Chapter 10
Insect Screening

Vegetable production under protected cultivation in humid tropics and generally in warm climates is vulnerable to climate stresses (temperature, humidity), biotic stresses by insects, and plant virus diseases vectored by insects (Kumar and Poehling 2006). Pests penetrating the greenhouse damage the crop by feeding and by transmit of phytopathogenic organisms. Therefore, the exclusion of pests by insect screens is an important factor for an integrated approach of pest management (Teitel 2007). Fighting against insect pests in greenhouses becomes more and more important, because many chemicals are not allowed anymore, and pest insects become resistant against special chemicals. Physical and optical methods should be used therefore for integrated production and protection (IPP). The IPP aims in finding alternative solutions for reducing pesticide application (Fig 10.1).

Insect screens are used in front of the ventilation openings and doors to keep useful insects inside, and to prevent pest insects from penetrating the greenhouse. They have different mesh openings because the insects are of various sizes.

Criteria for the choice of insect screens are:

- The species of insects to be screened out
- The influence on the greenhouse climate
- The UV stability and the mechanical durability (thickness of threads)
- The cost in comparison to the economical value of the crop

The efficiency of insect screens depends on the mesh size of the screens, the cross-section of the screens, and the colour of the screens, as well as on the tightness of the greenhouse structure and doors, and on the tight fastening of screens. Insect screens can prevent the penetration of insects only if the mesh size is smaller than the widest part of the insect.

The following insect pests can be screened out by the given mesh sizes (Bethke and Paine 1991; Bethke 1994; Bethke et al. 1994; Teitel 2006, 2007):

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Fig. 10.1 Greenhouses with insect screens (Turkey and Malta)

Insect pest	Hole size (mm)	
	Bethke	Teitel
Leaf miners (*Lyriomyza trifoli*)	0.64	0.61
White fly (*Bemisia tabaci*)	0.462	0.46
Aphid (*Aphis gossipii*)	0.341	0.34
Greenhouse white fly (*Trialeurodes vaporariorum*)		0.29
Silverleaf white fly (*Bemisia argentifolii*)		0.24
Thrips (*Frankliniella occidentalis*)	0.192	0.19

Insect screens have to be installed without gaps in the structure. Insecure insect screens where insects can penetrate are useless (Fig. 10.2).

A *disadvantage* of insect screens is the *reduction of ventilation efficiency* with influence on temperature and humidity, as well as reduction of *light transmittance*.

Fig. 10.2 Secure and insecure insect screens

Sufficient ventilation efficiency has to be guaranteed even in screened greenhouses. To guarantee similar climate conditions to those in unscreened houses, enlarged ventilation openings should be designed. Different principles of greenhouse construction, cladding materials and climate control measures are available to meet the requirements.

The main factors of characterisation of insect screens are:

- The porosity, the ratio of open area to total area of the screen
- The mesh or hole size
- The thread dimension (woven or knitted)
- The light transmittance
- The colour and its influence on pest behaviour.

The expression "mesh" means the number of open spaces per inch in each direction. The characterisation of insect screens only by the expression "mesh" is not sufficient, because it does not give information about the thread diameter and thereby about the hole size. Data about insect screens should contain thread diameter, hole size in both directions and porosity.

10.1 Enlargement of Screened Vent Openings

The ratio of ventilator opening to greenhouse floor area in unscreened houses should be 18–29% (see Chap. 9, Ventilation).

The ANSI/ASAE (2003) gives values of 15–25%.

There are two possibilities when designing screened openings:

- The enlargement of vent openings and direct screening by nets
- Enlargement of the screened openings in front of the existing vent opening

New greenhouses can be designed according to the requirement for enlarged vent openings. If the vent openings of existing greenhouses cannot be enlarged easily, enlarged screened components have to be installed in front of the vents, Fig. 10.3.

