COMBINED EFFECT OF WHITENING AND VENTILATION METHODS ON MICROCLIMATE AND TRANSPERSION IN ROSE GREENHOUSE

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Abstract

In this communication the effect of roof ventilation, roof & side ventilation (opening angle 15° and 45°) and fan-pad cooling methods on transient response of inside air temperature, plant canopy temperature, growing media temperature, relative humidity and transpiration rate in a single span rose greenhouse size 22m x 10m x 4.90m located at the department of Environmental Horticulture, University of California, Davis, CA (38°N, 122°.06' W) have been studied theoretically. The results were compared for clear and whitewash coating on glass cover greenhouse.

The theoretical investigation was carried out by writing energy and mass balance equations for different components of the greenhouse. The equations were solved by adopting the finite difference technique. The results revealed that whitewash helped to reduce the plant temperature and transpiration rate significantly. The effect of opening angle for clear glazing was more prominent as compared to whitened glazing. For small vent opening angle (β=15°), the cooling was more effective in case of roof & side ventilation as compared to only roof ventilation whereas for large vent opening angle (β=45°), the effect of whitening was found insignificant. During sunshine hours, the difference in average inside air and plant temperatures at pad and fan locations in fan-pad cooling system were 10.26°C and 5.0°C respectively for the clear and 8.98°C and 4.5°C for whitened glass cover respectively.

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INTRODUCTION

Greenhouses used in crop production are well known to trap heat, resulting elevated temperatures inside the greenhouse (as known as “greenhouse effect”). Seasonal changes in solar energy impinging on the greenhouse and amount of heat loss from the greenhouse, result in seasonal patterns of heat built up. Thus greenhouse crops require different cooling strategies depending on such factors as latitude, local weather patterns, etc. Thus some greenhouses require only passive cooling systems, while others require intensive use of energy to maintain ideal growing conditions. The least expensive cooling method in greenhouses is natural ventilation provided on the top of the structure, on the side or both. However, frequently natural ventilation is not effective for many greenhouses during the summer. In geographic areas where low humidity predominates during summer, evaporative cooling is used to lower inside air temperature. Another passive method is to reduce the intensity of transmitted radiation in greenhouse by providing shade curtains or applying coating of white paint (whitewash) on covering. One of the most used methods adopted by growers due to the low cost is whitewashing (whitening) the cover material.

Theoretical and experimental studies have been carried out by several researchers to study microclimate and crop transpiration in various crop greenhouses. Takakura et. al (1971) developed the simulation model to study the effect of environmental condition on the plant leaf within a greenhouse and by that to predict the plant photosynthetic rate based on leaf temperature. He suggested that more sophisticated models can be achieved by involving time function of stomata aperture. Kindelan (1980) developed a dynamic model of greenhouse, which was based on primary boundary conditions and included the heat storage capacity of soil in order to simulate the internal environment by the energy balance equations. He found that just before sunset and near sunrise, relative humidity and evaporation rate increases with the ventilators still close, followed by a steep drop when ventilators are opened. Chandra et. al
(1981) developed a procedure to predict heating or cooling loads and moisture addition or removal required to determine specific conditions within a greenhouse to control thermal stress on plants and to design so as to reduce heating and cooling requirements. Jolliet (1994) presented a model to predict humidity and transpiration directly as a function of the outside climate, with the particular objectives of developing optimal control strategies for humidity in greenhouses. The developed model includes the processes of transpiration, condensation, ventilation and humidification and dehumidification. The model allows the inside vapor pressure to be directly calculated as a function of the outside conditions and the greenhouse characteristics. The effect of natural ventilation on microclimate and energy partitioning of a well watered rose canopy was investigated by Kittas et. al (2001). In their study they reported that high ventilation rate is not a priori the best solution for alleviating crop stress in greenhouses during summer conditions. Abreu and Meneses (1999) studied the effect of whitening on microclimate in a plastic greenhouse for tomato crop. They found that the Whitening of the roof led to a radiation transmission reduction of about 50%. This significantly reduced the frequency of periods with air temperatures above 30 °C. Whitening also reduced over 80% the frequency of periods with leaf temperature equal or higher than air temperatures. Baille et. al (2001) recently studied the effect of whitening a greenhouse roof on intercepted net radiation, canopy temperature and canopy transpiration rate of a well–watered soil less rose crop. They found that whitening reduced the average glasshouse transmission coefficient for solar radiation from 0.62 to 0.31 and as a result of that air temperature, vapor pressure deficit and canopy to air temperature difference experienced drastic changes while transpiration rate was not strongly affected.

