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Insect Screens for Integrated Production and Protection in Greenhouses: A Review of the Physical and Technical Basics

Insektenabwehrnetze in der Integrierten Produktion im Gewächshaus: Ein Review der physikalischen und technischen Möglichkeiten

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Summary

Insect screens are increasingly being used for Integrated Production and Protection in greenhouses. This paper presents a literature review of the engineering basics involved in the design and selection of insect screens. Models that have been developed to predict the effect of the insect screens on the internal climate are also described. Future research perspectives arising from the literature review are briefly discussed.

Zusammenfassung

Insektenabwehrnetze finden in der Integrierten Produktion im Gewächshaus in zunehmendem Maße Verwendung. Dieser Artikel ist ein Literaturreview über die technischen Möglichkeiten im Hinblick auf Konstruktion und Auswahl der Netze. Außerdem werden Modelle beschrieben, die entwickelt wurden, um die Auswirkung der Netze auf das Klima im Gewächshaus zu beschreiben. Zukünftige Untersuchungsfragen, die sich aus der Literaturzusammenstellung ergeben werden kurz diskutiert.

Introduction

Integrated Production and Protection (IPP) can be defined as the rational use of resources for optimal production processes while ensuring maximum protection, and hence sustainability, of the environment. It embraces the life-cycle assessment of the environmental effects of all resource inputs in production and factors this into resource use decisions. The use of screens to exclude insects from greenhouses may lead to reduced pesticide use but the materials used for the screen may turn out to be non-biodegradable. The commonly used term, Integrated Pest Management (IPM), can thus be regarded as a component of IPP systems.

Avoidance of chemical applications in plant production is one of the ultimate aims of IPP systems. With respect to pest management, biological control, climate control and the use of physical barriers such as insect screens on ventilation inlets and doors, are increasingly becoming a major component of IPP systems for greenhouses. Three main reasons have contributed to this development. Firstly, the acquisition of resistance to pesticides has made insect control very difficult in greenhouses. Secondly, environmental and health problems associated with pesticides have sensitised greenhouse workers to pesticide issues. Lastly, insect pests are the vectors for some viruses. For example the tomato spotted wilt virus can be transmitted by thrips sucked into the greenhouse during the hot weather. Insect screens are therefore used to reduce human exposure to pesticides, exclude or eliminate disease-causing insects, slow the build-up of pesticide resistance and conserve the usefulness of pesticides.

With regard to insect exclusion, screens with small holes are most effective. However, the small hole screens have been shown to severely reduce ventilation efficiency in greenhouses due to high resistance to airflow. In any ventilation system, a screen with too much restriction of airflow can cause higher static pressure drops, inadequate air exchange and higher greenhouse temperatures. In a forced ventilation system these factors will lead to increased energy consumption by the fans and excessive wear on fan motors (NGMA 2001). Other problems have been identified as increased sizing and fastening difficulties, reduced access to greenhouses and added maintenance costs. In addition, screens can keep insects in as well as out.

Thus, farmers considering installing insect screens in greenhouses have to confront several practical questions. For example, what type of insect screen is suitable for the greenhouse? What is the optimal ratio of the area of the insect screen and the ventilation opening to the growing area? What is the effect of the screen on the greenhouse internal climate (temperature, air humidity, light and solar radiation) and thus on crop growth? What type of ventilation system is suitable when using the screens? What level of reduction in pest infestation or disease severity can be achieved and at what cost?

An understanding of the physical and technical principles of insect screens is necessary to get satisfactory answers to the most of the questions above. In this paper, a literature review of the developments in the theory of physical and technical aspects of insect screens, is presented. Future perspectives are also discussed.

Developments

Types of Insect Screens

Four different insect screen materials are in use in the USA (NGMA 2001). Screens made of stainless steel and brass are common. Whilst they are the longest lasting, they are also the most expensive. Polyethylene screens are available in two forms: one is monofilament, woven with solid strands similar in appearance to a fishing line which is very rigid and strong. The other type of polyethylene is made of film that is punched full of "micro-holes" and used as a crude but, low-priced insect barrier. Drawbacks include weak construction and low UV protection as well as restricted airflow. The third type of screen is polyethylene/acrylic. This material is made of many fibres (multifilament) which causes resistance to smooth yarns sliding together and therefore maintains the integrity of the holes. The fourth type is nylon. This is good for shorter-term, low-cost and light duty exclusion. It is less durable and is relatively more restrictive to airflow.

