

Winter Ventilation And Heating Requirements Of PRIVATE Fiberglass Greenhouses For Condensation Control¹

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Condensation forming on the inside surfaces of greenhouses is of considerable economic significance. Economic problems associated with condensation in greenhouses are fungus diseases; difficulty in maintaining a clean greenhouse; more rapid deterioration of structural components; and damp, uncomfortable environmental conditions for the workers. Furthermore, the presence of condensation is unsightly and a nuisance.

Condensation occurs when warm, moist air in a greenhouse comes in contact with a cold surface such as glass, fiberglass, plastic or structural members. The air in contact with the cold surface is cooled to the temperature of the surface. If the surface temperature is below the dew point temperature of the air, the water vapor in the air will condense onto the surface. For example, condensation will occur if air in a greenhouse at 70°F and 70 percent relative humidity comes in contact with a surface that is 60°F or colder.

Most of the condensation problems in greenhouse occur when the minimum outside temperatures drop below 50°F. This occurs between the months of November and March, except for unenvironmental circumstances. Condensation will form heaviest in greenhouses during the period from sundown to several hours after sunrise. During the daylight hours, there is sufficient heating in the greenhouse from solar radiation to minimize or eliminate condensation from occurring except on very cold, cloudy days. The time when greenhouses are most likely to experience heavy condensation is sunrise or shortly before. At this time, the outdoor air temperature is usually at a minimum.

Four general methods exist for controlling condensation:

- exhausting moist air and replacing it with heated, outside air,

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- providing continuous air movement,
- applying double layer covering, and
- using a wetting agent.

Of these four methods, only exhausting moist air and replacing it with heated outside air is really effective in eliminating condensation. The other methods reduce and minimize the amount of condensation that may occur, but in themselves are not solutions to eliminating condensation formation. This publication deals with ventilation and heating requirements of greenhouses to prevent conformation.

MATERIALS AND METHODS

Environmental conditions were recorded inside and outside a large, double-vaulted commercial, fiberglass greenhouse in Apopka, Florida, during two consecutive cold seasons. Inside surface temperatures, bed temperatures, and air temperatures were measured with copper thermocouples at 16 locations. These measurements were recorded on a thermocouple recorder. Inside and outside air temperatures and relative humidities were measured and recorded with hygrothermographs.

RESULTS AND DISCUSSION

The nine inside surface temperatures that were recorded at the time of the minimum temperature of the day were averaged to obtain the mean inside surface temperature. Based on the measured data points obtained during the two cold seasons, the mean inside surface temperature was found to be simply the average of the inside and outside air temperatures, within 2°F. This result appears to be reasonable when one considers that the fiberglass material, about 1/32 in. thick, has essentially no thermal resistance. The only resistance to heat flow is that offered by the inside and outside air films. These two air films would have approximately the same thermal resistance at the time of the minimum temperature of the day, because then the outdoor air is usually very still.

Having established the relationship between inside surface temperature and inside and outside air

temperatures, the minimum ventilation requirement to prevent condensation can be calculated. The calculated ventilation rates for the stated inside and outside air temperatures in columns 1 and 2 are presented in column 3 of Table 1. To greatly increase the application of the calculated values for ventilation and heating to maintain desired conditions, the rates are expressed per unit of greenhouse bed area. Ventilation is expressed in units of cfm (cubic feet of air per minute) per square foot of actual bed area of the greenhouse.

The ventilation rate was calculated by analyzing a conservation of mass equation; that is, the moisture entering the greenhouse in the ventilation air plus the moisture produced within the greenhouse equals the moisture leaving the greenhouse in the ventilation air. In equation form, the moisture conservation balance becomes:

$$MW_0 + W_{prod} = MW_i$$

M = mass flow rate of ventilation air, pounds of dry air per hour per square foot of bed area

W_0 = humidity ratio of outside air, pounds of water per pound of dry air

W_{prod} = moisture production rate within the greenhouse, pounds of water per hour per square foot of bed area

W_i = humidity ratio of inside air, pounds of water per pound of dry air

The ventilation rate was calculated from Equation 1 by first solving for M , the mass flow rate of the ventilation air. The mass flow rate of air was then converted to ventilation rate, with units of cfm per square foot of bed area, by multiplying air mass flow rate and specific volume of 13.33 cubic feet per pound and dividing by 60 minutes per hour. The conversion factor obtained was 0.222.

