Heating & Lighting in Greenhouses and High Tunnels: How Much is Needed and What is the Cost?

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Average temperature in Indiana

![Graph showing average temperature in Indiana with optimal temperature range indicated.]
Heating is needed to grow crops during winter

Pay attention to weather forecasts

Daily min. temperature predictions are 75 to 77% accurate
How is heat lost from greenhouses or high tunnels?

Heat required = Heat lost

Heat lost (Q, BTU/hr) =
Heat lost through \([\text{Radiation} + (\text{Conduction} + \text{Convection})] + \text{Infiltration}\)

\[ Q = Q_{rc} + Q_i \]

\( Q_{rc} \) is heat lost through conduction + convection + radiation (BTU/hr)

\( Q_i \) is heat lost through infiltration (BTU/hr)
\[ Q_{rc} = U \times A \times (T_i - T_o) \]

\( Q_{rc} \) = Heat loss through conduction, convection and radiation (BTU/hr)
\( U \) = overall heat transfer coefficient (BTU/hr ft\(^2\) °F)
\( A \) = Surface area (ft\(^2\))
\( T_i \) = Inside temperature (°F)
\( T_o \) = Outside temperature (°F)

<table>
<thead>
<tr>
<th>Greenhouse covering</th>
<th>Wi(m(^2)-°C)</th>
<th>Btu(h-ft(^2)-°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single glass, sealed</td>
<td>6.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Single glass, low emissivity</td>
<td>5.4</td>
<td>0.95</td>
</tr>
<tr>
<td>Double glass, sealed</td>
<td>3.7</td>
<td>0.65</td>
</tr>
<tr>
<td>Single plastic</td>
<td>6.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Single polycarbonate, corrugated</td>
<td>6.2-6.8</td>
<td>1.1-1.2</td>
</tr>
<tr>
<td>Single fiberglass, corrugated</td>
<td>5.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Double polyethylene</td>
<td>4.0</td>
<td>0.70</td>
</tr>
<tr>
<td>Double polyethylene, IR inhibited</td>
<td>2.8</td>
<td>0.50</td>
</tr>
<tr>
<td>Rigid acrylic, double-wall</td>
<td>3.2</td>
<td>0.56</td>
</tr>
<tr>
<td>Rigid polycarbonate, double-wall(^1)</td>
<td>3.2-3.6</td>
<td>0.56-0.63</td>
</tr>
<tr>
<td>Rigid acrylic, w/polyethylene pellets(^2)</td>
<td>0.57</td>
<td>0.10</td>
</tr>
<tr>
<td>Double polyethylene over glass</td>
<td>2.8</td>
<td>0.50</td>
</tr>
<tr>
<td>Single glass and thermal blanket(^3)</td>
<td>4.0</td>
<td>0.70</td>
</tr>
<tr>
<td>Double polyethylene and thermal blanket(^4)</td>
<td>2.5</td>
<td>0.44</td>
</tr>
</tbody>
</table>

\(^1\) Depending upon spacing between walls.
\(^2\) 32 mm rigid acrylic panels filled with polystyrene pellets.
\(^3\) Only when blanket is closed and well sealed.
Surface Area Calculation

Surface area = \( 2(A \times C) + 2(B \times C) + 2(E \times B) + AD \)

Surface Area Calculation

Surface Area = \( \frac{\pi}{2} (A \times B) + \pi \left( \frac{A^2}{4} \right) \)
Qi = K × V × C (Ti-To)

Qi = heat loss through infiltration (BTU/hr)
K = 0.02 BTU/ ft³ °F
V = volume of greenhouse (ft³)
C = air exchanges per hour
Ti = Inside temperature (°F)
To = Outside temperature (°F)

Volume Calculations

\[ Volume = (A \times B \times C) + \frac{1}{2}(E \times E \times B) \]

\[ Volume = \frac{1}{2}(\pi \times \frac{A^2}{4} \times B) \]
Air Exchanges per hour

