# Air Circulation In Greenhouses

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In the last few years, methods of temperature control in greenhouses have received new attention. We are becoming more aware of the necessity of avoiding abrupt temperature fluctuations. At the present time, there are on the market various devices for vigorously stirring air within closed greenhouses. Supposedly, such forced circulation reduces temperature variation from one area to another, increases the sensitivity of the thermostat, brings plant temperatures closer to the air temperature and it is known that increasing the rate of air flow past the leaves of plants usually increases the supply of $CO_2$ (2).

During the process of installing new temperature control equipment in some of our greenhouse compartments, we have been able to make a series of observations evaluating some air circulating equipment in closed greenhouses. Under our conditions, we have found that the use of one or more centrally located fans usually reduces vertical temperature variations, increases the efficiency of heating pipe an estimated 15 to 20 per cent and increases the sensitivity of the thermostats. However, overhead circulators may markedly increase temperature variations in a horizontal plane. For our purposes, we have decided to avoid the use of overhead circulators except where it is desired to maintain temperatures of 70°F or higher.

## Part I.

The problems that may arise from the use of overhead air circulators in closed greenhouses were first brought to our attention in a greenhouse where studies on soil aeration are presently being carried out. The greenhouse is 36 x 75 feet, with manually operated ventilators, and is equipped with 2-36 inch fans blowing air directly into the ridge. Their positions in the greenhouse may be seen in Figures 1 and 3. In addition, the thermostat shelter contained a small 4 inch fan for aspirating the thermostat. A 16 point remote temperature recorder was installed and temperature recordings taken at opposite ends of the house and at the thermostat.

Figure 2 shows the temperatures recorded with forced air circulation. A marked temperature differential existed from one end of the house to the other. There was a difference of 1° to 2° from the west (cold) end to the thermostat and 2° to 4° from the east (warm) end to the thermostat. At any station, the variation of temperature during heating cycles (steam valve on) was relatively small. The temperature differential of 4° to 6° from west to east ends caused the experimental plots located at the warm end to flower 2 to 3 weeks ahead of all other treatments.

*Air circulation*—In a class exercise, students studied the air circulation pattern in this house by means of smoke generators. The results, which were later verified by the authors, are presented in Figure 3. The use of 2 fans set up 2 independent air circulation patterns. Apparently the thermostat was located a majority of the time in the air flow system caused by the west fan, which would account for the small temperature differential from the west end to the thermostat (Figure 2).

*Temperature differential without forced air circulation*: With the above information, it was decided to turn off the overhead circulators. The thermostat, however, continued to be aspirated. The effect of "normal" air circulation commonly present in the closed greenhouse can be seen in Figure 4. The average temperature variations from west to east ends of the greenhouse were reduced to an average of less than 1°. Aspirating the thermostat had a decided effect upon the temperature at the thermostat, increasing the temperature fluctuation (Figure 4). This large difference, however, was not felt to be typical of temperatures in general in that area of the greenhouse.

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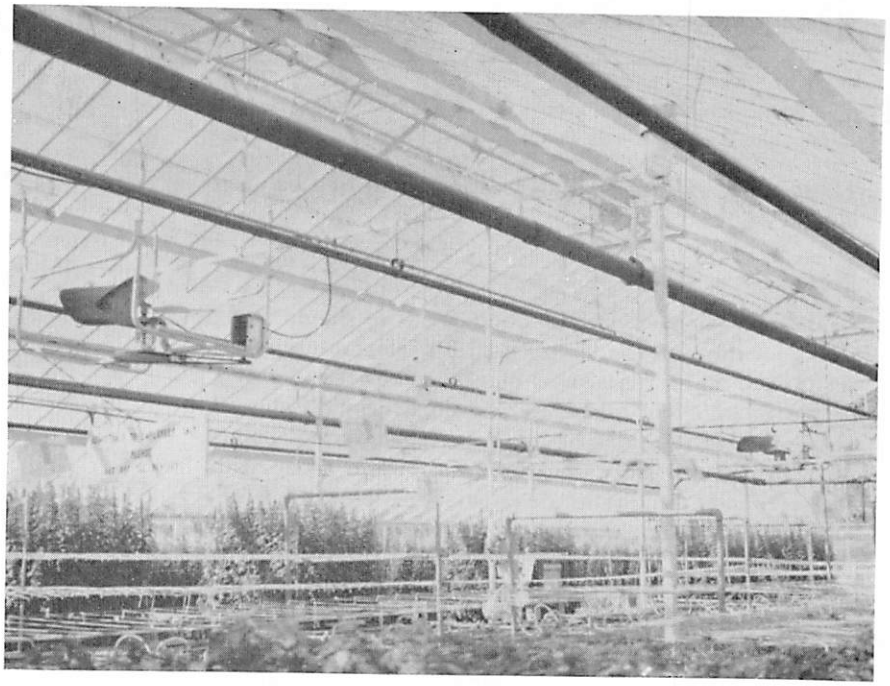

**Figure 1.** Two 36 inch overhead circulating fans in a greenhouse. In operation, the fans blow air directly into the ridge.

