

Enough Already! How Can I Lower My Energy Bill?

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Useful References

- *Energy Conservation for Commercial Greenhouses*, NRAES 3
- *Greenhouse Engineering*, NRAES 33
- <http://www.hrt.msu.edu/Energy/Notebook.htm>
- <http://www.ofa.org/energy.aspx>

Natural Resource, Agriculture, and Engineering Service (NRAES)
Ithaca, NY (607) 255-7654
<http://www.nraes.org>

Greenhouse Heat-Loss Calculations

To size heating system (boiler capacity):

- Structural heat loss
- Infiltration (air movement)
- Perimeter heat loss (along outer wall)
- If needed: adjustments for high wind and large ΔT
- Total heat loss = sum of structural, infiltration, and perimeter heat loss (plus adjustments if needed)

Structural Heat Loss

- Heat transfer through the structure depends on:
 - Heat transfer coefficient, U ($U = 1/R$)
 - Area, A
 - Temperature difference: $T_{\text{inside}} - T_{\text{outside}} (\Delta T)$
- Equation:

$$Q = U \times A \times (T_{\text{inside}} - T_{\text{outside}})$$

or

$$Q = UA \Delta T$$

Design Temperature

- For heating capacity calculations use the 99% outdoor design temperature

T_{outside} :

- Portland, ME: -6°F
- Worcester, MA: 0°F
- New Haven, CT: 3°F
- New Brunswick, NJ: 7°F
- Washington, DC: 14°F

Note: T_{outside} (99%) was determined for Dec, Jan, and Feb i.e., 120 days or 2880 hours; 1% \approx 29 hours, 1.2 days

U-values

Material	U (Btu/hr per ft ² per °F)
Single (double) layer glass	1.1 (0.7)
Single (double) layer poly	1.1 (0.7)
Double layer + energy curtain	0.3 - 0.5
Double layer acrylic	0.6
Double layer polycarbonate	0.6
1/2" Plywood	0.7
8" Concrete block	0.5
2" Polystyrene ($R = 10$)	0.1

Air Infiltration Heat Loss

• Equation: $Q = 0.02 \times V \times C \times (T_{\text{inside}} - T_{\text{outside}})$

where:

V = greenhouse volume (ft³)

C = number of air exchanges per hour

Construction	C
New, glass	0.75 - 1.5
New, double poly	0.5 - 1.0
Old, glass and good condition	1.0 - 2.0
Old, glass and poor condition	2.0 - 4.0

Perimeter Heat Loss

• Equation: $Q = F \times P \times (T_{\text{inside}} - T_{\text{outside}})$

where:

F = perimeter heat loss Factor

P = greenhouse Perimeter (in feet)

F	(Btu/hr per linear foot per °F)
Uninsulated	0.8
Insulated	0.4

- If you have a high water table: also consider heat loss to the soil underneath the greenhouse

Perimeter Insulation



- At least 1 foot deep (preferably 2 feet)
- At least 1 inch thick (preferably 2 inches)



- Avoid gaps
- Try to work neatly around post footings

Effect of Wind Velocity and ΔT

- If $\Delta T > 70^\circ\text{F}$ (difference between inside and outside temperature), and if average wind speed > 15 mph:

Multiply the calculated heating requirement by:

(1 + 0.08) for every increase in ΔT of 5°F

(1 + 0.04) for every 5 mph increase in wind speed

- For example, if $\Delta T = 80^\circ\text{F}$ (1.16) and the average wind velocity is 25 mph (1.08): multiply the calculated heating requirement by a factor of: $1 + (0.16 + 0.08) = 1.24$

Common Heating Systems...

Hot Air or Hot Water?

- Hot water is preferred over hot air (uniformity)
- Hot water systems require water treatment
- Hot air systems are cheaper to install
- Root zone heating:
 - Uniform heat
 - Heat close to the crop
 - Floor heating: acts as buffer in case of failure
 - Requires additional heat supply

Radiant (IR) Heating?

- Only heats surfaces 'in view of' radiator
- After absorption, heat is dissipated by re-radiation and convection
- As a result, potential uneven canopy heating
- Mounting above canopy can be a challenge
- Quick response time

Heating Systems

- Steam (large systems, not too common)
- Hot air (furnaces, unit heaters)
- Hot water boilers
- Perimeter and overhead heating (hot water)
- Bench heating (hot water)
- Floor heating (hot water)
- 'Waste' heat
- CHP/Cogeneration

Steam Boiler



Hot Air



Hot air furnace



Unit heater



Poly tube

Hot Water Boilers



Perimeter Heating



Overhead Heating (Space Efficiency)



Floor Heating



Bench Heating

- Underneath benches
- Not insulated

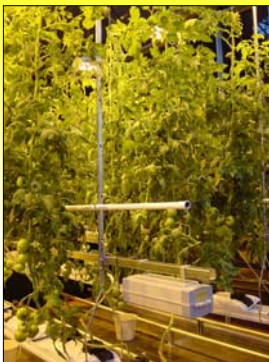


- Directly underneath flats
- (Not) Insulated

Dual Use: Heating & Transportation



Dual Use: Heating & Lighting



Alternative Energy Systems...



