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Biological Resources Engineering ***FACTS***

Insect Screening for Greenhouses

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Greenhouse screening is an attempt to prevent the entry of very small insect pests into the production greenhouse. The net free open area for air movement per square foot of screening is small. Unless the screened area is much larger than the inlet vent openings, all the ventilation air must pass at a higher velocity through a much smaller area. This creates a large static pressure drop and reduced air flow through the exhaust fan. Reduced ventilation causes higher greenhouse temperatures.

The maximum static pressure limit of the exhaust fan is critical in this design process. For any given greenhouse air flow, the smaller the screening area, the higher the air velocity and the higher the static pressure difference. A large screen area is more difficult and costly to provide, but the larger the screen area, the lower the air velocity and the lower static pressure difference between inside and outside. Exhaust fans move more air at lower static pressure difference.

Insect screening reduces the number of insects entering the greenhouse and reduces the need for insecticides. Weeds and other insect host plants need to be removed from around the outside of the greenhouse. Employees must understand that doors cannot be left open and any tears in the screening material and greenhouse cover must be repaired quickly. Also, plants, plugs and root cuttings brought into the greenhouse must be inspected to make sure that they are free of insects. The screening will keep both beneficial insect and pest populations inside a greenhouse if they are brought in on plants or allowed to enter through doors left ajar. Screening, used correctly, is an important integrated pest management (IPM) tool for many crops.

Screening is used over all air inlet louvers and other vents. Exhaust fan openings need to be covered by tightly closing louvers. Any openings along the perimeter of the greenhouse base and cracks around doors and closed vents must be sealed.

Pesticide-use reductions of between 50 and 90 percent have occurred in North America, Europe and Israel for fine mesh screen users. Impatiens Necrotic Spot Virus (INSV) and Tomato Spotted Wilt Virus (TSWV) are two major diseases that can devastate a wide range of greenhouse plants. Both diseases are vector transmitted by the Western Flower Thrips, *Frankliniella occidentalis.* Thrips often migrate into greenhouses from spring through the fall and are among the most difficult pests to control. Flower thrips and western flower thrips have developed resistance to several synthetic insecticides. Excluding thrips from greenhouses should be one of the highest priorities. To prevent inward migration of nymphs of the Western Flower Thrips, a very fine mesh screening must be installed.

Several serious greenhouse pests can be excluded by screens with the following hole sizes or smaller (Bethke, 1990):

Insect	Size hole: microns	Size hole: inches
Serpentine leaf miner (*Liriomyza trifolii)*	640 µm	0.025 in.
Sweet potato whitefly (*Bemisia tabaci*)	462 µm	0.018 in.
Melon aphid (*Aphis gossypii*)	340 µm	0.013 in.
Greenhouse whitefly (*Trialenrodes vaporariorum*)	288 µm	0.0113 in.
Silver leaf whitefly (*Bemisia argentifolii*)	239 µm	0.0094 in.
Western flower thrips (*Frankliniella occidentalis*)	192 µm	< 0.0075 in.

One inch is 25,400 microns and one mil is 0.001 inches. Winged aphids are physically larger than whiteflies but must be excluded with a finer mesh due to differences in wing placement and/or behavior.

Many of the species of aphids that infest greenhouses overwinter as eggs on weeds and woody plants. In the spring, winged aphids migrate through ventilation vents and open greenhouse doors. Microscreening can be used to effectively prevent inward migration of aphids. Microscreening will also work to keep insect predators and parasites from migrating out of the greenhouse if you are using biological releases of beneficial insects and mites.

The purpose of this publication is to discuss how to plan and install an effective screening system. General considerations are that small screen openings restrict air movement and thus a large screened surface must be provided to allow the necessary ventilation air into the greenhouse. There are three approaches used to size a screening system and each will be explained.

Understanding Ventilation and Static Pressure

The desired mechanically forced ventilation rate through a greenhouse is normally a three-fourths to one air change per minute. This is expressed in cubic feet per minute, CFM. The quantity can be calculated by first determining the interior volume of the greenhouse using the equation of the length times the width times the average height. Exhaust fans are then sized to 3/4 to 1 times this volume. As a rule of thumb, the ventilation exhaust fans are sized to provide 8 cubic feet per minute of air flow per square foot of floor area.

As a general rule, exhaust fans are selected to provide the required air flow in CFM at a static pressure of either 0.125 inch water gauge (w.g.) pressure or 0.10 inch w.g. Some newer equipment is advertised to be designed to be more efficient and so there is less pressure drop. Air moving through the inlet louvers, through cooling pads (if present), past crops and structural members, and out the exhaust fans meets with some resistance which results in static pressure loss.

The exhaust fan is not able to move as much air against a large pressure loss as against a small pressure loss. As the static pressure loss increases, the air flow decreases proportionally. The fan capacity in CFM printed in the catalog demonstrates this point (Table 1). The fan also has a limiting static pressure loss, and, for greater static pressures, the fan's air flow capacity drops quickly. The insect screening must not be allowed to cause the static pressure loss to get too large.

Table 1. Air Flow Versus Static Pressure for Exhaust Fans.

		Static Pressures, inch water				
Fan		0.000	0.100	0.125	0.150	MAX
Model	HP	CFM	CFM	CFM	CFM	in. w.g.
30 inch	1/3	8185	7225	6870	6430	0.20
	1/2	9375	8580	8340	8065	0.25
	3/4	10620	9940	9750	9550	0.30
36 inch	1/3	10005	8555	8035	7330	0.15
	1/2	11585	10475	10110	9670	0.20
	3/4	13325	12225	11930	11615	0.30
42 inch	1/2	14690	12465	11775	10920	0.20
	3/4	16710	15190	14725	14165	0.25

Adapted from ACME DCA Series Super Windmaster fans for illustrative purposes.

