Effect of Screen Porosity on Selected Microclimatic Parameters of Naturally Ventilated Tropical Greenhouses

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ABSTRACT

Investigations were carried out in greenhouses cladded with insect screens and natural ventilation in tropics, to quantify the phenomenon of air-mass adherence to screen-enclosure. Four greenhouses 3 m x 6 m x 3.2 m (W:L:H) with 53, 34, 33 and 19% porosity insect screens were used with two plant maturity stages and two plant density levels. The shorter plants occupied 5% of gutter height while the taller stood at 50%. Plant density was doubled from 1.7 plant/m^2 to 3.3 plants/m^2 with three and five rows kept parallel lengthwise respectively. Air temperature was recorded in close proximity of cladding and observations were made to determine the influence of screen porosity on soil temperature, evapotranspiration and leaf temperature representing external and internal microclimate. A heat envelope was observed up to 15 cm distance from the outside screen. A concept of *heat envelope* has been proposed and discussed in terms of air temperature gradient, to explain how wide and strong the field of influence around the insect screens, offering resistance to mass and momentum transport. Inward and outward temperature gradients were higher with less porous screens (-0.88 ^{0}C and +5.7 ^{0}C) compared to porous screens (-0.44 ^{0}C and +3 ^{0}C). Similarly, higher plant density claimed larger outward gradients (4 ^{0}C) than single plant density (2.6 ^{0}C). Soil temperature was recorded for 5 and 10 cm depths in greenhouse pots. Porous screens evidenced maximum downward and upward soil temperature gradients (-2.2 ^{0}C and +3.8 ^{0}C), while less porous screens showed smaller values (-0.63 ^{0}C and +2.1 ^{0}C). Plant evapotranspiration with matured plants inside was found to decrease from 2,593 ml/day/plant for porous greenhouse to 2,053 ml/day/plant in less porous greenhouse.

Keywords: Heat envelope, temperature gradients, insect screens, greenhouse microclimate

1. INTRODUCTION

Greenhouse, in the tropics, protects inside crop against extreme temperatures, high winds, heavy rains, destructing storms, and insect and diseases. Insect screens are widely used in protected cultivation to reduce human exposure to pesticides, exclude or eliminate disease-causing insects, slow build up of pesticides resistance and conserve the usefulness of pesticides. Insect exclusion screens, due to their ability to minimize pesticide application and cost, have gained vast popularity among tropical greenhouse growers (Fatnassi et al., 2004; Snyder, 2003). Natural ventilation, being inexpensive, has been extensively used in the tropics. Two physical processes- stack and wind effects describe natural ventilation, where stack effect is due to thermal buoyancy generated by internal and external temperature difference, and wind effect is due to the three dimensional distribution of wind turbulence created by the mean component of wind (Parra et al., 2004; Bartzanas et al., 2004).

So far, several studies have been dedicated to investigate the natural ventilation process. The majority of them were conducted either without insect screen (Fernandez & Bailey, 1992; Feuilloley et al., 1994; Kittas et al., 1995; Papadakis et al., 1996) or were executed with insect-protective screens inside wind tunnels (Kosmos et al., 1993; Miguel et al., 1997; Montero et al., 1997; Teitel and Shlykar, 1998). Resistance offered by such screens was evaluated and the pressure drop was calculated by various researchers (Brundrett, 1993; Kosmos et al., 1993; Pearson & Owen, 1994; Miguel, 1998; Teitel, 2001), while other studies were devoted to the greenhouses with insect screens for estimating the ventilation rate, either placed horizontally above the canopy or at the ventilator openings of greenhouses (Sase & Christianson, 1990; Munoz et al., 1999). Tanny et al. (2003) considered greenhouses, completely enclosed by insect screens. But none of the above discussed the concept of heat envelope and its extent and strength for describing temperature gradients, soil temperature gradients, evapotranspiration and leaf temperature variation upon using fully cladded screen-house of different porosity values. Also, little is known about the effects of insect screens on the crop microclimate and transport phenomena of heat, mass and momentum. Irrigation in such greenhouses is currently being done on trial and error basis (Fatnassi et al., 2004; Tanny et al., 2003; Tanny and Cohen, 2003).

