Insect Exclusion from Greenhouses

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1. Introduction

While controlled environment facilities have been used to grow plants for many purposes, biological security is not always a design requirement. In recent years the commercial greenhouse industry has shown increased interest in security measures incorporated in the facility to reduce infestations of insects and disease. Some research facilities and government agencies operate quarantine facilities, which have long required biological safeguards with a wide variety of specifications depending upon perceived risk. The design of both commercial production greenhouses and quarantine facilities can benefit by careful integration of some of the principles common to both. The authors have experience controlling ingress and egress of insects in either quarantine facilities or commercial greenhouses (Albright and Both, 1990 and Mears and Kahn, 1998). This paper will begin with a discussion of the relatively new concepts for quarantine facility design and then review some of the significant developments in insect exclusion from commercial facilities. Finally, some concepts are presented that hold promise to further increase the effectiveness of insect exclusion from commercial greenhouse production facilities.

2. New concepts in quarantine facility design

The programs of the National Bureau of Plant Genetic Resources (NBPGR), of the Indian Council for Agricultural Research (ICAR), in India, have facilitated the development and implementation of an integrated approach to the design of plant quarantine facilities. The preparation of a proposal for significant support of the NBPGR by the U.S. Agency for International Development (USAID) in 1986-88, led to collaboration with the leadership and scientific staff of NBPGR while the first author was on assignment in India as a scientific advisor to a USAID mission. He was assigned to seek out new opportunities for high quality scientific collaboration between the U.S. and India that could serve as a basis for supporting projects. One such project was is in support of NBPGR. During the period of project development, close collaboration began with the scientists in NBPGR, who have a vast knowledge of the functional requirements that must be met for their facilities and the agroclimatic conditions at candidate sites for the facilities, and an expert in plant protection and quarantine issues retired from APHIS/USDA. These collaborations have led to development of new design concepts for the design of quarantine and related facilities (Kahn and Mathur, 1998).

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Facilities have been designed and erected for the National Bureau of Plant Genetic Resources of the government of India for quarantine operations related to both import and export of seeds for research and breeding purposes. In these facilities four major functions of varying biological containment requirements were carried out: greenhouses for plant quarantine, plant propagation, and virus indexing, and so-called screenhouses for both the grow-out test to determine seed health, and for the production of seeds. The key underlying philosophy of the engineering design of the quarantine facilities in India has been the integration of state of the art commercial structures and environmental control practices with the functional requirements for optimal plant growth under phytosanitary and safeguard conditions.

The overall design of the greenhouse complex is based on major input from the NBPGR staff and administration, a consideration of climatological factors, site visits, and greenhouse engineering data and concepts (Mears, 1989). The level of safeguarding required varies with the level of disease and insect risk associated with the various plant introduction activities undertaken by NBPGR. To reduce construction costs and operation expenses, it is not economically prudent to design all units to the highest level of perceived risk, (Kahn and Mathur 1998). Some lower risk activities can be conducted safely at a lower level of safeguarding. In addition to risk reduction, the design must accommodate significant differences in agroclimatic conditions, both seasonally and from location-to-location. The full spectrum of functional requirements for these facilities was described in more detail in Kahn and Mathur (1998), and in Mears et al. (1997).

Facility Design Requirements:

Generally, plant propagation facilities are required to grow a wide range of virus-indicator plants (temperate, tropical, and subtropical), throughout the year. These units must be protected (screened) against the ingress or egress of insects and mites, as well as provide optimum environment conditions for successful plant growth. A double-door entry is required.

NBPGR planned plant propagation facilities at four locations: New Delhi, Hyderabad, Bhowali and Kanpur. There are significant differences among these sites. Especially the topography at Bhowali was a critical factor as the location in the Himalayas provides steep slopes to contend with and the elevation of 1660 meters above sea level had to be considered in designing successful temperature control systems.

The plant production activities at all four locations were very similar though the major crops to be quarantined varied among locations. Program activities required a single zone for environment control with a night temperature of not less than 15^{o}C and a target day temperature of not more than 30^{o}C. Evaporative cooling was supplemented with partial internal shading to reduce plant stress during days of high solar irradiation and high relative humidity.