The air inlet louvers are usually selected to be roughly the same size or preferably slightly larger than the exhaust fans to reduce pressure loss. Ventilation air flow, CFM, is air velocity in feet per minute (fpm) times the open area of the inlet louver, sq. ft. (Figure 1). Technically, there are orifice coefficients to account for edge effects. Examples of coefficients are shown in a table much later in this publication. Typical static pressure loss for a system with an inlet louver, exhaust fan, and shutter for low velocity air flow is 0.03 inch w.g. Changing all the air in a 100-foot long greenhouse each minute means the average air velocity must be 100 fpm.

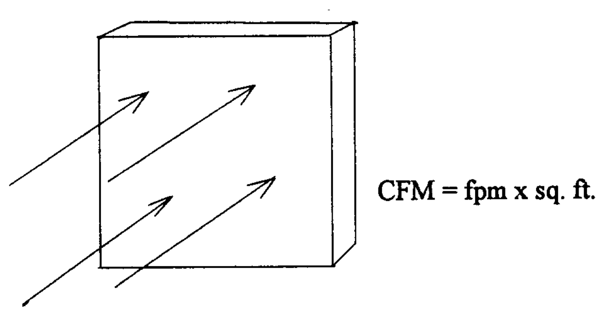


Figure 1. Ventilation air flow, CFM, is air velocity, fpm, times open area of louver, sq. ft.

For winter ventilation, a restricted air inlet louver may raise the air velocity to 700 fpm to achieve good mixing of cold air into the greenhouse. This restriction may raise the static pressure loss to 0.07 inch w.g. The addition of evaporative cooling pads, insect screening, or dense plant foliage may also raise the pressure loss to 0.07 inch w.g. Air movement through plant material in the greenhouse can account for 0.01 inch w.g. pressure. Pressure losses through screening materials will vary with air velocity and clogging (Figures 2 and 3).

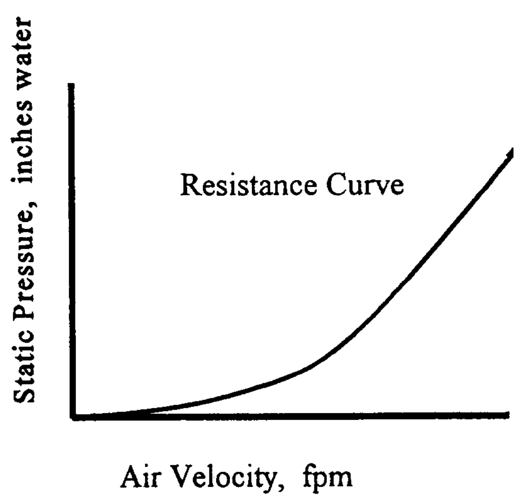


Figure 2. Curve showing pressure loss for air movement at different velocities through screening material.

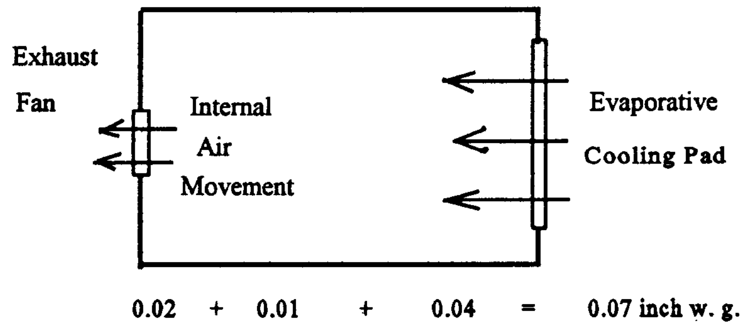


Figure 3. Restrictions cause pressure losses as air moves through greenhouse. Static pressure drop measured as inches of water.

An example of static pressure considerations follows. If an exhaust fan has a maximum static pressure capacity of 0.15 inch w.g., the total of all pressure losses and safety margins cannot exceed 0.15 inches. The earlier example of a pad system had a loss of 0.07 inch w.g. through the greenhouse. If screens are added, a safety margin of 0.05 inch w.g. is recommended due to possible clogging. This leaves 0.03 inch w.g. for screening or other sources of pressure loss. A screening material with a pressure loss up to 0.03 inch w.g. can be installed.

Static pressure is measured with a simple U-shaped tube (manometer) filled with liquid. One end of the U-shaped tube is exposed to the inside atmosphere of the greenhouse and the other end is exposed to the outside atmosphere. The level of the liquid will rise on the inside greenhouse side of the manometer as the higher pressure outside the greenhouse pushes the liquid column to equilibrium. The difference in column heights in the U-shaped tubing can be read as inches of water of static pressure.

Commercial manometers use an inclined tube to measure the pressure of the system in inches of water. The Mark II model 25 from Dwyer Instrument Company, P.O. Box 373, Michigan City, IN 46360, sells for less than $25.00. The instrument is mounted level inside the greenhouse. One pressure port is left open to sense interior pressure and the other port is connected to plastic tubing going to the outdoors. A scale on the instrument shows the static pressure difference (Figure 4).

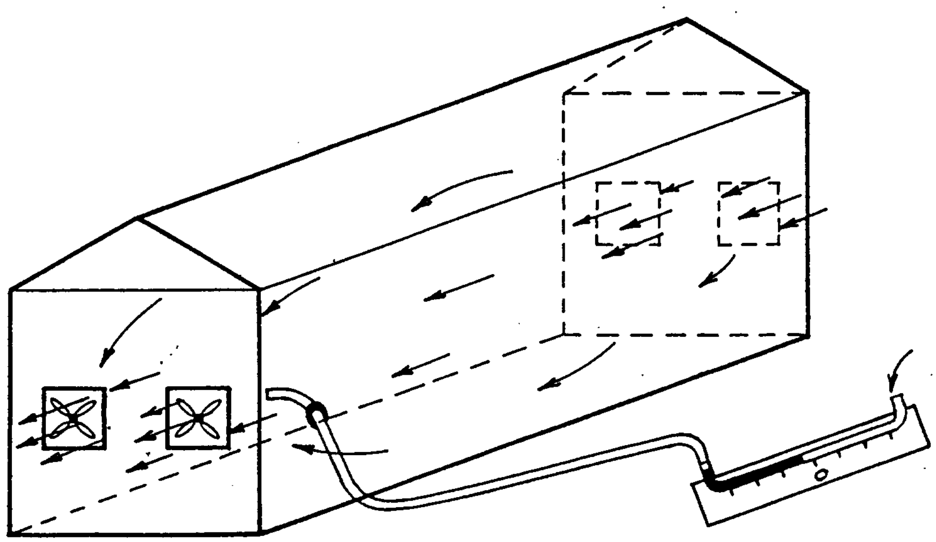
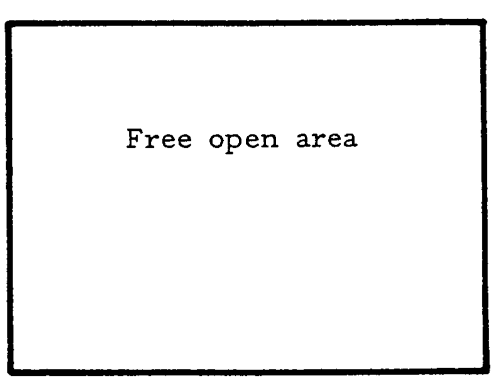