<table>
<thead>
<tr>
<th>Construction</th>
<th>Air exchange (h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>New Construction</strong></td>
<td></td>
</tr>
<tr>
<td>Double plastic</td>
<td>0.75 - 1.5</td>
</tr>
<tr>
<td>Glass or Fiber glass</td>
<td>0.5 - 1.0</td>
</tr>
<tr>
<td><strong>Old Construction</strong></td>
<td></td>
</tr>
<tr>
<td>Glass, good maintenance</td>
<td>1.0 – 2.0</td>
</tr>
<tr>
<td>Glass, poor maintenance</td>
<td>2.0 – 4.0</td>
</tr>
</tbody>
</table>

Double poly with IR blocker

\[ T_i = 70 \, ^\circ F \]
\[ T_o = 40 \, ^\circ F \]
\[ A = 5417 \, \text{ft}^2 \]
\[ U = 0.5 \, \text{BTU/hr ft}^2{\circ F} \]
\[ V = 35325 \, \text{ft}^3 \]
\[ C = 1.0 \, \text{h}^{-1} \]

\[ Q_{rc} = 0.55 \times 5417 \times (70 - 40) = 0.5 \times 5417 \times 30 = 89381 \, \text{BTU/hr} \]
\[ Q_i = 0.02 \times 35325 \times 1 \times (70 - 40) = 0.02 \times 35325 \times 30 = 21195 \, \text{BTU/hr} \]
\[ Q = 89381 + 21195 = 110576 \, \text{BTU/hr} \]
BTU values of different fuels

- 1 gal propane gives 91000 BTUs
- 1 gal gasoline gives 124000 BTUs
- 1 lb wood gives 8000 BTUs
- 1 KWh electricity gives 3412 BTUs
- 1 cu. ft. natural gas gives 1000 BTUs

How much does this cost?

\[ Q = 89381 + 21195 = 110576 \frac{BTU}{hr} \]

Using propane as fuel (i.e., 91,000 BTU/gal), the greenhouse burns

\[ \frac{110576 \text{ gal}}{91000 \text{ hr}} = 1.22 \frac{\text{gal}}{hr} \]

to maintain 70°F air temperature

Assuming propane cost of $2.50/gal and heating for 12 hours every day, the monthly cost of heating the greenhouse is

\[ = \$2.50/\text{gal} \times 1.22 \text{ gal/h} \times 12 \text{ h/day} \times 30 \text{ days} = \$1098 \]
Monetary value of sunlight received annually in a 3000 ft² greenhouse is approx. $278000 annually!!

What is a mol. of light?
High intensity supplemental lighting options

SE 400W $235
DE 1000W $450
320 W $750

Light Output efficiency = Light Output/Energy Input

Light output efficiency = 595/400 = 1.5 µmol/J
Light Output Efficiency and Electrical Costs

- Photon efficiency = light output/energy input = \( \frac{110}{400} \times \frac{\mu\text{mol/s}}{\text{joule/s}} = 0.275 \frac{\mu\text{mol}}{\text{J}} \)

- 1 KWh = 1 unit of electricity = 3,600,000 J = $0.10

- Using a KWh of energy, fixture produces 0.275 \( \times \) 3,600,000 = 1 million \( \mu\text{mol} \) or 1 mol
Fixed costs of supplemental lighting

• One bulb is needed for 150 ft²

• In 3000 ft² greenhouse needs 20 bulbs

• Investment on fixtures : 20 X $235 = $4700 (+ add wiring and electrician costs)

Operational costs of supplemental lighting

• Lettuce requires 10 mol/day for 30 days = 300 mol during winter months

• Fixture produced 1 mol/KWh energy consumption

• To produce 300 mol, the fixture uses 300 KWh or $30 per fixture

• For 20 fixtures, cost of supplemental lighting is $600/month in a 30’ x 100’ greenhouse

Questions?

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