Quarantine greenhouses are usually required to house the higher-risk plant introductions. The design specified greenhouses that were divided into compartments of about 4.5 m^2. They were screened against ingress or egress of insects and mites. Each compartment had a single door opening into a service corridor with its own door, thus providing double-door entry. The entry from the outside to the central corridor was protected by a double-door. Some sealed compartments were equipped to operate under a microbiological containment system. These compartments required negative pressure relative to the corridor, realized by exhausting air from each compartment through high efficiency particulate air (HEPA) filters which discharge into the corridor. These compartments were mechanically air-conditioned.

Screened greenhouse space was required for virus indexing. Two shade curtains, one furnishing 30% shade and the other 50%, provide movable internal shading. The curtains operated independently, or in tandem to produce a maximum of 65% shade. Shading was required to relieve heat stress and to promote symptom expression in virus indexing. A single zone for environment control was required providing not less than 20°C at night, and a target of not more than 25°C during the day. High-pressure fog was utilized in combination with the movable shading for maximum cooling without the use of mechanical refrigeration.

Grow-out units were required for the growing out tests of seed-borne pathogens and for seed production to increase quantities of scarce important accessions. The major environmental requirement is to be able to grow plants in an insect-free environment, but the temperatures can be the same as the ambient environment. NBPGR originally requested a structure that was either all screen or a glazed roof with screened walls. However, these designs would be undesirable because indoor temperatures would substantially exceed outdoor ambient temperature in either case under high solar irradiation. Insect screens needed for biological containment have significant resistance to airflow and severely inhibit natural convection (Mears, 1989; Sase and Christianson, 1990). Therefore, greenhouse units with mechanical fan ventilation through screened inlet openings were required. Heating was not necessary, but evaporative cooling of the intake air was included in the design.

Facility Design:

The three functions of propagation, virus indexing, and quarantine were accommodated in a single compact structure. The biological security of this combination of units placed in a single structure can be somewhat greater than that provided by separate but screened units protected by a double-door entry. Through careful design of the unit layout and ventilation system, a facility has been developed in which airflow is always through a screened exhaust fan regardless of what combination of doors are open at any time. This design enabled some quarantine compartments of the facility to provide a high level of biological security when needed. These quarantine units can be sealed, mechanically air-conditioned and their exhaust protected by HEPA filters. These filter units were sized to draw air from the access corridor when the door is open, thus capturing any dangerous particles in the filter. High-risk plants can thus be evaluated in quarantine units placed close together since cross-contamination is not a factor. In this compact design, conventional main corridors are eliminated resulting in a reduction in construction and operating costs. This compact facility is both more cost effective and biologically secure than others designed earlier (Kahn and Mathur, 1998).

The integration of the design concepts for the quarantine, plant propagation, and virus indexing areas are shown in Figures 1, 2, and 3. Figure 1 shows a plan view of the three areas with the ten quarantine compartments being the smaller units, five on each side. The end wall elevation in Figure 2 shows the exhaust fans mounted high over the common entry corridor. The exhaust fans for the quarantine units were mounted above the screened ceiling, which was placed in the top part of the access corridors to the individual compartments. Figure 3 shows a detailed cross section through one of the quarantine compartments.

One of the most critical design features of this facility is the use of screens as part of the ventilation and cooling system to prevent insect passage. It is very important that these screens be properly installed and maintained. The screens in this system are used as:

- Insect barrier for all openings inside the greenhouse. Note: the screens must be installed in removable panels for easy cleaning and replacement if necessary.
- Insect barrier for every ventilation opening (inlet and outlet) in the outer greenhouse wall.

To insure proper airflow, sufficient screen area must be provided so that air velocities will be low enough not to cause unacceptable back pressure on the fans. In the quarantine compartments, air flows through three layers of screen, and in all other compartments through two screens. Since the total static pressure drop contributed by all the screening should be no more than 1.5 mm water column, screen pressure drops should be under 0.5 mm for any single screen layer. Tests under certified conditions must be conducted to determine the airflow/pressure drop relationship as it depends on the geometry of the holes, the shape of the wire or fabric strands, and the nominal percentage of opening. Tests were conducted on screen material available in India to discover the actual airflow/pressure drop relationship for the screens to be used. The test procedure and results are presented in Sase and Christianson (1990). The screen recommended is made of stainless steel wire and is manufactured in India. The screen has a nominal open area of about 38% and the individual holes are 0.25 mm square. The actual screen used was imported from the U.S. at far greater cost than would have been the case had the locally available material been utilized. Several plastic mesh screens were evaluated for their pressure drop/airflow characteristics and could be utilized for such a project. Plastic insect barriers are widely used commercially and their lower cost relative to stainless steel is an important factor in most applications. For this project the perception of higher risk weighed heavily in the client's decision to decide on stainless steel.