Figure 4. A manometer measures static pressure drop of air flow through greenhouse.

Screening Material Blocks Air Flow

Screening materials must have openings through them that are as small as or smaller than the insect to be excluded. Many materials are made out of uniform threads and are called mesh materials. Mesh refers to the number of threads per inch in each direction. A 60-mesh material has 60 parallel threads in each direction in a square inch piece of screening. Assuming 59 rows and 59 columns of open spaces between the threads, there are nearly 3,500 openings in a square inch. Each thread has a thickness or diameter that partially blocks the formerly open space. When the thickness of the thread is accounted for, the "net free open area" for air passage through the screen is greatly diminished. The total free open area is a factor of both the mesh number and diameter of the thread (Figure 5).



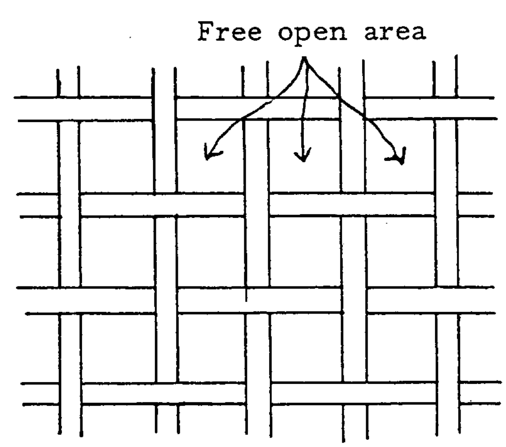


Figure 5. The free open area for air movement is reduced by the threads of the screening material.

The greater the mesh or thread diameter in a square inch, the greater the interference is with air flow in the greenhouse. Note that more important than the mesh number or thread diameter is the ratio of free open area of the screen to its total area.

The total free open area through the material may be only a small fraction of what it was before the screening was applied. As the fan tries to force air through the openings in the screening, the static pressure drop increases and the total air flow may decrease. The air must go faster to get through the remaining holes and this results in a pressure loss. To overcome the air resistance, a much larger surface area of the screening is needed to provide the original amount of free area.

If the free open area ratio is 0.2 and the inlet vent opening is 30 square feet, then the total amount of screened area needed is 30/0.2 or 150 square feet of screening. In this case, about five times as much screened area is needed as the original inlet area. Currently, the free open area ratio is used in one of the selection processes (Figure 6).

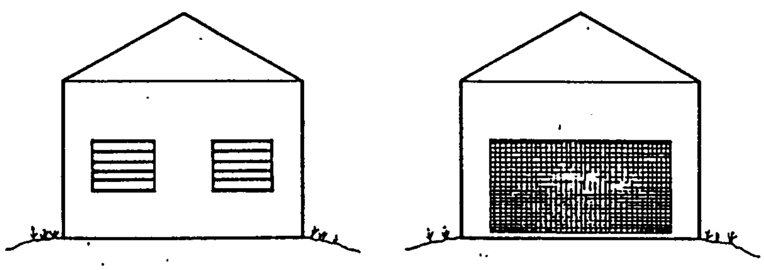


Figure 6. Screening material covers much greater area to allow same ventilation air flow.

Retrofitting a Greenhouse with Screening

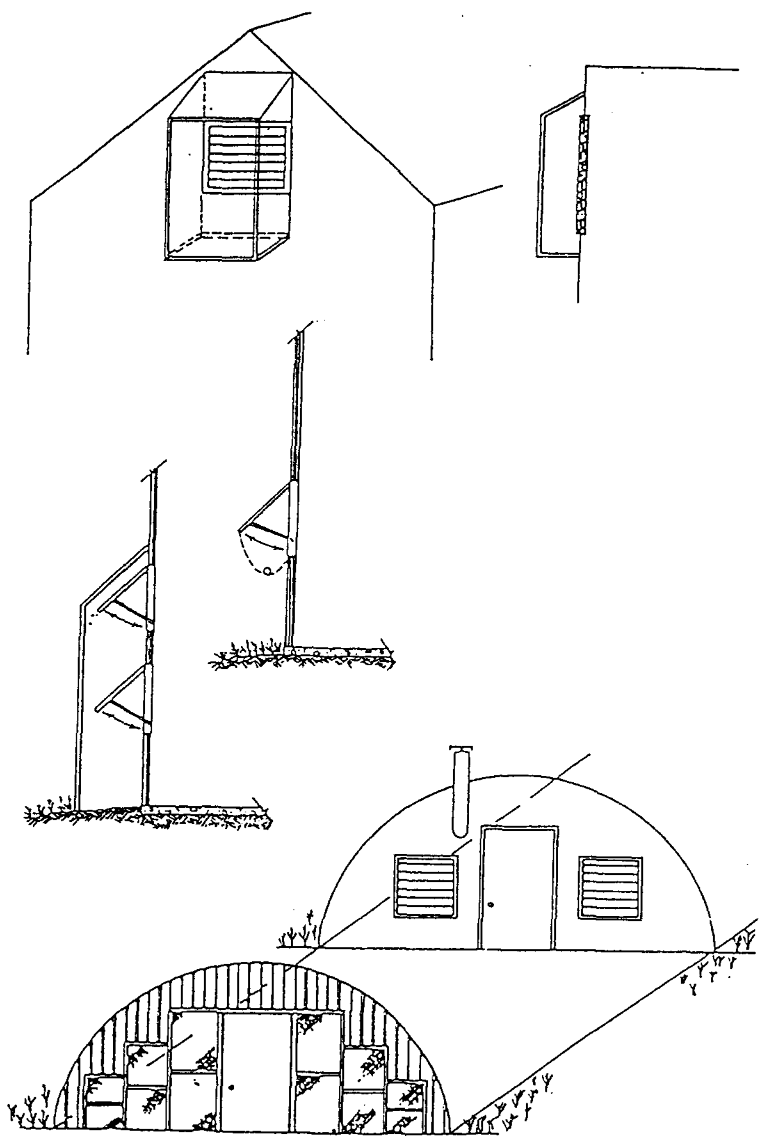
The screening material requires several times more surface area than the inlet openings being protected. Retrofitting means building some kind of support structure onto the greenhouse.

