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FOREWORD

This report covers recommended practices in the design and construction of cooling and ventilating systems used in glass or plastic greenhouses.

DEFINITIONS

A. ***Ventilation*** is the exchange of air between the inside and outside of the greenhouse to remove heat from solar radiation, to replenish carbon dioxide and to help control the levels of relative humidity.

B. ***Ventilation rate*** is the amount of ventilation per unit area. It is measured as cubic feet of air per minute per square foot of greenhouse floor area (CFM per square foot) because the heat load derives from solar radiation and is directly proportional to floor area.

C. ***Natural ventilation*** is the ventilation that results from wind and stack action from ventilator sashes.

D. ***Mechanical ventilation*** is the ventilation created by electric fans and related equipment.

E. ***Cooling,*** for purpose of this report, consists of reducing the air dry-bulb temperature by the adiabatic evaporation of water into the airstream. The system that does this and moves the cooled air through the greenhouse and exhausts the warmed air is the cooling system.

F. ***Circulation*** is the movement and mixing of air in a greenhouse to promote uniformity in temperature and humidity and to provide proper air motion throughout the greenhouse.

SUMMER MECHANICAL VENTILATION AND COOLING

PRINCIPLES

The need for better greenhouse climate conditions have brought about improved and more positive ways of controlling temperature and humidity through mechanical ventilation and cooling. The better control of temperature has also allowed a substantial increase in light intensity, important to good plant growth because solar heat can be more effectively removed.

Exhaust fans are used to provide sufficient airflow through the greenhouse to remove solar heat as fast as it enters. Because the air is warmed gradually as it passes through the house, absorbing heat, the flow rate should be sufficient both to hold this temperature rise to minimum and be economically practical.

The selection and arrangement of the ventilating and cooling equipment is determined by the size and type of greenhouse structure, the direction of the airflow through the house. Allowances also should be made for air density, light intensity and the permissible temperature variation through the house.

For optimum performance, it is necessary to properly size and arrange air inlet openings to produce a uniformity distributed, nonturbulent airflow pattern in the growing area to avoid the mixing of the air there with the hot air in the upper section of the greenhouse. A definite airflow pattern is a given direction requires an air inlet opening continuous for the entire side or end of the greenhouse. The inlet opening should introduce the air in a horizontal direction at crop level, should not be deflected up or down and should have a low velocity to minimize turbulence and mixing.

During the summer, mechanical ventilation alone usually will not maintain the desired greenhouse temperature because the outdoor air is too warm. A means for cooling the incoming air should be provided. Through adiabatic cooling by the evaporation of water in the entering airstream, the air can be cooled to within 2 to 4 degrees F. of the outdoor wet-bulb temperature during the hottest weather. When pad cooling is used, the pad system in effect becomes the air inlet opening; therefore, the conditions noted for air inlet openings also hold for the pad system.

As the cooled air proceeds through the house, it picks up solar heat and increases in temperature by the time it reaches the exhaust fans. (An optimum design increase of 7 degrees F is used.) This temperature increase is a result of the heat removal process and will vary depending on design; it can be reduced by increasing the airflow or reducing the light intensity. Increased fan capacity can produce increased airflow; shading can reduce light intensity; and good maintenance can minimize infiltration or air leakage.

DESIGN RECOMMENDATIONS

Because solar heat in the greenhouse is related to ground surface area, the airflow rates for cooling always are determined by measuring cubic feet of flow per minute (CFM) for each square foot of ground area. The basic airflow rate at eight CFM per square foot has been determined to be sufficient for moderately shaded greenhouses having maximum interior light intensity of about 5,000 foot-candles. The basic airflow design equations is Total CFM – 8LW where L is the length and W is the width of the greenhouse in feet. This basic airflow rate is then adjusted for elevations in excess of 1,000 feet above sea level, the expected interior light intensity, the allowable greenhouse temperature increase and the distance from the pad to the fan.