Figures 10.3–10.5 show the possible enlargement of existing vent openings by insect screens at side walls with flap ventilation, with roll-up ventilation and with ridge ventilation. If the flap ventilation opens, a tube in a longitudinal direction

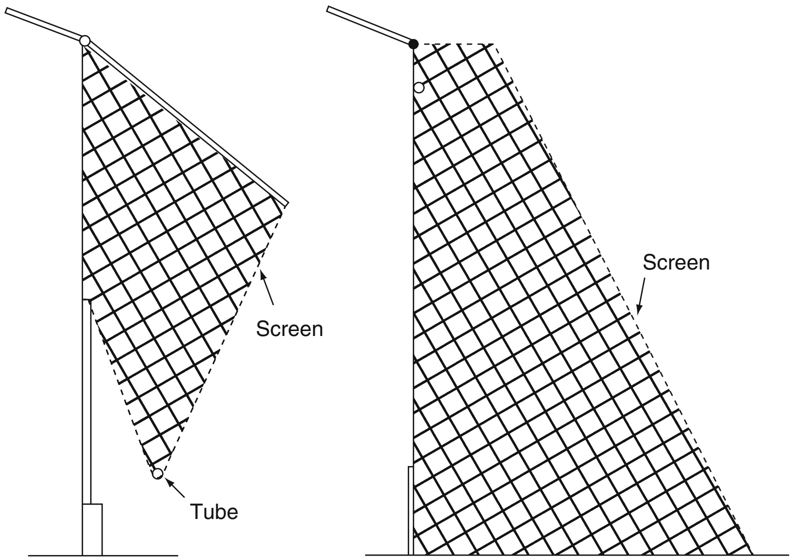

Fig. 10.3 Enlargement of existing vent openings covered by insect screens

Fig. 10.4 Screened side wall vent openings (USA)

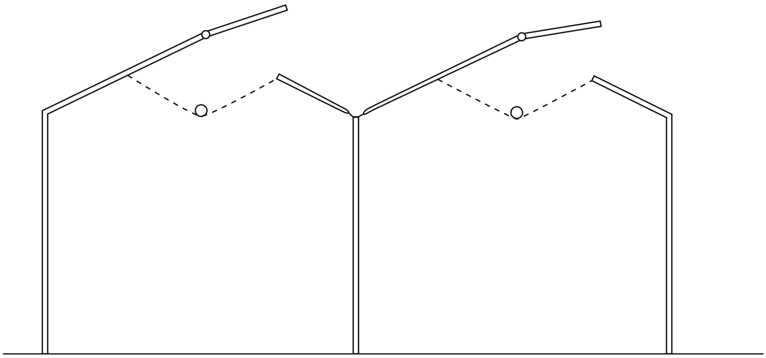

Fig. 10.5 Screened ridge vent openings

inside the net will be raised up and the net is stretched. Screened porches can be installed in front of smaller roll-up ventilation openings.

The inclination of screens relative to the horizontal air stream influences the flow rate through the screen (Teitel et al. 2008a; Teitel et al. 2008b; Teitel et al. 2009). Experiments were carried out with screens of different porosities, and with inclinations of 45°, 90°, and 135° to the horizontal air flow direction. A forty-five degree inclination means that the upper edge of the screen is directed towards the air flow. The flow rate is highest with an inclination of 45°, followed by 90° and 135°. The air flow with 45° inclination is 10 and 6% higher than with 90° for porosities of 0.4 and 0.52 respectively. The air flow through a 135° inclined screen is 14 and 6% lower than with 90° for 0.4 and 0.52% porosity.

10.2 Necessary Enlargement of Screened Vent Openings

The question is:

How much have the vent openings to be enlarged to guarantee nearly the same climate conditions as in unscreened greenhouses?

Harmanto (2006) investigated insect screens under a hot climate in Thailand (Table 10.1).

10.2.1 Method of Sase and Christiansen (1990)

Sase and Christiansen (1990) presented a diagram that gives the relation of the ratio screened vent opening to unscreened opening (A_S/A_V) versus the discharge coefficient (C_d) for screened vents to achieve the same ventilation rate.

Table 10.1 Insect screens investigated by Harmanto (2006), Harmanto et al. (2006a, b)

	Econet M 40 mesh Anti leaf miners and larger	Econet SF 52 mesh Anti white flies and larger	Econet T 78 mesh Anti thrips and larger
Hole size (mm)	0.4 × 0.45	0.25 × 0.8	0.18 × 0.29
Thread diameter (mm)	0.25	0.31	0.19
Discharge coefficient C_d	0.31	0.28	0.21
Screen porosity ε	0.41	0.38	0.3