For an existing quonset greenhouse, the simplest retrofit may be the addition of one more structural frame (hoop) on the inlet louver end of the greenhouse. This new end hoop can be framed to hold the screening material. A plastic film roof can be added.

In new quonset construction, the inlet louvers and an outside door can be installed on the second hoop or frame. The screening and second outside door can be on the outside frame or hoop. The roughly four feet between end walls is covered as part of the whole greenhouse.

Greenhouses with side vents are more difficult in some cases to screen. If the side vents are on the end wall of a series of gutter connected houses, a roofed shed can be attached to the greenhouse. Or, for a single vent window, the screening material can be fastened to the lower edge of the vent window and to the lower edge of the window sill. The screening material will hang down. To help keep the screening material in place, a pipe can be laid the length of the house in the fold of the material (Figure 7).

Roof vents are difficult to screen because of their location and construction. If screening can be placed inside the roof vent, it will catch dirt that comes in through the roof vent. There is difficulty in cleaning the upper side of the material. The percentage of insects entering the roof of the greenhouse should be small compared to those entering the sides. The insects are expected to be lower to the ground near host plants. Put sticky tape targets near the roof inlets to count the population there as an indication of possible infestation from that entry.



a) Build frame to support screening material for the vent.

b) Build continuous frame along sidewall or use pipe to hold screening attached to openings.

c) Add one more hoop to support the screening material.

Figure 7. Illustrations of screening installations on greenhouses.

Three Screening Design Procedures

The process for selecting the amount of screening surface area needed has not been standardized yet. For mechanically ventilated greenhouses, there are currently three design methods being used. The design method to use depends largely on the information available about the screening material.

Method A is best and most direct from an engineering viewpoint. The use of real measurements helps the design and later the management of the system. Method B sets an allowed static pressure loss for all structures and does not monitor losses as the screen clogs. And, Method C does not consider static pressures at all. Methods B and C could result in erroneous designs if the greenhouse was poorly designed initially.

Each of these three design methods will be illustrated with examples using three materials and the information provided in the manufacturer literature available.

A. The National Greenhouse Manufacturers Association (NGMA) proposes a design practice that uses a manometer to measure existing greenhouse static pressure and uses information about the static pressure versus air velocity relationship of the screening material to size the screened area. A safety margin of 0.05 inch water static pressure is included to protect the exhaust fan from overloading. The maximum static pressure of the exhaust fan must be known.

B. The second method uses the air flow velocity or air "approach velocity" established by equation or from air flow tests at 0.03 inch water static pressure loss through the screening material. The air velocity is used to calculate the screening surface area by dividing the ventilation air flow rate by the approach velocity. The ventilation air flow rate must be known. Static pressures are not evaluated in the greenhouse.

C. Free open area calculations must be made for those screening materials for which no air velocity versus static pressure relationships are known. For this method, the dimensions of the threads and their spacing (mesh or other configuration description) are needed. The goal is to determine the amount of free open area per square foot. The amount of screening surface needed to provide the amount of free open area of the inlet vents can be found. Physical characteristics of the threads that affect air flow are not considered.

While only the NGMA procedure recommends the use of a manometer, a manometer is an inexpensive tool for monitoring the static pressure initially and as the screening material becomes clogged. A manometer is a good investment.

NGMA Guidelines.

The National Greenhouse Manufacturers Association (NGMA) suggests "*the resistance in the greenhouse plus the resistance of the screening material plus a 0.05 inch w.g. safety operating margin for clogging be less than the maximum upper static pressure limits of the exhaust fan.*" The upper limits for greenhouse exhaust fans are usually in the range of 0.15 and 0.35 inch w.g. For design purposes, NGMA has considered using an upper limit of 0.15 inch w.g. for the exhaust fan. Hopefully, a standard will follow shortly.

Five-Step NGMA Procedure. A five-step procedure is used to evaluate whether screening can be applied directly to the inlet louvers or whether a larger amount must be applied to the greenhouse.

1. Install a manometer to measure static pressure.

The suggested manometer costs $20.00 to $25.00 and is used to monitor the greenhouse static pressure over time.

Install the manometer according to manufacturer instructions near the exhaust fan end of the greenhouse. Tighten the manometer in a level, zero reading position. Be sure the manometer is firmly mounted in a level position before connecting the tubing to the outside. Be sure all doors are closed and all fans are operating before taking readings.

For a greenhouse with just inlet louvers and exhaust fans, a static pressure of 0.03 inch w.g. is in order. A fan and evaporative cooling pad system will typically have a static pressure loss of 0.07 inch w.g. If the reading is much higher, check the size of the inlet louvers. They may be undersized and may need to be replaced at this time with larger ones to reduce loss.

