Section 3

Energy-Saving Technologies

Ten Ways to Reduce the Greenhouse Energy Bill

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Introduction

Unfortunately, as we enter the beginning of 2007, the greenhouse industry is faced with high fuel prices and the general consensus is that prices will remain high for the foreseeable future. In addition, the situation may get worse depending on weather conditions during the current heating season. Thus, growers should not only focus on quick fixes, but also on long-term improvements. Shortly after the last energy crisis in the early seventies, many research projects were undertaken to study energy saving technologies for commercial greenhouse production. Many different ideas were investigated and described in various publications. However, due to the relatively cheap energy prices during the eighties and nineties, many energy saving technologies were eventually abandoned. Nevertheless, the ideas that were developed in the seventies combined with recent technology developments can be used to help reduce our energy consumption in the early 21st century. The following list of ten different approaches, in no particular order, may give some ideas for where to start.

1. Install Energy Curtains

Energy curtains are relatively easy to install, especially in newer gutter-connected greenhouses that have sufficient space for curtains between the trusses and the gutters. A properly installed curtain system can save a significant amount of energy. With the current fuel prices, these systems will pay for themselves in a short time period (generally 2-3 years). An added advantage is that curtain systems can also be used as shade devices during periods of the day with high solar radiation. For even greater energy saving, two curtains can be installed: one for maximum energy saving and another for shading. One potential problem with trying to close the greenhouse for maximum energy saving is that the relative humidity can increase because the air exchange rate (leakage) is usually significantly reduced. Thus, growers should pay attention to their humidity control strategy and make changes where appropriate. In addition, growers should be careful when opening an energy curtain early in the morning. At that time, the air volume above the curtain is still cold and could cause problems when it falls down onto the crop underneath (cold air is heavier, or more dense, than warm air). Therefore, growers usually open curtains in small increments in the morning to allow the colder air mass above the curtain to heat up. Growers are advised to consult with curtain manufacturers/installers to investigate alternative installations in older greenhouses. For example, in some of these greenhouses the curtains could be installed parallel and closer to the glazing. In that case, special supports have to be used to support overhead heating pipes and supplemental light fixtures, etc. Or external curtains can be installed. Depending on the type of curtain material, these external curtains can also help reduce radiation losses from the greenhouse to a cold night sky.

2. Reduce Air Leakage from the Greenhouse

Depending on temperature differences between inside and outside air, and wind speed and direction, air will move through cracks or other openings either into or out of the greenhouse. Therefore, it is important to close these openings to prevent this unwanted movement of air (and thus potential energy loss). Such unintentional openings are often found around doors and windows, and where the glazing attaches to the greenhouse frame. In addition, it helps to insulate openings that are temporary out of use (e.g., ventilation fans that are turned off or ventilation windows that remain closed during the winter season). Over time it is not uncommon for louvers on ventilation openings or for ventilation windows to only partially close (e.g., when parts are bent or warped). Therefore, it is important to make sure that these systems close properly and tightly in order to minimize unwanted air movement between the inside and outside of the greenhouse.

3. Provide Heat Only Where it is Needed

Bench and floor heating systems provide heat close to where the crop is grown. The clear advantage is that less energy is needed to heat the rest of the greenhouse air volume. Many growers that use bench or floor heating systems report that they are able to successfully grow a crop while maintaining a lower air temperature (resulting in energy savings). However, this practice should be carefully evaluated since lower temperatures generally reduce plant growth and development rates. The installation of circulation fans (HAF: horizontal airflow fans) inside the greenhouse will help provide uniform temperatures throughout the growing areas.

4. Install an Energy Efficient Heating System

It is recommended to install the highest efficiency units one can afford (these are generally more expensive to buy, but save in operating cost by reducing fuel consumption). In addition, try to use so-called separated combustion units that use outdoor air for the combustion process and return this air to the outside without it making contact with any indoor greenhouse air. Using separated combustion units ensures that combustion gasses will not contaminate the greenhouse air (some by-products, e.g., ethylene, are known to cause plant stress). Some growers have opted to install dual fuel systems (that can burn two different fuels), which allow switching between fuel sources when one of the fuels becomes more expensive or is not easily available.

