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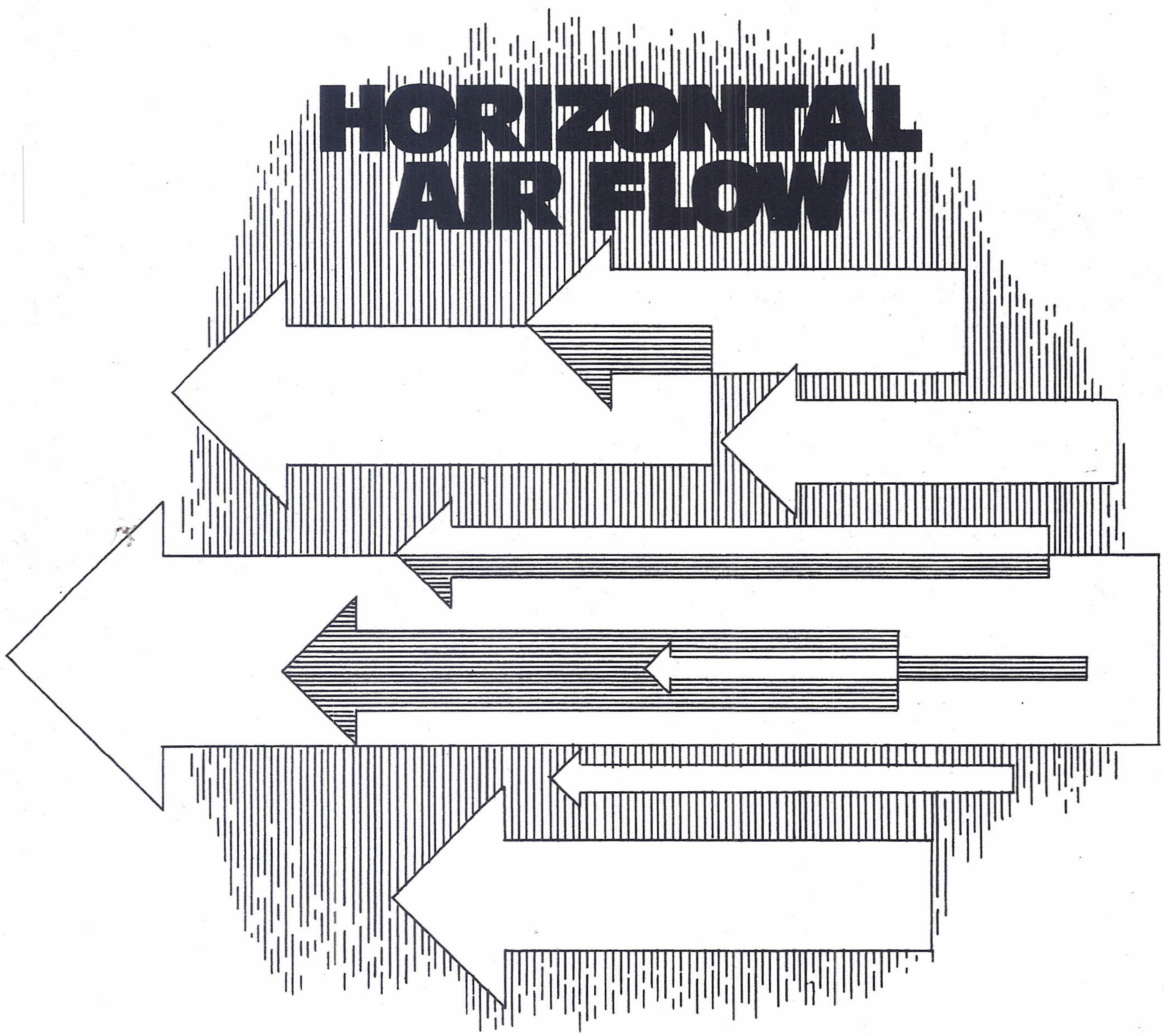

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HORIZONTAL AIR FLOW

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John W. Bartok, Agricultural Engineer

Introduction

Plants grow better when air is continuously circulated in a greenhouse. This cools or warms the leaf surfaces and evaporates disease-promoting moisture. Also the circulation of CO_2 is improved thus increasing growth potential. Although several systems provide air movement, the Horizontal Air Flow (HAF) method has been found to be the most effective.

The HAF concept typically uses small circulating fans operating continuously to push the air horizontally on one side of a greenhouse and back in the other direction on the other side. If houses are gutter connected, the air moves down one house and back another. This creates a circular horizontal pattern. Mixing of the air occurs from the ceiling to the floor.

Other systems use different concepts. The fan-jet system uses perforated plastic tubes suspended in the peak of the greenhouse and inflated with a 1/6 to 1/2 HP fan. The lighter heated air in the upper portion of the greenhouse is forced downward through the holes in the tube and tries to displace the heavier cooler air near the floor. The turbulence and plant canopy slow the air movement. Losses from friction in the tube and from forcing the air through the small diameter holes in the tube increase the motor hoursepower needed and the energy used.

The turbulator system uses vertical shaft fans mounted above eave height to stir the air and force it toward the eaves and back across the floor, resulting in a cold spot below the fan. These fans draw air from a limited area and many fans are needed to make the system effective.

Basic Air Movement Concept

When a fluid is enclosed in a container it may be moved in a coherent pattern with a minimum of energy. Fluid flow is energy efficient, being slowed more from turbulence caused by obstructions than by surface friction in the container.

