High Tunnel Heating Alternatives

by
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for
Midwest Winter Vegetable
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What We’ll Discuss

• Site selection and energy considerations
• Structural approaches for saving energy
• Technological approaches for saving energy
What is a High Tunnel?

• Unheated greenhouse; same as “hoop house”
  – Not for year-round protection or production
• Uses solar heat (back-up heaters optional)
• No electricity (fans, heaters, vents, etc.)
• Vented through sidewalls or end walls
• Drip irrigated
• Ground culture
• Single layer of plastic (6-mil)
High Tunnels - Advantages

• Extends growing season 4 weeks (maybe more)
  – Night-time air and soil temps indoors average 4°F higher than outdoors
  – Increases production & marketing opportunities
  – Offers shelter from wind, hail and insects, and can reduce disease pressure
  – Gives ability to control water supply

• Many designed as “drive through” for use of field equipment
High Tunnels - Disadvantages

• Labor-intensive; requires regular monitoring of temperatures
• Heavy rain, snow or wind can damage them
• High humidity early in growing season can lead to increased disease problems
• Construction requires more startup costs compared to conventional outdoor production
• Have to water crops, even when it rains
Greenhouse Energy Use

• Energy
  – 3rd largest cost (~15%)
    • 70-80% for space heating
    • 10-15% for electricity

• The Agronomic-Economic Balance
  – Light transmission for plant growth
  – Environmental factors – humidity, temperature
  – Structure cost
  – Operating costs
Site Selection and Energy Considerations
High Tunnels - Orientation

Without Solar Energy there is nothing

Wisely choose location
Orient the structure
  E to W for Oct – May
  N to S for year round production; most yearly light
Solar angle more critical than type of glazing for sunlight

Almeria, Pennsylvania 1999

Source: Gene Giacomelli - University of Arizona
High Tunnels - Location

• Place on 0-1% slope, well-drained, accessible site
• For stationary unit, plan to amend the soil each season or year to maintain fertility
• Orient perpendicular to the prevailing winds on your farm
  - All ventilation is manual, so you depend on the wind to ventilate
  - Face end wall toward winter wind
  - In Missouri, for our S-SW summer winds, use north-south orientation
What is the Best Location?

• Site selection factors
  – Availability of sunlight (8-10 hours/day)
  – Topography (near-level building site)
  – Wind break or hill to north (reduce heat loss)
  – Proximity to trees
  – Drainage (inside & outside)
  – Logistical convenience
  – Aesthetics

Decision usually permanent
Wind Breaks

- 15 mph wind doubles heat loss
- Wind break reduces loss ~ 5-10%
- Reduce snow accumulation
- Wind damage

H = Mature Height of Trees

50% speed reduction

4 to 6 x H

Prevailing Wind

4-5 rows
Mixture: Coniferous & Deciduous

Fast growing trees
Principles of Heat Loss

• Conduction
  – Heat conducted through a material
  – U-value – BTU/(hr-°F-sq.ft.)

• Convection
  – Heat exchange between a moving fluid (air) and a solid surface
  – Not of importance where fans are used

• Radiation
  – Heat transfer between two bodies without direct contact or transport medium – Sunlight

• Infiltration
  – Exchange of interior and exterior air through small leaks/holes in building shell
Calculating Heat Requirements

Basic equation =

sq. ft. greenhouse surface x temperature difference (inside temp.* minus outside temp.**) x 1.2 = BTU/hour heat needed

*Desired temperature in greenhouse

**Average low outside temperature for area
Example Heat Requirements

Assumptions:
Free-standing greenhouse
10’ W x 12’ L x 6’ H with
6/12 roof pitch

Calculations:
Sides: 2 x 6’ x 12’ = 144 sq.ft.
Ends: 2 x 6’ x 10’ = 120 sq.ft.
Roof: 2 x 5.5 x 12’ = 132 sq.ft.
Roof peaks: 2 x ½ x 10’ x 2.5 ‘ = 25 sq.ft.
TOTAL = 421 sq.ft.

