Greenhouse Energy Conservation Checklist/Audit

(Adapted by A.J. Both, Rutgers University, and Paul Fisher, University of Florida from a checklist developed by John W. Bartok Jr., Professor Emeritus, University of Connecticut) 2007

Structure #/name _______________

Approximate year built ___________

Dimensions and space use

Size: length _______ ft., bay width _______ ft., number of bays:_______

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 (consult an expert) to improve space utilization:_____________________________

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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 <u>outside</u> 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:____________________________

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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:_______________________________

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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:__________________________

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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:______________________________

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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 (VER) 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:_________________________

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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:_____________________________

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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:___________________________________

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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:__________________________________

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Equations, figures and tables useful for heat loss 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 side wall area: 2N(E x B) + (E x 2C) =
Upper side wall area: 2N(F x B) + (F x 2C) =
Or, Single material side 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 =

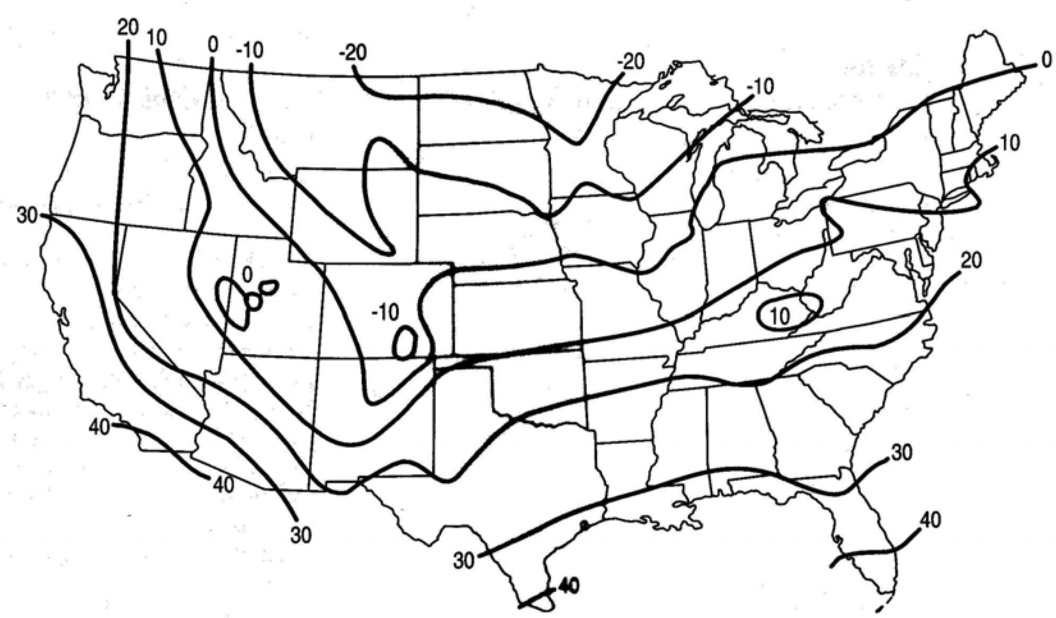
End wall area: U_4 =
Roof: U_5 =

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

Material	*U in Btu/hr per ft² 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)
$Q_{STRUC} = \Sigma(U_i \times A_i) \times \Delta T$ (i.e., the sum of all applicable heat losses)
Heat loss from lower wall area: Lower side wall area x U_1 x ΔT =
Heat loss from upper wall area: Upper side wall area x U_2 x ΔT =
Or, Heat loss from single material wall area: Single material side 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 (pronounced ‘delta T’) 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.

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. http://www.nraes.org.