This is an important concept in the movement of air (a fluid) in a greenhouse (a container). The air mass, once in motion, will continue to move until obstructions such as plants and surface friction slow it. For efficiency, the air mass should be as large and coherent as possible.

In a single house, the air should move down one side and back the other with as little mixing between the air streams as possible (Figs. 1-2). In

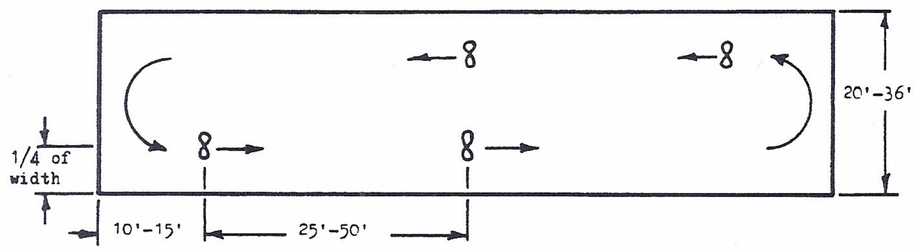


Fig. 1 Typical HAF* fan placement (16″ dia.) in a narrow individual greenhouse.

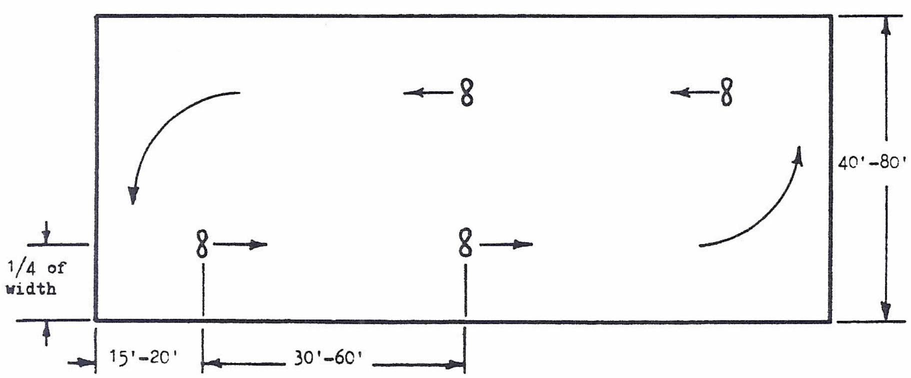


Fig. 2 Typical HAF* for placement (30″ dia.) in wide individual greenhouse.

* For each additional 50′ of greenhouse length, an additional pair of fans is required.

gutter connected houses, the air should move down one house and back the other provided the gutters are high enough (6 or 7 feet) to permit smooth air flow from one house to another (Figs. 3-4).

Moving air horizontally in coherent masses is readily accomplished with relatively few small fans. Consider a 30 x 100 foot greenhouse. Four 16″ fans of 1/15 -1/30 horsepower will circulate the air down one side and back the other at a speed of up to 100 feet per minute (fpm). Even with normal crop obstruction the air flow should remain above 50 fpm. Dr. John N. Walker, in research at the University of Kentucky, states that 40 fpm is adequate but this is not achieved by air flow systems such as fan-jets.

The placement of fans is important. In individual houses, the fans should be placed as in Fig. 1 so that the energy is directed primarily to increasing the speed of the already moving air, not pumping static air. Fans should be no closer than 10-15 feet from the end wall. They should be 1/4 the distance across the house and should point directly down the house in order to minimize turbulence. The height of the fans should be between 6 and 10 feet from the floor but at least 12 inches from the roof. For crops such as roses or tomatoes the bottom of the fan should be located above the maximum crop height. When fans are located above 7 feet from the floor, guards are not needed and efficiency of air movement is increased.

In gutter connected (ridge and furrow) houses the fans are placed in the centers of the bays so that all of the air in each bay becomes a coherent airstream and returns in the next bay. With multiple bay houses, set the system up to move the air in the same direction in two (or more) adjacent bays to increase efficiency and reduce turbulence due to counter-flowing airstreams (shear planes) (Figs. 3-4).

In gutter-connected houses the number of bays does not have to be equal (Fig. 4) since the air flow speed is not critical and may be greater in one bay than another.

As a general rule, a 16″ fan should be placed every 50 feet down

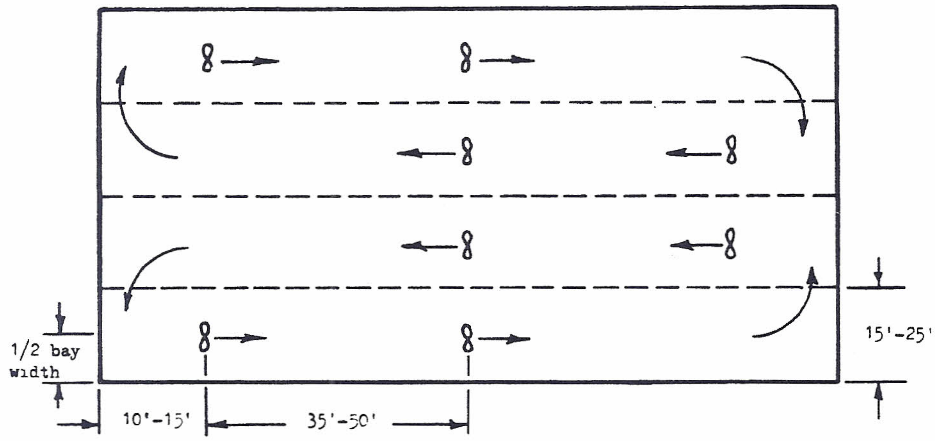


Fig. 3 Typical HAF fan (16″ dia.) placement* for even number of gutter connected greenhouse bays.