5. Regularly Calibrate Temperature Sensors

It is important to regularly calibrate temperature sensors. Every environment control system responds based on temperature readings and if the sensor provides incorrect measurements, the control system will not be able to provide the intended temperature set points. In addition to potentially increasing energy consumption, plant growth can be negatively affected. Some growers have decided to lower their temperature set points in order to save energy. However, one should be cautious because lower temperatures reduce plant growth rates, and can increase insect and disease problems when plants are grown under sub-optimum conditions.

6. Perimeter Insulation

The installation of perimeter insulation (e.g., 2-inch polystyrene board installed vertically around the entire perimeter to a depth of two feet or 0.6 meters) will reduce the heat loss through the greenhouse floor to the ground directly surrounding the greenhouse. Usually, the heat loss to the ground underneath the greenhouse floor is relatively small, but if the water table underneath the greenhouse is high (less than 6 feet [1.8 meters] below the floor), it may be worthwhile to install insulation (e.g., 2-inch polystyrene board) underneath the entire floor. And for opaque sidewalls and doors, use insulation material with the highest possible R-value.

7. Use a Double Layer Glazing System

Over a typical heating season, double poly or even double glass will reduce the heat loss by approximately 50% compared to a single layer of glazing material. However, most glass-clad greenhouses are constructed with a single layer of glass. In those cases, installing an energy curtain can significantly reduce heating costs. Sometimes, especially in the colder regions of the country, growers install a temporary layer of (inflated) plastic film over the single layer of glass during the heating season to reduce the heat loss through the roof.

8. Install Windbreaks

In areas with high wind speeds, especially during the heating season, it is recommended to install windbreaks (shrubs and trees) around the entire greenhouse or at least in the upwind direction from the prevailing wind. However, these windbreaks should not reduce the amount of light entering the greenhouse (especially during the winter) and should be designed so that snowdrifts do not accumulate against the greenhouse.

9. Use the Cheapest Fuel

It is not always easy to determine which is the cheapest fuel (prices fluctuate depending on many different factors), but one should be able to get a good idea by talking to other growers and local fuel suppliers. As discussed earlier, dual fuel or even triple fuel systems allow one to switch fuels depending on availability and price. This flexibility has the potential of realizing significant cost savings. Initial installation, however, will be somewhat more expensive. Growers using natural gas can in many cases negotiate usage charges when contracting with their supplier of choice. Some growers using fuel oil have installed storage capacity allowing them to buy in bulk when prices are low (e.g., outside the heating season).

10. Alternative Energy Sources

It is a good idea to investigate alternative energy sources (biomass, wind, water, solar, etc.). Financial incentive programs may be available to help with the installation costs. In some cases, recent technological developments have resulted in significant improvements in conversion efficiencies. Co-generation units (producing both electricity and heat) can be an attractive alternative making growers less dependent on local power companies, and boosting the overall conversion efficiency of the fuel source used. In some areas it is possible to sell any excess electricity back to the local utility, generating additional revenue.

Sources for More Information

Aldrich, R.A. and J.W. Bartok. 1994. Greenhouse Engineering, NRAES Publication No. 33. Natural Resource, Agriculture, and Engineering Service. P.O. Box 4557 Ithaca, NY 14852. Available at: http://www.nraes.org.

Bartok, J. W. 2001(revision). Energy Conservation for Commercial Greenhouses. NRAES Publication No. 3. Natural Resource, Agriculture, and Engineering Service. P.O. Box 4557 Ithaca, NY 14852. Available at: http://www.nraes.org.

Greenhouse Energy Conservation Checklist

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Increasing energy costs make conservation and efficient use of facilities an important part of today's greenhouse operation. New greenhouse designs, better glazing, improved heating and ventilating equipment and new management systems should be included when upgrading or adding on. With typical annual energy usage being 75% for heating, 15% for electricity and 10% for vehicles, efforts and resources should be put where the greatest savings can be realized.

Reduce Air Leaks

- **Keep doors closed** - use door closer or springs.
- **Weatherstrip doors**, vents and fan openings. For example, a 48" fan louver that fails to close properly leaving 1" gaps, allows 23,000 Btu/hr of heat to escape costing $0.35 if you are burning $1.50 fuel oil.
- **Lubricate louvers** frequently so that they close tight. A partially open louver may allow several air changes per hour. Additional fuel is needed to heat this air. Shut off some fans during the winter and cover openings with insulation or plastic to reduce infiltration of air.
- **Repair broken glass** or holes in the plastic covering.

