

ANSI/ASAE EP406.4 JAN2003 (R2008)
Heating, Ventilating and Cooling Greenhouses



American Society of
Agricultural and Biological Engineers

**S
T
A
N
D
A
R
D**

ASABE is a professional and technical organization, of members worldwide, who are dedicated to advancement of engineering applicable to agricultural, food, and biological systems. ASABE Standards are consensus documents developed and adopted by the American Society of Agricultural and Biological Engineers to meet standardization needs within the scope of the Society; principally agricultural field equipment, farmstead equipment, structures, soil and water resource management, turf and landscape equipment, forest engineering, food and process engineering, electric power applications, plant and animal environment, and waste management.

NOTE: ASABE Standards, Engineering Practices, and Data are informational and advisory only. Their use by anyone engaged in industry or trade is entirely voluntary. The ASABE assumes no responsibility for results attributable to the application of ASABE Standards, Engineering Practices, and Data. Conformity does not ensure compliance with applicable ordinances, laws and regulations. Prospective users are responsible for protecting themselves against liability for infringement of patents.

ASABE Standards, Engineering Practices, and Data initially approved prior to the society name change in July of 2005 are designated as 'ASAE', regardless of the revision approval date. Newly developed Standards, Engineering Practices and Data approved after July of 2005 are designated as 'ASABE'.

Standards designated as 'ANSI' are American National Standards as are all ISO adoptions published by ASABE. Adoption as an American National Standard requires verification by ANSI that the requirements for due process, consensus, and other criteria for approval have been met by ASABE.

Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution.

CAUTION NOTICE: ASABE and ANSI standards may be revised or withdrawn at any time. Additionally, procedures of ASABE require that action be taken periodically to reaffirm, revise, or withdraw each standard.

Copyright American Society of Agricultural and Biological Engineers. All rights reserved.

ASABE, 2950 Niles Road, St. Joseph, MI 49085-9659, USA ph. 269-429-0300, fax 269-429-3852, hq@asabe.org

Heating, Ventilating and Cooling Greenhouses

Developed by the Greenhouse Engineering Practices Subcommittee of the ASAE Environment of Plant Structures Committee; approved by the ASAE Structures and Environment Division Standards Committee; adopted by ASAE April 1981; reconfirmed December 1985, December 1986, December 1987, December 1988; revised April 1990, February 1995; approved as an American National Standard October 1995; revised December 1997; revision approved by ANSI March 1998; revised January 2003; revision approved by ANSI February 2003; reaffirmed by ASABE and ANSI February 2008.

Keywords: Coding, Greenhouses, Heating, Ventilation

1 Purpose and scope

This Engineering Practice presents design information for heating, ventilating and cooling greenhouses. Generally accepted methods of heating, ventilating and cooling are presented and the important design features of typical systems are indicated.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Standards organizations maintain registers of currently valid standards.

ANSI/AMCA 210-99, *Laboratory Methods of Testing Fans for Aerodynamic Rating*

ANSI/ASAE S493 NOV98, *Guarding for Agricultural Equipment*

ASAE D271.2 DEC99, *Psychrometric Data*

ASAE EP460 DEC01, *Commercial Greenhouse Design and Layout*

3 General definitions

3.1 air circulation: The process of moving or mixing air within a greenhouse to control temperature, humidity and carbon dioxide distribution.

3.2 aspirate: To circulate air continuously across or through an object, such as a temperature sensor.

3.3 cooling: Generally, the removal of heat from the interior of the greenhouse; however, the term may also be applied to the conversion from sensible to latent energy, as in evaporative cooling (see 3.4).

3.4 evaporative cooling: The addition of moisture to air (usually ventilation air) to reduce its dry bulb temperature. Sensible energy is converted to latent energy with negligible change in the enthalpy of the air.

3.5 glazing: The transparent or translucent covering of a greenhouse; e.g., glass, plastic film, rigid plastic panels, etc.

3.6 heating: The addition of heat to the interior of the greenhouse from any energy source, including the sun.