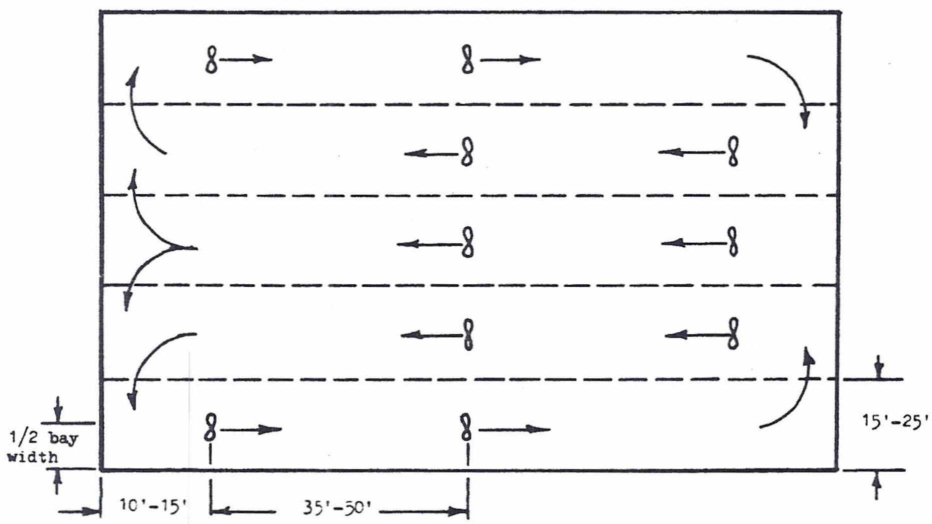


Fig. 4 Typical HAF fan (16″ dia.) placement* for uneven number of gutter connected greenhouse bays.

* For each additional 50′ of greenhouse length an additional set of fans is required.

the house. In longer houses (Fig. 4) the efficiency may be greater so that 3 fans may move the air efficiently for 180 feet or more. In general the total capacity of the fans in a house should be between 2 1/2 - 3 1/2 times the cross-sectional area of the floor in square feet. Any circulating fan can be used although an exhaust fan with ring or venturi is less efficient. A 16″ fan, with a 1/15 to 1/30 horsepower permanent split-capacitor (PSC) motor works well. PSC motors are more efficient than the shaded pole motors used on most small fans and will deliver perhaps 50% more air per unit of electricity consumed than ordinary fans. There are several sources of PSC motors. For reference, the following specifications were taken from the Spring, 1984 W.W. Grainger Co. catalog.

Motor #3M499, PSC 1/15 HP, 5/16″ shaft, 115 V 1.2 amps	$23.66
Capacitor #4X426	3.32
Capacitor mounting kit #3M533	.83
Fan Blade #2C406, 16″, 5/16″ bore (lots of 4) 1860 cfm	4.96
	$32.77

Optional are a belly band mount and a blade guard if not over 7′ feet from the floor.

In gutter connected houses over 25′ wide and with high gutters (over 8′), and in houses 50′ or more in width, larger fans with 230 volt motors may be more efficient. One possible fan is described as follows in the Grainger Spring '84 catalog.

Motor #3M804, PSC 1/6 HP, 1/2″ shaft, 230 V 0.9 amps	$44.35
Fan Blade #2C374, 30″, 1/2″ bore (lots of 4) 4380 cfm	15.68
	$60.03

— plus a belly band mount and a blade guard if not over 7′ feet from the floor.

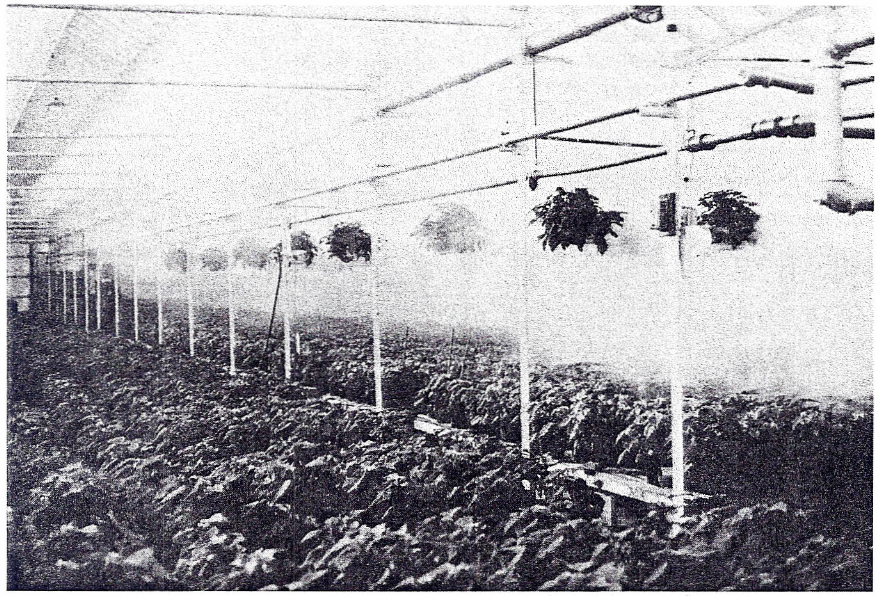
Assembly and mounting are required to make the fan unit.