Heat transfer relates the energy value or heat content, whereas mass transfer reveals the amount of fluid used as a carrier to transport this energy. Momentum transfer is associated with the rate with which fluid and its heat content is transferred. Overall the fore mentioned transport of heat, mass and momentum mainly depends on the driving force (pressure drop) and resistance offered by the boundary layer (porous screen).

As the distance increases, outward away from a heat source, the temperature observed decreases for obvious reasons- the intensity in most of the general point sources, varies inversely with the radial distance at different rates. Greenhouses, in one way or other, store solar energy entrapped within its microclimate, and thus can be considered acting like a heat-tank or reservoir. Since the heat storage capacity of a microclimate to trap energy is a function of various climatic and physical factors including greenhouse cladding properties, hence the amount of energy radiated from or transmitted through would certainly be different.

The peculiar behavior of insect screen cladded around greenhouses is quite similar to the one associated with heat source, corona around the Sun, or distribution of earth pressure as a pressure bulb, for instance. The extent and amount of influence of screens with different porosities, on surrounding air in terms of air-temperature was studied; the effect was termed by authors as a *heat envelope.* Since this is assumed to be the first report on heat envelope for greenhouses completely enclosed with insect screens, no published data are yet available in literature to compare with the results obtained in this study (Soni, 2003).

Soil temperature probably plays a crucial role in sub-soil zone, as it alters nutrient absorption from substrate to plant roots. Soil temperature, not only varies between layer to layer, but also changes with prevailing solar radiation (Table 1). While dealing with greenhouse systems for plant production, the soil scientists might be interested to know the sub-soil environment, which could have been altered due to the enclosure above it. Furthermore, water uptake and transpiration rates might be affected as a cumulative effect of greenhouse microclimate change.

Keeping in view the interwoven and complex linkages among various factors, governed by cladding characteristics, the effect of screen porosity has been studied on selected microclimatic parameters- including heat envelope, soil temperature gradient, leaf temperature, and evapotranspiration, of naturally ventilated tropical greenhouses.

2. MATERIALS AND METHODS

Research was conducted at the greenhouse complex of the Asian Institute of Technology, Bangkok (Thailand) having 14^0 04' N latitude and 100^0 37' E longitude with 2.27 m altitude (Soni, 2003). Tomato seedlings were transplanted into plastic pots and placed in the greenhouses. Each pot contained approximately 4 kg (oven dried) soil substrate.

2.1 Greenhouse Construction

Four greenhouse skeletons of GI-pipes were erected with East-West (EW) orientation, i.e. the central major axis of the greenhouses was parallel to EW direction, and named as A to D. Right-sided hinged doors of 2.2 m x 1 m were provided on the Eastern side with handle lock. The structures had EW dimension of 6 m (length), North-South (NS) dimension of 3 m (breadth) with vertical dimension (height) of 3.2 m, while gutter stood 2.2 m high from the ground. Greenhouses, throughout its roof length (*i.e.* 6 m) were provided two-way roof openings (ridge-vents) with 40 cm wide air passage.

2.2 Insect Screens

The roofs of all four greenhouses were covered with LDPE (low density polyethylene) sheet. Locally used HDPE (high density polyethylene) insect screens with 53, 34, 33 and 19% porosity were used for cladding. Eastern-most greenhouse 'A' was covered with 53% porous and successively in the sequence; the Western-most was cladded by 19% porous screen (Table 2).

2.3 Irrigation and Fertigation System

An automatic drip irrigation and fertigation system was used to irrigate tomato plants in all four greenhouses. The fertigation system was attributed to soil temperature and solar radiation for automatic actuation. Drippers of 2 lit h^{-1} capacities were connected to lateral pipes for each individual plant. Irrigation duration was set 10 minutes per application during young plant stage, while it was increased to 14 minutes at matured plant stage. Depending on climatic conditions, irrigation frequencies of 6 to 8 times a day were used.