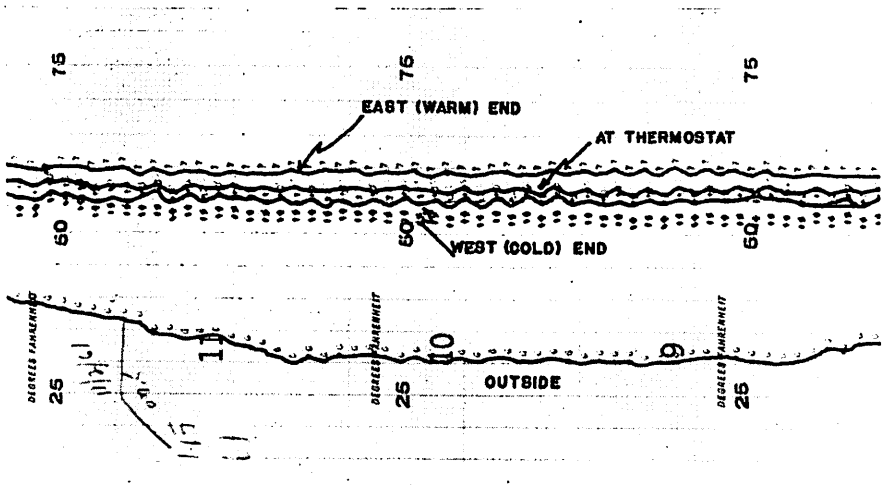


**Figure 2.** The effect of forced air circulation on temperatures in a 36 x 75 foot greenhouse with ventilators closed. Thermostat aspirated with a 4-inch fan.

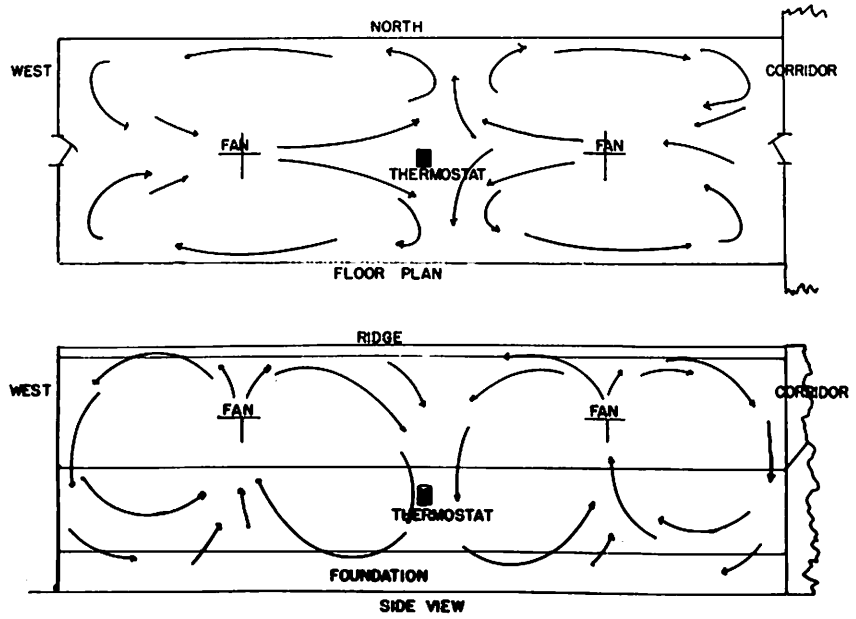


**Figure 3.** Air circulation patterns in a 36 x 75 foot closed greenhouse, using 2 36-inch fans blowing air directly in ridge.

Temperature variations at all locations increased between on and off heating cycles.