In order to solve Equation 1 for M , the value of W_i was determined from a psychrometric chart such that the dew point temperature of the inside air mixture was 4 °F below the predicted inside surface temperature. By choosing W_i in such a manner incorporated a modest safety factor into the values presented in Table 1. The 4 °F margin also takes into

Table 1. Minimum ventilation and heating rates required to prevent condensation inside fiberglass greenhouses.

Outside Temperature, °F	Inside Temperature, °F	Ventilation Rate, cfm	Heating Rate*, Btu/h	Resulting Inside Relative Humidity,
10	50	1.76	92.0 + 40S**	38
	55	1.48	87.8 + 45S	36
	60	1.23	81.8 + 50S	34
	65	1.11	82.3 + 55S	30
20	55	1.38	68.1 + 35S	43
	60	1.11	62.8 + 40S	41
	65	0.97	62.7 + 45S	38
	70	0.85	61.5 + 50S	35
30	55	1.39	52.2 + 25S	54
	60	1.17	53.5 + 30S	50
	65	0.97	52.2 + 35S	46
	70	0.85	51.1 + 40S	43
40	55	1.71	43.3 + 15S	65
	60	1.31	44.3 + 20S	60
	65	1.01	42.8 + 25S	56
	70	0.82	42.2 + 30S	52
	75	0.67	40.8 + 35S	48
50	60	1.71	34.7 + 10S	73
	65	1.17	34.3 + 15S	67
	70	0.89	34.9 + 20S	62
	75	0.72	35.4 + 25S	57
60	65	2.02	27.5 + 5S	80
	70	1.23	30.1 + 10S	74
	75	0.89	31.4 + 15S	68
	80	0.65	30.2 + 20S	63
70	70	2.47	11.1	88
	75	1.31	23.0 + 5S	80
	80	0.82	24.7 + 10S	74

*Ventilation rate and heating rate are expressed per ft² of greenhouse bed area.
 **S = exposed surface area of greenhouse, ft²/bed area of greenhouse, ft².

consideration that the surfaces of the greenhouse with an unobstructed view of the sky will be cooler than other surfaces of the greenhouse due to the radiation losses.

The values of W_0 and W_1 can be obtained most conveniently from a psychrometric chart. The rate of moisture production by the plants and soil was estimated to be 0.00275 inches of water per hour

based on calculations involving data collected in the greenhouse and on results published by Stewart and Mills (1). The resulting relative hu for the recommended ventilation rate is presented in column 5 of Table 1. This value was also obtained from a psychrometric chart.

The heating required to prevent condensation was calculated by analyzing a conservation of energy equation; namely, the heat content (enthalpy) of the ventilation air entering the greenhouse plus the heat added by the heating equipment equals the heat content of the ventilation air leaving plus the heat lost by conduction through the exposed surface area of the green. In equation form, the total heat balance equation is:

$$Mh_0 + Q_{htr} = Mh_i + Q_{cond}$$

where:

M = mass flow rate of ventilation air, pounds per hour per square foot of bed area

h_0 = enthalpy of outside air, Btu per pound of dry air

Q_{htr} = heating rate within greenhouse, Btu per hour per square foot of bed area

h_i = enthalpy of inside air, Btu per pound of dry air

Q_{cond} = heat lost by conduction, Btu per hour per square foot of bed area

The rate of heat conduction through the exsurface areas of the greenhouse was calculated according to:

$$Q_{cond} = S \cdot \Delta T / R$$

where:

S = ratio of exposed surface area of the greenhouse to the bed area of the greenhouse

ΔT = temperature difference between inside and outside air temperatures, °F

R = overall resistance to heat flow, hour-square foot- °F per Btu. A constant value of 1.0 (hour-square foot-er Btu was used throughout this study.

Having determined the mass flow rate from Equation 1, the heat loss by conduction from Equation 3, and h_0 and h_i from a psychrometric chart, the heating rate required to prevent conwithin the greenhouse was calculated from Equation 2. The

results, in terms of S, are presented in column 4 of Table 1.