Table 1. Average monthly values of climatic factors at experimental site

Climatic factors		February	March	April	May
Monthly average air temp., ^{0}C	Max.	34.2	34.7	37.1	35.1
	Min.	22.1	23.9	25.6	25.8
	Mean	28.1	29.3	31.3	30.4
Monthly average RH, %	Max.	90.9	91.8	91.9	84.5

	Min.		42.0	44.7	41.8	44.3
	Mean		66.5	68.3	66.9	64.5
Monthly average solar radiation, MJ/m^2			19.7	20.6	22.7	24.9
Monthly average soil temp., ^{0}C	0700 h	5 cm	25.5	27.7	29.4	29.6
		10 cm	27.3	29.2	30.3	30.5
		15 cm	27.7	29.6	30.7	30.9
		20 cm	28.7	30.6	30.7	29.8
	1400 h	5 cm	31.9	33.2	34.8	33.6
		10 cm	29.2	30.9	32.4	32.1
		15 cm	28.8	30.5	31.9	31.8
		20 cm	28.9	30.8	31.1	29.7
Wind speed (m/s) and direction	Day speed		0.6	0.7	0.9	1.1
	Night speed		11.2	10.9	6.1	5.2
	Direction		SSE[†]	SSE[†]	S[†]	SW[†]

[†] SSE: South Southeast; S: South; SW: Southwest

Table 2. Properties of insect screens used

Insect screen	Material[1]	Mesh[1]	Wire diameter[2] (µm)	Opening size[2, 3] (µm x µm)	Opening area (nm^2)	Percent opening (%)
A	HDPE	32	285	780 x 755	589	53
B	HDPE	40	245	355 x 330	117	34
C	HDPE	50	265	785 x 210	165	33
D	HDPE	78	175	135 x 135	18	19

[1] as claimed by supplier
[2] measured with *profile projector,* average of three repetitions
[3] opening size: inside to inside dimensions of hole

2.4 Instrumentation and Accessories

Outside climatic data including temperature, humidity, wind velocity, wind direction, rainfall, outside solar radiation, and soil temperatures were recorded. The data logging system for greenhouses mainly comprised of thermocouple sensors (TC), multiplexer boards (*Campbell AM416 relay multiplexer*), dataloggers (*Campbell CR-21*x*)*, storage modules, interface card (*Campbell PC 532*), personal computer and compatible software. Sixteen-gauge solid alloy, twisted single paired, overall shielded, ANSI color-coded, Copper-Constantan (Type-TX, ANSI standard) thermocouple extension wires were used to measure temperature at various locations. The thermocouples were calibrated before use.

2.5 Experimental Setup

For analyzing zone of heat influence or *heat envelope*, TC sensors were mounted at 1.5 m above ground in and outside insect screen of southern sidewall of greenhouses; 5 cm inside house and 5, 10, and 15 cm outside screen. *Figure 1* depicts mounting TC sensors at various locations across insect screens. Soil temperature in pots inside greenhouses was recorded at 5 and 10 cm depths from substrate-surface in pot (*Fig. 2*). Three TC sensors were used to record leaf temperature of the plant.

Each pot in all four greenhouses was equipped with individual evapotranspiration (ET) measuring arrangement. To make portable-lysimeter, plastic stands were used to hold the pots lifted above ground to facilitate inserting plastic boxes, which were used to collect and measure the water drained from the pot. *Figure 2* shows such lysimeter arrangement.

Two plant densities, single and double were used for study. As the local practice for the variety selected for tomato, a plant density of 1.7 plants/m^2 was considered as single density (S), which was obtained by placing three rows of 10 plants each. For double plant density (D) of 3.3 plants/m^2, five rows of 12 plants each. Rows were placed lengthwise (EW). Temperatures inside the greenhouses and ambient air temperatures were simultaneously recorded every minute. Observations were recorded for five vegetative configurations: Empty- without plants inside; YS- young plant single density; YD- young plant double density; MS- matured plant single density; and MD- matured plant double density for all greenhouses.

Figure 1. Evaluating heat envelope (5, 10 and 15 cm outside the screen)

Figure 2. Soil temperature measurement at two depths (5 and 10 cm) and lysimeter arrangement for evapotranspiration mesurement

3. RESULTS AND DISCUSSION

3.1 Heat Envelope

Heat envelope or corona was analyzed for all vegetative configurations. Table 3 gives minimum and maximum temperature values obtained for all five vegetal configurations; both, minimum and maximum temperature differences were calculated from many repetitions for bright sunny days. Time of occurrence for minimum and maximum temperature gradient slightly shifted to delayed hours with decrease in screen porosity and increasing vegetation. Positive values of difference (i.e. maximum difference between TC located at 5 cm and 15 cm away from the insect screen, measured outside) shows an outward heat-gradient, while negative values reveal inward heat-gradient. The characteristics and magnitude of air temperature gradient was significantly altered by corresponding greenhouse cladding screen, plant density, and solar radiation; but the plant maturity did not show any significant effect. It was observed that the more the resistance to air flow, steeper was the gradients, and widely extended envelopes.