The materials are constructed using three different methods: weaving, knitting, or punching. Weaving is the most common and provides a trade-off between hole-size and airflow. Knitted materials are durable and resistant to tearing. Punching is used to make micro holes in films. The resulting film is very restrictive to airflow and must be applied with the correct side out.

Apart from the conventional insect screens, ultraviolet-absorbing screens (bionets) have been reported (ANTIGNUS et al. 1998). The study compared the insect infestation and disease incidence in tomatoes grown under a tunnel covered with a conventional screen on one hand and a bionet on the other hand. The results showed that plastic screens with UV absorbency in the UV-A and UV-B range serve as optical barriers to protect tomatoes from certain virus and insect pests. Reduced tomato disease incidences were also reported. However, the study noted that size of thrips populations under the different screens was similar and unaffected by either the mechanical or optical properties of the nets.

Insect screens are available in different hole sizes. Apart from commercial names, the screens are normally described by mesh sizes, which give the number of threads per inch in each direction. For example, a 68 mesh screen has sixty-eight threads per inch in each direction (SASE and CHRISTIANSON 1990).The selection of the hole size of the screen to use depends on the insect to be excluded. Laboratory investigations of the effectiveness of various screening materials has been conducted by BETHKE (1994). He found that the following common insect pests of greenhouses can be excluded using screen with hole sizes (or smaller) shown in Table 1 below.

Table 1. Screen mesh sizes needed to exclude major greenhouse pest species
Mindestmaschenweiten um die Hauptschädlinge im Gewächshaus abzuhalten

	Screen Hole Size	
Insect Pests	Microns	Mesh
Leafminers	640	40
Whiteflies	462	52
Aphids	340	78
Flower thrips	192	132

Source: Bethke 1994

Static Pressure Drop and Coefficient of Discharge of Insect Screens

For steady flows of inviscid, incompressible fluids of low density, flow may be described by the continuity equation plus the Bernoulli energy equation in the following form

$$\frac{\rho}{2} * V^2 + P = \text{constant} \quad (1)$$

where:
V = velocity [m/s]
P = static pressure [Pa]
ρ = density [kg/m³].

The term $\rho V^2/2$ is the velocity pressure, VP, which when added to the static pressure yields the total pressure, TP, of the moving fluid. As air leaves a screened inlet, its static pressure is that of the airspace it enters. Thus, the static pressure difference, $\Delta P = P_o - P_i$, is that between the space behind and in front of the inlet. The static pressure drop is generally known to vary linearly with the square of the approach velocity of the air.

The Bernoulli equation written for air outside a ventilated building and within the screened inlet, respectively is,

$$\frac{\rho}{2} * V_o^2 + P_o = \frac{\rho}{2} * V_i^2 + P_i \quad (2)$$

If the inlet has a total cross-sectional area of A_i, the actual cross-sectional area (A_a) of the fluid passing through the inlet area is likely to be less than area A_i. This is due to the contraction at the inlet The actual velocity V_a at the inlet will thus be different from the ideal velocity (V_i). If the outside ambient air velocity is essentially zero, then the ideal velocity within the inlet can be calculated as;

$$V_i = \left[\frac{2(P_o - P_i)}{\rho}\right]^{0,5} \quad [m/s] \quad (3)$$

Thus, ideal volumetric air flow rate Q_i is given by;

$$Q_i = A_i * V_i \quad [m^3/s] \quad (4)$$

And the actual volumetric flow rate can be computed using the continuity equation;

$$Q_a = A_a * V_a \quad [m^3/s] \quad (5)$$

The actual volumetric flow rate at the inlet is related to the ideal discharge through the coefficient of discharge, C_d.

$$Q_a = C_d * Q_i = C_d * A_i * \left[2 * \frac{(P_o - P_i)}{\rho}\right]^{0,5} \quad (6)$$

