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Air Infiltration in Greenhouses

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Air infiltration rates are important in determining greenhouse heating requirements. Design recommendations usually suggest one to two complete air exchanges per hour under calm conditions (1, 3, 4). Tests made in 10 commercial ranges showed no greenhouse in excess of one exchange per hour, with one as low as 0.34 per hour, and an average of 0.56. However, additional tests at CSU showed marked variation, depending upon greenhouse size and heating methods, as well as type of structure and outside wind velocity.

Method

The method does not appear to have been frequently applied to commercial ranges for field determinations of air infiltration (2). Methane was injected into the greenhouse to provide concentrations 5 to 10 times the outside air, generally ranging from 1.5 to 2.5 ppm. After a period for mixing, samples were taken at regular intervals and the methane concentration determined by gas chromatography. The total volume of methane in the house at each sample interval was calculated and expressed as liters of methane per 10,000 cubic feet.

By transforming concentration to logarithms, a straight line could be calculated, the slope of the line being the rate at which methane escaped from the house. Arbitrary levels of 20 to 10 liters methane were assumed, and the time required for the concentration to go from 20 to 10 was calculated. This was the half-time for methane dissipation. Doubling this interval and expressing in terms of one hour resulted in the air exchanges per hour given in this report.

At least two sampling runs were made for each value given in Table 1. Each run was tested to see if the slope was statistically different from the others. If not significant, the results were averaged. Problems were encountered when gas-fired unit heaters were in the greenhouses tested. Methane concentration at the start occasionally exceeded 7 ppm if the heaters were firing heavily. If insufficient methane were then injected, the calculated exchange rate would tend to be too low.

Results

The exchange rates for 10 commercial greenhouses are given in Table 1, with the conditions of each test. It was not always possible to accurately calculate total volume if the house opened into an adjacent area such as a boiler room. None of the calculations in Table 2 take into account the volume occupied by benches and vegetation. Table 3 presents results for a series of tests at CSU. The slope of the curves from which each exchange rate given in Table 3 was calculated were statistically different from each other.

Greenhouse type was not always the important factor in determining exchange rate per hour. There could be marked variation, depending upon heating system, internal circulation, and size of greenhouse. For example, a heavy heating load on gas-fired unit heaters (Table 3, No.'s 3, 4, and 5, Bay Farm) appeared to increase infiltration rate. This is logical to expect as requirements for combustion air increases. It emphasizes the need for adequate infiltration for such heating systems as the heating load increases.

The smaller the house, the larger its surface area in proportion to the enclosed volume. In the small air-inflated house (Table 3), the blower to inflate the house and the gas unit to heat it resulted in one of the highest infiltration rates found.

Table 1. Air infiltration rates in greenhouses, commercial ranges, minimum area, 6000 sq.ft.

Greenhouse type	Air exchange rate (exchanges per hour)	Conditions
1. Fiberglass, corrugated arch, 12-ft. eave, steam heat	0.38	0-10MPH, 40-43°F outside, no circulation
2. Fiberglass, corrugated, 8-ft. eave, steam heat	0.92	0-10MPH, 28-38°F outside, vigorous circulation
3. Fiberglass, corrugated, ridge-and-furrow, 8-ft. eave, combination steam and gas units	0.40	0-10MPH, 32-34°F outside, vigorous circulation
4. Fiberglass, corrugated, ridge-and-furrow, gas-fired unit heaters, 9-ft. eaves	0.40	0-10MPH, 13-20°F outside, vigorous circulation
5. Air-inflated, steam heat, 12-ft. eave, side walls glass and fiberglass, attached boiler room	0.51	0-10MPH, 11-14°F outside, moderate circulation
6. Air-inflated, steam heat, 3-ft. eave	0.48	0-10MPH, 21-28°F outside, no circulation
7. Film plastic, steam heat, 8-ft. eave	0.34	0-10MPH, 25-31°F outside, vigorous circulation
8. Old glass, steam heat, 8-ft. eave, attached boiler room	0.96	0-10MPH, 34-44°F outside, moderate circulation
9. New glass, steam heat, 8-ft. eave	0.59	0-10MPH, 35-37°F outside, moderate circulation
10. ½ glass, ½ fiberglass, steam heat, 9-ft. eave	0.61	
Average all houses	0.56	

Table 2. Calculated BTU's per hour required for infiltration rates given in Table 1, for design temperatures of -5°F and 52°F.