Inward and outward gradients were the highest in greenhouse D (-0.88 ^{0}C and +5.7 ^{0}C). Double-plant density exhibited significantly higher (4 ^{0}C) outward gradients than single-plant densities (3.5 ^{0}C). Outward gradient was found to be the least for empty greenhouse (2.6 ^{0}C). Maturity level did not affect heat-envelope build-up. The outward heat envelope was not significantly different with matured-plants and young-plants for a particular density. Isothermal plots with time are shown in *Figure 3*, where temperature contours are plotted for insect screen A (53% porosity) and D (19% porosity) for YS, MS and MD vegetal conditions.

These plots suggest that both direction and intensity of temperature gradients vary with time and screen porosity.

Table 3. Temperature values at different locations and temperature gradient outside insect screen, ^0C

Greenhouse			Time of occurrence, h	Location from screen -5cm†	5 cm	10 cm	15 cm	Temperature gradient‡ (outside screen)	Ambient temperature
Empty greenhouse	A	Min	0500	25.3	25.0	25.0	25.4	-0.46	25.9
		Max	1200	39.0	41.5	41.4	38.8	2.67	38.2
	B	Min	2000	30.9	30.3	30.6	31.0	-0.68	30.0
		Max	1600	40.5	41.3	40.4	39.9	1.35	35.0
	C	Min	2000	31.1	30.4	30.5	30.9	-0.47	30.0
		Max	1200	41.1	43.4	42.1	39.4	3.91	38.2
	D	Min	2000	30.9	30.3	30.7	31.1	-0.85	30.0
		Max	1300	44.0	45.8	42.7	41.9	3.96	38.2
Young plant single density	A	Min	2200	30.3	30.0	30.1	30.6	-0.62	31.1
		Max	1600	42.5	42.5	40.7	39.5	2.95	39.9
	B	Min	1200	42.6	42.0	44.5	44.0	-1.98	40.1
		Max	1600	44.4	45.8	43.1	42.0	3.78	39.9
	C	Min	1900	33.7	32.8	33.0	33.5	-0.69	32.9
		Max	1300	46.0	46.6	45.1	41.9	4.67	40.9
	D	Min	2000	32.9	32.5	32.9	33.5	-1.02	32.9
		Max	1300	45.9	48.6	43.6	43.4	5.19	40.9
Young plant double density	A	Min	0000	24.9	24.9	24.9	25.5	-0.69	26.2
		Max	1400	41.1	41.0	39.0	37.4	3.66	38.5
	B	Min	0000	26.1	25.8	25.9	26.2	-0.43	26.2
		Max	1500	42.3	43.7	41.2	40.4	3.33	38.3
	C	Min	0000	26.3	26.0	26.2	26.5	-0.47	26.2
		Max	1500	43.6	42.8	40.2	38.2	4.52	38.3
	D	Min	0000	26.8	26.4	26.5	26.9	-0.51	26.2
		Max	1500	42.8	46.6	41.2	39.6	6.93	38.3
Matured plant single density	A	Min	2200	26.5	26.1	26.3	26.7	-0.67	27.7
		Max	1400	41.6	41.8	39.5	37.5	4.29	38.4
	B	Min	1900	30.5	30.2	30.5	30.9	-0.68	28.0
		Max	1400	42.7	43.9	42.5	41.5	2.34	38.4
	C	Min	1900	30.9	30.8	30.9	31.3	-0.58	28.0
		Max	1400	43.6	43.0	40.9	39.5	3.53	38.4
	D	Min	1900	29.4	29.0	29.6	30.3	-1.31	28.0
		Max	1400	42.6	47.4	41.8	40.6	6.79	38.4
Matured plant double density	A	Min	0000	26.5	26.4	26.6	27.0	-0.62	28.0
		Max	1300	40.4	40.3	37.5	36.4	3.93	38.1
	B	Min	0600	26.0	25.8	26.1	26.5	-0.66	28.0
		Max	1500	41.7	41.8	40.8	40.0	1.83	37.9
	C	Min	0500	26.2	26.3	26.5	26.9	-0.58	28.0
		Max	1300	41.3	40.6	38.2	37.2	3.44	38.1
	D	Min	0100	26.4	26.1	26.6	27.3	-1.20	28.0
		Max	1300	40.7	46.7	39.4	37.6	9.03	38.1