The value of S generally ranges from 1.5 to 3.0, depending on the configuration of a greenhouse. A large multi-vaulted greenhouse will have a S-value closer to 1.5 or 2.0. The value of S must be calculated for each particular greenhouse in order to determine the total heating required to prevent condensation from Table 1.

The greenhouse that was monitored for this study was used for propagating cuttings. Consequently, most of the water produced inside the greenhouse during the early morning hours was evaporation from the bed media. In greenhouses used for growing larger plants, transpiration from the plants would produce more water within the greenhouse. Under such circumstances, the ventilation and/or heating rates may need to be increased to prevent condensation. Only experience with a particular greenhouse operation can dictate whether an increase would be necessary.

An alternative to increasing the ventilation and/or heating rates presented in Table 1 would be to add air mixing devices, such as turbulators, inside the greenhouse. A turbulator is effective in reducing thermal stratification, thereby insuring a more uniform air temperature throughout the entire greenhouse (2). Turbulators, or similar air mixing devices, would be most needed in those greenhouses having a large portion of their surareas exposed to an unobstructed view of the sky. When a surface has an unobstructed view of the sky, its temperature will drop several degrees below ambient temperature on clear nights because of radiant cooling.

In any greenhouse, some ventilation will occur because of natural infiltration. The magnitude of the rate of natural infiltration depends on the openness of the greenhouse. The more open the greenhouse, the more infiltration will take place. However, it is most difficult to try to effectively eliminate condensation by manipulating the openness of the greenhouse, especially when desiring to control temperature and to minimize amount of heating fuel required.

To illustrate the use of the data presented in Table 1, consider the following example.

EXAMPLE

The cross-section dimensions of a large, double vaulted fiberglass greenhouse are shown in Figure 1. The greenhouse is 372 feet long. By using basic arithmetic methods, the exposed surface area is calculated for the different structural components, and then totaled as shown in Figure 1. Note that the floor is not considered as part of the exposed surface area.

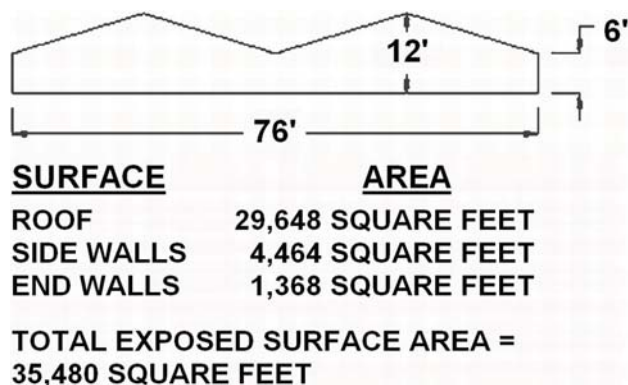


Figure 1. Cross-section view of double-vaulted greenhouse used in the example.

The bed area, assumed to be 75 percent of the total floor area, is 21,204 square feet (.75 x 372 x 76). Therefore, the S-value equals 1.67 (35,480 square feet/21,204 square feet).

Consider the case when the outside temperature is forecast to reach a low of 30°F. Assume you desire to maintain an inside temperature of 65°F and that you want no condensation to occur. Referring to the values presented in Table 1, the ventilation rate is 0.97 cfm per square foot of bed area, or 20,600 cfm (0.97 x 21,204); the required heating rate is 110.65 Btu per hour per square foot of bed area (52.2 + 35 x 1.67); the total heating required is 2,345,000 Btu per hour (21,204 x 110.65); and the resulting inside relative humidity would be about 46%.

SUMMARY

Temperature and humidity measurements were recorded inside and outside a commercial greenhouse in Apopka, Florida, during two consecutive cold seasons. Predictive equations were developed to

determine the minimum ventilating and heating requirements to prevent condensation from forming inside the greenhouse. The equations were formulated based on the environmental conditions, ventilation rates, physical characteristics of greenhouses, and principles of heat and mass transfer. Calculations from the predictive equations are tabulated to present the ventilating and heating requirements for a wide range of inside and outside environmental conditions.

REFERENCES

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