421 sq. ft. x (65°F - 10°F) x 1.2 = 27,786 BTU/hour
heat needed

(about the same heating needs as 1,350 sq.ft. insulated home)
Example Heat Requirements

Assumptions:
Free-standing high tunnel
30’ W x 72’ L x 5’ H sidewall with
12.5’ H ~28° Gothic roof pitch

Calculations:
Ends:  \(2 \times ((5’ \times 30’) + (7.5’ \times 30’/2))\) = 525 sq.ft.
Sides: \(2 \times (5’ \times 72’)\) = 358 sq.ft.
Roof: \(2 \times (15.4’ \times 72’)\) = 2218 sq.ft.
TOTAL = 3100 sq.ft.

3100 sq. ft. \(\times (45^\circ F - 10^\circ F) \times 1.2\) = 130,200 BTU/hour
heat needed

(about the same heating needs as four 1,600 sq.ft. insulated homes)
Structural Approaches for Saving Energy
## Frame Shape

<table>
<thead>
<tr>
<th>Shape</th>
<th>Easy to construct</th>
<th>Holds up well in wind</th>
<th>Sheds snow moderately well</th>
<th>Less area for tall crops</th>
<th>Less expensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quonset</td>
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<tr>
<td>Gothic</td>
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<tr>
<td>Gable</td>
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</tr>
</tbody>
</table>

### Quonset
- Easy to construct
- Holds up well in wind
- Sheds snow moderately well
- Less area for tall crops
- Less expensive

### Gothic
- More difficult to construct
- Stands up in wind moderately well
- Sheds snow well
- More growing space for tall crops
- More expensive

### Gable
- More difficult to construct
- Does not hold up in wind as well
- Sheds snow well
- More growing space for tall crops
- More expensive
Frame Shape

• Sidewall height
  – Shorter walls require less heat in spring/fall
  – Taller walls give easier equipment access
  – Taller walls easier to ventilate summer heat

• Length
  – 2:1 length to width for temperature management
Layers of Plastic

- Single layer poly
- Double layer poly
- Dead air space provides insulation (4” max.)
- Inflating devices may be AC, DC solar electric, air-driven motors, or wind-driven passive systems
Factors affecting Solar Gain

• % light = % growth
• Glazing transmittance
  – Differences between materials - (75% to 94%)
  – Condensation – can reduce light 15-25%
    • Anti-condensate films (additive)
    • Anti-condensate spray (Sun Clear®)
  – Dust
    • Anti-dust additive
Double Poly Inflation Blower

- Located on inside but drawing air from outside
- Cold air has lower humidity
- Less condensation between sheets
- Jumpers to ensure proper inflation
Inflating Devices: DC Solar Electric

Photo credit: Tim Baker

Photo credit: Tim Baker

Photo credit: Tim Baker
Inflating Devices: Air-Driven Motor

Photo credit: Tim Baker
Inflating Devices: Wind-Driven
Internal Coverings

• Think of this as a very wide double layer of poly
• More insulating effect
• Many approaches to this idea
Internal Coverings

Photo credit: Tim Baker
Internal Coverings

Photo credit: Tim Baker
Internal Coverings

Source: Ted Cary, Lewis Jett, et. al.
Energy Curtain

Source: Scott Sanford, University of Wisconsin
Energy Curtain

Source: Gene Giacomelli – University of Arizona
Energy Curtain

Can save 30-50% on heating costs
Multiple-Bay Approaches


Source: Ted Cary, Lewis Jett, et. al.
Multiple-Bay Approaches

Polyethylene Film with IR Additive

- Reduces IR heat loss by 15-20%
- Incremental cost ~ $0.015 / sq. ft.
- Payback ~ 2-3 months / one season
- No light transmittance losses
- Diffuses light – faster, fuller more even crop growth
- Often combined with anti-condensate (AC) coating
- Installation
  - IR film on inside with anti-condensate side down (inside greenhouse)
  - Standard poly film used for outer layer