3.7 horizontal air circulation: A system utilizing fans to generate a horizontal air circulation pattern above and through the plant canopy.

3.8 infiltration: Uncontrolled air exchange which occurs through small, uncontrolled openings in the greenhouse covering, such as gaps around doorways, utility service entrances and between cover sections. These exchanges are driven by wind pressure and/or temperature differentials

inside and outside the greenhouse. Infiltration rate is generally expressed in terms of internal air volume changes per unit of time (e.g., air exchanges per hour).

3.9 fan ventilation: Air exchange through side wall and/or roof openings, which occurs when fans are used to move air into, and exhaust air out of, the greenhouse. Fans may be located either at the inlet end (positive pressure) or the exhaust end (negative pressure); however, the most common location is at the exhaust end.

3.10 natural ventilation: Air exchange which occurs in response to temperature and pressure variations inside and outside the greenhouse. These variations are created and maintained by solar energy, internal heat sources, and/or wind.

3.11 ridge and furrow: A type of greenhouse construction where modular units are connected at the gutters to cover large ground areas; also called gutter-connected greenhouses.

3.12 ventilation: The process of exchanging air inside the greenhouse with outside air to control temperature, humidity and carbon dioxide levels.

3.12.1 ventilation rate: The volume of air exchanged per unit of time per unit floor area. Ventilation rate is often expressed as $\text{m}^3/(\text{s} \cdot \text{m}^2)$ (cfm/ft^2) of greenhouse floor area.

4 Principles of heating and heat loss determination

4.1 Most undesirable heat loss from a greenhouse occurs by long-wave radiation, conduction and convection (q_{rc}) and by infiltration (q_i). Heating requirements are determined by calculating the sum of q_{rc} and q_i based upon the guidelines in 4.6 and 4.7.

4.2 The heat loss by radiation, conduction and convection, q_{rc} , (W or Btu/h) can be determined by:

$$q_{rc} = UA_c(t_i - t_o) \quad (1)$$

where:

U is overall heat transfer coefficient (table 1), $\text{W}/(\text{m}^2 \cdot ^\circ\text{C})$ ($\text{BTU}/[\text{h} \cdot \text{ft}^2 \cdot ^\circ\text{F}]$);

A_c is area of the cover, m^2 (ft^2);

t_i is greenhouse air temperature, $^\circ\text{C}$ ($^\circ\text{F}$);

t_o is outside air temperature, $^\circ\text{C}$ ($^\circ\text{F}$).

4.3 Greenhouse heat loss by infiltration, q_i , (W or Btu/h) can be estimated by considering that the total exchange will be the sum of the sensible and latent energy exchanges:

$$q_i = \rho_i NV [c_{p_i}(t_i - t_o) + h_{fg}(W_i - W_o)] \quad (2)$$

where:

Table 1 – Approximate overall heat transfer coefficients (*U*-values) for greenhouse glazing methods and materials

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

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.

- ρ_i is density of the greenhouse air, kg/m³ (lb/ft³);
- c_{p_i} is specific heat of the inside air, J/(kg·°C) (Btu/(lb·°F));
- N is infiltration rate (table 2), s⁻¹ (h⁻¹);
- V is volume of the greenhouse, m³(ft³);
- h_{fg} is latent heat of vaporization of water at t_i , J/kg (Btu/lb);
- W_i is humidity ratio of the inside air, kg_{water}/kg_{air} (lb_{water}/lb_{air});
- W_o is humidity ratio of the outside air, kg_{water}/kg_{air} (lb_{water}/lb_{air}).

4.4 If outside temperatures are near or below – 20 °C (– 4 °F), and inside relative humidities are 40% or less, latent heat exchange will be limited, and equation 2 can be approximated by

$$q_i = 1800VN(t_i - t_o) \quad (3)$$

where:

- q_i is in watts;
- t_i is in °C;
- t_o is in °C;
- N is in s⁻¹,
- V is in m³.