Air's capacity to remove heat depends on its weight, not its volume. Because air is less dense at high altitude, the elevation of the greenhouse must be considered in design calculations. At higher elevations a greater volume of air is needed to provide the equivalent weight of air required at elevations that have been established as "normal." Variations from the norm can be compensated for by an elevation factor, ^{F}Elev, where BP is local barometric pressure:

$$^{F}\text{Elev} = 29.92 / \text{BP}$$

The interior light intensity, which depends on the location of the greenhouse and the amount of shading, determines the amount of heat input into the greenhouse. If the interior light measured in foot-candles is FC, then the light intensity factor ^{F}Light is:

$$^{F}\text{Light} = \text{FC} / 5.000$$

The greenhouse temperature increase from pad to fan (T) is a design factor. It is inversely proportional to the airflow rate and can be adjusted to any value desired. If this value is to be other than 7 degrees F, the temperature increase factor ^{F}Temp is:

$$^{F}\text{Temp} = 7.0 / \Delta \text{T}^{o}$$

This completes the adjustment and design factors necessary for a heat balance. Combining all these factors determines the house adjustment factor ^{F}House, which is used to complete the design capacity of the cooling system.

$$^{F}\text{House} = {}^{F}\text{Elev} \times {}^{F}\text{Light} \times {}^{F}\text{Temp}$$

For design convenience all these factors have been calculated and are listed in Tables 1 through 3.

For short pad-to-fan distances the cross-sectional airflow velocity within the house becomes too low and the house often feels clammy or stuffy even though the airflow rate is sufficient for heat balance. To help avoid this and to produce a more desirable air velocity level within the house a velocity adjustment factor ^{F}VEL is used when the pad-to-fan distance D is less than 100 feet:

$$^{F}\text{VEL} = 10 / \sqrt{\ } \text{D}$$

The velocity adjustment factor is ignored for pad-to-fan distances of 100 feet or more. For houses having less than 100 feet pad-to-fan distances, it is necessary to determine both the house adjustment factor ^{F}VEL (Table 4) and use the larger of the two in completing the cooling system design calculation. (For pad-to-fan distance of 100 feet or more ignore ^{F}VEL and use only ^{F}House.)

After selection of the proper adjustment factor, ^{F}House or ^{F}VEL, the total volume of air required for a greenhouse cooling system is found by multiplying the greenhouse floor area by the basic airflow rate and by the proper adjustment factor. For a house or group of connected houses of length L and width W, the total CFM is:

Total CFM = L x W x 8.0 x ^{F}House
(Unless ^{F}VEL is larger – then use ^{F}VEL)

Elevation, feet above sea level
TABLE 1

Feet	>1000	1000	2000	3000	4000	5000	6000	7000	8000
^{F}Elev	1.00	1.04	1.08	1.12	1.16	1.20	1.25	1.30	1.36

Maximum interior light intensity, foot-candles
TABLE 2

FC	4000	4500	5000	5500	6000	6500	7000	7500	8000
^{F}Light	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60

Pad-to-fan temperature variation, ΔT ˚F
TABLE 3

˚F	10	9	8	7	6	5	4
^{F}Temp	0.70	0.78	0.88	1.00	1.17	1.40	1.75

Pad-to-fan distance, feet
TABLE 4

^{F}VEL	20	25	30	35	40	45	50	55	60
Feet	2.24	2.00	1.83	1.69	1.58	1.49	1.14	1.35	1.29
^{F}VEL	65	70	75	80	85	90	95	100	
Feet	1.24	1.20	1.15	1.12	1.08	1.05	1.03	1.00	

House temperature above outdoor temperature ˚F
TABLE 5

˚F	18	17	16	15	14	13	12	11	10	9
^{F}Winter	0.83	0.88	0.94	1.00	1.07	1.15	1.25	1.37	1.50	1.67

The proper size and number of fans are then selected to produce the required volume of air at 0.1 SP (inches of water static pressure). The pad area is then determined, and the complete pad system is designed. This includes specifying the length and height of the pad system and the size of pumps, filters, sumps, and related components.

The preferred pad-to-fan distance ranges from 100 to 225 feet for the best airflow velocities within the house and for easiest pad installations. For very long houses, growers should consider the installation of a pad at each end with the exhaust fans located at the midpoint, using sidewall or roof-mounted fans. The cooled air then flows in from each end and is exhausted at the midpoint of the house.

Sufficient fans should be selected to provide the required amount of air at a static pressure of 1/10 inch of water static pressure. A 15-mile-per-hour wind is approximately equal to 1/10 inch of water static pressure.

The size of fans selected determines the number of fans required. Adequate fans should be used to provide a spacing of not more than 25 feet along the exhaust side of the greenhouse.

When possible, the fans should be located on the downwind side of the greenhouse. If the fans must be located on the windward side, the design ventilation rate should be increased at least 10 percent, and fans having at least 3/4 HP or larger motors should be used.