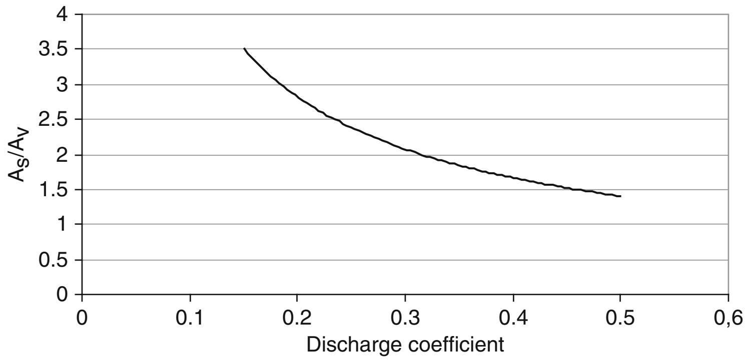

Fig. 10.6 Relation of screened vent opening to unscreened opening depending on discharge coefficient (Sase and Christianson 1990)

Figure 10.6 shows the function for 50° flap opening (global radiation: 500 W/m^2; wind speed: 1 m/s). This function approximately can be taken for open ventilators. The function can be represented by the equation:

$$\frac{A_S}{A_V} = 0.8294 \times C_d^{-0.7608} \tag{10.1}$$

The enlargement of the screened vent opening A_S in comparison to the unscreened opening A_V becomes for the three screens:

	Econet M	Econet SF	Econet T
C_d (Harmanto 2006):	0.31	0.28	0.21
A_S/A_V	2.02	2.18	2.72

10.2.2 Calculation of A_S/A_V *by using methods of Bailey et al. (2003) and Teitel (2006)*

The pressure loss through ventilation openings without insect screen is:

$$\Delta p_0 = \frac{1}{2} k_0 \rho \left(\frac{V_V}{A_V} \right)^2 \tag{10.2}$$

For a rectangular opening without flap is:

$$k_0 = [1.9 + 0.7\exp\{-(L_0/32.5 \times H_0)\}] \tag{10.3}$$

L_0 = length of vent opening
H_0 = height of vent opening
With $L_0/H_0 = 40$ is
$k_0 = 2.64$
The pressure loss through a screen is:

$$\Delta p_S = \frac{1}{2} k_S \rho \left(\frac{V_V}{A_S}\right)^2 \tag{10.4}$$

with

$$k_S = \left[\frac{1-\varepsilon^2}{\varepsilon^2}\right]\left\{\frac{18}{Re} + \frac{0.75}{\log\,(Re + 1.25)} + 0.055\log Re\right\} \tag{10.5}$$

The Reynolds number was calculated with the thread diameter

$$Re = \frac{d \times v_w}{v}$$

The pressure loss coefficient k_S for different porosities ε becomes with $Re = 20$:

ε	0.5	0.41	0.38	0.3
k_S	3.07	7.59	9.1	15.5

The total pressure loss through the ventilator opening with insect screen Δp_{Sco} is the sum of the pressure losses Δp_0 and Δp_S (Teitel 2006; Bailey et al. 2003; Fatnassi et al. 2002):

$$\Delta p_{Sco} = \Delta p_0 + \Delta p_S = \frac{1}{2}\rho\left(\frac{V_V}{A_S}\right)^2 (k_S + k_0) \tag{10.6}$$

If the ventilation openings for unscreened and screened greenhouses have the same size and if the air flow should be the same to keep the same temperature difference, then the pressure loss through the screened opening is much higher than through the unscreened opening, because $k_S > k_0$. Higher pressure loss reduces the ventilation rate. Assuming that the pressure losses should not be too different to guarantee a reasonable ventilation efficiency, one can assume

$$\Delta p_0 = \Delta p_{Sco}$$

Combining equation (10.2) and (10.6):

$$k_0\left(\frac{V_V}{A_V}\right)^2 = (k_S + k_0)\left(\frac{V_V}{A_S}\right)^2 \tag{10.7}$$

The discharge coefficient C_d is by definition

$$C_d = \frac{1}{\sqrt{k}}$$

If V_V should not change, (10.7) becomes

$$\frac{A_S}{A_V} = \sqrt{\frac{k_S + k_0}{k_0}} \tag{10.8}$$

The enlargements of the ventilation openings for different porosities ε are:

Screen		Econet M	Econet SF	Econet T
Porosity ε	0.5	0.41	0.38	0.30
Enlargement A_S/A_V	1.47	1.96	2.1	2.62

The values correspond well with the data of Sase and Christiansen.

The ventilation openings covered by different insect screens for various insects have to be enlarged by the following factors to get the same climate conditions compared to unscreened openings:

Econet M against leaf miners $A_S/A_V = 1.9–2.03$

Econet SF against white flies $A_S/A_V = 2.1–2.2$

Econet T against thrips $A_S/A_V = 2.6–2.7$

10.3 Climate Conditions and Pest Control

The climate conditions of screened greenhouses have been investigated by several authors.

