Ventilation and Cooling of Greenhouses

Professor Emeritus William J. Roberts,
Horticultural Engineer George H. Cook College, Rutgers University
New Brunswick, NJ 08903
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Cooling and Ventilating greenhouses is usually more difficult than heating them. It is always possible to add more heat to control temperatures but it is difficult to lower temperatures if outside conditions are extreme.

Many of the principles discussed above concerning air movement for heating systems also apply to ventilation systems. The National Greenhouse Manufacturing Association has developed excellent standards for ventilating and cooling greenhouses.(2) These include recommendations and designs affecting site elevation, sunlight intensity, orientation and shape of the greenhouse and crops being grown. The following is a discussion of systems and requirements.

Greenhouse ventilation is required to control temperature and moisture levels and provide CO_2 for good crop production. There are two basic ventilation systems used in greenhouse production systems, natural and mechanical ventilation systems. Natural ventilation depends upon normal air movement created by wind pressures or by gradients induced by differences in air temperatures between the growing area and outside the greenhouse. Mechanical ventilation is air movement created by fans that bring air into the growing area through controlled entrances built into the greenhouse area and exhaust it through the fan assembly. The ability to change the size of inlets is important to the design of good mechanical ventilation systems. Fan ventilation is normally controlled by thermostats and in some cases by humidity-sensing devices when relative humidity is the controlling factor for disease control.

NATURAL VENTILATION

Natural ventilation is driven by temperature differences or wind conditions. Natural ventilation occurs when there is a temperature difference between the inside and the outside of the greenhouse and a vent is opened to allow the warmer air to leave and cooler replacement air to enter. The greatest potential for natural ventilation is during the winter, when the temperature difference between inside the greenhouse and outside is the greatest. Unfortunately, this occurs when the need for ventilation is the least. On excessively hot summer days, the outside temperature may be only slightly cooler than the inside temperature. The ventilation potential is practically nonexistent when the need is the greatest. Adequate ventilation during warm and hot summer periods must be wind-driven and is often site-specific. Areas of naturally occurring breezes provide the best opportunities for warm weather ventilation.

Naturally occurring breezes with proper greenhouse orientation can provide excellent ventilation at some sites. The wind in some areas is often unpredictable, however, and adequate temperature control is very difficult to achieve. Knowing the meteorological information about the proposed site is essential in designing a natural ventilation system.

Natural ventilation system designs include roll-up sides, either hand or automatically operated, and ridge vents constructed as an integral part of the greenhouse structure. Although difficult to install, ridge vents in polyethylene- glazed structures can provide good options for natural ventilation. In gutter-connected or ridge-and-furrow greenhouses, ridge vents perform better than the vents that open at the gutter. Although the gutter units are easier to recover and construct, they do not perform as well as ridge systems. Time required for attention each day and the loss of control, particularly during cold weather, are the most often mentioned complaints of natural ventilation systems using roll-up sides. Most glass greenhouses are ventilated naturally using ridge and side ventilators. These are usually automated systems, but are still limited by the factors listed above.

GREENHOUSES WITHOUT GLAZING

Several newer greenhouse designs for warmer climates feature greenhouse structures with no glazing. These are designed with retractable thermal screens and provide opportunity for excellent environmental control during warmer weather. Site selection is important for heating considerations when growing throughout the year. Some growers use them for increasing growing space and hardening off areas in the spring. Open-roof greenhouses are also new on the market and are performing very well.

MECHANICAL VENTILATION

Fan ventilation systems with properly designed inlets can provide excellent temperature control in all seasons. The most desirable feature is the ability to easily automate the entire system. This has become increasingly true with the use of computer based control. This feature is especially useful to growers with other responsibilities who may be away from the greenhouse during the day and who have difficulty obtaining labor on the weekends. The negative aspects of mechanical ventilation systems are the higher installation and operating costs.