4.5 Natural air exchanges (table 2) can be very low if cracks become sealed with frozen condensate. During low wind conditions, even unfrozen condensate can serve to seal cracks. The degree to which either will happen will depend upon the type of cover, size and orientation of the cracks, the inside and outside temperatures, and the amount of transpiration by the canopy.

4.6 Outside design temperatures for heating are tabulated for various locations in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Handbook—Fundamentals. The 99% winter design dry bulb temperature is recommended for sizing greenhouse heating systems that are to be used year round. A warmer temperature may be selected if use is intended only during warmer parts of the year. Local weather data should be consulted where available.

4.7 Maximum design heating load should be based upon the inside temperature required by the plants at night. A temperature of 16 °C

Table 2 – Estimated infiltration rates for greenhouses by type and construction

Type and construction	Infiltration rate (<i>N</i>) ¹⁾	
	s ⁻¹	h ⁻¹
<u>New construction:</u>		
double plastic film	2.1×10 ⁻⁴ –4.1× 10 ⁻⁴	0.75–1.5
glass or fiberglass	1.4×10 ⁻⁴ –2.8× 10 ⁻⁴	0.50–1.0
<u>Old construction:</u>		
glass, good maintenance	2.8×10 ⁻⁴ –5.6× 10 ⁻⁴	1.0–2.0
glass, poor maintenance	5.6×10 ⁻⁴ –11.1×10 ⁻⁴	2.0–4.0

¹⁾Internal air volume exchanges per unit time (s⁻¹ or h⁻¹). High winds or direct exposure to wind will increase infiltration rates; conversely, low winds or protection from wind will reduce infiltration rates.

(60 °F) generally meets the needs of most plants. While daytime temperature settings are generally 6 to 11 °C (10 to 20 °F) higher than nighttime settings on bright sunny days and 3 to 6 °C (5 to 10 °F) higher on cloudy days, solar radiation will generally provide the necessary additional energy.

4.8 Heat loss through concrete or masonry walls should be calculated by conventional means such as those described in ASHRAE Handbook—Fundamentals.

5 Heating and air circulation systems

5.1 Central heating

5.1.1 Central heating systems generally use hot water or steam distributed to heat exchangers made up of standard black pipe (natural convection), finned-pipe (natural convection), or steam/hot-water unit heaters (forced convection). Hot water may also be circulated through hollow structural members.

5.1.2 Sizing of the heat exchangers is accomplished by standard heat transfer calculations taking into account heating requirements, heating fluid characteristics and exchanger characteristics. Manufacturer's data may be required to get accurate results for finned-pipe and unit heaters. Additional considerations for unit heaters are presented in 5.2. Considerations for standard-pipe and finned-pipe heat exchangers are discussed in clauses 5.1.3 to 5.1.6.

5.1.3 Greenhouses 9 m (30 ft) or less in width may be heated with standard black pipe or finned-pipe placed only along the sidewalls. For single-span houses wider than 9 m (30 ft), distribute the pipes along the sidewalls and below/between the crop (or under the benches) in proportion to the expected heat loss for the walls and roof, respectively.

5.1.4 If steam is used as the heating medium, heating surfaces should be installed at least 0.30 m (12 in.) away from any plant material. For narrow-span ridge and furrow houses, heating pipes should be placed along the exterior walls and below the gutters between sections. Pipes may also be placed below benches, between the rows or adjacent to root media for root zone heating.

5.1.5 When using black-or finned-pipe, naturally induced air circulation does not always provide sufficiently uniform air temperatures at plant height. If increased temperature uniformity is desired, air circulation fans can be installed in accordance with 5.4.

5.1.6 Since maximum heating capacity is rarely needed all of the time, central heating systems should be designed with two or three zones. The primary zone should be floor or under bench heat. In ridge and furrow houses, the heat pipes under the gutters should be capable of being operated manually to melt snow, if necessary.

5.1.7 All boilers and hot water heaters shall have appropriate valves, controls and safety devices and shall be installed in accordance with all applicable codes.