Fig. 10.7 shows a screened greenhouse for tropical regions. Harmanto (2006) measured the climate conditions in this greenhouse with different ratios of vent opening (Figs. 10.8 and 10.9).

The functions for the air exchange rate for fully cropped and empty greenhouse can be expressed by:

Fully cropped greenhouse:

$$N = -24.65\left(\frac{A_V}{A_G}\right)^2 + 46.5\frac{A_V}{A_G} + 11.16 \tag{10.9}$$

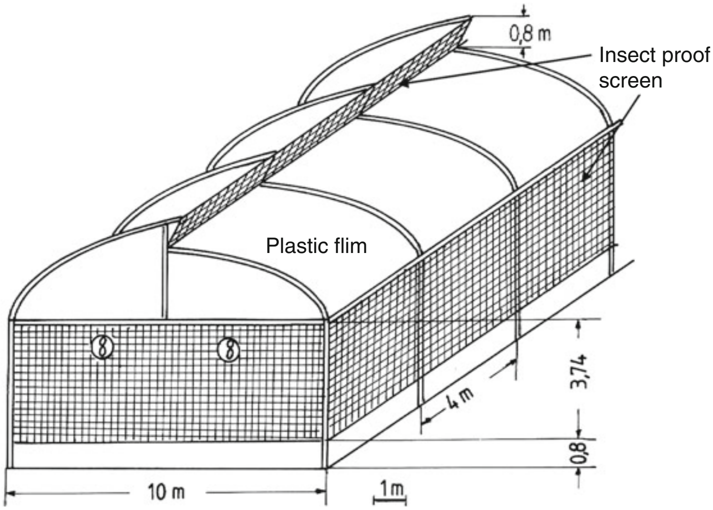

Fig. 10.7 Screened greenhouse for tropical regions (manufactured in India, built and investigated in Thailand). The relation A_S/A_G is 1.05 with fully opened ventilators. The vent openings were covered by a screen against white fly (52-mesh), porosity $\varepsilon = 0.38$ (Harmanto 2006; Harmanto et al. 2006a, b)

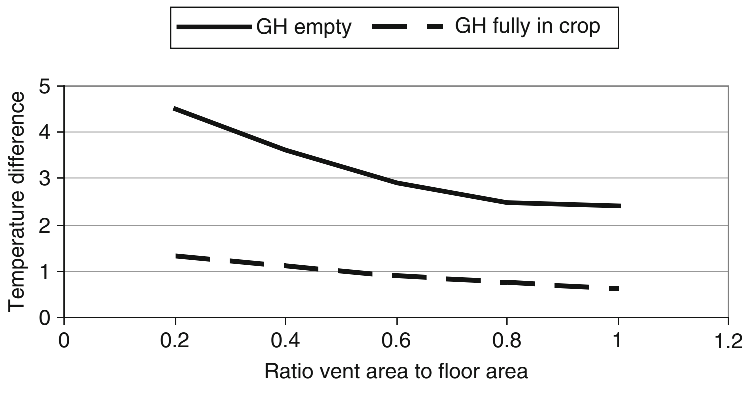

Fig. 10.8 The temperature rise in the greenhouse, shown in Fig. 10.7, depending on the ratio A_S/A_G for fully cropped and empty greenhouse

Empty greenhouse:

$$N = -\left(\frac{A_V}{A_G}\right)^2 + 46.5\frac{A_V}{A_G} + 7.21 \tag{10.10}$$

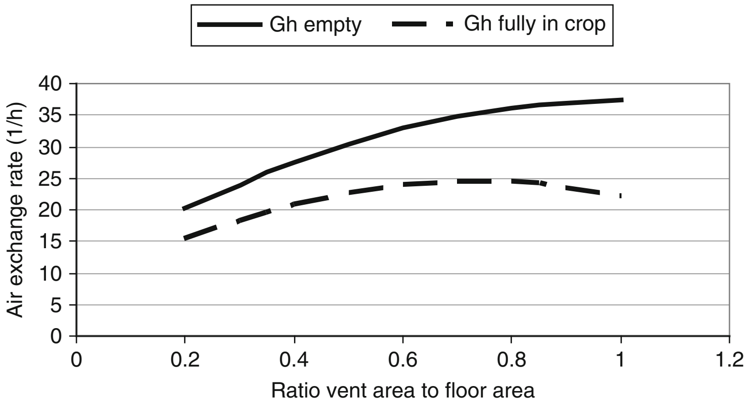

Fig. 10.9 Air exchange rate *N* (1/h) in the greenhouse, shown in Fig. 10.7, depending on the ratio of vent opening to floor area, vent opening covered by 52-mesh insect screen (see Table 10.1)