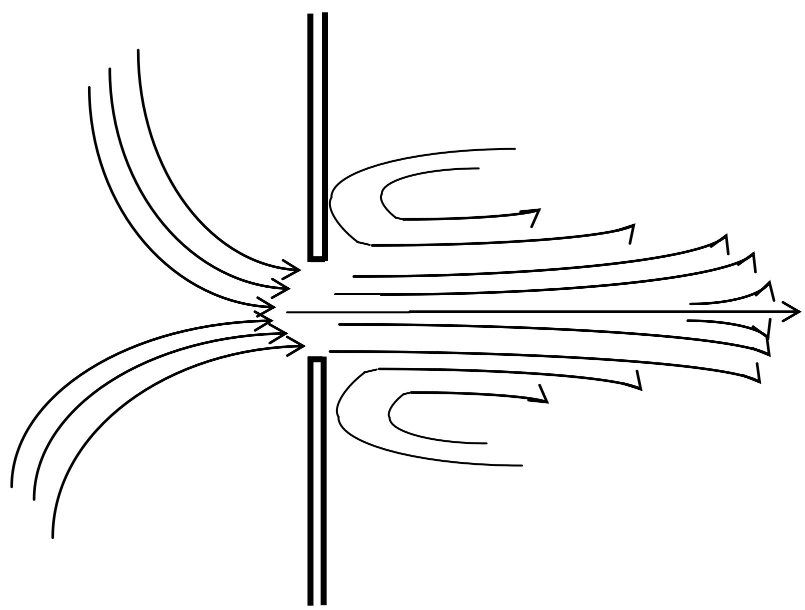

Figure 1 View showing the effects created by a gas or a liquid going through a sharp edged opening at high velocity. As the air leaves the opening it causes the ambient air to mix with it creating a mixture of incoming air and static ambient air. In a ventilation situation small quantities of outside air at 40^{0}F mix with large quantities of with 70^{0}F air giving the desired cooling effect without sub-cooling crops growing in the immediate area of the inlet.

Fan systems are designed to provide approximately one air change per minute for the growing area. Recommendations vary but generally 7-10 cfm per square foot is used as a design parameter. If thermal screens are used for summer shading, 7 cfm/sq ft is the preferable design parameter. It is generally desirable to provide this ventilation capacity with two fans, unless the greenhouse is very small and costs for installation would become too high. The use of multiple fans provides an easy opportunity for using more than one ventilation stage, a feature very desirable in cooler times of the growing season.

The design for a 30-x 96-ft greenhouse would be as follows.

Design cfm = (length) (width)(7) or (10)

A: 30 x 96 x 7 = 20,160 cfm

B: 30 x 96 x 10 = 28,800 cfm

For two fan installation *A* = 2 @ 10,000

B = 2 @ 15,000

The fans would be rated at 0.1 inch static pressure and have an electric motor capable of delivering 15,000 to 20,000 cfm per horsepower.

If one of the fans selected were a two-speed fan, three levels of ventilation could be provided. If the higher air exchange rate were desired, the ventilation rates would be (1) 7500 cfm, (2) 15,000 cfm and (3) 30,000 cfm. This provides the opportunity for better and more uniform environmental control.

In any ventilation system the size and location of the inlets are the most important design consideration. Air entering the greenhouse is always cooler than the inside temperature during colder weather. It is important to obtain proper mixing of the inlet air with the ambient greenhouse air, so that local cold spots or unequal temperatures locations are not experienced