Double Covering

- **Line sidewalls and endwalls** of greenhouse inside with poly or bubble wrap to achieve the thermopane effect. Install double wall polycarbonate structured sheets to get insulation effect and reduce recovering labor.
- **Use poly with an infrared inhibitor** on the inner layer for 15% savings. Payback is 2-3 months.
- **Add a single or double layer of plastic** over older glasshouses to reduce infiltration and heat loss by 50%.

Energy Conserving Blanket

- **Install a thermal blanket** for 20%-50% savings. Cost is $1.00 - $2.50/sq ft. Payback is 1-2 years. Tight closures should be maintained where curtains meet sidewalls, framing or gutters. Use a U-shaped trap to prevent heat from escaping overhead. Heat and water lines should be insulated or located below the blanket.

Foundation and Sidewall Insulation

- **Insulate the foundation** - place 1-2" polyurethane or polystyrene board to 18" below ground to reduce heat loss. This can increase the soil temperature near the sidewall as much as 10 degrees during the winter.
- **Insulate the kneewall** or sidewall to bench height. Use 1" to 2" of insulation board. Applying 2" of foam insulation to a 3' high kneewall on a 28' x 100' greenhouse will save about 400 gallons of fuel oil/year.
- **Insulate behind sidewall heat pipes** - Use aluminum faced building paper or insulation board behind to radiant heat back into the growing area. Leave air space next to wall to prevent frost damage to the wall.

Site Location

- **Locate new greenhouses in sheltered areas** to reduce wind-induced heat loss, if this does not reduce light.
- **Install windbreaks** on the north and northwest sides of the greenhouse. The windbreak can be a double row of conifer trees or plastic snow fence.

Space Utilization

- **Increase space utilization** to 80% - 90% with peninsular or movable benches.
- **Install multi-level racks** for crops that don't require high light levels.
- **Grow a crop of hanging baskets** on overhead rails or truss-mounted conveyor system.
- **A roll-out bench system** can double growing space. Plants are moved outside during the day.

Efficient Heating System

- **Installation of floor or under-bench heat** will allow air temperature to be set 5º - 10ºF lower.
- **Yearly maintenance** - Check boiler, burner and backup systems to make sure they are operating at peak efficiency. Have furnaces cleaned and adjusted and an efficiency test run before heating season. A 2% increase in efficiency for a 30' x 150' greenhouse will save about 200 gallons of fuel oil.
- **Clean heating pipes** and other radiation surfaces frequently.
- **Check accuracy of thermostats** – correcting a reading that is 2ºF high will save $100-$200.
- **Install electronic thermostats** or controllers with a 1° F accuracy. Potential yearly savings of 500 gallons of fuel oil in a 30' x 100' greenhouse when changing from a mechanical to electronic thermostat or controller.
- **Aspirate thermostats or sensors** for more uniform temperature control. Differential between on and off can be reduced as much as 6ºF.
- **Install horizontal air flow (HAF) fans** to get more uniform temperature in the growing area.
- **Insulate distribution pipes** in areas where heat is not required.
- **Check and repair leaks** in valves, steam traps and pipes.

Efficient Cooling System

- **Build new greenhouse with open-roof design** to eliminate the need for fans.
- **Install roll-up or guillotine sides** to reduce the need for fan ventilation.
- **Use shading** to reduce the need for mechanical cooling.
- **Install evaporative cooling** to get better temperature control during the summer.
- **Select fans that meet AMCA standards** and have a Ventilation Efficiency Ratio greater than 15.Use the largest diameter fan with the smallest motor that meets ventilation requirements.
- **Keep doors closed when fans are operating**.
- **Locate intake louvers to give uniform cooling.**

Conserve Electricity

- **Have wiring system inspected** for overloading, corroded parts and faulty insulation.
- **Replace 3 hp or larger motors** with high efficiency ones to reduce electric consumption by 2-5%.
- **Check for proper belt tension** and alignment.
- **Replace incandescent bulbs** with low wattage fluorescent or HID bulbs. Save 2/3rds on electricity.

- **Install motion detectors** to control security lights so they are not on all the time.