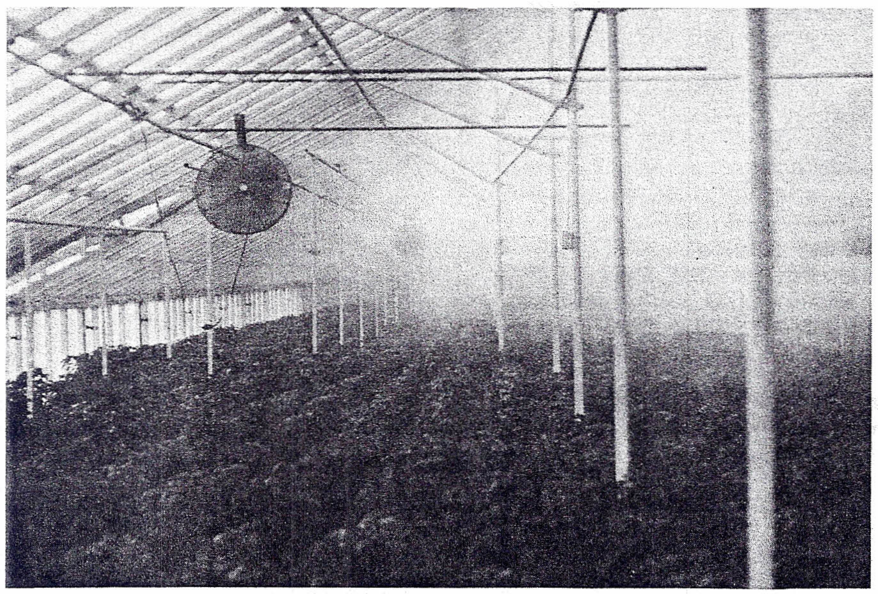
The pay back time realized using permanent split-capacitor (or other energy efficient types) rather than shaded-pole motors is estimated to be about 2000 hours of operation (less than 3 months) so it is important that these motors be used.

Why is HAF important? Plants grow faster and healthier in moving air and HAF moves air more effectively and more efficiently than any other system.

Advantages of HAF

1. The cost of installation is only a fraction of that of other air movement systems.
2. Only about half as much power is required, especially with permanent split capacitor (or split phase) fan motors.
3. Little system maintenance is required.
4. Temperatures within the greenhouse are uniform; both hot and cold spots are eliminated.
5. Heat loss is reduced since stratification of warmer air is practically nonexistant, reducing the air temperature in the ridge.
6. Humidity within the plant canopy is reduced.
7. Moisture condensation on plants is reduced, aiding in disease control.
8. Carbon dioxide utilization is improved since the leaves are "scrubbed" by the air.
9. No special system of distribution for CO_2 is required; it may be injected anywhere since the air is moving and mixing.





Figs. 5-6. Horizontal air flow in a single house may not be as distinct as in gutter-connected houses. Figure 5 shows the coherent air mass moving down the right side of the greenhouse. In Figure 6 the leading edge of the returning smoke is less distinct since the jets from the HAF fans are sending some smoke ahead of the main mass of moving air. Air movement was estimated at 80 feet per minute using six 18″ fans in a 178 x 42′ greenhouse.

10. Air infiltration (and heat loss) is reduced.
11. Leaf temperatures will be closer to air temperatures.

Installation

After determining the optimum number and placement of fans a method of mounting them must be considered. Belly bands are available for the Grainger fan units listed in this publication. The band which supports the motor and fan can be a bracket, chain, strap or wire suspended from the overhead greenhouse frame or truss. The fan when mounted should be rigid enough that it does not swing while in operation. Floor mounting is also acceptable as long as the fan is located above the plants.

Manual or automatic control can be used with HAF. Manual control consists of wiring all the fans in one house or bay to an on/off switch. Care should be taken that the wire size and switch capacity are adequate for the number of fans used.

In houses with fan ventilation it is desirable to have the HAF system (which is circulating air around the house) turn off when the exhaust fans (which are moving air down or across the house) are started. This can be done through the use of common double throw thermostats or by a computer.

After installation, the system should be checked by using a smoke bomb to observe the movement of the air. Start the fans and allow the air moving pattern to become established for several minutes. Use a large smoke bomb or several smaller ones. Ignite the bomb and place it on the floor or bench under one of the fans. A system that is working properly should; 1) dissipate the smoke evenly across the width of one-half the greenhouse or the bay, 2) move the smoke at a speed of 50 to 100 feet per minute and 3) not short circuit to the other side before reaching the next fan or endwall.