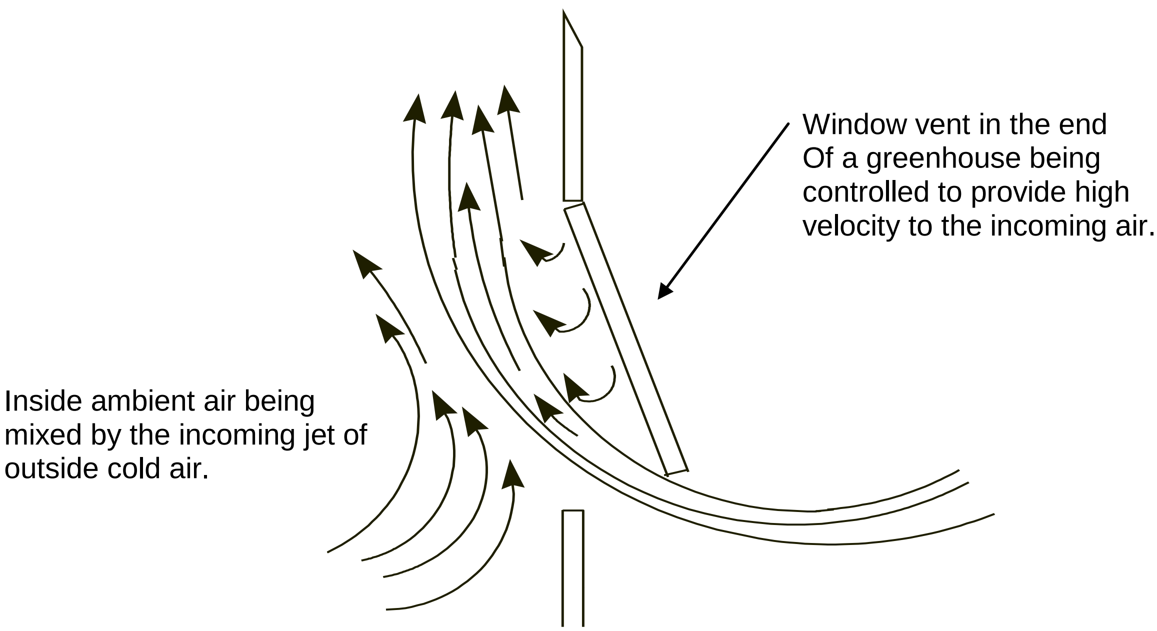

Figure 2 View of the window vent at the end of a greenhouse being opened in increments which match the exhaust fan volume so that there is high velocity through the inlet causing the mixing as indicated in the sketch.

throughout the growing area. Figure 2 as indicated earlier, illustrates the action of air moving through a restricted opening and the resultant distribution pattern. The high-velocity air moving through the opening causes significant mixing of the cold incoming air with the ambient greenhouse air. It is similar to using a jet of water coming from a hose to mix the liquid in a barrel. Another similarity is the human nose. We exhale CO_2 from our lungs and inhale O_2. The reason we do not inhale the breath we just exhaled is because of the mixing action of the tiny jets of air created by our lungs when we exhale. The action of these jets mixes the CO_2 with the ambient air so that when we inhale we get a proper mixture of air.

Observations taken in a double glazed polyethylene greenhouse, 72' x 210' on a bright January day revealed that the first fan stage was cycling and ventilation was taking place when the outside temperature was 0^0F and the inside temperature was 75^0F. Thorough mixing was occurring without any cold damage to the crop adjacent to the window because the air was coming through the window inlet at high velocity and directed upward as indicated in Figure 2. The fans were operating in cycles of about 2 minutes on and 15 minutes off during these conditions.

In ventilation systems the location of the inlets is of paramount importance. It is desirable to keep the length of air travel to approximately 100 feet in free-standing houses. The upper limit for gutter- connected greenhouses appears to be 200 feet. Fans are usually mounted in one end of the house and air inlets on the other end. Fans should be provided with gravity shutters and safety wire screens and have the fan motors protected locally with proper electrical protection and an on-off switch to protect workers when servicing the fans. Inlet shutters should be motorized. Gravity- type shutters have been used, but are subject to wind action in adverse weather and are not suitable for winter operation.

Inlets should be sized to provide an apparent velocity of 700 feet per minute or 1.4 square feet of inlet per 1000 CFM of installed fan capacity. The cross-sectional area can be determined by dividing the air capacity of the fan in cfm by the inlet pre-determined design velocity in fpm, which gives excellent mixing. Following is an example of a suggested procedure for determining the appropriate size of a ventilation inlet

In the example cited earlier a 30' by 96' greenhouse with two 15,000 cfm fans would require the following inlet area:

Area = CFM/velocity

Area Case (1) 30,000/700 = 43 square feet

Area Case (2) 20,000/700 = 29 square feet

For case (1) two 48" by 48" motorized shutters and one 4"by 42" would provide 44 square feet.