Alternative Energy Sources

- Solar (electricity, hot water heating)
- Wind (electricity)
- Geothermal (hot water heating)
- Ground-source heat pump
- Wood (waste wood, fire wood)
- Other solid biomass (corn, switchgrass)
- Biodiesel (diesel equivalent from biomass)
- Waste oil (fast food industry)
- Waste hot water (power plants, industry)
- CHP/Cogeneration (e.g., microturbines)

Outdoor Wood Stove



Waste Hot Water



Combined Heat and Power (CHP)

- Energy source: (non-)renewable fuels
- Systems produce electricity and heat simultaneously
- High overall system efficiencies: 80-90%
- Possibility for CO₂ capture and enrichment

250 kW Microturbine



Heat Pumps

- 'Reversible refrigerator'
- Energy source: electricity
- Heating and cooling using the same system
- High efficiency (year-round operation)
- Can be connected to warm and cold water storage for even greater efficiency
- Ground source heat pump: use constant ground temperature for heating and cooling



Recent Developments....

New Unit Heaters (*Priva, Ermaf*)

- Direct-fired (no heat exchanger)
- 99% efficient
- Natural gas or propane
- Various safety features
- Some have outside air-intake
- Very low CO and NO_x production
- CO₂ enrichment

New Boiler Technology

- **Condensing boilers (95-98% efficient):**
 Made of stainless steel, allowing condensation of water vapor produced during combustion (producing more heat), and equipped with a heat exchanger to pre-heat the boiler water with heat from combustion gasses
 - Low mass (boiler components and water)
 - Operated on demand (no stand-by losses)
 - Heat delivery in minutes
 - Small foot-print
 - Low maintenance
 - *Can be combined with high mass boilers*

Heat Pumps

- Energy source: electricity
- Heating and cooling using the same system
- High system efficiency (year-round operation)
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‘Closed’ Greenhouse

- Innogrow: “Gesloten Kas”
- Uses a heat pump, (underground) cold & warm water storage, and heat exchangers
- 20% higher crop production (CO₂ = 1,000 μmol/mol, RH = 75-90%)
- 80-100% reduction in crop protection
- 30-40% energy savings (heat storage)
- 40-50% less water use (recovery of evapotranspiration)

Energy Conservation Strategies



Heating Fuels

Fuel	Efficiency (%)	Heat Value
Electricity	95-100	3,413 Btu/kWh
Natural gas*	80	1,000 Btu/ft ³
Propane	80	91,000 Btu/gal
No. 2 fuel oil	75	140,000 Btu/gal
No. 6 fuel oil (pre-heat)	75	150,000 Btu/gal
Hard coal (anthracite)	65	13,000 Btu/lb
Soft coal (bituminous)	65	12,000 Btu/lb
Hard wood (dry)**	65	7,000 Btu/lb
Wood chips	60	3,800 Btu/lb

* 100 ft³ of natural gas = 1 therm

** oak ~ 26,000,000 Btu/cord (8 by 4 by 4 feet)

Reducing Energy Costs (I)

- Use an energy/shade curtain (30%)
- Consider high efficiency heaters/boilers (20-40%)
- Oil: install a flame retention burner (15-20%)*
- Perform timely maintenance (5-10%)
- Use computer control and variable speed motors and pumps (5-10%)
- Lower heating system temperature (5-10%)

*results in better mixing of fuel and combustion air

Energy (and shade) Curtain



Reducing Energy Costs (II)

- Provide a wind barrier (don't block light; 2-5%)
- Ensure inlet openings & fan shutters close tightly (2-5%)
- Check greenhouse for leaks (2-5%):
 - Caulk and weatherstrip doors, windows, etc.
 - Seal all cracks in walls
 - Repair broken glazing
- Use highest R-value for insulation (2-5%)
- Use "smart" raming (2-5%)
- Select the cheapest fuel supplier (2-5%)
- Use a different fuel and/or a dual fuel system (2-5%)

Side Wall Insulation





Dual Fuel Boiler (Natural Gas and Fuel Oil)

Supplemental Lighting with LEDs



<http://www.lemnislighting.nl/>

Energy Usage Meters

- Real-time monitoring (display and recording) of specific equipment and overall facility
- Preferably integrated with environmental control system
- Educational and instructional
- Potential energy savings (5-15%)



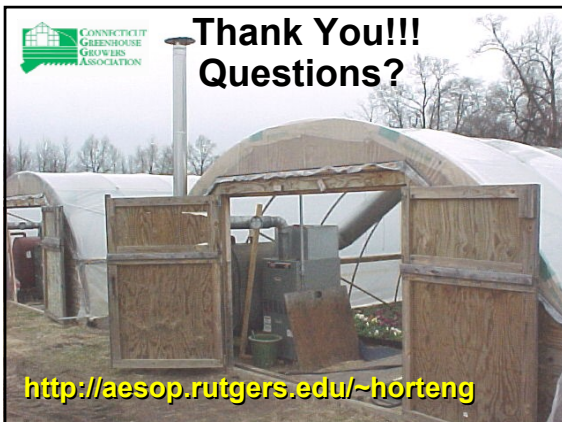
Expert Monitoring Ltd., Cardiff, UK

Heating System Operation

- Clean all heat exchangers regularly
- Provide sufficient make-up air (1 square inch of opening per 2,000 Btu/hr of heating unit output)
- Maintain sufficient updraft in the exhaust stacks
- Locate stack outlet at least two feet above the highest point of the structure
- Insulate transportation pipes (between boiler and greenhouse)
- Two smaller boilers are better than one large one



Thank You!!!
Questions?



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