The coefficient of discharge accounts for energy losses due to friction, turbulence, section changes and other entrance effects. It is largely the product of the coefficients of velocity and contraction. The coefficient of velocity accounts for the fact that airflow is not frictionless, and the coefficient of contraction accounts for the contraction of the jet stream at the vena contracta. The coefficient of discharge is a function of inlet type and design, and must be determined experimentally for each type of air inlet (WILSON et al. 1983). The discharge coefficient of a screen varies according to the approach velocity of the air it transmits. Thus, for purposes of comparison, the dis-

charge coefficients for different screening materials should be determined at the same approach velocity. SASE and CHRISTIANSON (1990) reported discharge coefficients ranging from 0.05 to 0.5 for a variety of screens. MONTERO et al. (1997) showed the existence of a linear relationship between the discharge coefficient and aspect ratio (ratio of length to height) of greenhouse ventilation openings. They reported discharge coefficients of 0.3–0.4 for anti-thrips nets and 0.40–0.5 for anti-aphid nets depending on aspect ratio of the vents.

Fans used for greenhouse cooling are typically of low pressure design with a normal operating range up to 3.2 mm water (32 Pa) of static pressure (ROBERTS et al. 1995). These fans are unable to move air at higher pressures because as the pressure differential between the greenhouse and the outside atmosphere increases, air tends to move off the blades at the end of the blade and return to greenhouse through the centre of the fan. High pressure fans often have large hubs to eliminate this imperfection. Evidently, any insect screen that causes more than a 32 Pa pressure drop across the vent opening will be ineffective.

Thus, a common criterion for greenhouse air inlets is to design window opening control systems so that at the first stage the pressure drop across the window is about 2.5 mm water (25 Pa) pressure resulting in air velocity of about 3.6 m/s (ROBERTS and MEARS 1984). At maximum ventilation rate the window should open at least wide enough that this velocity and pressure drop across the window are not exceeded. In designing for a screened window opening the pressure drop across the screen and the window inlet taken together should not exceed this figure. As the system operates the screen will accumulate dirt and the pressure drop across the screen will increase so allowance must be made for some significant pressure drop build-up between the cleanings. SASE and CHRISTIANSON (1990) suggested the following screened inlet design approach:

– Assume the window opening can be adjusted so that for the window alone the pressure drop across the window at maximum ventilation rate will be 0.8 mm of water (8 Pa).
– Design the inlet area of the screen so that at maximum ventilation the pressure drop across the screen alone will be 0.8 mm of water (8 Pa).
– Assume that the screen will be cleaned when the pressure drop across the screen and the window total 2.5 mm of water (32 Pa).

Commercial screen manufacturers normally specify the static pressure drop expected across their insect screens at different approach velocities. For example, a static pressure drop of 0.75 mm water (7.5 Pa) at an approach velocity of 0.55 m/s has been reported for Econet T screens (ROBERTS et al. 1995).

Determination of Optimal Screen Area

For ventilation openings without screens, nomographs for determining the optimal area of the vents for different climatic conditions have been developed (BAYTORUN 1986). For screened ventilation openings, a simplified approach is given below.

If the climatic conditions in a given area are known, the ventilation requirement for a greenhouse can be estimated by solving the following energy balance model (ALDRICH 1986).

$$q_f + q_s * A_f = U * A * (t_i - t_o) + w * C_p * (t_i - t_o) + E * F * q_s * A_f \quad (7)$$

where:

q_f = furnace heat (only for heated greenhouses) [W]
q_s = solar gain [W/m²]
A_f = floor area [m²]
U = overall heat transmission coefficient [W/(m² K)]
t_i = temperature inside the greenhouse [K]
t_o = outside air temperature [K]
w = mass flow rate of air (ventilation requirement) [kg/s]
C_p = specific heat capacity of air [J/(kg K)]
E = ratio of evapotranspiration to solar radiation [–]
F = greenhouse floor use fraction [–]
A = Surface area of greenhouse [m²]

The calculated mass flow rate, w, should be multiplied by the appropriate value of the specific volume of the air to determine the volumetric flow rate in m³/s. For efficient ventilation, the resulting volumetric flow rate should result in a greenhouse air change of at least 0.75–1 volumes per minute. To obtain the required screen area, the volumetric flow rate should be divided by the approach velocity corresponding to the recommended pressure drop across the selected screen. The values commonly used for allowed pressure drops across insect screens in mechanically ventilated greenhouses are 0.75–0.8 mm of water (7.5–8 Pa). The resulting area gives the optimal area of the insect screen. Note that the approach velocity will be lower for screens with smaller holes than for screens with larger holes. Consequently, for a given ventilation rate, a larger screening area will be required if small-hole screens are to be used instead of the large-hole screens.

