Reinforced polyethylene
Film Plastic Greenhouses

*Double-layer Covering*

- Plastic expands and contracts with temperature changes
  - Leave 2-3 inches or more when warm
  - Pull plastic tight when cold
- Air space (inflated)
  - 4-inches
  - Not too much – Not too little
Inflation Fan
Rigid-Plastic Greenhouses

*Fiberglass Reinforced Plastic (FRP)*

- Less popular in the past
- Flexible and can be bent over a Quonset frame
- More resistant to glass to breakage
- More light diffusion than glass
Rigid-Plastic Greenhouses

**Fiberglass Reinforced Plastic (FRP)**

- Surface easily abraded
  - Results in a pitted surface
  - Frayed fibers “bloom”
  - Gather dirt and debris
- Transmits 88% PAR
- Light – less structure
Rigid-Plastic Greenhouses

*Fiberglass Reinforced Plastic (FRP)*
Rigid-Plastic Greenhouses

Fiberglass Reinforced Plastic (FRP)
Rigid-Plastic Greenhouses

*Fiberglass Reinforced Plastic (FRP)*

- Bows / trusses / rafters placed 8 to 10 feet apart
- Distance between purlins is dependent on:
  - Weight of FRP used
  - Live load
- FRP is very flammable
Rigid-Plastic Greenhouses

*Polycarbonate*

- Considered relatively new
- 10-year life span guarantee
- Widely used to glaze end walls and gables of Quonset houses
- Easily retrofitted to glass houses
- High impact resistance
- UV protectant added to most products
Rigid-Plastic Greenhouses

Polycarbonate

- Available as:
  - Corrugated
  - Double wall
  - Triple wall
- PAR light transmission about 79%
- Not considered flammable
Rigid-Plastic Greenhouses

Extruded aluminum locks and seals
Rigid-Plastic Greenhouses
Rigid-Plastic Greenhouses

**Acrylic**

- Good PAR transmission – 83%
- Very flammable
- Guaranteed for 10 years
- More resistant to breakage than glass, but less than polycarbonate
- Attachment similar to polycarbonate
Orienting a Greenhouse

- Want to maximize light (and uniformity of light)
  - Percent light entering a greenhouse depends on “angle of incidence”
    - Angle that a light ray striking a surface makes with a line perpendicular to the surface
    - An angle of incidence=0° allows the most light to enter the surface
    - Reflective loss increases as AOI increases (up to 90°)
Reflection
Orienting a Greenhouse

• Above 40° latitude:
  – Run ridges of single-span houses E-W to maximize light intensity
  – Run ridges of multi-span houses N-S for light distribution
    • Must accept lower winter light transmission to avoid shadow pockets
    • N-S ridge and gutter shadows “move” but E-W shadows do not
Angle of Incidence during winter at a high latitude
Orienting a Greenhouse

• Below 40° latitude:
  – Run ridges of all houses N-S
  – Better light distribution (moving shadows) is more important than light transmission optimization
  – Remember: WINTER light is the factor
Angle of Incidence during winter at a low latitude

- Imaginary line perpendicular to the roof surface
- Angle of incidence

Our Greenhouse

Angle of Incidence is smaller so light entering greenhouse is greater
Greenhouse Floor Plans

- Plan for “ultimate size”
- Plan for materials and product movement
  - Height of carts
  - Width for passing carts
  - Paved aisles / monorails
Carts
Monorails
Conveyer
Conveyers
Conveyer
Basket Lines
Moving Tables
Cut Flower Beds

*Height dependent*

- Tall crops
  - Typically grown on or in the ground
  - Roses, carnation, tomatoes, and peppers
Cut Flower Beds

*Height dependent*

- Medium height crops
- May be grown in raised benches
- Consider harvest techniques
- Chrysanthemums, snapdragons, and lilies
Cut Flower Beds

**Height dependent**

- Some crops require trellising
  - Tall crops require wire supports to prevent crooked stems
  - Select material allowing easy handling and convenient access
  - Roses and carnations
Cut Flower Beds