Trucks and Tractors

- **Regularly scheduled tune-ups** can save 10% on fuel usage. Keep tires properly inflated.
- **Avoid lengthy idling.** Idling can consume 15-20% of the fuel used.
- **Run equipment in the proper gear** for the load.

Water Systems

- **Locate hot water tanks** as close as possible to the largest and most frequent use. Insulate pipes.
- **Heat water to the lowest temperature needed**, usually 120ºF is adequate.
- **Use pipe size large enough** to supply necessary water at minimum friction loss.
- **Eliminate water leaks** – A dripping faucet at 60 drops/min. will waste 113 gallons/month.

Management

- **Lower night temperature** – Fuel consumption is reduced 3% for each 1ºF night temperature is lowered.
- **Delay starting the greenhouse** by a week or more. Build a germination/growth chamber to start seedlings.
- **Keep growing areas full** at all times.

Additional information can be found in **Energy Conservation for Commercial Greenhouses** – NRAES-3, 100 pages, $20.00 available from the Department of Natural Resources Mgt. & Engr., 1376 Storrs Rd., UConn, Storrs CT 06269-4087. Make check payable to UConn. Price includes postage and handling.

Individual Greenhouse Energy Conservation Checklist

(Adapted from a checklist developed by John W. Bartok Jr., Professor Emeritus, University of Connecticut by A.J. Both, Rutgers University, and Paul Fisher, University of New Hampshire) February 2006

Structure #/name _______________

Approximate year built __________

Dimensions and space use

Size: total width _____ ft. bay width _____ ft. number of bays:______ length _____ ft.

Square feet of floor space:__________ Sq. ft. of bench/floor space covered by crops:___________

% Space utilization (floor area used for crop production/total floor space)?_________________

Number of hanging baskets:____________ sq.ft. of floor space per hanging basket:__________

List main crops [in general groups (e.g. plugs)] grown in the greenhouse at different times of year:

Crop type	Months	sq.ft. of greenhouse space filled

Is the greenhouse used for production?____________ retail?____________ both? ____________

Are crops grown on floor ______, benches ______, overhead ______? (check all that apply)

Are plants grown in one or multiple levels (e.g., hanging baskets)? Yes No

Is a roll-out bench system used for spring bedding plant production? Yes No

Is the greenhouse completely filled with plants during the time it is heated? Yes No

Suggestions to improve space utilization:____

____

____

____

Greenhouse glazing and leaks

What type(s) of film/rigid panel/glass is(are) used?______________________________________

What is the condition of the glazing material? Excellent Good Fair

If polyethylene film, does it have an IR barrier? Yes No
does it have a no-drip surface? Yes No
is it inflated using outside air? Yes No

Which greenhouses surfaces are covered with a double layer (including multi-wall panels)?
End walls Sidewalls Roof

Is the greenhouse located in a wind sheltered area (without reducing sunlight)? Yes No

Are windbreaks installed around the greenhouse (without reducing sunlight)? Yes No

Does the greenhouse feel drafty? Yes No

Do you observe any undesirable leaks/openings in the greenhouse cover? Yes No

Are doors/windows closing properly and kept closed when not in use? Yes No

Does the ventilation window close properly? Yes No

Do the fan louvers close properly? Yes No NA

Suggestions (consult an expert) in terms of glazing and leaks:______________________________

____

Shade curtain

Is a shade curtain installed? Yes No

If yes, does the shade curtain also serve as energy blanket? Yes No
what is the shade factor (%) of the curtain?________________________________
what is the energy savings factor (%) of the curtain?_________________________
what is the control strategy followed for closing the curtain to conserve energy?

____

what is the control strategy followed for opening the curtain after a cold night?

____

what is the control strategy for using the curtain as shade screen?