2. Check the maximum static pressure limit of the exhaust fan.

The goal is to use a maximum static pressure limit of 0.15 inch w.g. for the exhaust fan. Allowing for clogging of the screening material, do not exceed the fan's maximum capacity. Check manufacturer literature for the fan's maximum static pressure limit and do not exceed it.

3. Determine the total air flow through the greenhouse and the air velocity through the inlet louvers.

Specifications may be available on the existing greenhouse design ventilation rate. One can calculate the air volume equal to the length times the width times the average height. An alternative is to use a rule-of-thumb that suggests the ventilation rate be equal to 8 CFM per square foot of floor area times the floor area. A ventilation rate is typically 3/4 to 1 air change per minute. Check the air flow specs for existing exhaust fans at 0.125 inches w.g. and at 0.15 inches w.g., if available, in company literature.

The air velocity, fpm, through the existing inlet louvers can be estimated by dividing the ventilation rate, CFM, by the open area of the inlet louvers, sq. ft. Watch the dimension units. Note one square foot is 144 square inches.

Example: The greenhouse ventilation rate was found to be 24,000 CFM. The open area of the louvers was calculated to be 60 square feet. The air velocity through the inlet louvers is 24,000 CFM divided by 60 square feet to give 400 feet per minute, fpm.

4. Can screening be placed directly over the existing inlet louvers?

This is a quick check to see if the screening can be applied directly to the existing inlet louvers. Most of the time a larger surface area of screening will be needed. With experience, this check is useful for deciding the next value to try.

Example: Go to the Static Pressure vs. Air Velocity curve to find the static pressure corresponding to 400 fpm (the calculated inlet air velocity). Check to see if there is enough static pressure capacity available from the exhaust fan for this situation.

By the NGMA Guidelines of 0.15 inch w.g. maximum, the static pressure can be

greenhouse pressure + X (screen) + safety margin = maximum value (0.15)

$$0.03 + X + 0.05 = 0.15$$

$$X = 0.15 - 0.03 - 0.05$$

$$X = 0.07 \text{ inch w.g.}$$

Does the air flow of 400 fpm through the screening material cause more than 0.07 inch w.g. static pressure? If yes, proceed.

5. Calculate the area of screening required to lower the static pressure loss to an acceptable level.

The allowable static pressure is calculated (shown to be a max of 0.07 inch w.g. above) and the air velocity is read from the Static Pressure vs. Air Velocity Curve. The greenhouse ventilation rate, CFM, is divided by the air velocity, fpm, to get the net surface area, sq. ft., of screen material.

NGMA guidelines applied to three screening materials. Three screening materials will be discussed to illustrate their specs, static pressure losses, and required screening areas. The three materials are:

1. Green Thumb Group BugBed, 123 mesh
2. Green-Tek, Inc. "No-Thrips," 81 mesh
3. Green-Tek, Inc. Antivirus, 50 x 24 mesh

The specification information given here is from the product literature or from the distributor. No tests were made. This information is provided to give the reader a more detailed look at the products. The exhaust fan has a maximum static pressure limit of 0.15 inch w.g. All calculations are shown so differences can be reviewed.

For each screening example, the greenhouse will be 100 ft long by 30 ft wide by 10 ft high with a static pressure loss of 0.03 inch w.g. A safety factor of 0.05 inch w.g. will be reserved for each case to allow for some dirt clogging and to protect the fan motor.

Screen Sizing — Green Thumb Group BugBed™ Environmental Screening, 123 mesh

Specs: mesh:	123 (threads per inch)
opening:	0.135 mm, 0.0053 inches
thread size:	0.070 to 0.090 mm, 0.0028 to 0.0035 inches
shade value:	(Not given)
light transmission:	(Not given)

(Threads may vary slightly in size for batches of this product).

Try BugBed thrips-proof 123 mesh at 450 fpm air velocity where the static pressure is 0.065 inches of water (Figure 8).

Static pressure loss through greenhouse	0.030 inch w.g.
Safety allowance for clogging	0.050 inch w.g.
Adding screening	0.065 inch w.g.
Total resistance:	0.145 inch w.g.

Since 0.145 inch w.g. total resistance is less than the 0.15 inch w.g. maximum, the system will operate as intended as long as the screen is cleaned periodically.

$$\textit{The screened area must be } \frac{\textit{Air Flow Rate}}{\textit{Average Air Velocity}} = \frac{30{,}000 \ \textit{cfm}}{450 \ \textit{fpm}} = 66.7 \ \textit{square feet}$$

This is an area of 2.7 ft high and 25 ft wide, allowing for a door and framing materials.

Table 2 illustrates the relationship of the allowed screen static pressure loss on the air velocity through the screen and the total screen area required by the greenhouse. A static pressure loss for the screening material of 0.050 to 0.065 inch w.g. seems appropriate. The static pressure loss through the house plus the 0.050 inch w.g. allowed for clogging keep the total under the 0.15 inch w.g. maximum for the exhaust fan.

Table 2. BugBed Screening Areas for Several Static Pressures.

Screen static pressure, inch w.g.	Air velocity, fpm	Screen area, Sq. ft
0.100	550	54.5
0.080	500	60.0
0.065	450	66.7
0.050	400	75.0
0.037	350	85.7
0.025	300	100.0
0.020	250	120.0

Figure 8.
BugBed Environmental Screening - Static Pressure vs. Air Velocity Curve.

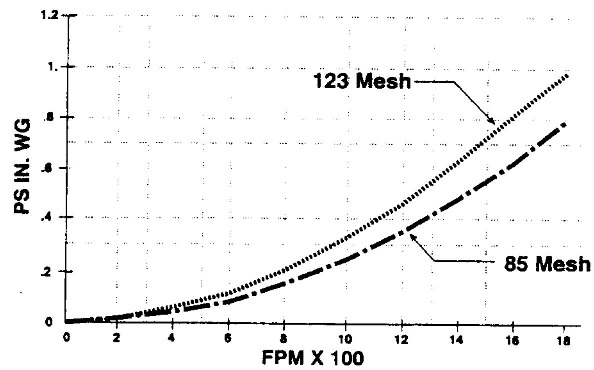


Figure 9.
Green-Tek, Inc. "No-Thrips" Screen - Static Pressure vs. Air Velocity Curve.