The fans should have at least 1 1/2 times the diameter of clear space between their discharge opening and the nearest obstruction, such as a building wall.

When three fans or fewer are used in a given installation, one of them should be a two-speed fan to provide for more flexibility of ventilation.

Fans should be guarded properly to prevent workers or animals from coming in contact with any moving parts.

For most reliable fan performance, only fans that have been tested and rated in accordance with the Air Movement and Control Associations (AMCA) standard test code and which bear the AMCA Certified Rating Seal should be used. This assures the user the capacity in the manufacturer's catalog.

The operation of a fan-and-pad cooling system puts the greenhouse under a slight vacuum, so the house should be kept in good repair. Excessive infiltration of warm air will cause a greater temperature rise as the air passes through the house.

The cooling pad at the inlet side should be sized to accommodate 150 CFM per square feet of pad area if the pad is made of aspen wood. If made of corrugated cellulose, pads should be sized to accommodate 250 CFM per square feet and 350 CFM per square feet for 4 and 6-inch thickness, respectively.

When construction limitations make it impossible to provide the recommended pad area, it may be reduced to 75 percent of recommended area. However, this reduction will also reduce the pad efficiency somewhat, and extra effort should be made to have a tight house to hold infiltration to a minimum.

The cooling pad should be continuous along the entire side or end of the greenhouse. Pad height is determined by dividing the total pad area by the length.

Cooling pads should provide at least 75% evaporated efficiency at a pressure loss not exceeding .06 inch water static pressure and not exceeding an airflow velocity of 350 feet per minute.

Pads should be confined and secured in a way that provides uniform airflow, prevents sagging, avoids puncturing holes or large openings in them and promotes uniform water flow through the entire length of the pads. The pads should be installed for ease of removal and withstand normal handling and usage.

Whenever possible, the air inlet opening should be constructed in such a way that it can be readily opened and closed without removing the pads.

It is preferable to have the pad assembly located inside the air inlet opening; this will produce less turbulent airflow through the house. For such an arrangement, the air inlet opening need not be continuous but should be at least 1 square foot per 450 CFM and reasonably well distributed.

If the pad assembly is located outside the air inlet opening, the opening should be at least 1 square foot per 350 CFM, should be continuous, should have no large obstructions and should be centered in elevation on the center of the pad so that the airflow is horizontal as it leaves the opening.

When the height of the pad exceeds that of the inlet opening, the pad will extend above and/or below the opening. When this occurs, the pad should be set back from the wall or sash at a distance of at least half the amount of the extension to provide ample room for air to pass uniformly through the entire pad.

When possible, the pads should be located on the prevailing wind side of the greenhouse. When the greenhouse is sheltered from prevailing winds by another building or greenhouse located within 25 feet, the location of the pads in relation to prevailing winds is not significant.

When fans and pads are used on a number of separate greenhouses, they should be arranged so the exhaust from the fans is not directed into the pads of the next house unless the houses are separated by at least 50 feet.

When fans face fans of adjacent separate houses within 15 feet of each other, they should be offset from each other so the exhausting air from one fan will not blow directly against that of another fan.

The cooled air passing through the house will tend to diverge at about a 7 degree-angle, or one-foot in every eight. Vertical baffles usually are installed, particularly with the house, to reduce mixing and keep the cool air down at plant level. The baffles should be transparent, spaced approximately 30 feet and held in a fixed vertical plane, and their lower edges should be well above plant level.

In greenhouses containing raised benches, a substantial volume of air may travel under the benches to the fan without removing much heat. A baffle covering two-thirds of the distance from the bench to the ground will force most of the cooling air to crop level for more effectively plant cooling.

The water flow rate for the pad system should provide a minimum of 1/3 gallon per minute (GPM) per lineal foot for aspen pads, 1/2 GPM for 4-inch-thick corrugated cellular pads and 3/4 GPM for 6-inch-thick corrugated cellular pads to insure adequate wetting and optimum performance. The design should provide for a slightly larger flow rate because it can be controlled with a valve to the proper rate during operation. However, a solid curtain of water on the pad must be avoided: This will block the flow of air through the pad and impair overall performance.

The sump should be sized to have working capacity of at least half a gallon per square foot of pad area for aspen wood pads. For corrugated cellular pads, the sump's working capacity should be 3/4 of a gallon per square foot of pad area for 4-inch-thickness and one gallon per square foot of pad area for 6-inch-thickness.