*Height dependent*

- Trellises require bracing to support weight
  - Greenhouse structure not the best choice
  - Adds to the dead load of the structure
Cut Flower Beds

*Height dependent*

- Climbing or vine crops use vertical netting or frames
  - Sweet peas
  - Tomatoes
  - *Stephanotis*
Cut Flower Beds

*Width dependent*

- Consider the length of a worker’s reach
- Accessible from both sides - 42 in.
- Accessible from one side - 18-20 in.
Construction - Cut Flower Beds

Growing directly in the ground

**Advantages**
- Cheapest construction
- Long term installation
- Easily modified for organic production
- Easily modified for other crops

**Disadvantages**
- Requires soil amendment
- Root spread not contained
- Exposure to potential pathogens in soil
- Drainage tiles may be required
- May result in non-point source pollution
Construction - Cut Flower Beds

- Isolate from native soil
  - Prevent root spread
  - Prevent pathogen exposure
  - Prevent co-mingling of roots
Construction - Cut Flower Beds

Typical ground bed

- Amended soil
- Native soil
- Gravel drainage
- Drainage tile
Construction - Cut Flower Beds

*Perched water table*

- Amended soil
- Perched water table
- Interface must be at saturation in order for profile to drain

![Diagram of perched water table](image)

The diagram shows a perched water table requiring saturation before leaching to the next layer.
Construction - Cut Flower Beds

**Concrete ground bed**

- Soil-borne disease
- Concrete prevents root egress
- Drain tile to remove excess water
- Pasteurization
- Raised edge to prevent debris
Construction - Cut Flower Beds

- Run beds the length of the greenhouse
- Narrow walks (18”) allows for 67% space use
- Orient north to south to maximize light penetration

Diagram:

- Cut flower beds
  - North
Benches, Beds and Floors

*Function Defines Structure*

- Potted Crops and Bedding Plants
  - Raised benches
  - Ebb and Flood (flow) tables
  - Trough systems
  - Flood floor systems
Benches - Potted Crops

- Raised benches
- Height should be adapted to worker height – 32 to 36 inches high
  - Width
    - One side - do not exceed 3 feet
    - Two sides - do not exceed 6 feet
    - Wider widths reduce labor efficiency
Benches - Potted Crops

• Air circulation
  – Bench top material must allow for air circulation
  – Bench top material must allow for water drainage
  – No sides
    • Reduces labor efficiency forcing a worker to lift a pot or tray over an edge
    • Reduces air circulation
Benches - Potted Crops
Benches - Potted Crops

• Construction Materials
  – Wire mesh or expanded steel (galvanized)
  – Redwood lath
  – Bench tops may be supported by concrete blocks, wood framing or steel framing
  – Provide support to prevent sagging
Benches - Potted Crops

- Peninsular layout
  - 80% of space use
- Benches typically run across width of greenhouse
- Aisles 18 in. wide
- Center aisle
  - 3-4 feet for carts
  - 8 foot for vehicles or larger transport systems
Fixed Bench Tops
Fixed Bench Tops
Under Bench Area Important
Benches - Potted Crops

- Moveable benches
  - 90% or more space use
  - One aisle, several benches
  - Each bench allowed to move opening a space
Rolling Top Benches
Rolling Top Benches
Rolling Top Benches
Moving Benches

- Bench moves on trolley
- Bench moves in and out of greenhouse
- Benches moved to worker for plant handling
- Adaptable to high degrees of automation
  - High initial investment
  - Low labor input
Moving Benches
Moving Benches
Ebb and Flood Tables and Floors

• Water tight benches allowing periodic flooding with water and fertilizer
• Trough systems
  – a modification of water tight benches where narrow troughs are used to hold plants for periodic flooding with water and fertilizer, allowing air circulation
Ebb and Flood Tables
Ebb and Flood Tables
Ebb and Flood Tables and Floors

• Flood floor systems
  – Floors designed for periodicflooding with water and fertilizer
  – Closed system preventing waste and point source pollution
    • Water
    • Nutrients
    • Pesticides
Capillary Mat Tables
Flood Floors
Floor Production
Floor Production
Hanging Basket Lines
Hanging Basket Lines