Greenhouse Energy Considerations

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Useful References

- *Energy Conservation for Commercial Greenhouses*, NRAES 3
- *Greenhouse Engineering*, NRAES 33
- http://www.njveg.rutgers.edu
- http://www.hrt.msu.edu/Energy/Notebook.htm
- http://www.ofa.org/energy.aspx
- http://www.ars.usda.gov/Research/docs.htm?docid=11449

Natural Resource, Agriculture, and Engineering Service (NRAES)
Ithaca, NY 14852   Phone: (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 (over 15 mph) and large ΔT (over 70°F)
- 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: $T_{inside} - T_{outside}$ (ΔT)
- Equation:

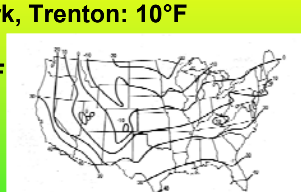
$$Q = U \times A \times (T_{inside} - T_{outside})$$

or

$$Q = UA\,\Delta T$$

Outdoor Design Temperature

- For heating capacity calculations use the 99% outdoor design temperature $T_{outside}$:
  - Atlantic City, Newark, Trenton: 10°F
  - Vineland: 8°F
  - New Brunswick: 6°F
  - Phillipsburg: 1°F



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

U-values

Material	U (Btu/hr per ft² 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: $Q = 0.02 \times V \times C \times (T_{inside} - T_{outside})$
  where:
  V = greenhouse volume (ft^3)
  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: $Q = F \times P \times (T_{inside} - T_{outside})$
  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

- When the water table is high: 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

Side Wall Insulation

Effect of Wind Velocity and ΔT

- If ΔT > 70°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 ΔT = 80°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

Heating with Air or 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
  - However, requires additional heat supply

Radiant (Infrared) 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

Alternative Energy Systems…

RUTGERS New Jersey Agricultural Experiment Station

PENNSTATE

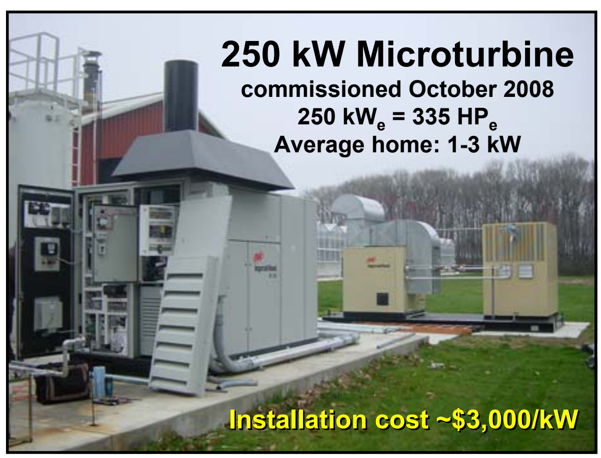
Alternative Energy Sources

- Solar (electricity, hot water heating)
- Wind (electricity)
- Geothermal (hot water heating)
- Ground-source heat pump
- Wood (waste wood, pellets)
- 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)

Burning Wood

Combined Heat and Power (CHP)

- Energy source: (non-)renewable fuels
- Systems produce electricity and heat <u>simultaneously</u>
- High overall system efficiencies: 70-80%
- Possibility for CO_2 capture and enrichment
- Waste heat can also be used for 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
- CO_2 enrichment

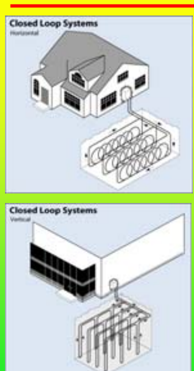
New Boiler Technology

- Condensing boilers (95-98% efficient):
  Made of stainless steal, 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

- '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

Ground Source Heat Pump



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 ft^3 of natural gas = 1 therm
** 20% moisture: oak ~ 26,000,000 Btu/cord (8 by 4 by 4 feet)

Reducing Energy Costs (I)

- Use an energy/shade curtain (20-30%)
- 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

Reducing Energy Costs (II)

- Use highest R-value for insulation (2-5%)
- 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 "natural" ramping (2-5%)
- Select the cheapest fuel supplier (2-5%)
- Keep track of energy usage…

Dual Fuel Boiler (Natural Gas and Fuel Oil)

Additional Considerations

- Energy conservation first!
- Clean all heat exchangers regularly
- Insulate heat transportation pipes (between boiler and greenhouse)
- 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
- For efficiency and redundancy: two smaller boilers are better than one large boiler