3. Screening commercial greenhouses equipped with mechanical ventilation systems

The use of screening to exclude some insects from commercial production greenhouses has become quite widespread in recent years and there have been a number of articles written in the popular trade magazines and extension fact sheets about the subject. Examples of these articles include Baker and Shearin (1994), Bethke (1994), and Ghidiu and Roberts (1994). The effective installation and use of insect screening necessarily involves making some tradeoffs of competing requirements. Good ventilation, particularly in warm climates and hot weather, requires adequate fan capacity and limited resistance to airflow into, through, and out of the greenhouse. Effective insect exclusion requires screening fine enough to prevent entry of the insects of concern. In general, finer screening capable of excluding smaller insects, restricts airflow more and is more expensive than coarser screening.

In selecting a screen, the first step is to determine what insects must be excluded and which of the available screening materials will exclude that insect and other, larger insects. Among others, North Carolina State University has done extensive work in evaluating the effectiveness of many commercially available screening materials for excluding insect pests of particular importance in the commercial greenhouse industry (Bell and Baker, 1995). Their study showed a marked difference in the relative effectiveness of commercial screening materials for excluding Silverleaf Whitefly and the significantly smaller Thrips. A number of materials quite effectively exclude Whitefly, but not Thrips.

The next step is to determine the area of screening required and the method of installation. It is important to know the resistance to airflow of the screening material selected. Testing of the screen material under controlled conditions, such as those described by Sase and Christianson (1990), is necessary to determine the coefficient of resistance of the screen. The resistance of the screen is reflected in a pressure drop across the screen, which varies with the square of the approach air velocity to the screen. Fans used for greenhouse cooling are typically of low pressure design with a normal operating static pressure range of up to 3.2 mm of water column (Roberts et al., 1995).

It is recommended that enough screen area be provided so that, with a clean screen installed, there is no more static pressure drop than 0.75 mm of water column across the screen material itself. This allows for an additional pressure drop due to the inlet windows, evaporative pads (if installed), and the fan fitting and housing. If all of these static pressure drops add up to an additional 1.7 mm of water column, there is an allowance of another 0.75 mm to account for dirt build up on the screen. It is good practice to monitor the pressure drop across the screen material periodically and when this resistance doubles, i.e., increases by about 0.75 mm of water column, the screen should be cleaned to reduce the resistance.

Roberts et al. (1995), described in detail the design procedure for a nominal 30 m long gutter connected commercial greenhouse utilizing a relatively fine insect screen anticipated to be effective in excluding Thrips. Using the airflow resistance coefficient for the screen material, the area of screening required was calculated while maintaining an overall static pressure drop of less than 3.2 mm water column. The greenhouse was equipped with a vent window running the full width of the greenhouse. An insect screen 1.5 m wide and as long as the length of the ventilation window provided the needed area. A very practical method of installing such a screen is illustrated in Figure 4. The screen material can be fastened along the bottom of the ventilation window and the windowsill with a weight attached to the center of then screen (resulting in a V-shaped installation) to keep it from being drawn into the greenhouse by the incoming air. For a longer greenhouse, more airflow and therefore more screen area would be required and this method of fastening would no longer be practical. For a greenhouse over 60 m long utilizing a screen fine enough to be effective at excluding Thrips, an installation such as that shown in Figure 5 will be required to obtain sufficient screen inlet area.

4. Potential for improved performance with positive pressure ventilation

Careful monitoring and evaluation of mechanical exhaust ventilation with screened air inlets showed that the need for pesticide spraying can be greatly reduced (Roberts et al., 1995). In some cases, the only reported spraying was spot spraying when sticky traps had indicated localized presence of insects. The authors propose that it is reasonable to expect insects to be drawn into an exhaust type mechanically ventilated greenhouse through open doors and/or any openings in the greenhouse structure (glazing and/or walls). A proposed improvement in this situation is the use of a positive pressure ventilation system where air forced into the greenhouse through screens as shown in Figure 6. The required capacity of the fans, the required area of screening, and the pressure drops through the various parts of the system can be similarly designed as in a regular negative pressure ventilation system.