### Part II.

The preceding observations indicated we should study air circulation in greenhouses used for temperature investigations. Figure 5 is a floor plan and cross section of 1 of the 27 x 35 foot temperature compartments. Figure 5 also indicates positions of the air circulators and points at which temperature measurements were taken with thermocouples. Studies of air circulation were made without forced circulation, with 2-18-inch uni-directional fans blowing directly into the ridge and with 1 turbulator. The compartment in which measurements were made was completely automatic, using 2-36-inch exhaust fans, 1 side ventilator to control incoming air and trombone heating coils; all being operated by a single aspirated thermostat.

Three, aspirated, remote temperature sensors for continuous recording were placed at various locations in the compartment. Representative results are given in Figure 6. Readings for Figure 6-A were obtained at locations 1-C, 3-C and 5-C (Figure 5), with the thermostat set at 55°F. For Figure 6-B, the locations were 2-C, 4-C and 5-C with a thermostat setting of 75°. Both types of air circulators caused considerable horizontal temperature variation, which was reduced to 1° or less when overhead fans were turned off.

Further measurements were made at all the stations indicated in Figure 5 with thermocouples. The results are presented in Tables 1 and 2. Each figure is an average of 4 separate temperature determinations. Observation of the average vertical temperature in both tables shows the use of an overhead circulator decreased vertical temperature variation. However, comparison of temperatures in any 1 horizontal plane indicated an increase in temperature variation with forced air circulation, substantiating the results given in Figure 6.

The maximum vertical variation when the circulator fans were on (Table 1) ranges from 2.3° to 5.7° and when the circulator fans were off (Table 2) from 7.0° to 9.5°. The horizontal temperature determinations (we feel more important because it indicates the area where the plants are growing) indicated a different picture. The maximum horizontal variation when the circulator fans were on (Table 1) ranged from 3.5° to 6.6°, and when the circulator fans were off (Table 2) from 1.8° to 3.7°. More important a comparison of the horizontal lines B and C in which plants are growing, in tables 1 and 2 show a maximum variation of 4.4° and 5.7° with the circulator fan on and 1.8° and 2.4° with the circulator fan off.

*Circulation patterns*—Smoke studies were also carried out in this compartment. The use of 2 fans set up 2 air circulation patterns. Fans or tubulator, however, caused subsidiary air flow patterns which apparently did not mix with the main circulating pattern fast enough to reduce horizontal temperature variation. The most important, and undesirable, subsidiary pattern occurred next to the side ventilator. The original design for side ventilator operation called for incoming air to be directed into the ridge of the greenhouse when the ventilator was only partially opened. The air circulators, instead, set up a downward flow of air along the roof of the greenhouse, and deflected incoming cold air with very little mixing. The flow pattern is depicted in Figure 7. The result was a cold area extending into the compartment 4 to 6 feet from the ventilator. When the ventilator was closed, this subsidiary pattern tended to become smaller. When fans were

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turned off, air from the ventilator flowed into the ridge with very little downward deflection.

## Summary

With the exception of compartments in which temperatures are maintained at 70° or higher, it was felt more important to maintain equal temperatures throughout a greenhouse in any one horizontal plane. As long as the operator is aware of the vertical temperature variation, allowance can be made assuming that the increase in temperature with height is the same at any point in the greenhouse. Above 70°F, side ventilators in the compartments are seldom open during cold weather and vertical temperature variations increase to such a degree as to require some method of control.

The main problem with internal air circulators appears to be that, except within the immediate vicinity of the fan blades, air is not moved fast enough to mix with the surrounding air. Went (2) stated if the velocity of air movement is less than 1640 feet per minute, it will not mix with the adjoining stationary air mass. In order to obtain thorough mixing of air injected into, or circulated within, a greenhouse, its velocity must exceed 1640 feet per minute. The use of polyethylene tubing recently described by Gordon Koons (1) may be a practical method for introducing new air and recirculating air in the greenhouse to achieve uniform temperatures horizontally as well as vertically.

We may sum up the advantages and disadvantages of internal, centrally located fans:

1) usually decrease vertical temperature variation in a closed greenhouse,

2) may increase horizontal temperature variation,

3) increase efficiency of heating pipe, allowing higher temperatures to be maintained,

4) usually increase sensitivity of the thermostat which may or may not be desirable depending upon type of thermostat and heating system,

5) may not thoroughly mix moving and stationary air within the greenhouse, and

6) may increase the supply of $CO_2$ to the leaves.

## Literature Cited

1. Koon, Gordon. 1962. Greenhouse growth control.: Air paths through plastic. Florists Review 130(3355):13.
2. Went, F. W. 1957. The Experimental Control of Plant Growth. Chronica Botanica, Waltham, Mass. 373 pp.