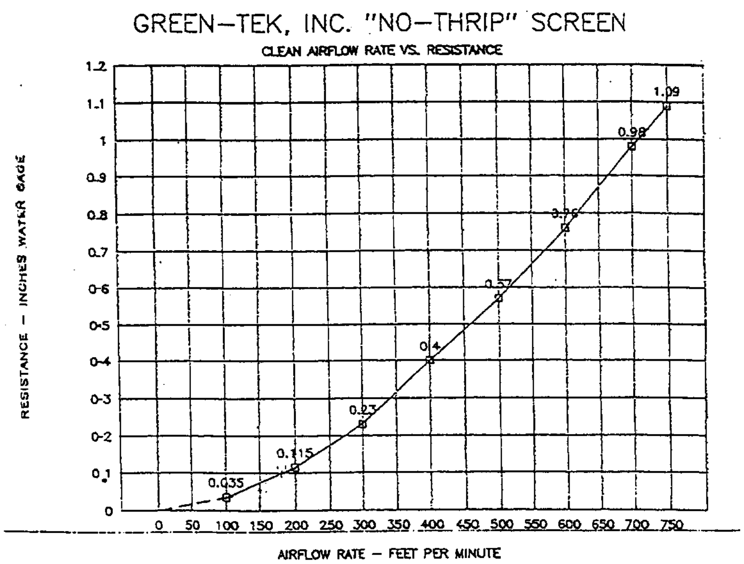
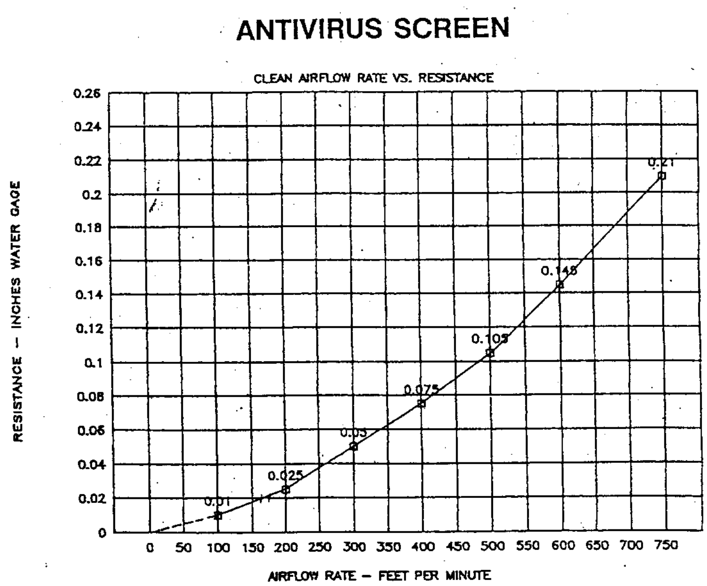


Figure 10.
Green-Tek, Inc. Antivirus Screen - Static Pressure vs. Air Velocity Curve.



Screen Sizing -- Green-Tek "No-Thrips"

Specs:	mesh:	81 x 81 (threads per inch each way)
	opening:	0.0059 inch x 0.0059 inch
	thread size:	0.15 mm, 0.006 inches
	shade value:	33%
	light transmission:	66%

Referring to the static pressure-air flow rate curve (Figure 9) for Green-Tek "No-Thrips," an air flow velocity of 140 feet per minute (fpm) is maximum for 0.07 inch w.g.

Static pressure loss through greenhouse	0.030 inch w.g.
Safety allowance for clogging	0.050 inch w.g.
Adding screening	0.070 inch w.g.
Total resistance	0.150 inch w.g.

$$\textit{Area of screening} = \frac{\textit{Greenhouse Air Flow Rate}}{\textit{Air Velocity}} = \frac{30{,}000\ \textit{cfm}}{140\ \textit{fpm}}$$

$$= 214\ \textit{square feet}$$

This is an area 8.6 ft high and 25 ft wide across the end of the greenhouse. Table 3 gives other options.

Table 3. Green-Tek "No-Thrips" Screening Areas for Several Static Pressures.

Screen Static Pressure, inch w.g.	Air Velocity, fpm	Screen Area, Sq. ft.
0.07	140	214
0.05	120	250
0.035	100	300

The Green-Tek "No-Thrips" screen has very small openings, smaller than the physical dimensions of the insect, so the resistance to air flow is high. The resistance is caused by the total area of the threads blocking the air path. A large screen area gives enough free open area for air passage through the screening.

Screen Sizing - Green-Tek Antivirus

Specs:	mesh:	50 x 24
	opening size:	0.0105 inch x 0.0322 inch
	thread size:	0.24 mm

shade value:	20%
light transmission:	80%

Static pressure through greenhouse	0.03 inch w.g.
Safety allowance for clogging	0.05 inch w.g.
Adding screening	0.07 inch w.g.
Total resistance	0.15 inch w.g.

Referring to the resistance-air flow rate curve for Green-Tek Antivirus, an air flow velocity of 380 fpm is given for a resistance of 0.07 inch w.g. (Figure 10).

$$Area\ of\ screening = \frac{Greenhouse\ Air\ Flow\ Rate}{Air\ Velocity} = \frac{30{,}000\ cfm}{380\ fpm}$$

$$= 79\ sq\ ft$$

This is an area 3.2 ft high and 25 ft wide. Table 4 illustrates other options.

Table 4. Green-Tek Antivirus Screening Areas for Several Static Pressures.

Screen Static Pressure, inch w.g.	Air Velocity, fpm	Screen Area, Sq. ft.
0.07	380	79
0.06	350	86
0.05	300	100
0.04	262	115

In Table 5, the design values of screen static pressure, inch w.g.; air velocity, fpm; and screening area, square ft. are summarized. The BugBed material has a three to one advantage over "No-Thrips," requiring 67 square feet of screening to 214 square feet. The air velocity of 450 fpm for BugBed is quite high compared to 140 fpm for "No-Thrips." Basically, it is a matter of getting enough free open area for the air to pass through without causing excessive pressure loss.