All elements of the water system should be kept well covered to protect it from insects and windborne dirt, which will ultimately cause clogging of the water distributor openings and the pump. The water returned to the sump should be screened. The ends of the water distribution pipes should be provided with removable caps or valves to allow easy flushing out for cleaning.

Because water is used up in the evaporative cooling process, a supply of makeup water is needed. An automatic float valve should be used for this purpose and also to maintain a proper water level in the sump. The water consumption rate will vary from little or none (at night or on a rainy day) up to one gallon per minute per 100 square feet of pad area (on hot days). In areas having high mineral salt concentration in makeup water, provisions should be made for a "bleed off" of recirculated water while a unit is in operation to prevent excessive buildup of mineral content. Sodium chloride begins to deposit on pads at concentrations greater than 50,000 ppm and disappears when it is below that level.

And finally, the National Greenhouse Manufacturers Association is studying alternative design methods. These may be included in the future.

WINTER MECHANICAL VENTILATION

Principles

Mechanical ventilation essentially provides the same benefits regardless of the season, but the use of exhaust fans to provide the proper amount and type of ventilation calls for the employment of different airflow principles in winter than in summer. In the winter, outdoor air is too cold to introduce directly on the plants.

Winter ventilation of a greenhouse is different from summer ventilation. In the winter, the flow must be turbulent. Small to moderate quantities of air are required.

Winter ventilation must be able to introduce very cold winter air into the greenhouse without producing cold drafts on the plants. This requires a thorough mixing of the cold outside air with warm inside air before air reaches the plant level.

Thorough mixing requires much turbulence and is readily achieved by admitting the air into the greenhouse in small, high-velocity jets. A jet of air at high velocity will almost completely mix and dissipate itself into the surrounding air in approximately 20 jet diameters. A jet of air coming through a 1/8-inch crack will be mixed in a 2 to 3-inch distance. Consequently, in a greenhouse, it is desirable to have many small openings rather than on large one for winter ventilation. Powered ventilation has the energy available to produce the turbulence necessary for thorough mixing; it supplies properly tempered fresh air.

With this type of air introduction and mixing the temperature of the air in any given area is determined largely by the air admitted in that area. Therefore, it is desirable to have the inlet openings well distributed. The air distribution is greatly affected by the location of the exhaust fans; consequently, their location should be determined by the requirements for best summer operation.

It is important that all parts of the greenhouse be the same temperature. To achieve this, the ventilating system must distribute the air uniformly throughout house and maintain positive air movement and continuous circulation. A powered ventilating system has a real advantage over gravity systems that they rely on thermal air currents because it has the energy required to provide uniform air distribution and mixing.

Fans that mechanically ventilate greenhouses, combined with perforated transparent plastic tubes, make an ideal system for introducing cold air into a greenhouse in the winter without cold drafts.

Design Recommendations

Essentially, winter and summer ventilation systems are two separate systems having different characteristics and requirements. However, they must tie in with each other to switch from one system to the other during spring and fall. The tie-in or transition point is very important; it determines the minimum inside-to-outside temperature difference available on a mild, sunny day, and it establishes the airflow design capacity of the winter ventilation system.

The flow rate for the transition point is determined by the heat-removal capabilities of the air and is largely affected by the increase in latent heat of the air going through the house. This increase depends on the outside wet-bulb temperature and the transpiration rate of the greenhouse crops. Increased transpiration results in an increase in the cooling effect for a given flow rate. For average conditions, an airflow of 1 1/2 to 2 CFM per square foot of floor space will hold the house temperature within 15 to 20 degrees F of outside temperature. Obviously, a large ventilation rate will reduce the inside-to-outside temperature differential, and a smaller one will increase it with application of the design factor ^{F}Winter as shown in Table 5.

The elevation of the greenhouse and the interior light intensity have a direct bearing on the amount of air needed to control the house temperature in the fall, winter and spring, just as they do in summer cooling. These factors (explained in the section on summer mechanical ventilation and cooling) also are used in designing winter ventilation systems. For convenience, ^{F}Elev and ^{F}Light are shown in Tables 1 and 2.

The winter ventilation rate of 1 1/2 CFM per square foot of floor space can be adjusted for elevation, light intensity or indoor-to-outdoor temperature by applying the following equation:

$$^{CFM}\text{Winter} = 1.5 \times {}^{F}\text{Winter} \times {}^{F}\text{Elev} \times {}^{F}\text{Light}$$

AIR CIRCULATION

PRINCIPLES

During the past few years, there has been an increase interest among many leading horticulturist and growers to provide a better greenhouse growing climate during the fall, winter and spring. There has been a desire for more uniform temperatures, less extremes in relative humidities and more active air circulation and movement, particularly over the leaf surfaces of the plants.