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT Plastics</td>
<td>Dura-Film 4 Thermal AC</td>
</tr>
<tr>
<td></td>
<td>Dura-Film 4 Thermal AC Plus</td>
</tr>
<tr>
<td>Covalence Plastics</td>
<td>Tufflite Infrared</td>
</tr>
<tr>
<td>Klerk's</td>
<td>K50 IR/AC</td>
</tr>
<tr>
<td></td>
<td>K3 IR/AC</td>
</tr>
<tr>
<td>Green-Tek</td>
<td>Sunsaver</td>
</tr>
<tr>
<td>Ginegar Plastics</td>
<td>Sun Selector AD-IR / Suntherm</td>
</tr>
</tbody>
</table>

Source: Scott Sanford, University of Wisconsin
Techniques to Reduce Temperature

• Shading - reduce energy absorbed
  – Shade curtain
    • Fabric over top of greenhouse/tunnel
  – Shading compound
    • Permanent shade after application
    • Removed Aug – Sept

• Evaporation of water - needs relatively dry air
  – Foggers
    • Requires fine nozzles, high pressure, and clean water
  – Evaporative pads
    • Require mechanical ventilation
    • Approximately 1 gal/min. of evaporating water will cool a 30’x150’ greenhouse 15°F with 1 air change/minute

Source: Greg Brenneman – Iowa State University with modification by Tim Baker
Thermal / Shade Materials

• Non-porous material
  – Highest heat retention
  – Impervious to water and air movement
    • Can fail if water collects on top of curtain

• Semi-porous materials (preferred)
  – Allows moisture to migrate
  – High heat retention – 50 to 75%

• Porous curtains
  – Allows condensate and rain leakage to drain
  – Lower heat retention than nonporous materials – 20 to 30%

• Shade in summer / heat retention
  – Higher shading factor = Higher heat retention

• Curtain life: 8 to 12 years
Curtain Materials: Semi-Porous
Aluminized and clear polyethylene woven fabric
Chinese High Tunnel Structure

- Three thick walls
- A thick roof (top)
- Support structure
- Plastic cover
- Insulation layer at night
Chinese High Tunnel

• It keeps the minimum temperatures at the coldest winter night above 50°F
• Greenhouse effect: Short wave (absorbed light) to long wave (radiated heat)
• Heat stored in soil; thick walls (1-1.5m)
• An insulation layer covers the plastic film at night
• The soil temperatures are relatively high and stable
• In colder regions, some additional heat can be used, but this is normally only done for research and breeding purposes
Chinese High Tunnel

• In-ground wall on three sides with thermal mass for heat storage
• Thermal curtain on roof holds heat in at night

Photo credit: NRCS - Curtis Millsap in his Chinese high tunnel north of Springfield, MO
Stop Infiltration Leaks

• Save 3-10% in heating costs
  – Check roof and wall vents - seal tight
  – Tight cover
  – Glazing / lap seals on glass
  – Fix holes in cover
  – Weather stripping around doors
  – Door sills
  – Roll-up doors – seal for winter?
  – Ventilation louvers close tight
    • Dry lubricant - use graphite or Teflon
  – Cover unneeded fans / vents during winter
    • Foam and plastic
  – Plug gaps around foundation – earth up to sill board
  – Double/single polyethylene over glass
    = 40% savings
Technological Approaches for Saving Energy
Which Fuel Source is the Best?

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Selling Unit</th>
<th>Avg. Efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>KwH</td>
<td>100-280</td>
</tr>
<tr>
<td>Natural gas</td>
<td>CCF (therm)</td>
<td>65</td>
</tr>
<tr>
<td>LP (propane) gas</td>
<td>Gallon</td>
<td>65-80</td>
</tr>
<tr>
<td>Wood</td>
<td>Cord</td>
<td>15-60</td>
</tr>
<tr>
<td>Wood pellets</td>
<td>Ton</td>
<td>80</td>
</tr>
<tr>
<td>Corn (shelled)</td>
<td>Bushel</td>
<td>80</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>Gallon</td>
<td>60</td>
</tr>
<tr>
<td>Kerosene</td>
<td>Gallon</td>
<td>85</td>
</tr>
<tr>
<td>Coal</td>
<td>Ton</td>
<td>60</td>
</tr>
<tr>
<td>Biomass</td>
<td>Ton</td>
<td>40</td>
</tr>
</tbody>
</table>
Standard Heating Unit (SHU)