Grower No. (Table 1)	Area[1] (sq.ft.)	Volume[2] (cu.ft.)	Exchanges per hour[3]	Cubic feet air per hour[4]	BTU's required per hour[5]
1.	9,750	160,783	0.38	61,098	62,686
2.	5,000	56,360	0.92	51,851	53,199
3.	12,000	144,000	0.40	57,600	59,097
4.	7,200	128,960	0.40	51,584	52,925
5.	33,000	548,618	0.51	279,795	287,070
6.	14,400	256,421	0.48	123,082	126,282
7.	10,120	103,730	0.34	35,268	36,185
8.	12,150	161,000	0.96	154,560	158,579
9.	15,360	175,000	0.59	103,250	105,935
10.	32,376	513,180	0.61	252,040	258,592
Average all houses			0.56		

[1] *Total ground area under cover.*

[2] *Total volume of greenhouse.*

[3] *Number of complete air exchanges per hour, mostly under calm conditions.*

[4] *Volume of air exchanged per hour.*

[5] *BTU's required to heat the air from -5 to 52°F. (1.062 BTU per cu.ft.).*

Table 3. Air infiltration in various greenhouses, CSU research range.

Greenhouse type	Infiltration rate (exchanges per hour)	Conditions
Bay Farm: Corrugated fiberglass, ridge-and-furrow, 10-ft. eaves, gas-fired unit heaters, 6600 sq.ft. area, variable circulation	1. 0.82	0-10MPH, 0°F outside.
	2. 0.56	0-10MPH, 35-40°F outside, mid to late afternoon sun.
	3. 1.44	0-10MPH, 5-8°F outside, changeover to day heat.
	4. 1.24	Conditions same as 3, coming to day heat.
	5. 0.96	Conditions same as 3 and 4, coming up to day heat.
	6. 0.91	0-10MPH, 14-30°F outside.
	7. 0.81	0-10MPH, 20-24°F outside.
	8. 0.64	0-10MPH, 23-28°F outside.
Average all tests	0.92	
House 5: Old glass, 9-ft. eaves, steam heat, no circulation, 2100 sq.ft. area	1. 0.91	0-10MPH, 30-50°F outside.
	2. 1.00	0-10MPH, 30-50°F outside.
	3. 1.33	0-10MPH, 30-50°F outside.
	4. 0.73	0-10MPH, 34-40°F outside.
	5. 1.07	0-10MPH, 34-40°F outside.
	6. 0.76	0-10MPH, 34-40°F outside.
	7. 4.80	30-50MPH, 36-37°F outside.
	8. 7.45	30-50MPH, 36-37°F outside.
Average (excluding 7 & 8)	0.97	
Air-inflated house, 1000 sq.ft., unit gas-fired heater, moderate circulation, air for inflation from inside	1. 1.70	0-20MPH, 25-31°F outside.
	2. 1.14	0-20MPH, 25-31°F outside.

Vigorous internal air circulation would tend to increase infiltration by steepening pressure gradients across cracks in the greenhouse wall. This is suggested when No. 1 is compared with No. 2 in Table 1. The effect of external wind movement can be seen in Table 3 for House 5, tests 7 and 8. At high wind velocities, air infiltration rates may be quadrupled. It would be expected that fiberglass and air-inflated houses would be less susceptible to the wind factor. Studies by the Atmospheric Science Department, CSU, have shown that the average wind movement along the front range seldom exceeds 5 MPH — if occasional high winds are excluded (5). The region is characterized by frequent temperature inversions during which wind movement is essentially zero. A wind factor based upon 15 MPH for this area is very conservative.

The effect of old, loose glass compared to new, tight glass is indicated in Table 1, tests 8 and 9. These ranges are comparable. But, No. 8 included an attached boiler and grading room opening directly into the greenhouse. The differences in BTU's required (Table 2) to heat the old glass as compared to the new glass was nearly 50%, despite a smaller volume.

It is evident that design values for calculating heat requirements needed for infiltration are conservative and safe. Obviously, the savings made by reducing infiltration depend upon the size of the range. A reduction of 0.10 for Test 5 (Tables 1 and 2) would amount to a 20% saving in required BTU's to heat the infiltrated air. A similar reduction for Test No. 2 (Tables 1 and 2) would give a 13% saving. A deliberate program to reduce air exchange rates by as little as 0.10 per hour would be significant. The effect of exchange rates on required BTU's for different

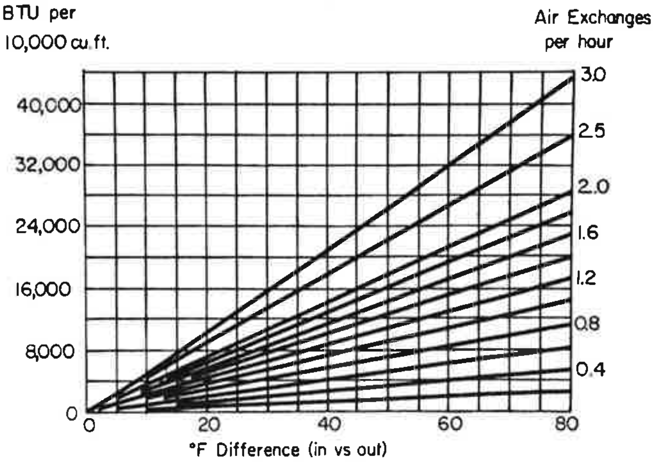

Figure 1. BTU's required to heat 10,000 cu.ft. of air for different temperature differentials and air infiltration rates based upon 0.018 BTU per cu.ft. air per °F.