Table 5. Design Values and Screening Area.

Material	Total Resistance, in. w.g.	Screen Resistance, in. w.g.	Air Velocity, fpm	Screening Area, sq. ft.
"No-Thrips"	0.150	0.070	140	214
BugBed	0.145	0.065	450	67
Antivirus	0.150	0.070	380	79

Approach Velocity Guidelines

It has been suggested by Johnson (1990) that a maximum static pressure of 0.05 inches w.g. at 250 fpm air velocity be used for sizing the screening. Sase and Christianson (1990) recommended that for clean materials a total pressure loss of 0.033 inches w.g. at 250 fpm air velocity be used for sizing the screening. The allowed screen pressure loss of 0.033 inch w.g. is gaining popularity and will be illustrated here. Very few calculations or measurements are used in this design method.

Static pressure drops vary considerably for the wide range of available materials and one report indicated that, at 250 fpm velocity, the best screening materials had a static pressure of 0.017 inches w.g. and the poorest material had a static pressure of 1.4 inches w.g.

Since the air velocity is needed for area calculations, the "approach velocity" is being reported. The approach velocity is the air velocity, in fpm, through a screening material for an allowed pressure drop of 0.03 inches w.g. Table 6 gives values for several materials. This table is based on the equation $C=P/v^2$ where P=0.03 inches w.g. and C is an orifice coefficient.

The sizing procedure uses the given approach velocity from Table 6 for a screening material in the following equation to calculate the area of screening needed. The greenhouse ventilation air flow is required.

$$\frac{Greenhouse\ Air\ Flow,\ CFM}{Approach\ Velocity,\ fpm} = Area\ of\ screening,\ square\ feet$$

Evaluate several materials. Obviously, the larger the approach velocity, the smaller the screening area needed.

A manometer should be used to establish the static pressure loss of the unscreened greenhouse and the maximum static pressure of the exhaust fan checked to be sure the design is acceptable. This method does not take into account other static pressure losses or the exhaust fan maximum static pressure capacity.

Table 6. Airflow Characteristics of Screening Materials.

Material		Discharge Coefficient[1]	"Approach Velocities" at 0.033 inch w.g.[2]
Unscreened opening		0.000000193	1200 at 0.1 inches 700 at 0.033 inches
Indian plastic - 32 X 36		0.000000205	400
Indian plastic - 30 X 42		0.000000282	350
Stainless steel - 60 mesh, 0.15 mm wire		0.000000343	310
Chicopee - 32 mesh		0.000000279	340
Chicopee - 52 mesh		0.000000453	270
Nylon - 68 mesh		0.000000491	260
Random woven fabric		0.000000853	200
Vispore - 6296	(female to male)	0.0000109	55
	(male to female)	0.0000126	50
Vispore - 6432	(female to male)	0.00000564	75
	(male to female)	0.00000571	75
Hydro Gardens fly bar	(clean)	0.000000707	220
	(dirty)	0.00000104	180
Econet T			110[4]
Dura Green			450[3]
Pak			300[3]
FlyBarr			200[3]
Israel Material			350[3]
Meteor			350[3]
Vispore			very low[3]
Vispore2			260[3]
Standard Screen			550[3]

Adapted from L. L. Christianson and G. L. Riskowski, July 14, 1992.

[1]The discharge coefficient is defined as the pressure drop (inches of water) divided by the air flow rate (cfm/square foot of screen area) squared. The equation is $C = P/v^2$.

[2]The air flow rate is cfm of air per square of screen area. These air flow rates are calculated for 0.033 inches of water pressure drop, which is our design recommendation. Also, these values are the "approach velocities," fpm, of air to the screening material at 0.033 inches water gage pressure.

[3]Estimated from DuraGreen literature (American Coolair Corporation, Jacksonville, Florida tests)

[4]Added from other sources.

Free Open Area Calculations/Guidelines

A few materials do not have static pressure versus air velocity data available so the pressure loss cannot be used for designing the screening system. Instead the physical dimensions of the material are used to calculate free open area per square foot.

The inlet louver and exhaust fan of a greenhouse have free open area for the ventilation air to pass through. When insect screening is considered to cover the inlet louver, the tightly spaced threads of the screening material occupy much of the former free open area. To avoid restricting the air flow, the free open area of the insect screening material must be as large as the original free open area. Thus, several times as many square feet of screening material will be required as there was unrestricted area.

As noted earlier, many of the screen materials are made from uniform threads called mesh. Mesh refers to the number of threads per inch in each direction. An 81-mesh screen has 81 threads running in each direction at right angles to each other. The diameter of the thread must be known to determine the net free open area through which air can flow.

<u>Two Free Open Area Calculation Methods</u>. For example, assuming a thread size of 0.006 inches and a mesh of 81 by 81, the net free open area can be calculated in a couple of ways.

One approach is to visualize the threads pushed to two sides of a one inch by one inch square (Figure 11). The width of the threads on two sides is 0.006 x 81 = 0.486 inches. This strip is 0.486 inches by 1 inch long or 0.486 square inches. Note, the threads have to overlap in one corner to double cover that corner. The area of that corner is 0.486 x 0.486 = (the width of each strip of threads) 0.236 square inches. The net free open area is 1.0 - (0.486 + 0.486 - 0.236) = 0.246 square inches. The net free open area is 0.264 divided by the total area of 1.0 or 26.4 percent. At a minimum it will take 1.0 divided by 0.264 or 3.7878 (3.8) times as much screening material as there is free open area in the inlet louver.

A second approach is to find the size of each individual opening in the screening material. Again, if the threads are 0.006 inch and the mesh is 81, the width of all the threads across an inch square is 0.486 inches (Figure 12). The open space remaining is 1.0 - 0.486 or 0.514 inches. This space was originally 80 openings between threads. With 80 openings across the inch, each opening is 0.006425 inches wide. In this case, the mesh is the same in both directions so the opening size is 0.006425 inch square, giving an area of 0.0000412 square inches. The total area is 80 openings times 80 openings times 0.0000412 or 0.26368 (0.264) square inch. In other words, the screen has a net free open area of 26.4 percent. To have 100 percent equivalent open area, one must use 100/26.4 or 3.7878 (3.8) times as much screening material as inlet louver open area. A small orifice coefficient exists but it is rather small.