During an undergraduate student design project it was shown that the velocity of air exiting the ventilation window can be controlled by the design of the exhaust window (Lorito and Ottes, 1999). A pulley and weight system that applies a relatively constant closing force on the window is balanced by the pressure of the air forced out of the greenhouse. At different stages of ventilation, the window will automatically adjust it's opening so that the pressure and the exit velocity of the air will be maintained at the desired level. With this design, no motorized window opening system is required. Potential disadvantages include the loss of control of air velocity at the inlet to the growing area under low stages of ventilation in cold weather, and the loss of screened growing area between the fans and screen. An alternative design would have the screen outside the fan wall similar to the screen installation shown in Figure 5. Even distribution of the ventilation air within the crop area is important and will be somewhat more difficult in this case. Evaporative cooling can be added by using evaporative pads in addition to the screen wall or by using high-pressure fog within the growing area. It is important that a prototype system be constructed and carefully evaluated to determine the effectiveness of both greenhouse cooling and insect exclusion.

5. Literature Cited

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6. Figures

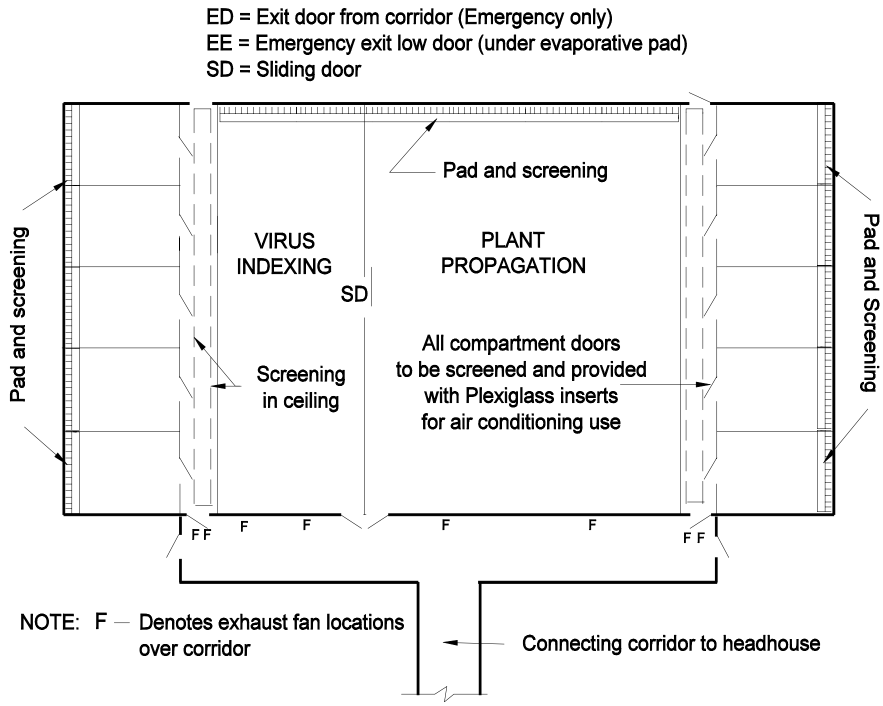

Figure 1. Plan view of compact quarantine facility containing 10 quarantine compartments and larger areas for plant propagation and for virus indexing.

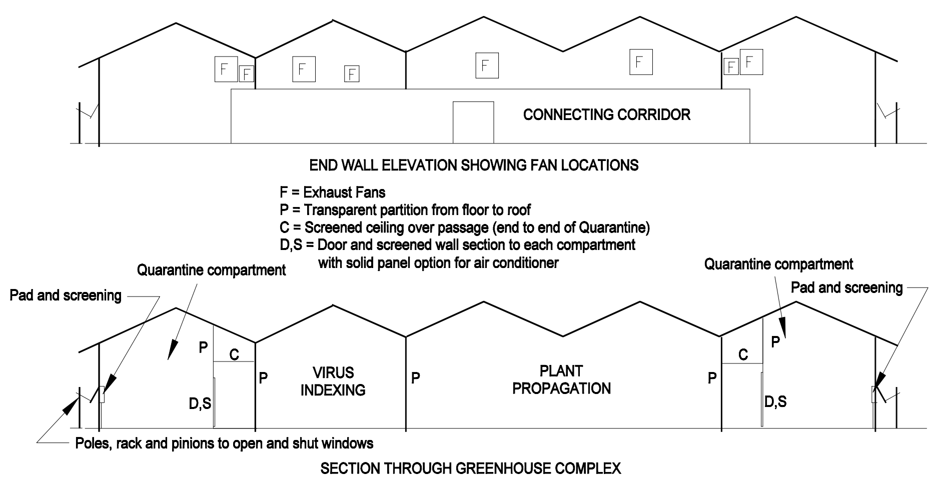

Figure 2. End wall elevation and section elevation of quarantine greenhouse complex.