During cold weather, when the greenhouses are virtually closed in, there is often insufficient air circulation to maintain the desired conditions. The proper type of air circulation within a greenhouse will greatly help obtain a more uniform temperature throughout the house, help eliminate cold or hot spots, provide more uniform relative humidities in dense foliage areas and provide good air movement.

Continuous circulation produces a gentle air movement that maintains a better leaf surface microclimate and prevents pockets of disease-producing high humidity.

DESIGN RECOMMENDATIONS

Best air circulation over a range of requirements is achieved with a specially constructed pressurizing fan attached to perforated plastic tube closed at its far end, located in the upper section of the house and extending along the length of the house.

The fan is mounted inside the greenhouse a specified distance from the gable end. The pressurizing fan runs continuously, inflating the tube and blowing air through the holes (in the form of jets) into the greenhouse space. This uniformly distributes the air for the full length of the tube, creating turbulence, thorough mixing and active air motion throughout the entire greenhouse. It maintains a more uniform temperature and humidity and prevents cold spots.

AUTOMATIC CONTROLS, OPERATION

PRINCIPLES

Thermostats to regulate greenhouse-heating systems have been in use for many years and are very effective in maintaining more uniform temperatures and reducing operating costs. In a similar manner, thermostats and humidistats are very useful in automatically regulating the greenhouse cooling and ventilating systems. Automatic controls are relatively inexpensive and quite reliable and normally give years of service with little maintenance.

Thermostats or controllers are used to turn fans and pumps on and off as required to meet changes in outdoor climate conditions and thereby maintain more uniform greenhouse temperatures with lower operating costs.

During warm weather a humidistat can be used to control the pump of the cooling pad system to help prevent excessive greenhouse humidity. A humidistat that is wired to operate exhaust fans also can help prevent excessive humidities.

RECOMMENDATIONS

The fans should be automatically controlled with thermostats or controllers that turn the fans on with temperature rise to obtain the best temperature regulation and to conserve power. In such cases, the fans should be equipped with automatic closures—such as shutters—to prevent back drafts through fans that are not operating.

The fans should be divided into three banks, each bank controlled by a separate thermostat. Each thermostat or controller should have a slightly different temperature setting to provide gradual changes in airflow and more uniform temperature control. Every third fan should be a member of one bank to provide a more uniform airflow pattern in the greenhouse.

A two-speed fan should be controlled with a two-stage thermostat or controller. This arrangement will permit the first stage to turn the fan on and off as required; the second stage will run the fan on low or high speed as required.

During the fall, winter and spring, when a thermostat controls the heating system, the cooling thermostat that controls the first stage fans should be set several degrees (usually five or more), above the setting of the heating thermostat to prevent the heating and cooling system from operating at the same time-which can happen because of an override tendency that frequently occurs in a heating system.

It is important to wire the cooling and ventilating equipment so that thermostats, humidistats or controllers can control the equipment in the proper sequence for best performance. This is usually requires dividing the fans into several circuits or stages so that specific fans can be turned on and off as required. All electric wiring and controls should comply with national or local electrical codes and ordinances.

The pumps should be controlled by humidistats or controllers, and thermostats should be wired in series. This will help maintain more uniform temperatures, avoid excessive humidities and conserve power and water.

In localities where the outdoor relative humidity tends to be high early in the evening, humidistats can help avoid excess humidity in the house. In all cases, though, a thermostat should be used for the main pump control. The thermostat should be set to stop the pump before all the fans are shut off so that the pad can dry out.

The thermostats, humidistats, sensors for controllers and thermometers should be shielded from the direct rays of the sun to avoid being influenced by solar radiation and to provide correct readings and control settings. Shielding with at least half an inch of thick wood is usually satisfactory. Sensing elements should be mounted to permit circulation of air about them and should be located where they represent the average greenhouse condition at plant level, with care to avoid locating them directly above heating lines or near a sizable air inlet opening.

Each thermostat and humidistat should have a manual control switch wired in parallel with it to permit manual control when desired.

A safety disconnect switch should be located near each fan and pump.

It is recommended that hinged-wall sash vents be installed at the pad system, motorized and controlled with a thermostat to provide more complete automatic operation of the greenhouse climate.