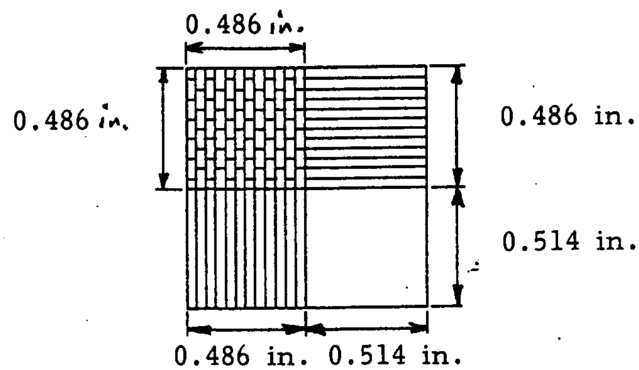


Figure 11. Threads are moved to the sides to illustrate area calculated by thread width times mesh number. Net free area is then calculated.

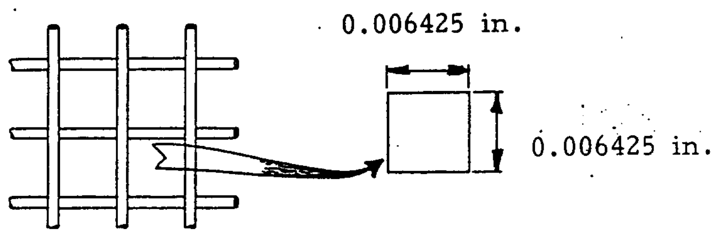


Figure 12. Net free area calculated from dimensions of individual openings.

Free open areas for three materials. There are considerable differences in the screening areas required by the "No-Thrips" (81 x 81 mesh), Antivirus (50 x 24 mesh), and BugBed (123 x 123 mesh) materials. Of course, the "No-Thrips" and BugBed materials are the two that exclude 100 percent of the thrips and can be compared directly. The Antivirus material excludes 80 percent of thrips per the manufacturer and has larger hole sizes. Green-Tek, Inc. distributes "No-Thrips" and Antivirus materials. The Green Thumb Group distributes the BugBed Environmental Screening.

Tables 7 and 8 were developed to explain the differences in the materials. Note in Table 7 that, while BugBed screening has more threads per inch, the threads vary in diameter, but are much smaller than those used in the other two materials. An average diameter was used to calculate the area of a square inch covered by the threads if all threads were pushed together, side to side and top to bottom. There will be double coverage in one corner to subtract.

Table 7. Screen Thread Area and Net Free Open Areas per square inch.

Material	Mesh	Thread diameter, inch	Width/inch	Total Area, sq. in.	Free Open Area, sq. in.
"No-Thrips"	81 x 81	0.006	0.486 in.	0.736	0.264
BugBed	123 x 123	0.00315 (avg.)	0.387 in.	0.624	0.376
Antivirus	50 x 24	0.0096	0.48 in. 0.23 in.	0.60	0.40

"No-Thrips" has thread diameters nearly double the BugBed and has two-thirds as many threads per inch. This means more thread material blocking air flow but maybe it is stronger. There was no data on strength. BugBed has 37.5 percent free open area compared to 26.4 percent for "No-Thrips."

For BugBed material, the area covered by threads was 123 threads times 0.00315 inch diameter equal 0.387 inch width of threads per inch of material. Since the mesh is 123 x 123, the area covered by threads is 0.387 inch wide by 1 inch long or 0.387 square inches in two directions less the area common to both in one corner. The area of double coverage is 0.387 x 0.387 or 0.150 square inches. The total thread-covered area is 0.387 + 0.387 - 0.150 or 0.624 square inch. The remaining area of each square inch is the free area or free open area. The free area is 1.0 - 0.625 or 0.374 square inches. The larger the free open area, the more open area for air to flow through and the resistance to air flow is lower.

In Table 7, BugBed material has a calculated 37.5 percent free open area while "No-Thrips" has 26.4 percent free open area. The BugBed material appears to have an advantage over the "No-Thrips" material with its 42 percent larger free open area. The Antivirus material has 40 percent free open area and larger hole sizes.

Table 8 uses the mesh specs and hole size dimensions to calculate the number of holes or openings per square inch and the total free open area using the hole size dimensions. The BugBed material has 1.42 times the free open area of "No-Thrips." BugBed has 2.33 times as many openings per square inch.

Table 8. Hole Sizes and Total Open Area.

Materials	Mesh	No. Holes	Hole Size, sq. in.	Total Free Open Area, sq. in.
"No-Thrips"	81 x 81	6,400	0.0000412	0.264
BugBed	123 x 123	14,884	0.0000252	0.375
Antivirus	50 x 24	1,127	0.0003552	0.400

The differences between these three materials are not adequately explained in this comparison. However, much more is known about each material. Other factors such as shape of hole, shape of thread, roughness of thread, and diameter of thread may affect performance. There may have been differences in the initial testing of the materials, particularly differences in the coefficient C. L. L. Christianson and Riskowski (1992) reported discharge coefficients varied for different materials. He used a test chamber to determine the relationship between the velocity of the air approaching and passing through a screen and the pressure drop required to force air through.

SUMMARY

Insect screening reduces the number of insects entering a greenhouse and reduces the need for pesticides. This is an important integrated pest management (IPM) tool for many crops.

Screening causes a restriction to the air flow so a larger screened area is needed to permit the same air flow as originally existed. One of three design methods is used, depending on the information available, to size the screening area.

A manometer is recommended for monitoring the static pressure in the greenhouse. Use the static pressure versus air velocity relationship, when available, to size the screening material. The total static pressure loss of the greenhouse must not exceed the maximum static pressure capacity of the exhaust fans.

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