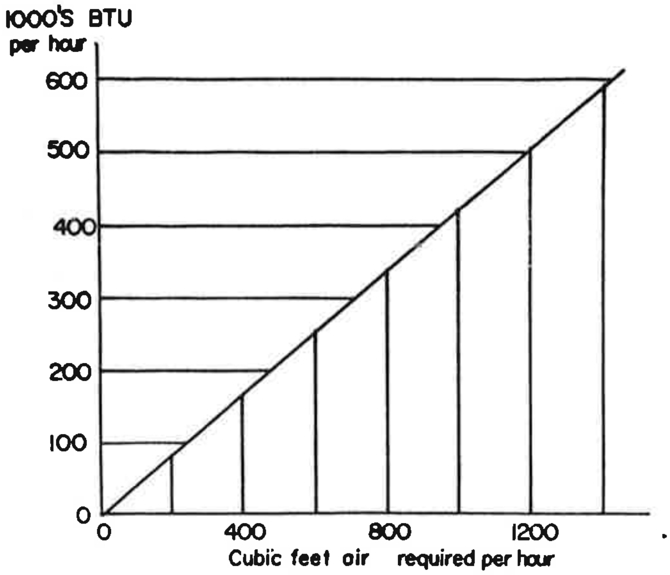

Figure 2. Cubic feet of fresh air required for varying amounts of BTU input. Based upon 800 BTU per cu.ft. of natural gas, 2 cu.ft. air per cu.ft. gas.

temperature differentials is given in Fig. 1. However, there are two important things to keep in mind: 1) Any heating units communicating with, or located within, the greenhouse require air for combustion (Fig. 2). A good allowance should always be made to meet these requirements which become more stringent as the outside temperature drops. 2) High infiltration rates reduce dangers of high humidity and water condensation on the foliage. Rapid infiltration also reduces effectiveness of summer cooling. If a deliberate policy to reduce infiltration is undertaken, specific provision should be made for humidity control.

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Crop Forecasting

Bunt, A.C. 1973. "Effect of season on the carnation (*Dianthus caryophyllus* L.) II. Flower production." *J. Hort. Sci.* 48:315-325.

The author planted 'White Sim' carnations at 14-day intervals, beginning on August 11, 1966, at the Glasshouse Crops Research Institute in England. The plants were single-pinched to 6 pairs of leaves, and the top 2 shoots designated as 'A' and 'B.' The dates were noted when: a) 8 pairs of visible leaves were present, b) the first visible bud appeared, c) the bud was 1 cm in diameter, d) color appeared, and e) the flower was fully opened. A total of 26 plantings were made.

The interval between planting and visible bud varied from 68 to 180 days, with flower development taking another 35 to 90 days. Plantings in May showed the fastest rates (110 days to flower), while those planted in early October required 230 days to flower. In general, growth from planting to visible bud was most influenced by mean daily solar radiation. However, when combined with a mean daily temperature, more than 90% of the variation in time to flower was accounted for. Separately, daily sunlight or temperature showed an exponential relationship with days to flower. The combined effects of temperature and light could be expressed by an equation with the form:

(The natural logarithm for days planting to visible bud) $= d + bT + bR + aR^2$

where the values a, b, c, and d are constants calculated by a computer program, 'T' is average temperature, and 'R' is the total daily solar energy.

Mean temperature had a greater effect than sunlight during the period from visible bud to flowering. The interval between 'A' and 'B' shoots varied with planting time and light regime. When light was low (30 cal/cm^2), flowering of 'B' (the second shoot) was delayed by 20 days. When light was high, (300 cal/cm^2), the delay was only 2 days. Day length had no particular effect on time to flower, although the photoperiod ranged from 8 to 16 hours during the investigation. During the period between mid-June to late July, each day's delay in planting resulted in about 3 days delay in cutting the first flower, with the second flower taking an additional 14 days.

The work by Bunt indicates the possibility of writing computer programs for predicting time of flowering and numbers of flowers produced on the basis of total solar radiation and temperature. Recent work by Marla Davis at CSU shows that more than 98% of the variation in carnation stem elongation can be accounted for by determining total accumulated radiation and accumulated temperature. J. J. H.