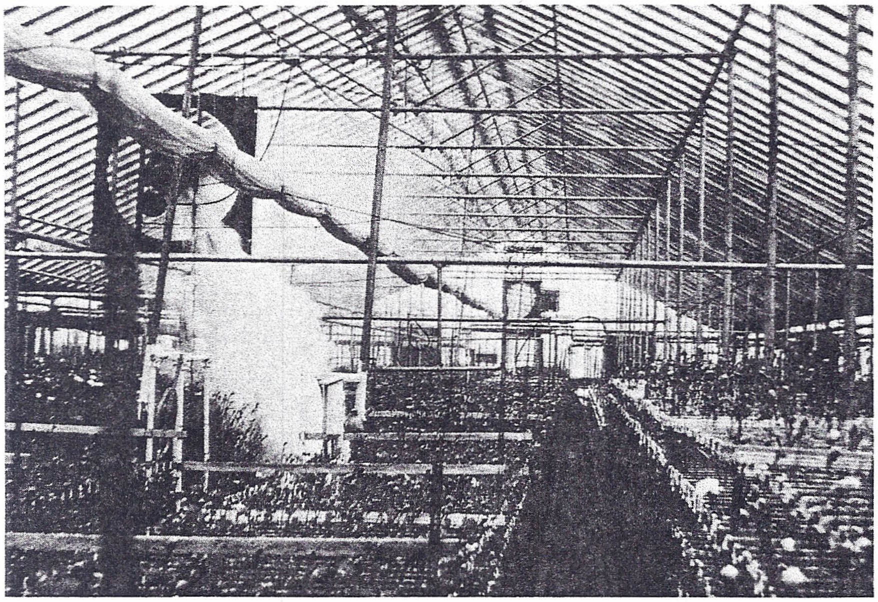
Maintenance

Fan blade, guard and motor casing should be cleaned twice a year. A dirty blade deceases fan efficiency. Sleeve motor bearings should be oiled with a drop or two several times a year.

Now that how to do it and why have been described, let's expand on a few concepts.

Air is heavy. Assuming an average height in a greenhouse to be 11 feet, each square foot of floor space has a column of air that weighs about one pound (1/2 ton per 1000 sq. ft.). A 30 x 100 foot greenhouse will contain about 1 1/2 tons of air. Once this air is moving, it will coast like an auto going down a level road. This is why HAF is so efficient and four small fans will keep the air flowing at 50-100 feet per minute in a 30' x 100' greenhouse. The moving air mass is only "kicked" along, not "pumped."

Installation cost of HAF is low. Air movement systems such as those with fans blowing air into perforated plastic distribution tubes must use excessive power to provide air movement both vertically and longitudinally



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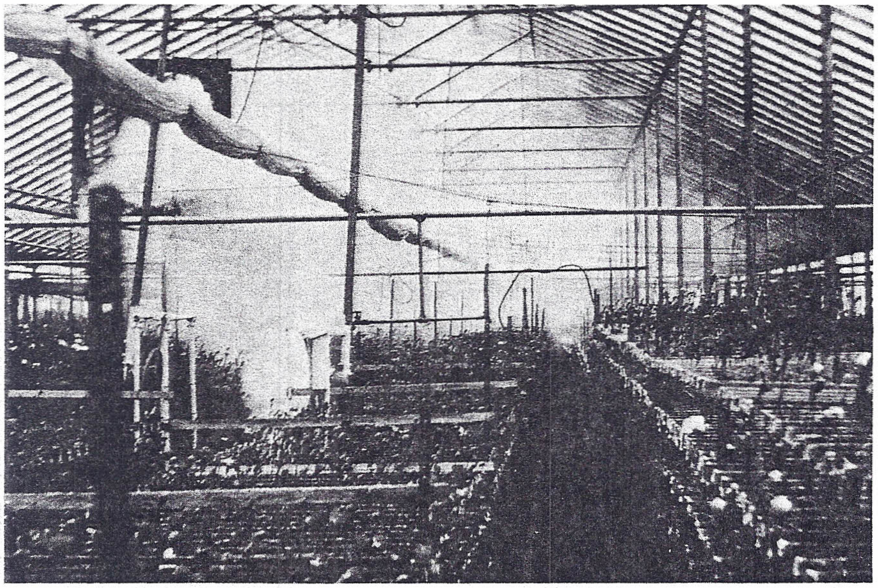

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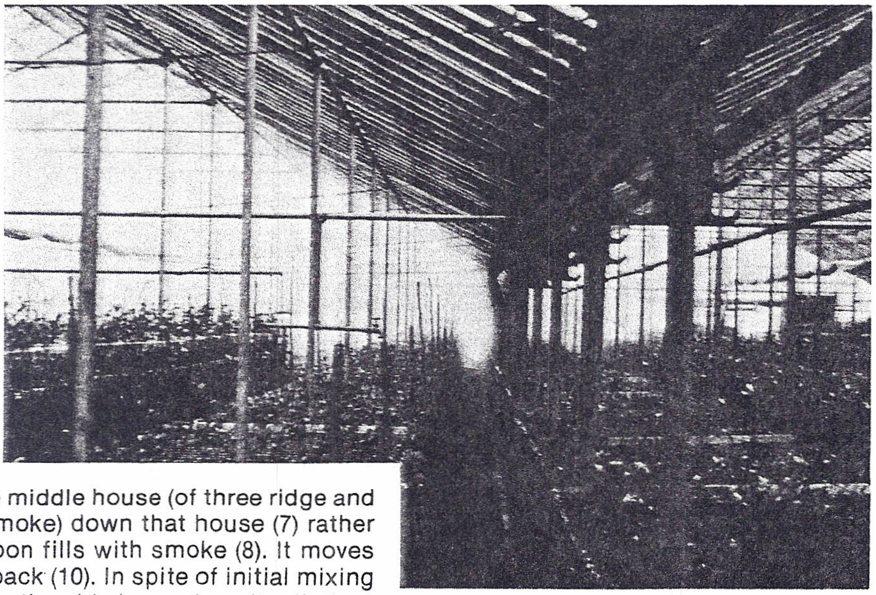

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Figs. 7-12. A 42", 3/4 HP fan mounted in the middle house (of three ridge and furrow 40 x 150' houses) moves the air (smoke) down that house (7) rather rapidly. The far end of the center house soon fills with smoke (8). It moves across to both side houses (9) and moves back (10). In spite of initial mixing by the oversized fan, the air front moving up the side house is quite distinct (11,12).