For case (2) two 48" by 48" motorized shutters would provide 32 square feet for the opening.

Motorized shutters can be a problem during the colder part of the year. The inlets direct a large volume of air to the crop directly in front of the opening and can cause reduced temperatures at that location. If the velocity of air moving through the shutter is low, then the cold air tends to settle without mixing and move across the greenhouse to the fan and be exhausted, having had no impact on the control thermostat located usually at the 6-ft level. The fan will continue to operate because the thermostat cannot sense the cold temperatures at the floor level. It would be desirable to open the shutters in stages to match the number of fans operating. Because of this, continuous window vents with openings that can be regulated are very popular. The manufacturer often provides continuous aluminum extrusions that serve as hinges, making the windows essentially maintenance free. They are normally glazed with acrylic or polycarbonate panels.

For example, a greenhouse which is 84' by 150' would have an installed fan capacity from 90,000 cfm to 126, 000 cfm. If six, 20,000 cfm fan were installed in the house, a total window inlet area of 168 square feet would be required. This would require, ten motorized 48" by 48" shutters. Another way to provide the inlet area required and give the desired effect of mixing mentioned above would be the use of a continuous vent window on the side of the greenhouse opposite the six fans. Since 168 square feet is required and the greenhouse is 84' wide, a maximum continuous opening of only 24 inches would be required, (2 x 84= 168). The window should be opened in stages to match the number of fans operating Table 1 illustrates a possible control strategy.

In the example, the design calls for six fans. A suggested control strategy would be to use three stages. If the fans were aligned along one wall, fan number 3 could operate as stage number 1. Fans 1 and 6 could be turned on for the second stage, and fans 2, 4 and 5 could be turned on for the final stage of ventilation. Table 1 indicates the three fan stages, the ventilation volume being delivered a each stage and the window opening required to provide a velocity of 700 fpm through the opening which results in good mixing of the incoming air. Computer-based systems provide excellent control by staging the inlet window opening depending upon the number of fans operating, based on desired temperature settings recorded in the computer program.

Table 1

Fan Staging Scenario

Temp	Stage	Fan number	cfm	Area required	Opening
72^0F	1	3	20,000	28 sq feet	4”
74^0F	2	3,1,6	60,000	84 sq feet	12”
77^0F	3	3,1,6,2,4,5	120,000	168 sq feet	24”

EVAPORATIVE COOLING

Evaporation of water requires the energy of conversion from a liquid to a vapor, which is approximately 1050 Btu/pound of water. In evaporative cooling systems, this energy is extracted from the air, which is cooled as it evaporates the water in the system. Evaporative cooling has been used successfully for many years.

The system outlined by Acme[3] uses fans on one side of the greenhouse and wetted pads mounted on the opposite side of the greenhouse at the ventilation inlet. The pads are wetted by water flowing down through them by gravity. Air is drawn through them, evaporating some of the water and causing the air to be cooled nearly to the wet bulb temperature. These systems are particularly successful in areas of low humidity, where 10^o F cooling is not uncommon. Problems with this system include maintenance of the system, depending upon the quality of water available for cooling. Salt buildup is a significant problem in some geographical areas.

Very high-pressure fog systems are also used successfully for greenhouse cooling. Since the fog nozzles are placed throughout the greenhouse, this system has the advantage of evaporating water throughout the greenhouse, rather than depending upon the evaporation that occurs only along one wall, as in the wet pad system. The fog systems tend to be expensive because of the large number of nozzles required and the expensive high-pressure pump (500-900 psi) utilized to create extremely fine droplet sizes. Water treatment is essential for good performance of fog systems. Biological, chemical and mechanical buildup within the nozzles can cause system failure.