On small installations consisting of three or four exhaust fans and a pump, line voltage controls are normally used. On large ranges, the fans are usually divided into three or four banks that are each controlled as a unit. For such cases, low-voltage controls should be considered for improved sensitivity and the reduction of wiring costs; relays are needed, anyway.

GREENHOUSE ASSOCIATION'S STANDARDS FOR HOBBYISTS

COOLING AND VENTILATING HOBBY HOUSE GREENHOUSES

PRINCIPLES

Most small or hobby house greenhouses are generally affected in the same manner and subjected to the same conditions of cooling and ventilating that apply to commercial greenhouses. Therefore, the principles and design recommendations previously listed for commercial greenhouses normally are used. For very small houses, however, package evaporative coolers provide simpler installation and more convenient operation.

DESIGN RECOMMENDATIONS

The summer ventilation rate design factor should be a minimum of 12 CFM per square feet of floor area.

The cooling pad should have a minimum height of 24 inches to provide a more suitable vertical air distribution within the hobby house.

Lean-to-hobby houses attached to the east, south or west walls of building have a greater solar heat load because of the building's wall area. This load should be compensated for by adding half of the building's wall area to the actual floor area to obtain an "equivalent" floor area. The total amount of air required is determined by multiplying the ventilation rate times the equivalent floor area.

Hobby houses having a floor area of about 300 square feet or less usually can be cooled and ventilated satisfactorily with a package evaporative cooler for less cost and greater operating convenience than a fan-and-pad system provides. The evaporative coolers usually are attached to the outside of the hobby house and blow air in through the register or grille. An exhaust opening, such as an automatic shutter on the opposite end of the house or a cracked-open ridge ventilator, must be provided to let out the warmed-up air. Evaporative coolers should be selected on the basis of 15 CFM per square feet of floor area.

Winter mechanical ventilation will experience extremes from no ventilation at night to the maximum requirements on a bright-sunny day. The maximum ventilation rate will be about half of summer ventilation requirements and will be greatest for lean-to-houses attached to the east, south or west wall of the building. Because of the wide range of ventilation required, the fans always should have 2-speed motors so that the low speed can be used in the winter. In addition the ventilators can be manipulated to restrict the airflow openings and thereby further reduce the ventilation flow rate. Thermostats or controllers should be used to operate the fans to maintain better temperature control and operating convenience.

RECOMMENDATIONS FOR USING INSECT_SCREEN IN GREENHOUSE STRUCTURES AN ADDENDUM TO NGMA VENTILATING AND COOLING STANDARDS

The NGMA, having had requested from its members and growers more information regarding the proper way to size and install insect screens, has developed the following recommendations:

For purposes here we will limit our discussion to mechanically ventilated greenhouses. As more information is obtained we will include naturally ventilated structures. It should be noted that using insect screens on greenhouse structures could have a significant impact on fan motor life.

It is intended that these recommendations become an addendum to the standards for ventilating and cooling greenhouses.

TEST STANDARDS

"Screens to be tested to a .50" WG. Final pressure drops in accordance with ASHRAE STD. 52.1-1992 using a synthetic test dust of 150-180 micron silica dioxide.

The recommended airflow range for the "AIRFLOW RATE vs. RESISTANCE" portion of the test is 0-600 FPM. The air flow rate for the "DUST FED vs. RESISTANCE" portion of the test and the "DUST FED vs. ARRESTANCE" portion of the test is to be determined by the manufacturer.

Comments: The purpose of this test is to develop, for the user/designer, performance data of the screen device as it relates to:

1. The restriction of airflow at varying rates on a clean device.

2. The restriction of airflow as the screen becomes loaded or clogged with insects or debris.

3. The ability of a screen device to capture insects in the size range of 150-180 microns or larger.

However, this is merely an indication of the ability of a screen to capture living insects in the 150-180 micron size range.

The use and results reporting of the recommended test methods shall be voluntary on the part of the screening manufacturers. This voluntary standard is the official recommendation of the NGMA in order that architects, engineers, greenhouse manufacturers, consumers and growers may request screening performance measurements based on this standard and that screening manufacturers voluntarily comply with those requests. Nothing contained herein shall be constructed as mandatory requirements (i.e. as a basis for NGMA membership). No comments or statements herein shall be constructed to imply that one type, shape, form or material content of screening is preferred over another nor that any brand name associated with NGMA membership is preferred over the other brands or non-member brands.