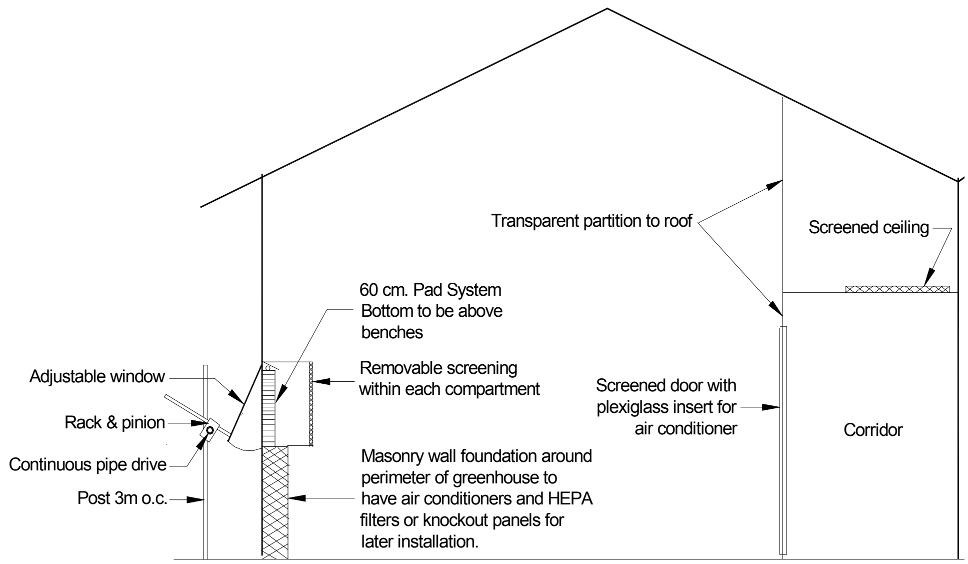

Figure 3. Detailed section through typical small quarantine compartment showing critical screening locations.