Table 10.2 Mean values for air exchange *N*, air temperature *T* and relative humidity φ (Harmanto et al. 2006b)

Screen	*N* (1/h)	V_E (m^3/m^2h)	*T* (°C)	φ (%)
Anti leaf miners (40-mesh)	52	250	30.8	69.7
Anti white fly (52-mesh)	33.6	161	31.1	70.3
Anti thrips (78-mesh)	26.1	125	31.9	74

A minimum vent area of 60% is necessary to maintain temperature rise and air exchange favourable for growing tomatoes in tropical greenhouses. The temperature difference was below 3°C in the empty greenhouse or in a greenhouse with small plants. The air exchange rate was not significantly changed with vent ratios above 60%.

The combination of side wall and roof ventilation plays a significant role in the greenhouse shown in Fig. 10.7.

If the ventilator opening in unscreened greenhouses is 25–29%, the vent opening in screened greenhouses should be about twice the size of that in the unscreened greenhouse.

Several scientists (reported in Teitel 2006) found a factor of about two for the temperature rise between screened and unscreened greenhouses for an anti white fly screen.

All those results confirm the necessary enlargement of the vent opening in screened greenhouses by about twice and more.

The climate conditions and air exchange were measured for the different screens (Table 10.1.) in three identical greenhouses (Fig. 10.7), with $A_S/A_G = 1.05$ (Table 10.2) (Harmanto et al. 2006b).

The temperature differences under the different insect screens with high rate of vent to floor area are not very different, although the mean air exchanges vary considerably.

Blue and yellow coloured sticky traps (10 × 12 cm) were mounted at various randomly selected locations in the greenhouses to capture white flies and thrips (Table 10.3).

The 40-mesh screen (anti leaf miners) was unable to exclude white flies. Only little thrips were found under 52- and 78-mesh screens on young plants, but many insects were found on mature plants. Bethke (1994) recommended much smaller mesh sizes to exclude thrips, but it is not possible to use these screens under tropical conditions, because of the reduction of ventilation rate and rise of inside temperature. The compromise of 78-mesh screen was unable to exclude thrips entirely, but it can reduce the infestation considerably.

The 52-mesh and 78-mesh screens cause similar climate conditions with a vent ratio of 1.05 and similar exclusion of insects on young plants. Thus, the 52-mesh screen can be taken for tropical regions.

Crop infestation can be reduced by UV-blocking greenhouse-covering materials, because the orientation of white flies, thrips and aphids are dependent on UV light (see Sect. 7.3). Material hindering insect invasion but permitting effective ventilation is desirable for humid tropics. Net or screen houses are not suitable for the humid tropics, because of heavy rain falls. Plastic film covering on the roofs, and suitable insect screens for the ventilation openings, should be used. Several combinations of UV-blocking PE film for roof covering and UV-blocking insect screens were investigated in eight small greenhouses with vertical side walls (Kumar and Poehling 2006).

The covering materials were:

- UV-blocking Bionet screen (50 mesh)
- UV-transmitting screen
- UV-blocking PE film
- UV-transmitting PR film

The four combinations were:
A: UV-blocking screen and UV-blocking film BN + BP
B: UV-transmitting screen and UV-blocking film TrN + BP
C: UV-blocking screen and UV-transmitting film BN + TrP
D: UV-transmitting screen and UV-transmitting film TrN + TrP

Each greenhouse had doors that were opened every morning from 6.00 to 10.00 to let in the insects during their peak activity time. White flies and aphids were captured by yellow sticky traps, YST. Figures 10.10 and 10.11 show the results.