Aspirated controls can be very effective in environmental control. Simple capillary bulb thermostats can be made quite accurate Aspiration simply means drawing air over them as indicated in Figure 3. This makes them more responsive and more accurate in their operation. Figure 4 shows a heating application where by aspirating the thermostats the environmental control was great improved by lowering the temperature spread between on and off from 8 to 2 degrees.

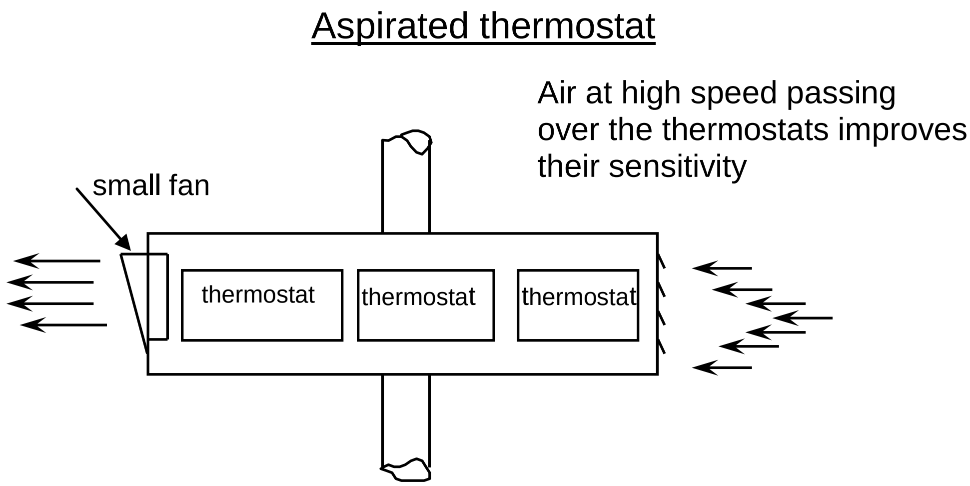

Figure 3 Wooden housing for aspirated thermostats with a small fan mounted in one end drawing air through a screened inlet causing it to pass over the capillary bulb of the thermostats.

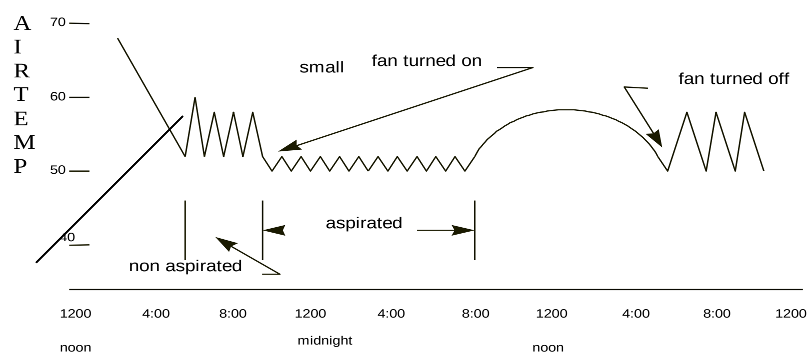

Figure 4 Graph showing the on-off sequence of a thermostat before and after an aspiration fan was turned on. The temperature difference went from approximately 6-8^{0} to about 2^{0}F.

SCREENING

Screens have been used for insect control in dwellings and the work place for many years. Insect screens limit air movement and provide an engineering challenge to exclude insects and not decrease the efficacy of the installed mechanical ventilation system. Fans used for greenhouse cooling are typically of low pressure design with a normal operating range up to 0.125 inches of water static pressure. Table 2 is a summary of some research work and lists the size of aperture of screening and the insects which can be excluded.

TABLE 2

Insect Pests	microns	inches	mesh
leafminers	640	0.025	40
whiteflies	462	0.018	52
aphids	340	0.013	78
flower thrips	192	0.0075	132

Air flow characteristics of fans are determined by their design. Propeller fans used for ventilating greenhouses have low pressure characteristics and move large quantities of air at low static pressures of approximately 0.1" to 0.15" inches of water. The design static pressure used for most systems is 0.10" inches of water.