Effects of Insect Screens on Internal Climate of Greenhouses

Screening materials can affect the quantity and quality of radiation inside the greenhouse. The materials come in different types and colours with different spectral transmission characteristics. Investigations going on at the Institute of Horticultural and Agricultural Engineering, University of Hanover, have shown that most screening materials have PAR transmission of over 70 %. However, some black screens have shown low PAR transmissivity, for example, 40 %. Thus, the choice of screens should always consider the spectral transmission properties of the individual materials. The selectivity of some insect screens to UV radiation is an important light quality phenomenon and has been mentioned above.

However, the reduction of ventilation rates (and the resulting effects on greenhouse air temperature and humidity) due to the use of insect screens seems to be the most critical aspect of their application. There has been significant research on this aspect. In general, the natural ventilation rate of a greenhouse equipped with side and roof openings can be described by the following simplified model (BOULARD and BAILLE 1995):

$$N = \left(\frac{3600}{h_g}\right)\left(\frac{a}{2}\right) C_{dn}\left[2g\left(\frac{\Delta t}{t_o}\right)\left(\frac{H}{2}\right) + K_w V_w^2\right]^{0,5} \quad (8)$$

where:
N = ventilation rate (air changes) [h^{-1}]
a = A/A_g is the ratio of vent opening A [m^2] per unit ground area A_g [m^2] [–]
h_g = average height of the greenhouse (h_g = Volume/A_g) [m]
t_o = external temperature [K]
Δt = the difference of temperature between the inside and outside of the greenhouse [K]
H = difference in mean heights of the side and roof vent openings (chimney height) [m]
K_w = wind effect (pressure drop) coefficient [–]
C_{dn} = discharge coefficient of the opening equipped with insect screen net [–]
V_w = wind velocity [m/s].
g = acceleration due to gravity [9.81 m/s^2]

The first term of the sum between the brackets of equation above gives the contribution of the bouyancy forces while the second term represents the contribution of the wind. In greenhouses equipped with roof openings (BOULARD and BAILLE 1995) the chimney effect can be neglected when the wind speed $V_w > 1–2$m/s and the relationship can then be simplified:

$$N = \left(\frac{3600}{h_g}\right)\left(\frac{a}{2}\right) C_{dn} \sqrt{K_w V_w^2} \quad (9)$$

FATNASSI et al. (2001a) investigated the ventilation performances of a large Canarian type greenhouse equipped with insect-proof nets on the vent openings. A ventilation model was deduced and the simulations showed that insect–proof nets induce a strong additional pressure drop through the opening, which reduces significantly the ventilation rate and generates an important greenhouse air temperature increase. They postulated that the ratio of the ventilation rates for a greenhouse with and without a net, can be considered as proportional to the ratio of their discharge coefficients:

$$\frac{N_n}{N} = \frac{C_{dn}}{C_d} = \frac{\sqrt{K_d}}{\sqrt{K_d V_{dn}}} \quad (10)$$

where:
N_n = ventilation rate with net [h^{-1}]
N = ventilation rate without net [h^{-1}]
K_d = the pressure drop coefficient of opening without insect net [–]
K_{dn} = the pressure drop coefficient of opening with insect net [–]
C_{dn} = discharge coefficient for opening with insect net [–]
C_d = discharge coefficient for opening without insect net [–]

Additionally, their research showed that the following equation can be used in estimating the increase in temperature due to the use of insect nets on the ventilation opening while maintaining the same ventilation rate:

$$\Delta t_n = \left(\frac{C_d}{C_{dn}}\right)^2 \Delta t + \frac{2t_o}{2gH} K_w V_w^2 \left[\left(\frac{C_d}{C_{dn}}\right)^2 - 1\right] \quad (11)$$

It should be noted that the wind coefficients and discharge coefficients in the above equation are climate specific and also depend on the structural design of the greenhouse. Using the above model it was shown that a significant temperature increase can occur in a greenhouse if anti-thrips or anti-aphids insect screens are installed while maintaining the same ventilation rate.