____

Suggestions (consult an expert) in terms of shade curtains:_________________________________

____

____

Perimeter insulation

Has perimeter insulation been installed? Yes No

If yes, what material, how thick and to what depth?__________________________________

If applicable, are knee walls (or side walls to bench height) insulated? Yes No NA

Is the wall area directly behind side wall heating pipes insulated? Yes No NA

What is the condition of the various insulation materials? Excellent Good Fair NA

Suggestions (consult an expert) in terms of perimeter insulation:____________________________

____

Heating system (Note: calculation methods are provided at the end of this checklist)

What type of heating system is used? Hot water Hot air Steam Other

What is the manufacturer and model of the heating system?________________________________

What is the total installed capacity of the heating system?__________________________________

What is the nighttime set point temperature?________°F

What is the local minimum design temperature (consult figure on page 7)? _________°F

What is the total calculated heat requirement (calculate yourself or ask manufacturer)? ________

Is the installed capacity adequate, given the heat requirement and desired delta T? Yes No

What fuel source(s) is(are) burnt in the boiler/heaters?_____________________________________

Does the grower use floor and/or bench heating? Yes No

Is the temperature sensor or thermostat shielded from sunlight? Yes No

in an aspirated box? Yes No

within 3 feet of the crop canopy? Yes No

at a representative location in the house? Yes No

calibrated during the last 12 months? Yes No

If the grower uses a thermostat, what is its accuracy? ±________°F

is it an electronic thermostat? Yes No NA

Are HAF fans installed and in use? Yes No

commercial grade or residential house fans? Commercial Residential

turned off when venting air? Yes No

Did you observe any leaks in the hot water distribution system? Yes No NA

Are the hot water heating pipes clean? Yes No NA

Are the hot water distribution pipes insulated? Yes No NA

Are hot water tanks close to largest and most frequent point of use? Yes No NA

What is the temperature setting on the hot water storage tank?________°F NA

Are heat exchangers (e.g., located inside unit heaters) clean? Yes No NA

Is the unit heater or boiler power vented? Yes No NA

Was the heating system serviced immediately before or during this cold season? Yes No

Is there more than one heating zone (e.g. bench/perimeter zones or multiple bays)? Yes No

Is there a backup heating source in case the main heater fails? Yes No

Suggestions (consult an expert) in terms of heating system:_______________________________

____

Ventilation and Cooling

Is the greenhouse naturally or mechanically ventilated? Naturally Mechanically

If naturally, is the ventilation system motorized? Yes No

is it an open-roof greenhouse? Yes No

If mechanically, are the fans AMCA rated (check AMCA seal) and do they have a ventilation efficiency ratio larger than 15? Yes No Don't know

are the fan motors variable speed motors? Yes No

are the fans staged (and what is their staging)? Yes No

are the belts on the fans tightened and aligned properly? Yes No

are the blades balanced and in good condition? Yes No

Are outside doors routinely kept closed when the greenhouse is venting? Yes No

Are indoor doors routinely kept closed between compartments? Yes No NA

Does the greenhouse have an evaporative cooling system? Yes No

If yes, what type? Pad and Fan System Fog System

Does the grower report any humidity problems? Yes No

Suggestions (consult an expert) in terms of ventilation and cooling:__________________________

____

____

Insect Screening
Is the ventilation opening outfitted with insect screening? Yes No

If no, does the grower report insect problems? Yes No

If yes, what is(are) the type(s) of insect(s) that need to be screened out?____________________

If yes, what is the mesh size (or opening size) of the screen material?______________________

If yes, what is the pressure drop across the screen material? Inches of water gauge___________

If yes, is the insect screen in good condition (i.e., without unwanted openings)? Yes No

If yes, how often is the screening material cleaned?

If yes, does the ventilation system provide adequate ventilation on warm summer days?
Yes No

Suggestions (consult an expert) in terms of insect screening:_____________________________

____

Drainage
Does rain and melt water drain away from the building properly? Yes No

Is there excess irrigation water on the floor Yes No

Suggestions (consult an expert) in terms of drainage:___________________________________

____

Conserving Electricity
Are all electrical motors high efficiency? Yes No

Were any incandescent lamp bulbs replaced with fluorescent or HID bulbs? Yes No

Was a licensed electrician involved in design of the system? Yes No

Has the entire electric system been checked recently by a licensed electrician? Yes No

How many phases does the electric system have?______________________________________

What is the voltage provided to the various electrical services?_____________________________