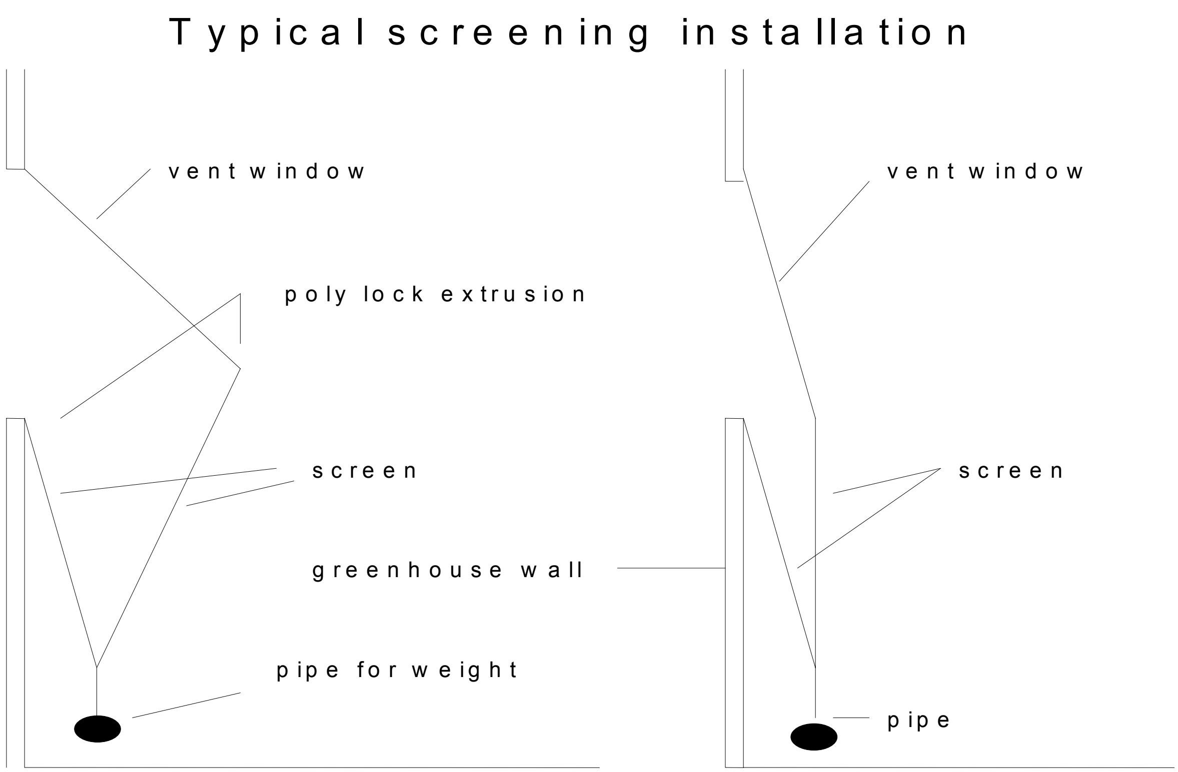

Figure 4. Window vent screening detail.

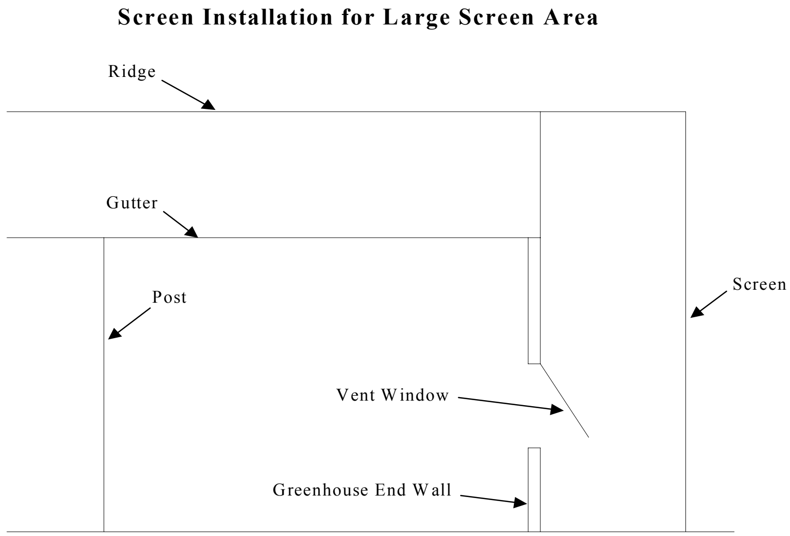

Figure 5. End wall inlet screening for large area screen requirements.

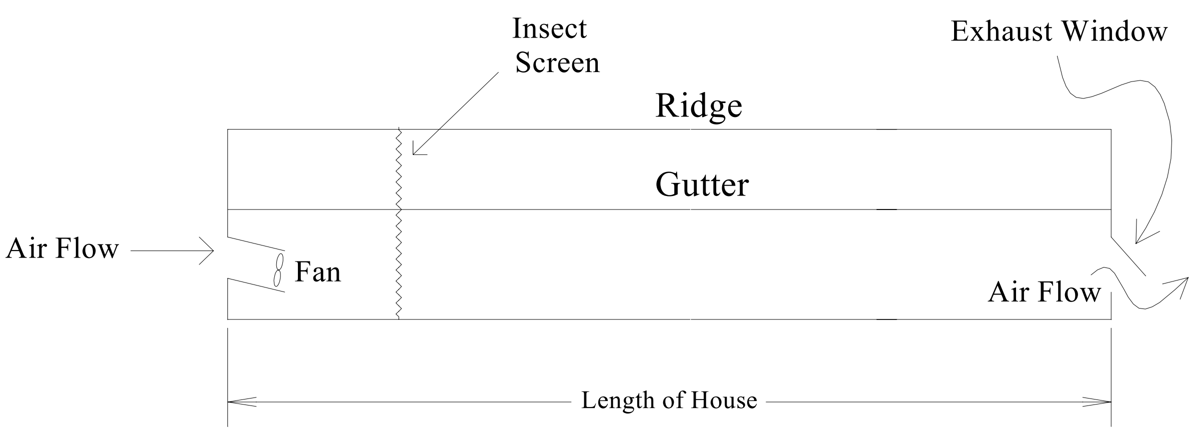

Figure 6. Positive pressure ventilation with inlet screening before growing area.