SASE and CHRISTIANSON (1990) simulated the effect of insect screens placed on ventilation openings on the greenhouse temperature and ventilation rate. The study showed that insect screens with very small discharge coefficients ($C_d < 0.2$) could cause a temperature rise of up to 10 °C when the net radiation is 500 W/m^2 and wind velocity is 1 m/s. The exact magnitude of the temperature rise depends on the angle of the vent opening (area of the ventilation opening) i.e. the discharge coefficient depends on the angle of the vent opening. However, it should be noted that in a greenhouse with crops, the temperature increase would be less due to the latent heat of evapotranspiration. They also showed that with a discharge coefficient of 0.05 a screened greenhouse will have about one-third the air movement of an non-screened house where there is no wind.

MEARS and BOTH (2001) investigated the use of positive pressure ventilation systems on tropical and subtropical greenhouses equipped with insect nets on the ventilation openings. The main attraction of the positive pressure ventilation system is the fact that it enables internal greenhouse pressures to be high enough so that the velocity of air going out through open doors or other openings in the structure exceed the flying speed of the insects of concern. Therefore, it should be more effective in excluding insects than an exhaust system which tends to draw insects through openings.

The effect of insect screens on naturally ventilated greenhouses has been investigated by some researchers. MUNOZ et al. (1999) developed a model of the air exchange rate in greenhouses with insect-proof screens over the vents. They used a simplified model incorporating the global wind effect coefficient and screen discharge coefficient to predict the greenhouse ventilation rate. They noted that vents located on lateral spans have a higher discharge coefficient than those located on central spans. Thus, better ventilation can be achieved with vents near the ridge of the roof instead of near the gutter of the tunnel-type greenhouse.

Computational Fluid Dynamics (CFD) approaches have been used to study the spatial heterogeneity of climate inside the greenhouses (temperature, air speed and humidity) and to suggest design improvements for combining good ventilation performance and efficient protection against insect vectors for viruses (TEITEL and SHLYKAR 1998; FATNASSI et al. 2001b).

Reduction of airflow rates in greenhouses due to the effect of insect screens can lead to increased humidity in the greenhouse. Such increase in humidity may cause a build-up of boundary layer on the screen surfaces, thus further restricting air movement. However, there is presently no publication that has addressed this problem comprehensively.

Screen Costs and Pest Exclusion Efficiency

Pest management practices that rely on pesticides have become more costly because acquired resistance to pests necessitates a lot of pesticide use for any effect to be realised. Thus, exclusion of pests using greenhouse screens is now more feasible than in the past. More-

over, the potential loss of market share due to failure to meet the maximum pesticide residue limits on products is an economic loss that no farmer would like to bear. Workmen compensation claims due to pesticide effects can also be avoided if insect screens are used to reduce pesticide applications.

The exclusion efficiency of several insect screen products against whiteflies and thrips, has been investigated under laboratory conditions (BELL and BAKER 1997).They noted that many screens on the market do not effectively exclude common greenhouse pests at air approach velocities required for adequate natural ventilation of a well designed greenhouse. Furthermore, choosing a screen with small holes and high resistance to air flow may not necessarily ensure adequate exclusion. The study showed that exclusion capability varied widely for the five screens exhibiting high or very high airflow resistance. However, it is noteworthy that they reported exclusion efficacy of over 90 % for some commercial insect screen products.

Perspectives and Conclusions

It is clear that attempts to offer more protection against pests to greenhouse plants using insect screens have far-reaching implications on the greenhouse climate, plant nutrition and plant development. This makes it necessary to find a compromise between optimal climate conditions for plant growth and the requirements of insect screens for plant protection. For given climatic conditions, the suitability of insect screens in forced or natural ventilation systems for greenhouses needs to be comprehensively investigated. Moreover, models that can be used to predict the effect of insect nets on the internal climate of the greenhouse, disease dynamics and crop development need to be developed. Whereas most of the previous research has largely involved model greenhouses, investigations of the effects of the insect screens under real growing conditions are necessary. The suitability of completely screen-covered crop production structures (screen houses) found in the humid tropics also need to be investigated .