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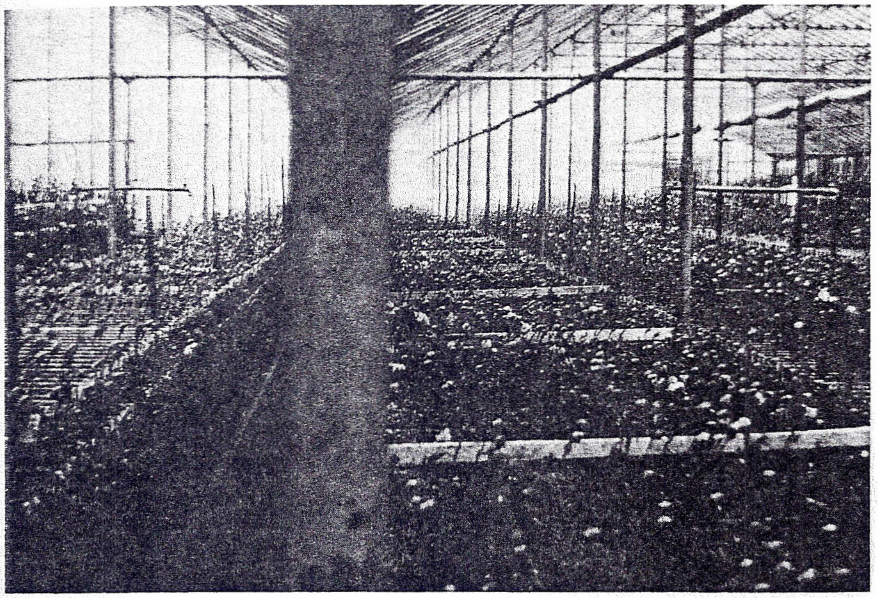

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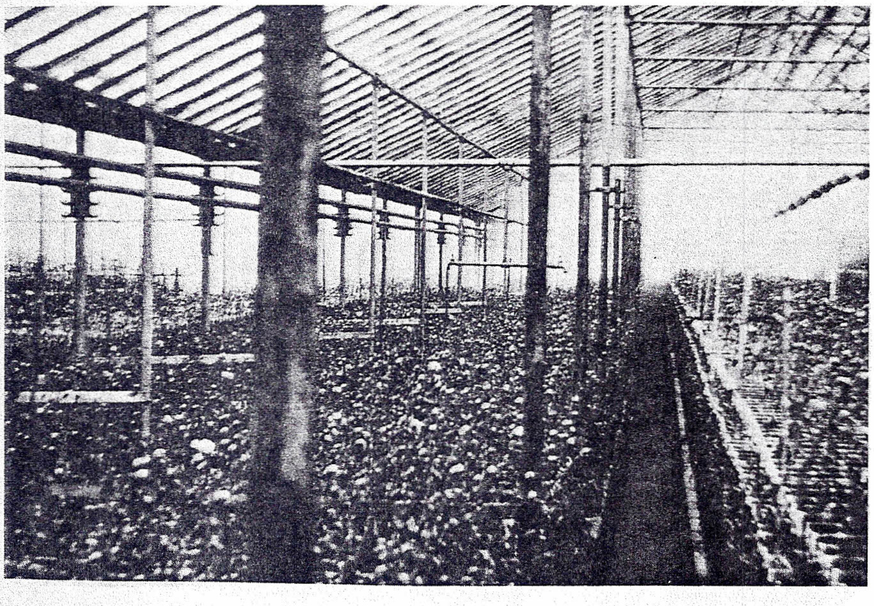

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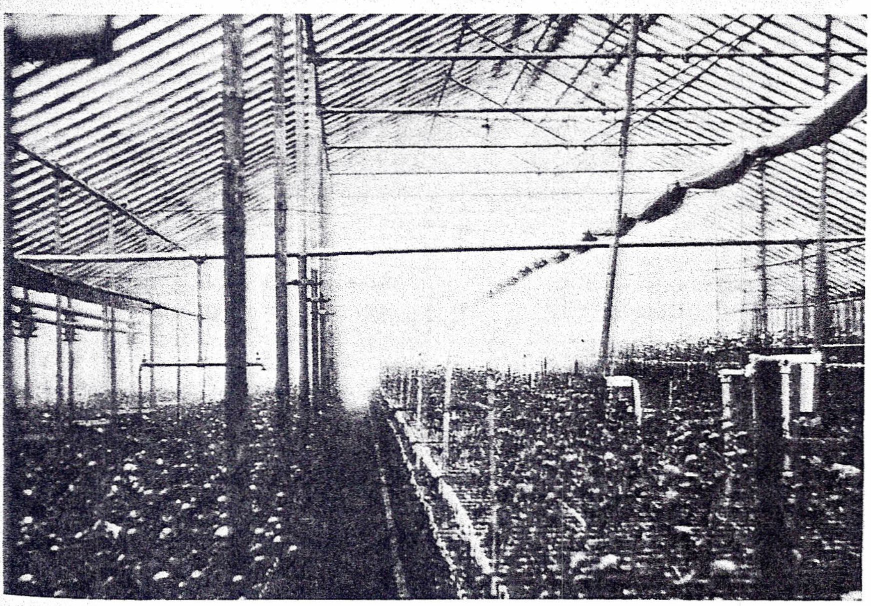

that will eliminate temperature stratifiction and cold/warm spots. Even one fan-jet in place of 4 PSC fans will cost 3 to 4 times as much while moving less air and not completely eliminating stratification.