Using this criteria the following design procedure seems appropriate. Approximately 30% to 50% of the total pressure drop allowable which the fan will experience should be attributed to the screening. This leaves the remaining 50% to 70% available for the normal pressure losses in the total ventilation system including, automatic fan shutters and the window vent openings. This allowance also provides for insect and debris buildup on the screening before cleaning is required.

Dr. James Baker and Mr. Ed Shearin of North Carolina State University have developed a computer model, programmed in QBasic to help designers calculate the area of screening required for a particular screening material being selected by the grower to exclude pests from their operation. This model requires for input parameters, the size of the greenhouse, the number, type and manufacturer of the fans being used, the static pressure of the building when all the fans are operating and all the vents are open, the physical characteristics of the window vents and the screening being selected. The program's output is the required area of screen for several different materials.

The design procedure using the computer program for a vegetable production greenhouse which is 30' by 84' feet, equipped with insect screening would be as follows. Greenhouse data, the type and number of fans and area of inlet would be entered into the program. Table 3 indicates the area of screening required for four types of screening compared to the pressure drop through the screening.

TABLE 3

Allowable SP Drop	Econet T*	Flybarr	Bugbed 123*	No thrips*
	Square feet of screening required for 30' by 84' greenhouse			
.03	130	127	104	328
.04	103	99	83	254
.05	87	82	69	211
.06	76	70	60	181
.07	68	62	54	160

**Reference to commercial products or trade names is made with the understanding that no discrimination or endorsement is intended or implied.*

For instance, the no thrips material would require 254 square feet of screening if an allowable pressure drop of 0.04" was the design parameter for the screen. This would leave .06" pressure drop available for the rest of the ventilation system. By allowing a pressure drop of .06" through the screen only 181 square feet of screening is required with only 0.04" available for the rest of the system including insect and debris buildup on the screening.

By selecting another material such as Econet T, 103 square feet of screening and 76 square feet of screening would be required under the same conditions as stated above.

This information can be used in several ways. For a typical free-standing greenhouse which uses fans on one end and motorized shutters on the other. Figure 6 indicates a means of calculating the area needed for enclosures to be built over the motorized shutter ventilation inlets. This design leaves the integrity of the motorized shutter in tact so that no changes are required in the operation of the ventilation system throughout the year. If screening is installed as a substitute for the glazing in the end of the greenhouse it is easy to have large areas of screening and a minimum of effect on the ventilation system. However, provisions for closing the end of the greenhouse by either covering over the screen or re-glazing with the covering is required for the greater part of the operating season.

A 30' by 84' greenhouse equipped with a continuous vent as indicated in Figure 5 for the same conditions would require a similar screened inlet area. This type of ventilation window permits a grower to design for a lower pressure drop through the screening because the ventilation inlet area of the continuous vent window is usually much larger than for a similar greenhouse equipped with two motorized shutters. If allowing a pressure drop of .04" then 103 square feet of screening is required. The greenhouse is 30 feet wide so the area of screening required per foot of width of the greenhouse is approximately 40 inches. If the screening material is available in 48 inch widths then the pressure drop through the system would be about 0.03" which is predicted for a 48 inch wide screen.

Growers who have installed screening are excited and optimistic about its performance. We have been testing several screens for many years. One grower reduced total sprays for white fly protection from 13 to 3 over a two year period and used only 8 spot sprays on the locations indicated by the yellow sticky indicator cards. There are certainly yearly differences, these data indicate the effectiveness of the screening.