By testing to the above standards, the screen manufacturer will be able to provide a pressure velocity curve that shows the characteristics of the different materials in the marketplace. The curve should have the velocity plotted on abscissa and pressure loss on the ordinate.

If one point is known on the curve then others can be calculated. The formula is:

$v = c\sqrt{pv}$ Where v = face velocity, c = resistance constant & *pv* = velocity pressure. Calculate the constant, c, using the tested data then develop other points using tested constant and selected velocities.

MECHANICAL VENTILATION *(Exhaust fans)*

Before sizing screens it is imperative that the characteristics of the exhaust fans be known, as different size and horsepower combinations have different maximum performance limitations. This information may be obtained by contacting the fan manufacturer. Because of the use of screens, it is recommended by the NGMA that fan manufacturers start providing the maximum static pressure in their literature. It is suggested that a safety operating range of 0.5” static pressure be provided to account for catching insects and debris. As an example, if the maximum performance of the fan was .30” static pressure, the design calculations would not exceed .25” static pressure.

In order to maintain the proper cooling (heat removal), it is necessary that the calculated CFM requirements be maintained. If fans were pre-selected prior to the additions of screens, the performance or CFM of air could drop below the calculated requirements. This will result in an increase in house temperature, increased electrical consumption and reduced motor life.

EXAMPLE:
A greenhouse with calculated requirements of 29,000 Total CFM has fans selected or installed that deliver 30,000 CFM at .10” SP.

Now with the addition of screens, the pressure increases to .20” SP and the fan performance drops to 25,500 CFM. This is approximately a 15% reduction of CFM, which will result in an increase of the temperature rise from pad or inlet to exhaust fans of 15% and approximately a 40% increase in operating costs.

EXAMPLE:
A greenhouse for which we want to screen both inlet and outlet (fan discharge) areas utilizing two fans that have a maximum static pressure of .25”.

House ventilation requirements: 24,000 CFM (see *NGMA Standard for Cooling and Ventilating Greenhouses* for standard calculations).

Maximum fan static pressure:	.25” static pressure
Safety operating range:	-.05 static pressure
Available operating range:	.20”static pressure
Standard operating pressure before applying screens:	-.10” static pressure
Available for screen use:	.10” static pressure

Divide available screen use static pressure by number of areas to be screened. In this example we have two, the inlet and the outlet areas. It should be noted that the available static pressure may be divided into proportion desired (i.e., .03” SP for inlet area and .07” SP for outlet area) as long as total available static pressure is not exceeded. For purposes of this example, we will treat inlet and outlet areas equal. Taking .10” SP divided by two areas equals .05” SP static pressure available per screen (inlet and outlet).

Looking at Chart 1 for screen material, “A” shows that for .05” static pressure, the velocity is 200 feet per minute.

24,000 CFM divided by 200 ft. per minute = 120 sq. ft. of screen required for screen “A” for each inlet and outlet area (fans). Using two fans will require 60 sq. ft. each of screen area (120 sq. ft. divided by 2 fans = 60 sq. ft.).

Now look at Chart 1 for screen “B” material. It shows for .05” static pressure, the velocity is 400 ft. per minute. 24,000 CFM divided by 400 ft. per minute = 60 sq. ft. of screening required for screen “B” for each inlet and outlet area (fans). Using two fans will require 30 sq. ft. for each screen area (60 sq. ft. divided by 2 fans = 30 sq. ft.).

By looking at the two materials you can see that it will require twice as much of the screen area of material “A” as material “B” to provide the same air entry into the structure at .05” static pressure.

These examples compare two clean screen materials. In practice, two materials may hold dirt and contaminant's at very different rates, dramatically changing static pressure differences over time.

OTHER CONSIDERATIONS

If there are other air entry levels, such as roof vents, which lead into a corridor area and allow air to go into individual greenhouse cubicle or units, it will be necessary to calculate the additional static pressure of the vent opening area and the vent screening area.