PSC motors are energy savers. Permanent split capacitor motors are about 75% efficient compared to perhaps 50% efficiency for shaded pole motors. Four 1/15 HP fans with 16″ blades should use about 300 watts of power. To move the same volume of air, shaded pole motors might consume 450 watts. At $.10/KWH. the power saving is $15 every 1000 hours of operation. This will pay for the more expensive PSC motor in a couple of months (Koths, 1981a).

To illustrate this further, a 3M557 (Grainger) 1/30 HP shaded pole Dayton motor is rated at 1.2 amps full load, the same as a 3M499, 1/15 HP Dayton PSC motor. In this case, the PSC motor would appear to be twice as efficient.

Low maintenance. No distribution tubes are required for HAF. However, with fan ventilation, it may be advisable to install a plastic distribution tube connected directly to a motorized louvre for winter ventilation. This eliminates the fan motor necessary for distribution of the incoming air in fan-jet systems.

Uniform temperatures. If the air in a 100′ greenhouse is circulating at 100 feet per minute (fpm), it will move all the way down and back in two minutes. Cold or warm spots do not develop in two minutes. Even with forced air heaters in one corner of the house, the only warm spot is in front of the heater before adequate mixing occurs and then only during heater operation. Siebring (1983) suggests placing hot air furnaces or overhead heating units in alternate corners of a house or in alternate houses (Fig. 16).

Temperature stratification. To check temperatures, mercury thermometers were placed in about 12 locations in 3 gutter connected houses with HAF one cold night. The air flow was down the middle house and back the side houses. Just before midnight, the only non-uniform temperature was read on a thermometer about 12″ from the roof near the ridge. It was 1° colder (not warmer). This was probably due to the radiation effect from the cold glass. The air is not warmer in the ridge, and therefore less heat is lost.

Plants remain drier. A number of years ago humidigraphs were placed in houses with and without HAF at The University of Connecticut. The humidity was higher with HAF than in the control house. Readings were then taken within the plant canopy. The humidity within the canopy was lower than in the control. This is reasonable. HAF moves air through the plants, removing moisture which mixes with the greenhouse atmosphere. The plants remain drier (Koths, 1983).

Diseases are reduced. Foliar diseases generally depend upon high humidity or moisture condensation to initiate infection. Lower humidity within the plant canopy can stop disease development. Moving air past a leaf "scrubs" some of the moisture away from the leaf resulting in a drier microclimate in the zone within which foliar diseases develop. HAF helps keep plants healthy.

Carbon dioxide is used more efficiently. A boundary layer of gases covers the leaves. It may be relatively thick in a stagnant atmosphere (Burrage, 1971). It contains higher levels of water vapor from transpiration while oxygen is higher and carbon dioxide (CO_2) lower due to photosynthesis. Moving air across the leaf reduces the thickness of this boundary layer facilitating diffusion of CO_2 into the leaf (Waggoner, 1963).

This means that as plants deplete the CO_2 in the greenhouse atmosphere they will continue to grow for a longer time in moving air. And if CO_2 is added to the greenhouse atmosphere, less is needed to obtain the same plant response. Our recommendation is to maintain 800-1000 ppm CO_2 in houses with HAF where 1000-1500 ppm is normally recommended (Koths, 1981b).

No CO_2 distribution system is needed. With no air movement in a greenhouse, a CO_2 distribution system is required. With HAF circulating the air through the entire greenhouse is a matter of minutes, CO_2 levels are uniform regardless of where it is injected.

Air in/exfiltration is reduced. HAF was installed in a leaky old greenhouse. Smoke bombs for pests were ignited. Instead of seeing the smoke pour out of glass laps as in the past, only faint wisps appeared. Why?

Moving air tends to follow a surface that it is traveling along. It does not readily change direction to move through a crack or hole in the surface. For this reason, air exchanges in greenhouses are reduced, saving heat and retaining pesticide smokes and injected CO_2 (Koths, 1980).

Plants are warmer. On cool, clear nights, radiant cooling may reduce leaf temperatures 3°F below air temperatures outdoors. Leaves in greenhouses will be cooler than the air if the roof is cold. Moving air transfers heat to the leaves and warms them to near air temperature.

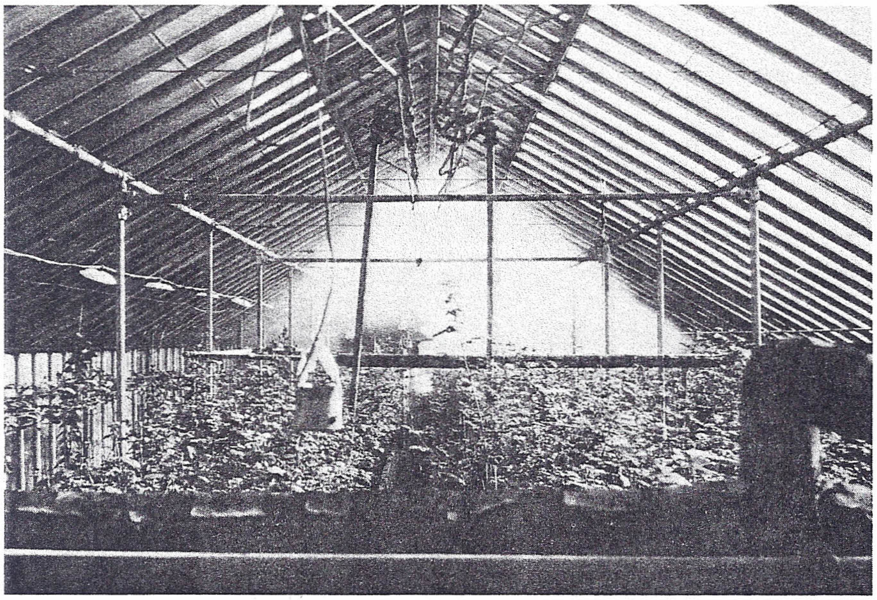

Fig. 13. In gutter connected houses, the air mass with HAF moves as a coherent front and returns in the adjacent house.