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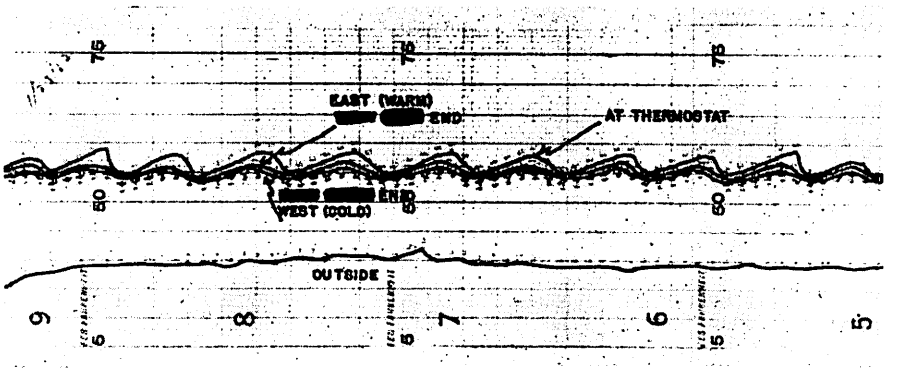


**Figure 4.** Effect of "normal" air circulation on temperatures in a 36 x 75 foot closed greenhouse. Thermostat aspirated with a 4-inch fan.

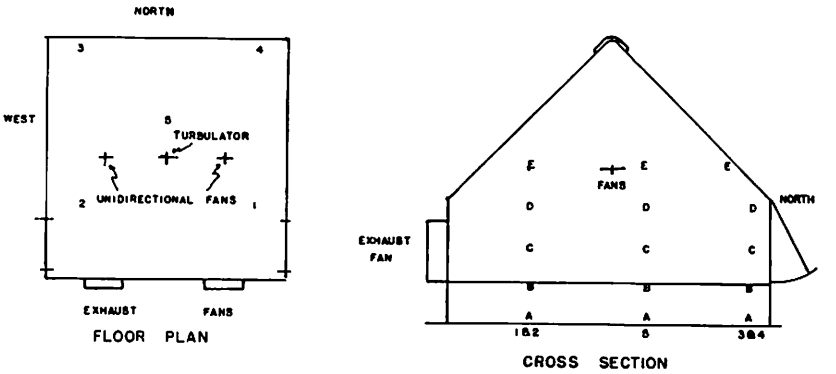


**Figure 5.** Floor plan and cross section of 1 of the 27 x 35 foot temperature compartments. Centrally located crosses indicate the positions of 2 18-inch fans, blowing directly into ridge, and 1 turbulator. Numbers and letters indicate points at which temperature determinations under various conditions were made.