Table 10.3 Mean values of captured insects in the greenhouses covered by three different insect screens

Screen	White flies/trap		Thrips/plant	
	Young	mature plants	Young	mature plants
Anti leaf miners (40-mesh)	0.43	1.46	2.08	77
Anti white fly (52-mesh)	0	0.08	0.63	42
Anti thrips (78-mesh)	0	0.04	0.55	21

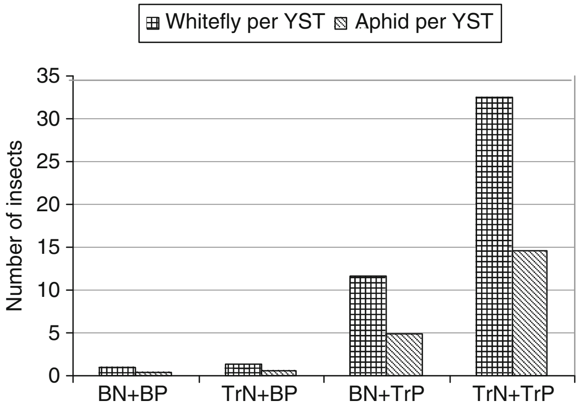

Fig. 10.10 Weekly mean number of white flies and aphids on yellow sticky traps YST 28 days after transplanting (Kumar and Poehling 2006). UV-blocking plastic film has the best effect on keeping out the pest insects, but UV-blocking insect screen keeps out many insects even if the plastic film is UV-transmitting, BN + TrP

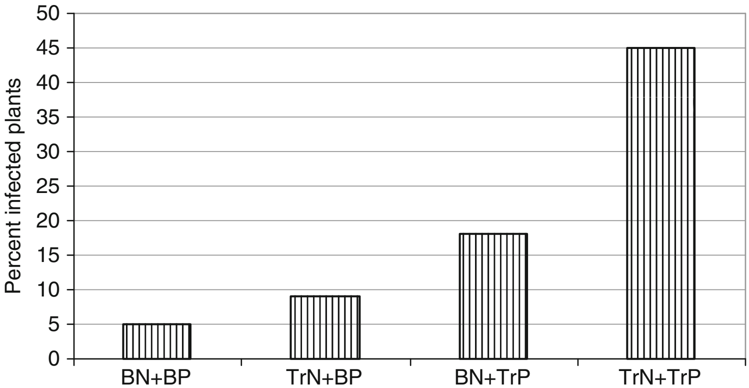

Fig. 10.11 Percentage of virus-infected tomato plants 35 days after transplanting (Kumar and Poehling 2006). UV-blocking insect screens protect the plants additionally from infestation by virus.

A three-span round-arched plastic-film greenhouse, 6.4 m width of span, 12 m length, 2.5 m height to the eave, 4 m ridge height, 230 m^2 floor area, has been investigated with two ventilation openings (Munoz et al. 1999):

G1: Half through roof flap vent on each span, linked to the ridge and opened 0.6 m at the gutter, maximum vent opening $A_V = 21.6\ m^2$, $A_V/A_G = 0.094$.

G2: The flap vent was replaced by a rolling-up roof vent so that each span has vent opening of half roof area. $A_V = 128.5\ m^2$, $A_V/A_G = 0.56$.

An anti-aphid insect screen of 0.4×0.4 mm mesh size and a porosity $\varepsilon = 0.45$ was installed on all vent openings.

The ventilation flow rate V_V was calculated for the ventilation openings:

Opening	Ventilation flow rate (m^3/s)	V_V for 2 m/s wind speed
G1 with anti-aphid screen	$V_V = 1.64v_w - 0.77$	2.51 (m^3/s)
G1 without anti-aphid screen	$V_V = 3.44v_w + 3.79$	10.67 (m^3/s)
G2 with anti-aphid screen	$V_V = 4.34v_w - 0.34$	8.34 (m^3/s)

The enlargement of the vent opening from G1 to G2 by five times causes an increase in ventilation flow rate by the factor 3.3 for screened openings at a wind speed of 2 m/s. The ventilation flow rate of G1 with screen is 76% lower than for G1 without screen. The ventilation flow rate for G2 with screen is not very different from G1 without screen.

The discharge coefficients for the vent openings were different at the central and lateral spans. The mean values for the discharge coefficients were found:

G1 with screen $C_d = 0.419$

G2 with screen $C_d = 0.121$

The global wind pressure coefficient C_w depends on the type of vent, type of screen, wind speed, wind direction and surroundings of the greenhouse. The mean wind-pressure coefficients were found for wind speeds $2 < V_W < 4$ m/s:

G1 with anti-aphid screen $C_w = 0.089$

G1 without screen $C_w = 0.32$

G2 with anti-aphid screen $C_w = 0.31$

Montero et al. (1999) evaluated the same greenhouse with an anti-thrips screen (0.18×0.18 mm mesh size) and found less than half of the ventilation flow rates in comparison to the anti-aphid screen. They got for $V_W = 2$ m/s:

G1 with anti-thrips screen $V_V = 1.3$ m^3/s

G2 with anti-thrips screen $V_V = 3.5$ m^3/s

They concluded that the climate conditions are not suitable enough by natural ventilation under anti-thrips screen.