The University of Hanover, in collaboration with other partner institutions, has started a multi-disciplinary research project involving scientists in plant protection, plant production, plant nutrition and horticultural engineering to help find solutions to problems raised above. Details about the project are available on the web site www.susvegthai.org.

Literature

ALDRICH, R. A. 1986: Environmental principles of crop growth structures. In: ESMAY M. L and J. E. DIXON. Environmental control of agricultural buildings. The Avi Publishing Company Ltd., Wesport, Connecticut.

ANTIGNUS Y., M. LAPIDOT , D. HADAR, Y. MESSIKA and S. COHEN 1998: Ultraviolet-absorbing screens serve as optical barriers to protect crops from virus and insect pests. Journal of Economic Entomology **91,** 1401–1405.

BAYTORUN, A. N. 1986: Bestimmung des Luftwechsels bei gelüfteten Gewachshäusern. Heft **27**, Institut für Technik in Gartenbau und Landwirtschaft, Universität Hannover.

BELL M. L. and J. R. BAKER 1997: Choose a greenhouse screen based on its pest exclusion efficiency. North Carolina Flower Growers' Bulletin **42**, No. 2.

BETHKE, J. A. 1994: Considering installing screening? This is what you need to know. Greenhouse Manager. **13**, 34–37.

BOULARD, T. and A. BAILLE 1995: Modelling of air exchange rate in a greenhouse equipped with continuous roof vents and side openings. J. Agric. Engng Res. **61**, 37–48.

FATNASSI, H., T. BOULARD, L. BOUIRDEN and G. SAPPE 2001a: Ventilation performance of large canarian type greenhouse equipped with insect-proof nets. Proc. of the International Symposium on Design and Environmental Control of Tropical and Subtropical Greenhouses. April 15–18 2001. National Taiwan University, Taichung, Taiwan.

FATNASSI, H., T. BOULARD, L. BOUIRDEN and G. SAPPE 2001b: Simulation of air flow and temperature patterns in large scale greenhouse equipped with insect proof nets. Proc. of the International Symposium on Design and Environmental Control of Tropical and Subtropical Greenhouses. April 15–18 2001. National Taiwan University, Taichung, Taiwan.

MEARS, D. R and A. J. BOTH 2001: Insect screening and positive pressure ventilation from tropical and subtropical greenhouse facilities. Proc. of the International Symposium on Design and Environmental Control of Tropical and Subtropical Greenhouses. April 15–18 2001. National Taiwan University, Taichung, Taiwan.

MONTERO, J. I., P. MUNOZ and A. ANTON 1997: Discharge coefficients of greenhouse windows with insect-proof screens. Acta Horticulturae **443**, 71–77.

MUNOZ, P., J. I. MONTERO, A. ANTON and F. GIUFFRIDA 1999: Effect of insect-proof screens and roof openings on greenhouse ventilation. J. Agric. Engng Res. **73**, 171–178.

NATIONAL GREENHOUSE MANUFACTURERS ASSOCIATION 2001: Hints on greenhouse screen standards. available on the worlwide web: www.ngma.com

ROBERTS, W. J. and D. R. MEARS 1984: Heating and ventilating greenhouses. Publication E-046, Department of Biological and Agricultural Engineering, Cook College-Rutgers University, New Brunswick, NJ.

ROBERTS, W. J., L. VASVARY and S. KANIA 1995: screening for insect control in mechanically ventilated greenhouses. Paper No. 9509. ASAE / Northeast Agri./Bio. Eng. Conf. Bar Harbor, Maine. July 31–August 2 1995.

SASE, S. and L. L. CHRISTIANSON 1990: Screening greenhouses – some engineering considerations. Paper No. NABEC 90-201. ASAE / Northeast Agri./Bio. Eng. Conf.. Penn State Univ. July 29–Aug 1 1990.

WILSON, J. D., L. D. ALBRIGHT and J. N. WALKER 1983:. Ventilation air distribution. In: HELLICKSON M. A. and J. N. WALKER (Eds). Ventilation of agricultural structures. ASAE Monograph No. **6**.

TEITEL, M. and A. SHLYKAR 1998:. Pressure drop across insect-proof screens. Trans. of the ASAE **41**, 1892–1834.

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