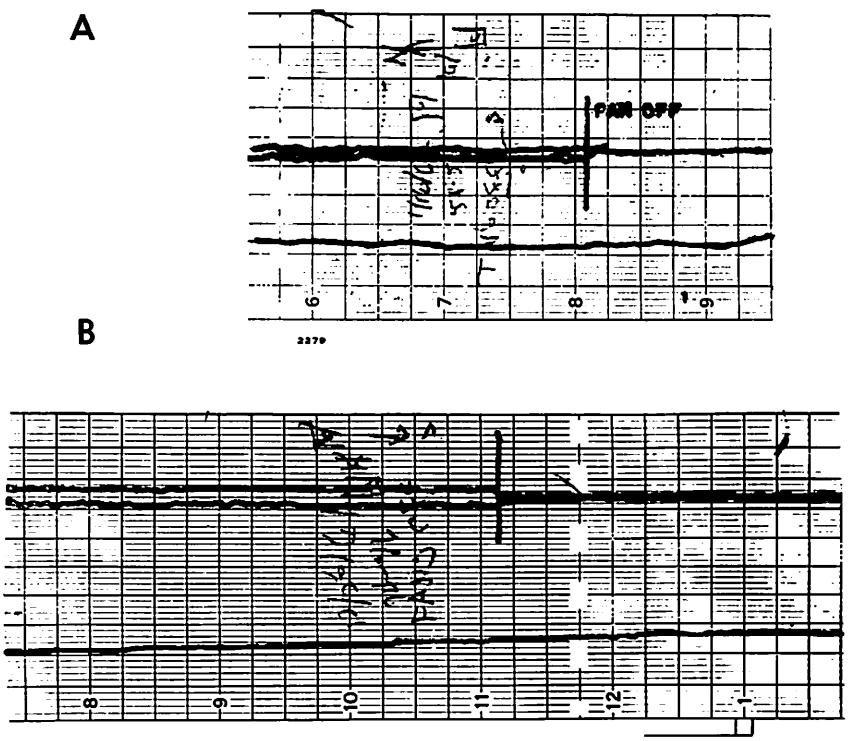


**Figure 6.** "*A*" Effect of 1 centrally located turbulator on horizontal temperature variation in a 27 x 35 foot greenhouse compared with "normal" air circulation. "*B*" Effect of 2 18-inch fans, blowing directly into ridge on horizontal temperature variations, in the same temperature compartment as "A", compared with "normal" air circulation.

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Table 1. Effect of forced air circulation on temperatures in a 27 x 35 foot greenhouse, using 2 overhead 18-inch fans blowing directly into ridge. See Figure 5 for temperature measuring stations. Each figure an average of 4 determinations.

| Sta. (vert.) | Station (Horizontal) Temperature (°F) | | | | | Avg. | Max. Hor. var. |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | |
| E | 72.6 | 73.0 | 74.5 | 71.2 | 74.7 | 71.8 | 3.5 |
| D | 72.2 | 72.3 | 71.9 | 70.9 | 75.3 | 72.5 | 4.6 |
| C | 71.8 | 70.9 | 70.6 | 70.4 | 75.0 | 71.7 | 4.4 |
| B[a] | 70.9 | 69.7 | 69.8 | 68.3[b] | 74.0[b] | 70.5 | 5.7 |
| A | 70.3 | 69.6 | 69.3 | 65.5 | 72.1 | 69.3 | 6.6 |
| Max. vertical variation | 2.3 | 3.4 | 5.2 | 5.7 | 2.6 | | |

[a] Corresponds to top edge of bench
[b] Station with maximum horizontal variation

Table 2. Effect of "normal" air circulation on temperatures in a closed 27 x 35 foot greenhouse on an overcast day. See Figures 5 for location of temperature measuring stations. Each figure an average of 4 determinations.

| Sta. (vert.) | Station (Horizontal) Temperature (°F) | | | | | Avg. | Max. Hor. var. |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | |
| E | 78.1 | 80.0 | 79.4 | 79.0 | 79.0 | 79.1 | 1.9 |
| D | 75.7[b] | 78.3[b] | 77.4 | 77.1 | 76.4 | 77.0 | 2.6 |
| C | 73.4 | 76.2 | 74.9 | 75.0 | 74.6 | 74.8 | 1.8 |
| B[a] | 71.2 | 73.6 | 72.4 | 72.8 | 72.3 | 72.5 | 2.4 |
| A | 70.2 | 71.0 | 73.2 | 69.5 | 71.2 | 71.0 | 3.7 |
| Max. vertical variation | 7.9 | 9.0 | 7.0 | 9.5 | 8.8 | | |

[a] Corresponds to top edge of bench
[b] Station with maximum horizontal variation

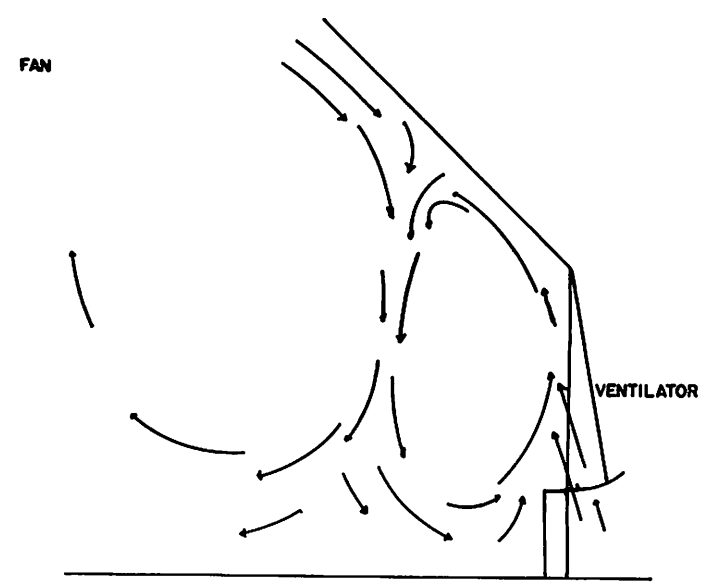


**Figure 7.** Subsidiary air circulation pattern occurring when ventilator partially opened and either fans or turbulator used to circulate air.