† With respect to insect screen as datum, positive outside and negative inside greenhouse

‡ Negative values correspond to inward gradient

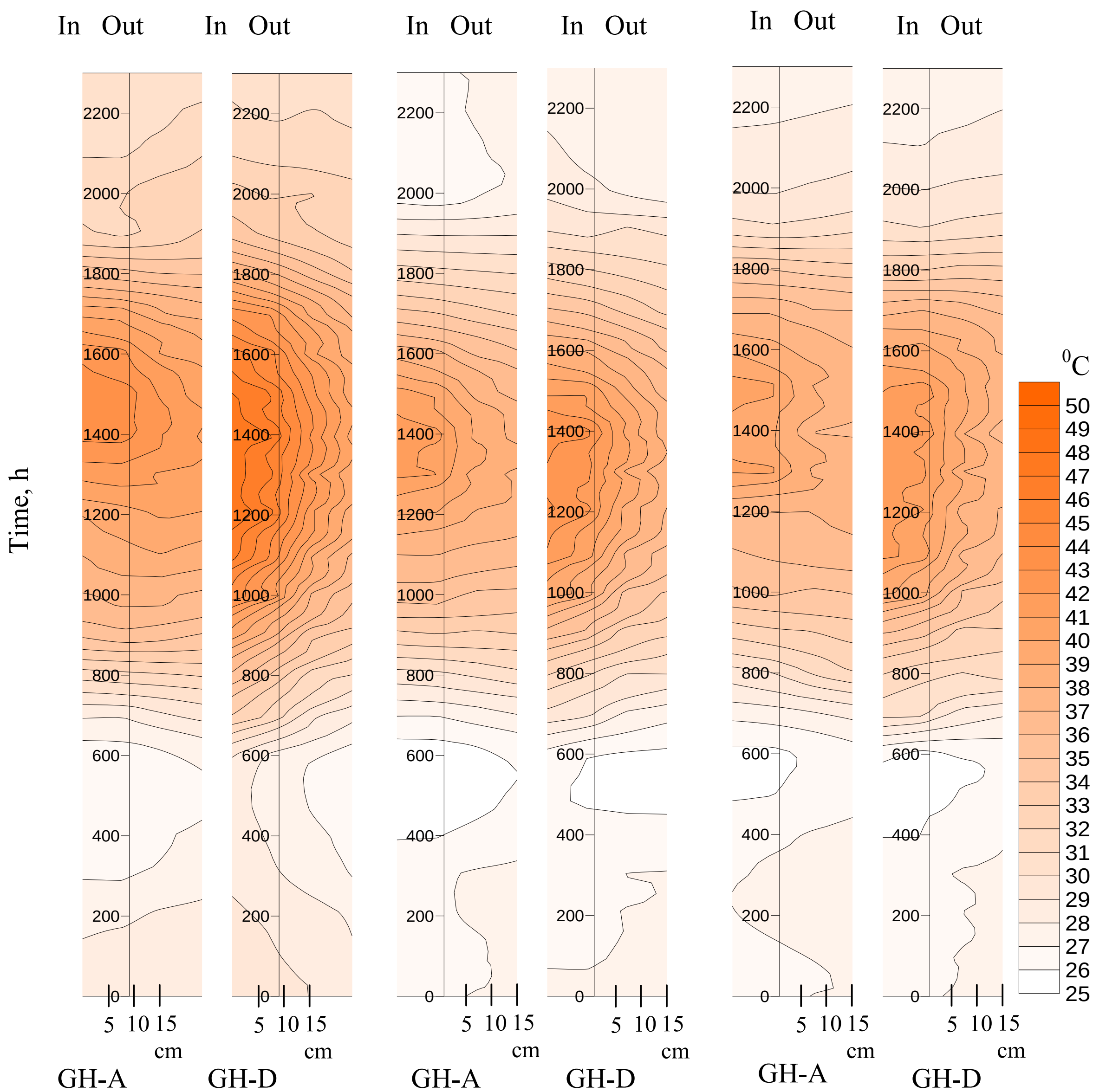
Less porous insect screens had larger heat envelope and eventually increased both outward and inward temperature gradients across the screen. These gradients result in wider envelope dimension of air adhered to or under influence of the insect screen, which might act as a thicker blanket of air-mass around the house. Fatnassi et al. (2002) found decreased ventilation rates with decreased size of opening. The insect screen induced a strong additional pressure drop through the screen, reduced ventilation and increased air temperature. Tanny and Cohen (2003) argued that the transport of heat, mass and momentum was greatly influenced with the net surrounding it. These transport processes were considered as the major factor influencing crop microclimate. Campen and Bot (2003) explained the ventilation phenomenon. The pressure difference over the openings was one of the driving forces for ventilation, which could be either due to the wind outside the greenhouse or due to the temperature difference over the openings. At lower wind speed, which was true under present case, mainly the buoyancy effect contributes in ventilation. Results from this study on various insect screens supported the concept of heat envelope. Related experiments confirmed that existence of higher air-temperature and humidity gradients are in close relation to the screen porosity, which hinders air exchange through cladding. Effects of adhered air-mass become more prominent with taller and/or denser vegetation inside. The blanket of air layer adjoining side walls not only hampers heat and momentum transfer, but also resists inside-air turbulence. The blanket of air layer adjoining side walls not only hampers heat and momentum transfer, but also resists inside-air turbulence. This results in temperature and humidity stratification of entrapped air within and outer proximity of greenhouse; severity of which apparently depends mainly on screen porosity, vegetation condition, and solar radiation.

