High Tunnel Heating Alternatives

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 (backup 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 - 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

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

Principles of Heat Loss
- Conduction
  - Heat conducted through a material
  - U-value – BTU/(hr^-1°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 = 

\[ \text{sq. ft. greenhouse surface} \times \text{temperature difference (inside temp.* minus outside temp.**) } \times 1.2 = \text{BTU/hour heat needed} \]

*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:

<table>
<thead>
<tr>
<th>Ends</th>
<th>2 x 6' x 12'</th>
<th>= 144 sq.ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sides</td>
<td>2 x 6' x 10'</td>
<td>= 120 sq.ft.</td>
</tr>
<tr>
<td>Roof</td>
<td>2 x 5.5 x 12'</td>
<td>= 132 sq.ft.</td>
</tr>
<tr>
<td>Roof peaks</td>
<td>2 x 1/2 x 10' x 2.5'</td>
<td>= 25 sq.ft.</td>
</tr>
<tr>
<td>TOTAL</td>
<td>= 421 sq.ft.</td>
<td></td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Ends</th>
<th>2 x ((5' x 30')+(7.5' x 30'/2))</th>
<th>= 525 sq.ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sides</td>
<td>2 x (5' x 72')</td>
<td>= 358 sq.ft.</td>
</tr>
<tr>
<td>Roof</td>
<td>2 x (15.4' x 72')</td>
<td>= 2218 sq.ft.</td>
</tr>
<tr>
<td>TOTAL</td>
<td>= 3100 sq.ft.</td>
<td></td>
</tr>
</tbody>
</table>

3100 sq. ft. x (45°F - 10°F) x 1.2 = 130,200 BTU/hour heat needed

(about the same heating needs as four 1,600 sq.ft. insulated homes)

Frame Shape

**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

Inflating Devices: Air-Driven Motor

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

Energy Curtain

- Insulating Blanket
- Support Track
- Edges Sealed

Source: Scott Sanford, University of Wisconsin

Source: Gene Giacomelli – University of Arizona
Energy Curtain

- Can save 30-50% on heating costs

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>Covance Plastics</td>
<td>Tuffite Infrared</td>
</tr>
<tr>
<td>Kline’s</td>
<td>K30 IR/AC</td>
</tr>
<tr>
<td></td>
<td>K3 IR/AC</td>
</tr>
<tr>
<td>Green-Tek</td>
<td>Sunshower</td>
</tr>
<tr>
<td>Ginegar Plastics</td>
<td>Sun Selector AD-IR / Suntherm</td>
</tr>
</tbody>
</table>

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
      - Requires mechanical ventilation
      - Approximately 1 gal/min. of evaporating water will cool a 30’ x 150’ greenhouse 15°F with 1 air change/minute

- 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

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>80</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 = Fuel cost \times \frac{100,000}{(Heat \ Content \times \text{Avg. Sys. Eff.})}

- LP (propane) gas = $1.56/gal \times \frac{100,000}{(91,000 \ BTUs \times 0.65)} = $2.64 per SHU
- Electricity = $0.09/KwH \times \frac{100,000}{(3413 \ 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>$2.00/ton</td>
<td>$1.32</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>$1.13/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

### 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

Active Water Heating

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

Hot Water Under Plants

- Rigid foam insulation board under pipes

Active Water Heating

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

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**Passive Solar Greenhouse**

![Passive Solar Greenhouse Diagram](image)

**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.

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**Water-to-Air Heat Exchanger**

![Water-to-Air Heat Exchanger](image)
Water-to-Air Heat Exchanger

Wood Pellet & Corn Furnace

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

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**

- Natural Convection / Thermal buoyancy
- No pumps

**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

**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/sites/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/wcenter/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/m171
- Watering and Fertilizing Tomatoes in a High Tunnel
  http://extension.missouri.edu/p/G6462
High Tunnel Resources

- 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 Extension AA/EEO Office
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- MU Human Resources Office
  130 Heinkel Bldg, Columbia, MO 65211

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- Office of Civil Rights, Director
  Room 326-W, Whitten Building
  14th and Independence Ave., SW
  Washington, DC 20250-0420

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