Colorado Flower Growers Association Inc.

IN COOPERATION WITH COLORADO STATE UNIVERSITY

Doris Fleischer, Executive Secretary

Bulletin 132 — 655 Broadway, Denver 3, Colorado — March 1961

Design Refinements In Greenhouse Cooling

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In most engineering applications the best solution is a compromise between the major factors involved that produce the most benefits desired at a practical cost, and this was true when Acme engineers developed fan and pad cooling for greenhouses. The design calculations for fan and pad cooling account for a variety of factors that affect the air flow rate, and air flow rate in turn influences certain climatic conditions in the greenhouse. A series of tests showed that 7 CFM (cubic feet per minute) of air per sq.ft. of floor area economically satisfied the requirements of most localities by removing the solar heat energy during the hottest weather and providing a good climate for general growing conditions. Continuous studies and experience by Acme engineers has produced adjustments that can be made in the original design calculations to meet specific situations or provide more exact conditions desired by some growers.

Infiltration

The operation of a fan and pad system puts the greenhouse under a slight vacuum. Since a greenhouse is not air tight, an allowance was made in the original calculations to compensate for normal infiltration of warm outdoor air through the joints in the glass. Excessive infiltration allows too much air to by-pass the pad and dilute the cooled air with warm air causing a greater temperature rise as the air passes from the pads to the fans. Pads that are too small, or too thick, or that are clogged will cause a higher vacuum than necessary and bring on excessive infiltration. Loose houses permit too much infiltration and should be repaired to obtain better performance. At least 15% or more air may be required for a system unless the conditions permitting excess infiltration are remedied.

More Uniform Temperatures

The sensitivity to temperature of certain plants has in some cases created a desire to maintain more uniform temperatures from the pads to the fans. This can be accomplished by increasing the capacity of the cooling system. The air in passing through the house is warmed up several degrees because it absorbs the sun's heat from the plants, benches, soil and fixtures. The magnitude of this temperature rise is principally determined by the amount of air moved through the greenhouse. When more air is used the temperature rise is less, and vice versa. The temperature rise of a fan and pad system can be closely estimated for different air flow rates by the formula:

$$\text{Temperature Rise } ^{\circ}F = \frac{K}{CFM/sq.ft.}$$

"K" is an empirical constant that relates air flow rate and temperature rise in a given installation and has a value of 50 for normal commercial growing procedures and operating conditions in normal localities and allows for standard static pressures, infiltration, light intensity, rates of heat transfer, air density, thermal capacities, air distribution and wind effects. Refer to the following table of air flow rates with related temperature rise.

CFM/sq.ft.	Approx. Temp. Rise °F.
5	10
6	8
7	7
8	6
9	5½
10	5
11	4½

Some growers have added misting nozzles 1/2 to 2/3 of tne way from the pads to the fans for supplementary evaporative cooling to reduce the temperature rise. This has given varying amounts of benefit and requires a good control system to prevent raising the level of the relative humidity too high in the latter part of the house. Actually the plants themselves add some moisture to the air going through the house and help maintain a more uniform relative humidity.

Providing Sufficient Air Velocity

The need for maintaining a good air velocity rate through the house and over the leaf surfaces has long been recognized. An air velocity that is too low usually causes a feeling of clamminess or stuffiness even though the temperature is satisfactory, and some growers consider such a velocity too low for the plants as well.

Low air velocities occur when the pad to fan distance is quite short as in crossflow systems of most single houses or in compartments of experiment stations and college greenhouses. This condition has been substantially improved by increasing the air flow capacity factor of CFM per sq.ft. of floor area. The following table shows CFM capacities for a number of pad to fan distances that have been recommended by Acme engineers for several years and have had general acceptance.

Distance From Pad to Fan in Ft.	Required Increase in CFM/sq.ft.	Corrected CFM/sq.ft.
100 & up	0	7
85 to 100	14%	8
60 to 85	28%	9
45 to 60	42%	10
30 to 45	56%	11
up to 30	70%	12

The Effect Of Elevation

Elevation affects the density of air and this in turn has some effect on the performance of the cooling system.

For several practical reasons the effects of elevation and air density on a fan and pad cooling system were not originally considered when calculating the required air flow capacity. First, the large majority of greenhouses are at an elevation of about 1000 feet or less, and at these elevations the air density varies only a slight amount and the effect on cooling performance is small. Second, at higher elevations where the effect on cooling systems becomes more pronounced the wet bulb temperature is from 10 to 15 degrees lower which permits cooling a greenhouse to a substantially lower temperature than is possible in many other localities.

However, the need for a more uniform greenhouse temperature is now generally recognized, particularly for growers in high elevation localities that have had a greater temperature rise from the pads to the fans than is experienced in greenhouses at lower elevations. Also, growers at high elevations want the lowest temperature possible throughout the houses even though it may be as much as 10 to 15 degrees lower than possible in other localities.

The density of air (lbs. of air per cubic foot) decreases as the elevation is increased by the ratio of barometric pressures. A 10,000 cubic ft. volume of air contains fewer pounds of air at 5000 ft. elevation than it would at sea level. The volume of air a fan moves is independent of air density. A fan that moves 10,000 CFM at sea level will also move 10,000 CFM at 5000 ft. elevation, but it moves fewer pounds of air at the 5000 ft. elevation.

The rate at which air removes heat from a greenhouse is determined by its thermal capacity per pound of air. More cubic feet of air would therefore be required at 5000 ft. elevation to provide the same number of pounds of air and the same cooling capacity as would be provided at sea level. Because of the lower air density, greenhouses located at high elevations will have a greater temperature rise than normal from the pad to fan. This is readily corrected by increasing the air flow capacity of the fan and pad system to compensate for the lower air density. The following table shows for different elevations the amount the CFM should be increased and the corrected CFM rate to equal the cooling capacity of average systems at or below 1000 ft. elevation.

Elevation in Ft.	Required Increase in CFM/sq.ft.	Corrected CFM/sq.ft.
sea level to 1000	0	7
1000 to 2000	4%	7.38
2000 to 3000	8%	7.56
3000 to 4000	12%	7.84
4000 to 5000	17%	8.19
5000 to 6000	22%	8.54

Affect Of Light Intensity

The fan and pad system was developed in an area having slightly above average light intensity where relatively heavy shade was previously used to help regulate greenhouse temperatures. With the introduction of fan and pad cooling the shading was generally reduced to a light shade, and the design factors for the cooling system were established on this basis. Since that time many growers have elected to eliminate shading completely. This has increased the solar heat input above the original design allowance on the cooling system and produces a greater temperature rise from the pads to the fans.

In high elevation areas such as the Rocky Mountain States, the light intensity is considerably above average due to less water vapor and dust particles in the air. For reasons previously mentioned above, this also increases the temperature rise of a cooling system.

Obviously, when the grower plans to use very little or no shade, more cooling capacity needs to be provided to maintain a normal temperature rise. It is difficult to specify an adjustment for the design air flow rate for such conditions because of the wide variety of light intensities and grower preferences. Data indicates that Colorado and all states west experience up to 15% more light intensity than average and to compensate for this 15% more capacity should be provided in the cooling system.