3.2 Soil Temperature Gradients

Soil temperature gradients between two depths (5 cm and 10 cm) were analyzed. Table 4 gives soil temperature-gradients (^{0}C), which is the difference between soil temperature at 10 cm (T_{10}) and soil temperature at 5 cm (T_5), for all combinations under study. Positive values show upward-gradient while negative represents downward-gradient.

Greenhouse A showed the maximum downward gradient of soil temperature of -2.2 ^{0}C while greenhouse C represented minimum downward gradient (-0.63 ^{0}C). There was no significant effect of vegetative condition on downward soil temperature gradient. Greenhouse B exhibited the maximum upward soil temperature gradient (3.8 ^{0}C) with greenhouse D (2.1 ^{0}C) the least. YS vegetative condition showed the highest upward gradient (3.9 ^{0}C) while MD remained the least with 1.8 ^{0}C. Single plant density showed significantly higher upward gradients than that exhibited by double plant density.

It was observed that greenhouses with porous insect screens showed steeper upward and downward soil temperature gradients as compared to greenhouses with less porous screens. This showed that decreasing porosity decreased both upward and downward soil-temperature gradients. The phenomenon is in line with heat envelope, which increased with decreased porosity and resulted in increased resistance to air exchange. The lesser the momentum transport, the lesser the variation in soil strata of substrate in pots. Further, increasing vegetation increased interception that reduced soil temperature gradients, allowing more stable heat distribution within the soil-media. Results are in-line with conclusions from study by Tanney et al. (2003), who characterized the internal screenhouse microclimate during mid day hours as a stable atmosphere, which resulted from reduced interaction with the external atmosphere.



(a) Young plant single density

(b) Matured plant single density

(c) Matured plant double density

Figure 3. Iso-thermal plots with time, showing heat envelope of greenhouses GH-A & -D with 53% and 19% porosity, respectively (a) Young plant single density; (b) Matured plant single density; (c) Matured plant double density

Table 4. Variation of soil temperature gradient (T_{10}-T_5), ^0C

Greenhouse	YS		YD		MS		MD	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
A	-3.60	5.56	-4.49	5.23	-1.80	2.32	-1.64	1.84
B	-2.30	5.85	-1.63	4.31	-0.95	4.07	-0.51	3.63
C	0.02	3.78	-0.35	2.59	-0.04	2.28	0.10	1.98
D	-0.12	3.48	-0.74	3.06	-1.72	1.90	-1.72	1.37

3.3 Evapotranspiration

Evapotranspiration (ET) is another parameter that can be used to quantify greenhouse microclimatic health, since it is also affected by cladding characteristics. ET observations were analyzed for two maturity levels i.e. young and matured plant of single density. With smaller plants inside, greenhouse-A exhibited the lowest ET value (362.7 ml/day/plant) than the others. There was no significant difference among greenhouses-B, -C and -D for ET values in young plant stage, having about 1,000 ml/day/plant of ET values. With taller plants, greenhouse-A exhibited the highest ET value (2,593.3 ml/day/plant), while greenhouse-D showed 2,053 ml/day/plant.