• One SHU = 100,000 BTUs

• Cost per SHU
  \[\text{Cost per SHU} = \text{Fuel cost} \times \frac{100,000}{(\text{Heat Content} \times \text{Avg.Sys. Eff.})}\]

• LP (propane) gas = $1.56/gal x \frac{100,000}{(91,000 \text{ BTUs} \times 0.65)}
  = $2.64 per SHU

• Electricity = $0.09/KwH x \frac{100,000}{(3413 \text{ BTUs} \times 1.00)}
  = $2.64 per SHU
## How They Rank (as of 11/2/2014)

<table>
<thead>
<tr>
<th>Heating System</th>
<th>Fuel Cost</th>
<th>Cost per SHU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-tight stove - dry red oak</td>
<td>$140 / cord</td>
<td>$0.92</td>
</tr>
<tr>
<td>Ground-source heat pump</td>
<td>$0.09 / KwH</td>
<td>$0.94</td>
</tr>
<tr>
<td>Pellet stove - shelled corn</td>
<td>$3.74 / bu.</td>
<td>$1.19</td>
</tr>
<tr>
<td>Pellet stove - wood pellets</td>
<td>$200 / ton</td>
<td>$1.52</td>
</tr>
<tr>
<td>Air-to-air electric heat pump</td>
<td>$0.09 / KwH</td>
<td>$1.60</td>
</tr>
<tr>
<td>Natural gas forced-air furnace</td>
<td>$1.33 / therm</td>
<td>$1.66</td>
</tr>
<tr>
<td>LP gas H.E. forced-air furnace</td>
<td>$1.83 / gallon</td>
<td>$2.51</td>
</tr>
<tr>
<td>Electric resistance heat</td>
<td>$0.09 / KwH</td>
<td>$2.64</td>
</tr>
<tr>
<td>LP gas older forced-air furnace</td>
<td>$1.70 / gallon</td>
<td>$3.09</td>
</tr>
<tr>
<td>Forced-air furnace - #2 fuel oil</td>
<td>$3.33 / gallon</td>
<td>$4.01</td>
</tr>
</tbody>
</table>
Keeping a Good High Tunnel Environment

- Some ventilation is needed for moisture control
- Air circulation within the high tunnel is important
- Ideally, natural ventilation has openings high in the roof
- ALL combustion gases must be vented outside

Photo credit: Tim Baker
Warning on Contaminant Gasses

• Combustion gasses from burning wood, propane, heating oil, natural gas, kerosene, or coal
  – Ethylene, sulfur dioxide, nitrogen oxides, and CO are the most common problems
  – Affects tomatoes, cucumbers, lettuce, melons, peppers, tobacco, some flowers, and bedding plants

• Plant sensitivity depends on:
  – Variety, species, age of plants
  – Light intensity and time of day
  – Humidity, watering and nutrient status
    • High humidity, well-watered plants most at risk
Ethylene Problems

- Ethylene (C₂H₄) is produced from incomplete combustion of fuels
- Incomplete combustion occurs with low oxygen supply to fire and wet wood
- Ethylene causes “2,4-D”-like symptoms
Warning on Contaminant Gasses

- Never use kerosene or fuel oil heaters indoors
- Venting is required!
- Keep wood boilers outdoors
- Inspect furnace and chimney for cracks, leaks & obstructions
- Use dry wood for fuel; avoid large loads of wood with low air supply (dampers closed down)
Supplemental Heating High Tunnels

• In-ground heating
  – Installed before planting, buried 2” deep
    • Electric heating cables
    • Pumped hot water through hoses or pipes
  – Heats soil to set temperature to hopefully extend season

• Above-ground heating
  – Heats air around plants
  – Typically used to protect against cold nights
  – More costly than in-ground
Hot Water Under Plants

- Plastic tents over plant beds on benches
Hot Water Under Plants

• Rigid foam insulation board under pipes

Photo credit: James Quinn
Active Water Heating

- Assure no leaks in boiler door
- Vent flue to outdoors
- Plants close to boiler may suffer

Photo credit: Tim Baker
Active Water Heating
Water for Storing Heat

- Water is one of the best naturally-occurring materials for storing heat
- Thermal mass moderates temperature swings
- Metal or plastic barrels
  - No temperature difference
  - Metal rusts; plastic deforms
  - Plastic may hold more
- Soil will steal heat away if pad not insulated
Passive Solar Greenhouse
Passive Solar Greenhouse

**SUMMER**
Sun is higher in the sky and casts a shadow over the water-filled tubes and drums of the Botanic Gardens greenhouse helping to keep the greenhouse cool.