Fig. 14. Unit heaters can provide HAF. The fans are not efficient since the air must move through the heater and turbulence decreases air speed. Also note that two heaters (near left and far right) are too close to the end walls. They should have been mounted at the mid point of the house.

Plants are cooler. Likewise, on sunny days the solar radiation heats the plants. This may cause burn on young rose leaves on a sunny day following cloudy weather, burn hydrangea "petals," or increase photooxidation of chlorophyll in Saintpaulias. Hanan (1970) reports that red carnation flowers can be as much as 15° warmer under direct solar radiation and states that air movement is critical under high irradiance and that the air should move at least 12 feet per minute if plant temperature extremes are to be avoided. Burrage (1971) reported similar temperatures on Plantago leaves. Carpenter and Navtiyal (1969) reported that Sansevieria leaves were 7.2°F warmer than air in sunlight (6685 foot-candles) but only 2.1° warmer when air was moved over them at 53 fpm. Plant growth increased from 11.9 cm (still air) to 14.4 cm (moving air) and chlorophyll content doubled. Philodendron and Codiaeum leaves increase in size. Moving the air does speed plant growth.

Coherence of air flow. The "air door" widely used in Europe for entrances to department stores blows air from the ceiling to a grid in the floor. This moving air is surprisingly coherent and does not mix with the outside or inside air unless a very strong wind blows. Moving at even 100 fpm in a greenhouse, the air flow is coherent. In Fig. 3, the temperature in the first two houses may be maintained about 5° higher or lower than the other two houses without a curtain separating them. The mixing of the two circulating masses of air is surprisingly small.

What about thermal blankets? HAF is beneficial under thermal blankets where the atmosphere is generally more stagnant. In houses without double trusses to provide a place to mount the fans, it is necessary to mount them on standards or attach them to side posts. If it is necessary to mount them off center in a house, make certain that they are pointed directly down the house to avoid turbulence. Remember that the fans may be thought of as "kickers" to simply keep the entire air mass moving.

HAF is used. You may recognize some of these greenhouses: Pierson (ca 10 acres of HAF), Carney, Pinchbeck, Oglevee, Ecke, Katayama, Dreisback, Timbuck Farms (and a host of small growers).. Many dozens of phone calls have come to 203-486-3435 requesting information. Only one complaint has been received... In one installation the workers objected to the draft since the fans had to be mounted rather low.

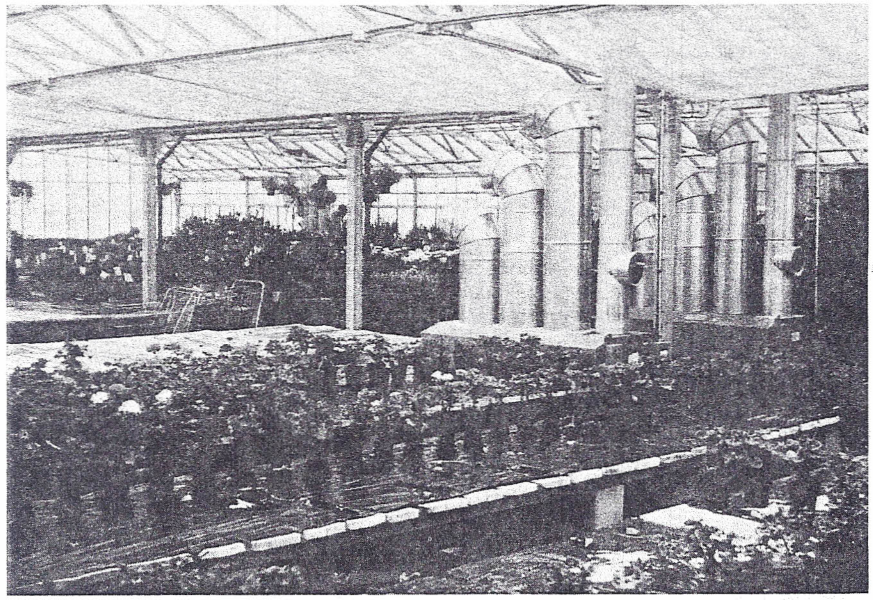

Fig. 15. Hot air unit heaters should be installed to reinforce HAF patterns as in these two gutter connected houses with small fans maintaining air flow when heaters are not in operation.

Table 1. Cost of operating HAF fans.

	Operating cost per 24 hour day — Cost of electricity — cents per kilowatt hour			
	6	8	10	12
1/15 HP — 16″ fan*	$ .11	$ .14	$ .18	$ .22
1/6 HP — 30″ fan	.30	.40	.50	.60
1/3 HP fan-jet	.60	.80	1.00	1.20

*note that 4 fans of 1/15 HP will require only 75% of the power required for a 1/3 HP fan-jet while installation costs are perhaps 25-25%.