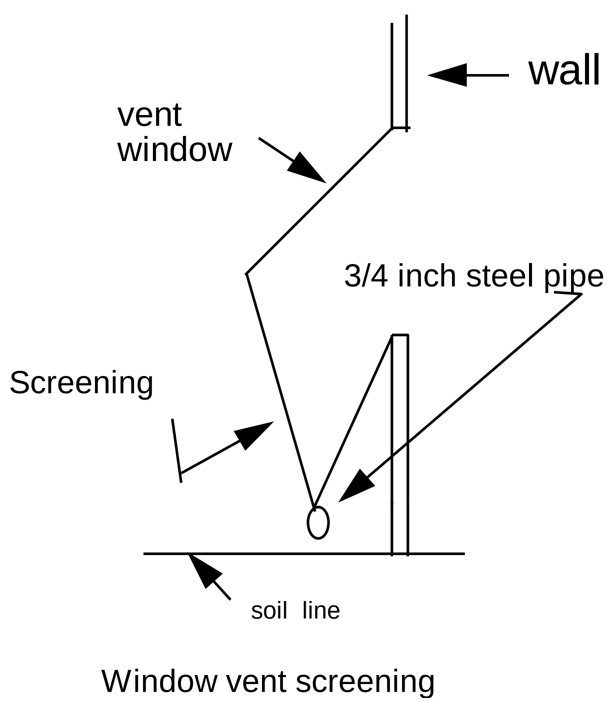

Figure 5 Window vent screening detail for a continuous vent window.

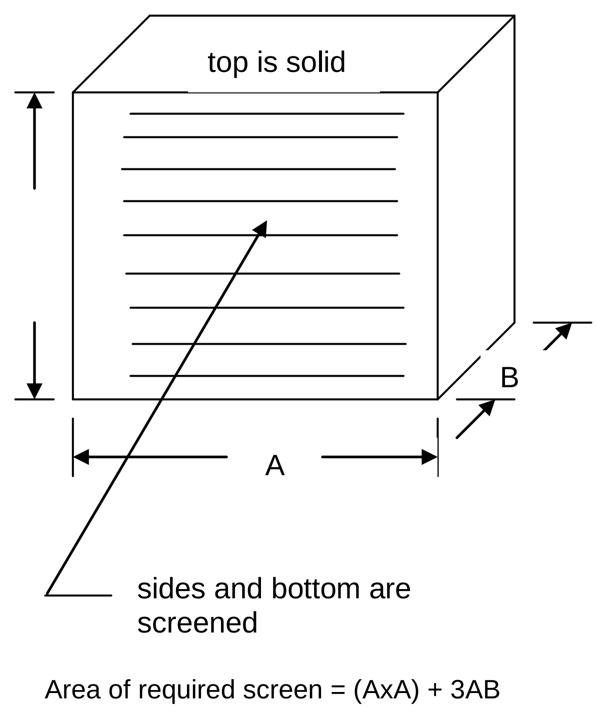

Figure 6 Screened inlet box over motorized shutter inlet.

Useful References for Greenhouse Environmental Control

E213	**Environmental Control of Greenhouses**		Rutgers University
E208	**Soil Heating Systems for Greenhouse Production**		Rutgers University
NRAES 3	**Energy Conservation for Commercial Greenhouses**		NRAES
E169	**Starting in the Greenhouse Business**		Rutgers University
NRAES 56	**Water and Nutrient Management for Greenhouses**		NRAES
NRAES 33	**Greenhouse Engineering**		NRAES
NRAES 51	**Produce Handling and Direct Marketing**		NRAES
NRAES 52	**Facilities for Roadside Markets**		NRAES
NRAES 78	**On Farm Agrichemical Handling Facilities**		NRAES
AEX 800-00	**Greenhouse Condensation Control**	Introduction Fact Sheet	Ohio State University
AEX 801-00	**Greenhouse Condensation Control**	Bottom heating	Ohio State University
AEX 802-00	**Greenhouse Condensation Control**	Thermal Screens	Ohio State University
AEX 803-00	**Greenhouse Condensation Control**	Improving Air Circ	Ohio State University

Helpful Websites:

Much information is available on lines from these and other websites.
http://www.oardc.ohio-state.edu/hydroponics/
http://aesop.rutgers.edu/~horteng
http://www.msstate.edu/dept/cmrec/ghsc.htm
http://ag.arizona.edu/ceac