**WINTER**
Sun is lower in the sky shining directly into the Botanic Gardens greenhouse directly illuminating and warming the water-filled tubes and drums. This helps keep the greenhouse warm.
Volunteer watering Plants. Water barrels are part of our passive solar system.
Water-to-Air Heat Exchanger
Water-to-Air Heat Exchanger

Photo credit: Scott Sanford, University of Wisconsin
Water-to-Air Heat Exchanger

Photo credit: Tim Baker
Wood Pellet & Corn Furnace
Circulation fans

- Mix air to prevent stratification of air
- Reduces heating
- Dries wet leaves faster – prevents disease

Paddle fans

Jet blowers

Basket fans
Good Air Circulation is Critical
Good Air Circulation is Critical
Under-Bench Forced Air

- Lowers heating costs 20-25%
- Same as a 5-10°F reduction in greenhouse temperature
- Study of bottom heated tomatoes = 7% increased yields
Under-Bench Hydronic heating
Under-Bench Hydronic Heating

- Natural Convection / Thermal buoyancy
- No pumps

Supply from boiler
Distribution to pipes running under benches
Return piping to boiler
Geothermal Cooling and Heating

- 8”-24” diameter tubes run underground; buried 6’-12’ deep
- Air drawn through tubes by blower
- Ground is cool in summer, therefore cool air comes out
- Hot air drawn in during summer also warms up ground
- In winter, the air is warmed by the soil
Geothermal Cooling and Heating
High Tunnel Resources – Page 1

• High Tunnels.org
  www.hightunnels.org

• Missouri Alternatives Center (click on “H” for high tunnels)
  agebb.missouri.edu/mac/links/index.htm

• Siting High Tunnels (eXtension)
  www.extension.org/pages/18365/siting-high-tunnels

• High Tunnel Construction Considerations (Iowa State)
  www.iowaproduce.org/pages/production/files/high_tunnel/high_tunnel_construction.pdf

• High Tunnel Hoop House Construction Guide (Noble Foundation)

• High Tunnel Fruit and Vegetable Production Manual (Iowa State)
  https://store.extension.iastate.edu/Product/pm2098-pdf
High Tunnel Resources – Page 2

• Passive Solar Greenhouse (University of Missouri)
  aes.missouri.edu/swcenter/research/Solar-heated%20greenhouse.pdf
  bradford.cafnr.org/passive-solar-greenhouse/
  bradford.cafnr.org/greenhouse-materials/

• Plasticulture (Penn State)
  extension.psu.edu/plants/plasticulture

• Horticultural Engineering (Rutgers University)
  aesop.rutgers.edu/~horteng/

• High Tunnel Tomato Production
  extension.missouri.edu/p/m170

• High Tunnel Melon and Watermelon Production
  extension.missouri.edu/p/m173

• Watering and Fertilizing Tomatoes in a High Tunnel
  http://extension.missouri.edu/p/G6462
High Tunnel Resources – Page 3

- AgEnergy Resource website (Univ. of Wisconsin)  
  www.uwex.edu/energy/greenhouses.html
- NRAES137 Greenhouses for Homeowners and Gardeners  
  extension.missouri.edu/p/nraes137
- Energy Self-Assessment website (NRCS)  
  www.ruralenergy.wisc.edu/default.aspx
- National Greenhouse Manufacturers Association  
  www.ngma.com
Questions??

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   ▪ MU Human Resources Office
      130 Heinkel Bldg, Columbia, MO 65211

USDA
   ▪ Office of Civil Rights, Director
      Room 326-W, Whitten Building
      14th and Independence Ave., SW
      Washington, DC 20250-9410

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