The pest control in the greenhouses G1 without screen and G2 with anti-aphid screen gave the following results of pest presence:

	Greenhouse G1	Greenhouse G2
White flies	Very serious attack	Light attack
Thrips	Very serious attack	Very serious attack
Aphids	Light attack	No attack

Katsoulas et al. (2006) investigated a single-span round-arched greenhouse with vertical side walls, 8 m width, 2.4 m height to the eave, 4.1 m height to the ridge, 160 m^2 floor area, and 572 m^3 greenhouse volume. The greenhouse was equipped with rolling-up side walls, $2 \times 0.9 \times 15$ m $= 27$ m^2 $= 117\%$ vent opening area, and a flap roof vent linked to the ridge, 2 m long, 0.9 m maximum opening height equal to 18 m^2 opening area. An anti-aphid insect screen with 50% porosity was installed.

The calculation resulted in the following values:

Vent	Screen	$C_d C_w^{0.5}$
Side wall	no	0.078
Side wall	yes	0.052
Roof flap	yes	0.028
Side wall and roof	yes	0.096

Neglecting the stack effect and considering the equation for the wind-driven ventilation only, the ventilation flow rate becomes (see Chap. 9):

$$V_V = \frac{A_S}{2} v_w C_d \sqrt{C_w}$$

In order to obtain the same ventilation flow rate for the screened and unscreened side wall ventilation and with the same wind speed, one can get the relation of screened and unscreened vent opening.

$$\frac{A_S}{A_V} = \frac{C_d \sqrt{C_W}}{C_{dS} \sqrt{C_{wS}}} = \frac{0.078}{0.052} = 1.5$$

This is nearly the same enlargement factor of 50% as given above for a porosity of $\varepsilon = 0.5$.

With regard to ventilator openings with screen, the most effective vent configuration was the combined roof and side wall, while the roof vent was the least effective one.

Fatnassi et al. (2006) carried out experiments and CFD calculations (computational fluid dynamics) in a four-span round-arched plastic-film greenhouse, 922 m^2 floor area (4 × 9.6 m width, 24 m long and 5.9 m maximum height) in Southern France. The greenhouse was equipped with roof flap vents, maximum opening height 1.5 m, and rolling-up side wall vents. Two types of insect screens were considered:

	Hole size (mm)	Thread diameter (mm)	Porosity ε
Anti white fly	0.78 × 0.25	0.22	0.41
Anti thrips	0.18 × 0.18	0.22	0.2

The parameter $C_d C_w^{0.5}$ for the roof flap vents with screen was 0.03. This value corresponds very well with the figure of 0.028 obtained by Katsoulas et al. (2006) for roof flap vents with an insect screen.

The mean temperature difference in the greenhouse with and without screens for the configuration open windward roof and side wall vent was:

Screen	Temperature difference (°C)
Without	2.4
Anti white flies	5.1
Anti thrips	7.1

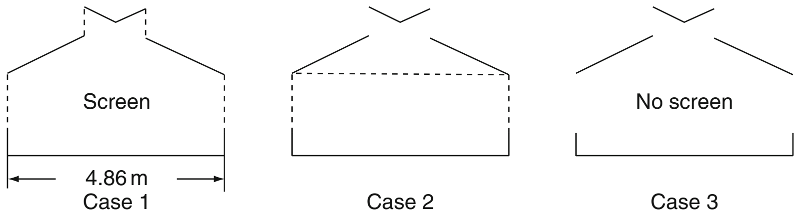

Fig. 10.12 Greenhouses with different screen installations (Sase et al. 2008)

The temperature rise under the white fly screen is twice the temperature difference without screen, and nearly three times that under thrips screen. The only possibility of getting appropriate climate conditions is the enlargement of the screen openings. Climate control under anti-thrips screen is very difficult by natural ventilation.

Sase et al. (2008) investigated three identical small greenhouses with continuous ridge vents and sliding door type side vents with different types of screen installation (Fig. 10.12). The dimensions of the greenhouses were: 4.86 m width, 7.44 m length. 1.74 m eaves height, and 2.98 m ridge height. The ratios of the vent area were: for the roof vent $A_V/A_G = 0.23$; for the side vent $A_V/A_G = 0.25$. Screen porosity 55%, thread diameter 0.15 mm, hole size 0.41 × 0.45 mm. Three cases were investigated:

- Case 1: Screens at side wall and ridge vent opening
- Case 2: Horizontally installed and side vent screen, about 10% light loss.
- Case 3: Control without screen.