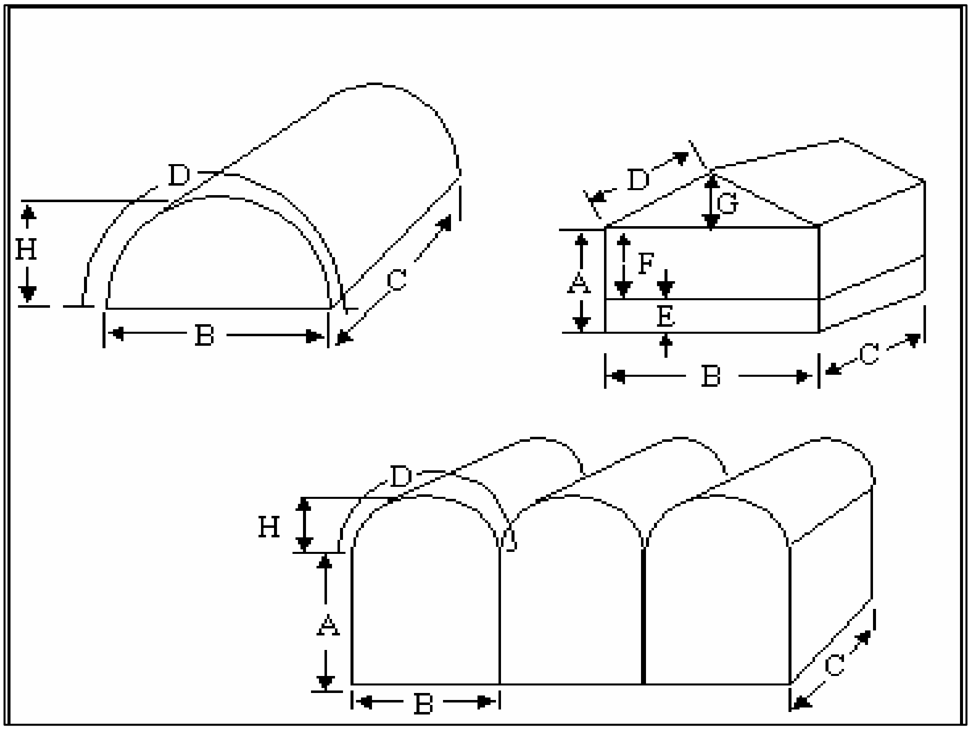
Is there a backup generator? Yes No

Suggestions (consult an expert) in terms of electricity:__________________________________

____

____

Equations, figures and tables useful for heat calculations:



Step 1: Determine greenhouse dimensions (in feet).
Wall height A =
House width B =
House length C =
Rafter length D =
Lower wall height E =
Upper wall height F =
Gable height G or H =

Step 2: Calculate surface areas (in ft^2) and perimeter distance (in ft)
Note: N is the number of greenhouse bays. N = 1 for a single bay greenhouse.
Lower wall area: 2N(E x B) + (E x 2C) =
Upper wall area: 2N(F x B) + (F x 2C) =
Single material wall: 2N(A x B) + (A x 2C) =
Gable-style greenhouse roof surface area: 2N x D x C =
Gable-style greenhouse gable area (end wall above gutter): N x B x G =
Curved-roof style greenhouse roof surface area: N x D x C =
Curved-roof style greenhouse gable area (end wall above gutter): 1.1N x B x H =
Hoop-house end wall area: 1.5N x B x H =
Perimeter: 2[(N x B) + C] =

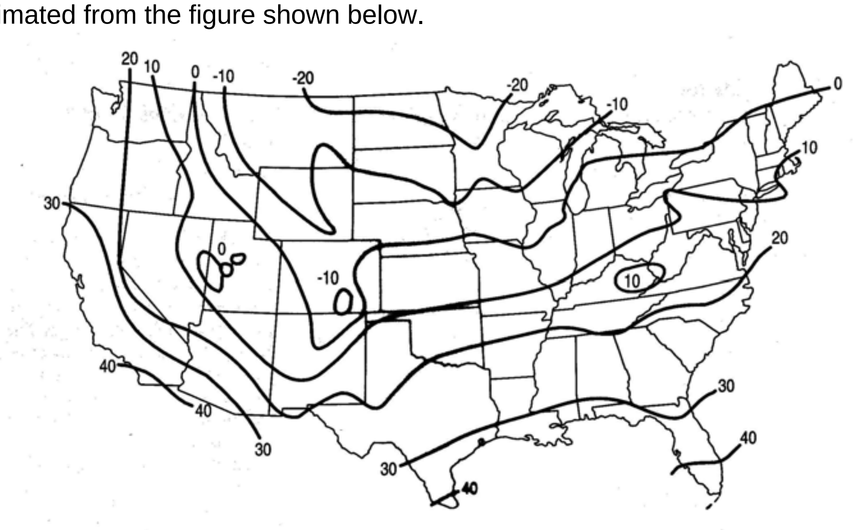
Step 3: Determine U-values for each material used in the various surface areas.
Lower wall area: U_1 =
Upper wall area: U_2 =
Single material wall: U_3 =
End wall area: U_4 =
Roof: U_5 =