The phenomenon could readily be explained by air exchange resistance offered by cladded screen. More porous screen provided less resistance to permit ventilation through it, while less porous screens impaired vapor transfer between greenhouse and the outside air. Results obtained in this study reconfirm the process, which establish air humidity gradient in both vertical and horizontal direction within a house; probably due to restricted turbulence and disturbed buoyancy. The results are contradictory to those obtained by Waggoner et al. (1959) who studied the effect of a cotton net tent over tobacco. They revealed that the effect on mass transfer was minor while that on momentum transfer was large. While the present results suggest that both the mass and momentum transfer are getting affected by porosity of screens used.

The matured plant stage showed significantly higher ET values than the young plants, as expected. ET in greenhouse A increased by four times in matured stage than the younger, while it was more than double in greenhouses-B, -C and -D. No significant difference in ET among the three rows within a greenhouse i.e. South, middle and North rows was observed. Perhaps being the relatively smaller dimensions of greenhouse, effect of plant distance from sidewalls couldn’t be identified.

3.4 Leaf Temperature

Leaf temperatures were measured for two plant densities i.e. single and double for a matured plant stage. Peak leaf temperature was computed from values at three locations of plant and then averaged hourly for several repetitions. *Figure 4* depicts dynamic variation of leaf temperature with time for four greenhouses in MS stage while *Figure 5* shows the same for MD configuration. Leaf temperature varies with time; it approaches to highest values when solar radiation is higher during daytime. It is clear from the figures that leaf temperature was influenced by plant density; no significant difference was noticed among greenhouses for leaf temperature. The reason could be assumed to rely upon the density of plant tissues. Having relatively smaller density than soil substrate, plant leaves were like tiny heat storage. Further, stratified humid air surrounding the plants acted as buffer for plant temperature rise. Higher specific heat of water vapor present in the air eventually shared most of the heat.

Double plant density showed significantly less leaf-temperature (33.3 ^{0}C) than that with single plant density (34.9 ^{0}C). Double plant density restricted the light transmission to reach lower parts of plant, which could be the probable reason for being its lower leaf temperature than the single density.

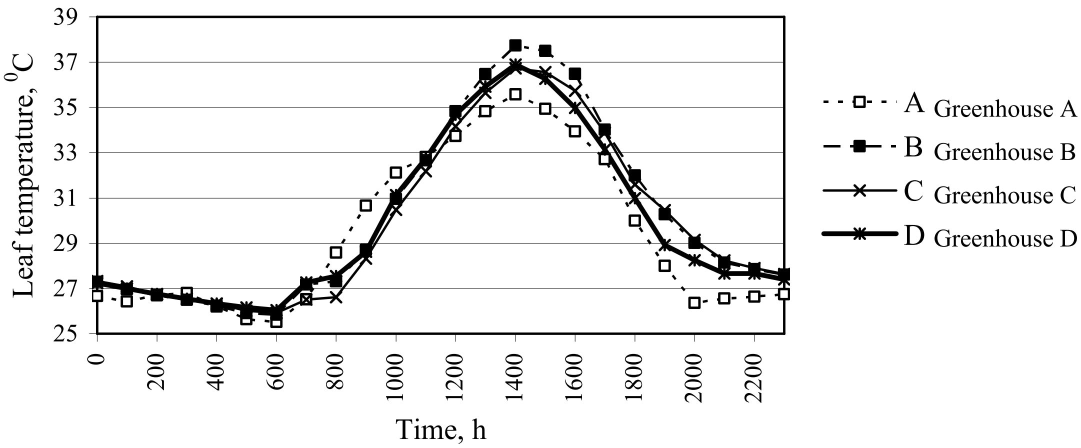


Figure 4. Dynamic variation of leaf-temperatures with matured, single density plants