The mean natural ventilation rate on a clear day with 782 W/m^2 radiation peak was 40 and 77% for cases 1 and 2 respectively in comparison to case 3. The horizontal installation of a screen might be a less limiting factor to the ventilation rate compared to the screen installation at the vent openings, but with the consequence of about 10% light loss.

The natural ventilation rate increases with increasing side vent opening, and the temperature difference decreases correspondingly:

Side vent opening (%)	Ventilation rate *N* (1/h)		
	Case 1	Case 2	Case 3
0	17.3	23.5	29
50	25.5	39	42.8
100	27.5	48.3	84.5

Ben-Yakir et al. (2008a, b) published the proposal to cover the vents only when and where risks of pest invasions are imminent. They made studies about the behaviour of white flies in a non-screened four-span greenhouse in Israel, north–south-oriented,960 m^2 floor area, 240 m^2 side vents, and four vertical roof vents with 84 m^2 total open area.

The number of white flies trapped in the greenhouse with closed side vents and open roof vents was:

Hour of the day	Night	7–8	8–9	9–10	10–11	11–12	12–13
% trapped white flies	0	2	20	41	28	8	1

There is a majority of white fly penetration in the morning hours between 8.00 and12.00. The number of white flies trapped at the eastern vents was two to three times higher than those trapped at the other vents.

The greenhouses for the studies of thrips behaviour were east–west-oriented round-arched tunnels, 6–8 m wide and 250–1,000 m^2 floor area, with open doors at the ends for ventilation. Two poles with blue sticky traps were positioned at the entrances of the tunnels and two in the open field nearby. Sixty to eighty percent of the thrips were caught below 1.0 m above ground in the open field: 85% were caught in the morning between 7.00 and 11.00, and 10% at dusk, when the wind speed was below 9 km/h (1.05 m/s). The prevailing wind speed exceeded 10 km/h between 11.00 and 18.00. The prevailing wind direction was south–west. The number of thrips caught at the eastern entrances was twice the number caught at the western entrance. This means that most of the thrips were caught at the leeward side, upwind.

Both white flies and thrips are relatively weak flyers, and therefore their penetration is affected by the prevailing wind direction and the air movement around the crop. The risk of penetration of the pests was significantly higher at the leeward side.

All these results indicate that greenhouses should be designed and positioned to minimise the risk of pest entry by wind flow. Ventilation openings and rolling-up screens should be correspondingly controlled.

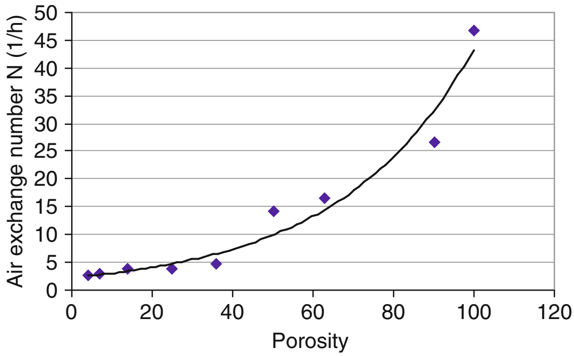

Fig. 10.13 Air exchange number N (1/h) depending on the screen porosity ε (Bartzanas et al. 2009)

A proportionality between screen porosity and air exchange number *N* (1/h) has been evaluated by Bartzanas et al. (2009) in a round-arched plastic-film-covered greenhouse with vertical side walls at 39°44′N latitude in Greece. The greenhouse, 2.4 m gutter height, 4.1 m ridge height, 8 m width, and 280 m length, had two side wall roll-up vents of 27 m^2 vent area (2 vents 0. 9 m opening, 15 m length). The ratio of vent area to floor area was 17%. The vents were covered by eight different

Fig. 10.14 Very well-installed and fixed insect screens at side walls and ridge ventilators

Fig. 10.15 The insect screens are not fixed tightly enough to the structure, so that leaks occur and pest insects can penetrate

insect screens with porosities from 4 to 90%. Figure 10.13 shows the air exchange number N (1/h) depending on the porosity of the tested screens. The temperature difference inside to outside the greenhouse changed from 4.14°C for 4% porosity to 3.12°C for 90% porosity, and 2.08°C for open vents without screens.

Figure 10.14 and 10.15 show examples for well-installed and insecure screens.