The U-values (heat transfer coefficients) can be determined from the data shown in the table below.

Material	**U in Btu/hr per ft^2 per °F**
Single (double) layer of glass	1.1 (0.7)
Single (double) layer of poly	1.1 (0.7)
Double layer plus energy curtain	0.3 – 0.5
Double layer acrylic	0.6
Double layer polycarbonate	0.6
½" plywood	0.7
8" concrete block	0.5
2" Polystyrene	0.1 (R = 10)

Step 4: Calculate the structural heat loss (Q_{STRUC} in Btu/hr)
$Q_{STRUC} = \Sigma(U_i \times A_i) \times \Delta T$
Heat loss from lower wall area: Lower wall area x U_1 x ΔT =
Heat loss from upper wall area: Upper wall area x U_2 x ΔT =
Heat loss from single material wall area: Single material wall area x U_3 x ΔT =
Heat loss from gable or curved-end area: Gable or curved-end area x U_4 x ΔT =
Heat loss from roof area: Roof area x U_5 x ΔT =
Total Q_{STRUC} =

ΔT is the temperature difference between inside and outside, or the difference between the nighttime temperature set point (inside) and the local minimum design temperature (outside). This minimum design temperature can be determined for a particular location from historical weather data, or estimated from the figure shown below.



Step 5: Calculate the perimeter heat loss (Q_P in Btu/hr)
Q_P = Perimeter heat loss factor x Perimeter x ΔT
For perimeter heat loss factor, use a value of 0.4 or 0.8 Btu/hr per linear foot of perimeter per °F depending on whether the perimeter is insulated or not.

Step 6: Calculate the greenhouse volume (in cubic feet)
Gable-style greenhouse volume: N[(A x B x C) + (B x G x C/2)] =
Single curved roof greenhouse volume: 2H x B x C/3 =
Multiple curved roof greenhouse volume: N[(A x B x C) + (2H x B x C/3)] =

Step 7: Calculate the infiltration heat loss (Q_A in Btu/hr)
Q_A = 0.02 x Greenhouse volume x Air exchanges per hour x ΔT =

For air exchanges per hour use the following table.

Type of construction	**Air exchanges per hour**
New, glass	0.75 - 1.5
New, double poly	0.50 - 1.0
Old, glass and in good condition	1.0 – 2.0
Old, glass and in poor condition	2.0 – 4.0

Step 8: Calculate the total heat loss (Q_T in Btu/hr)
$Q_T = Q_{STRUC} + Q_P + Q_A$ =

Adjustment to the heat loss calculations should be made for situations with a large ΔT and/or locations with high average wind velocities: If ΔT is larger than 70°F, and if the average wind velocity is larger than 15 mph, multiply the calculated total heat loss by: (1 + 0.08) for every increase in ΔT of 5°F above 70°F and (1 + 0.04) for every 5 mph increase in average wind velocity above 15 mph. For example, if ΔT = 80°F and the average wind velocity is 25 mph, multiply the calculated total heat loss by a factor of: 1 + (0.16 + 0.08) = 1.24.

If the greenhouse heating system is designed properly, the capacity of the heating system should match the calculated total heat loss Q_T (that is the predicted heat loss on the coldest night). Make sure that the heating system has an output rating that equals the calculated total heat loss. When the heating system is rated by input, multiply this value by the efficiency of the system (generally in the 70-80% range) to determine the rated output.

Additional Reading:

Aldrich, R.A. and J.W. Bartok. 1994. Greenhouse Engineering, NRAES Publication No. 33. Natural Resource, Agriculture, and Engineering Service. P.O. Box 4557 Ithaca, NY 14852. http://www.nraes.org.

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