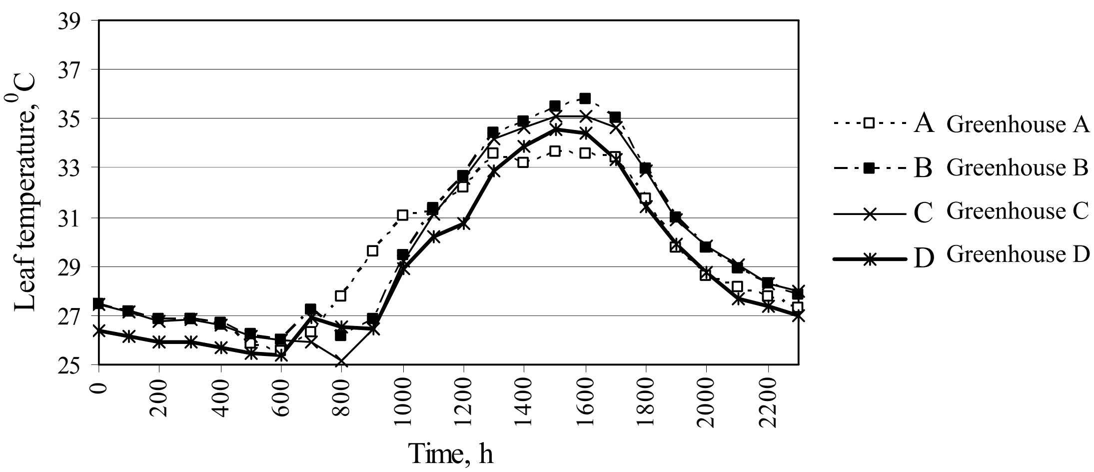


Figure 5. Dynamic variation of leaf-temperatures with matured, double density plants

4. CONCLUSIONS

The effect of different insect screens on inside microclimate of naturally ventilated fully-cladded greenhouses was studied. The temperature status adjoining air-mass was proposed as a *heat envelope*. Less porous insect screens offer high values of heat envelope build-up and thus eventually increased both outward and inward temperature gradients across the screen. Similarly, high gradients result in wider envelope of air adhered to or under influence of insect screen, which might act as a thicker blanket of air-mass around the house. Inward and outward gradients were the highest in the least porous greenhouse D (-0.88 ^{0}C and +5.7 ^{0}C). Double-plant density exhibited higher (4 ^{0}C) outward gradients than single-plant densities (3.5 ^{0}C). Outward gradient was found to be the least in empty greenhouse condition (2.6 ^{0}C). A proper screen porosity selection is thus required to balance heat gradient build-up and the largest dimension of insects' prevailing around.

Greenhouses with highly porous insect screens showed steeper upward and downward soil temperature gradients as compared to greenhouses with less porous screens. It revealed that lower porosity decreased both upward and downward soil-temperature gradients. With taller plants, greenhouse-A exhibited the highest ET value (2,593.3 ml/day/plant), while greenhouse-D showed 2,053 ml/day/plant. Evapotranspiration was found to be affected with screen porosity and obviously- with the plant maturity.

This is again, obvious from the discussion that less porous screen cladding hinders air turbulence and hence the mass and momentum transport both within and nearby surroundings of screen cladding of a greenhouse. The heat envelope phenomenon ultimately results in horizontal and vertical gradients of inside air temperature, air humidity gradients, soil temperature gradients, and evapotranspiration gradients. Influence of heat envelope was thus found both interesting and useful to be studied in more detail, addressing air exchange and gradient issues, particularly in tropical naturally ventilated greenhouses.

5. ACKNOWLEDGEMENTS

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6. ABBREVIATIONS

ET	-	evapotranspiration, ml/day/plant
GH	-	greenhouse
GH-A	-	greenhouse with 53% porosity insect screen
GH-B	-	greenhouse with 34% porosity insect screen
GH-C	-	greenhouse with 33% porosity insect screen
GH-D	-	greenhouse with 19% porosity insect screen
GI	-	galvanized iron
HDPE	-	high density polyethylene
LDPE	-	low density polyethylene
MD	-	matured plant stage with double density
MS	-	matured plant stage with single density
RH	-	relative humidity, %
T_{10}	-	soil temperature at 10 cm depth, ^{0}C
T_5	-	soil temperature at 5 cm depth, ^{0}C
TC	-	thermocouple
YD	-	young plant stage with double density
YS	-	young plant stage with single density

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