Vent opening vel = $4005\sqrt{pv}$
(pv = Velocity Pressure)

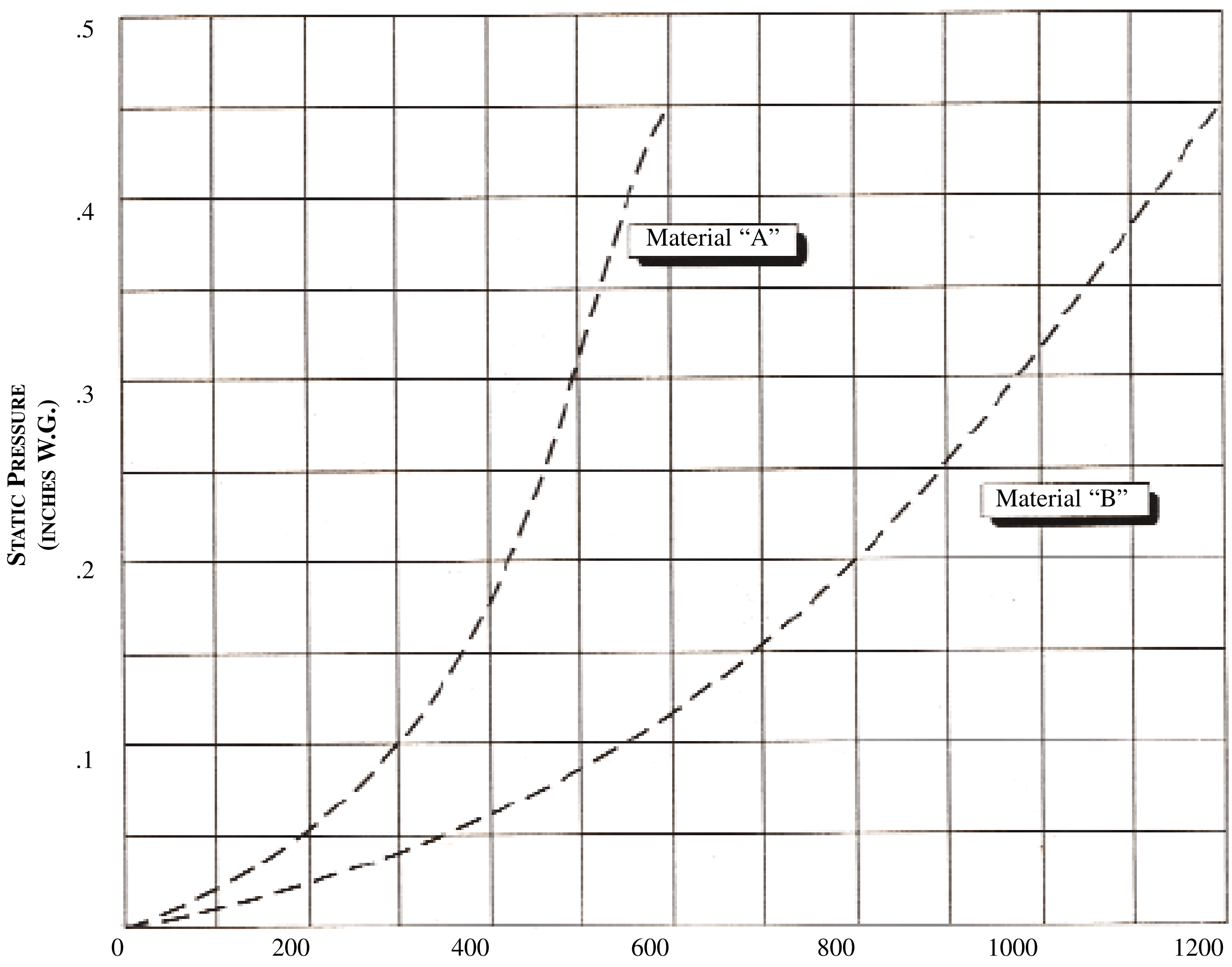
It is also recommended that the screen be kept dry. During ventilating it is recommend that the screens be placed on the inside of the fan where they will not produce as much restriction as when placed on the discharge side of the fan where the air is coming off of the blades in a turbulent motion.

If using different materials for inlet and outlet areas, it would be necessary to look at the performance characteristics of each material when determining the velocity or screening area required. Some growers have determined they want a finer mesh screen on the air entry into the structure with a coarser mesh material on the discharge or fan area.

DAILY OPERATION

It is highly recommended to use a manometer to measure pressure, across screen and/or cooling pads in the house. This will allow the grower to know when to clean the screens following the screen manufacturer's recommended methods. As pointed out earlier, if the screens are allowed to accumulate with insects or debris, the result will be a static pressure buildup, which will result in reduced airflow through the structure and a resultant higher temperature in the greenhouse structure.

We will update these recommendations, as more information becomes available to the National Greenhouse Manufacturer's Association.



**VELOCITY
(FPM)
CHART 1**

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