While the qualitative effect of greenhouse shading is well known, quantitative analyses are lacking. Greenhouse shading affects not just the air temperature and energy requirement for cooling, but also the rate of photosynthesis and transpiration as a result of plant temperature.
The literature related to the combined effect of whitening and different ventilation/cooling methods on microclimate and transpiration rate is very sparse. Hence in the present study, a detailed theoretical analysis has been carried out to study the combined effect of (1) whitening and natural ventilation by (a) roof opening (RV) (b) both side & roof opening (SRV) for different ventilator opening angles ($\beta=15^\circ \& 45^\circ$) and (2) whitening and fan-pad evaporative cooling (FP) on transient response of inside air temperature, plant canopy temperature, growing media temperature, relative humidity and transpiration rate. The results were compared with those of obtained for clear glass cover and without ventilation.

**THEORETICAL ANALYSIS**

Figure 1 shows the schematic view of various coefficients of heat transfer occurring at different components of the greenhouse considered in this study. The heat transfer in the analysis is assumed to be unsteady state. For mathematical simulation of the model, the weather input data for a hot summer day (20$^{th}$ June) of the year 2001 in Davis, CA, USA (38$^\circ$N, 122$^\circ$.06’ W) were obtained from the weather web site [www.cimis.wtraer.ca.gov](http://www.cimis.wtraer.ca.gov) (Fig.2). The other input data considered for the numerical computation are listed in Table 1.

The following assumptions were made in development of the mathematical model for studying combined effect of whitening and cooling methods on greenhouse microclimate and transpiration rate in rose plants.

1. Heat flow is one dimensional
2. The effect of shading due to structural members is negligible
3. Moisture is freely available at various surfaces for evaporation
4. Edge losses of greenhouse are negligible
5. In a fan-pad cooling system, the Inlet air temperature at pad is equivalent to wet bulb temperature of ambient air.

6. 30 per cent plant leaf area and 70 per cent floor area receive only diffuse radiation and remaining direct radiation.

7. During night the transpiration coefficient is assumed to be reduced to 10% of the normal sunshine hours value.

8. If \( t_{gh} < 18.0 \, ^\circ C \) then fan-pad are off. If \( 18.0 \, ^\circ C < t_{gh} < 25.0 \, ^\circ C \) then pad is off and fan is operating and if \( t_{gh} > 25.0 \, ^\circ C \) then both fan & pad are operating.

9. The reduction in transmission of solar radiation through glass cover due to whitewash coating is about 50% (Baille et al, 2001)

The energy and mass balance equations for different components of the greenhouse and their initial and boundary conditions are given below:

**Cover**

\[
M_{coco} C_{c} \frac{dt_{c}}{d\theta} = \alpha_{c} G A_{c} + A_{c} \left( h_{cog} / C_{gh} \right) (W_{gh} - W_{co}) \lambda_{co} + A_{c} h_{cog} (t_{gh} - t_{co}) + A_{p} h_{r,pc}(t_{p} - t_{co}) + A_{s} h_{r,cos} (t_{s(1)} - t_{co}) - A_{co} h_{coa} (t_{co} - t_{a}) - A_{co} h_{r,cosky} (t_{co} - t_{sky})
\]

(1)

**Greenhouse Air**

\[
M_{gh} C_{gh} \frac{dt_{gh}}{d\theta} = A_{co} h_{cog} (t_{co} - t_{gh}) + A_{s} h_{sg}(t_{s(1)} - t_{gh}) + A_{p} Li h_{pgh} (t_{p} - t_{gh}) + A_{p} Li f \lambda_{gh} (W_{sp} - W_{gh}) + A_{gm} h_{gmg}(t_{gm} - t_{gh}) + A_{gm} (h_{gmg} / C_{gh}) (W_{sgm} - W_{gh}) \lambda_{gm} - E
\]

(2)

Here, the heat loss (H) due to natural ventilation (\( H_{nv} \)) by opening roof vent, side & roof vents and forced ventilation (\( H_{fv} \)) due to fan-pad cooling was calculated using the following expressions:

**Natural Ventilation:**

\[
H_{nv} = Q C_{a} \rho_{a} (t_{gh} - t_{a})
\]

(3)
Table 1. Input parameters for numerical computation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
</tr>
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<tr>
<td>1. Size of greenhouse structure</td>
<td></td>
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</tr>
<tr>
<td>Length</td>
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<tr>
<td>Width</td>
<td>B</td>
<td>9.0 m</td>
</tr>
<tr>
<td>Height</td>
<td>Z</td>
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<td>2. Opening angles of vent</td>
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<td>3. Number, size and RPM of fan</td>
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<td>Thickness</td>
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<tr>
<td>Specific heat</td>
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<td>Absorptivity</td>
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<td>0.62G (clear glazing)</td>
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<tr>
<td>Shaded plant canopy &amp; floor (clear &amp; whitened glazing)</td>
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<td>0.31G (whitened glazing)</td>
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<tr>
<td></td>
<td></td>
<td>0.115G</td>
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</table>
Here, Q for roof ventilation and roof & side ventilation was calculated using the equations given by Okada and Takakura (1973) and Kittas et. al (1998) respectively.

**Forced Ventilation (Fan-Pad)**

\[ H_{iv} = m \ C_a \ (t_{gh} - t_a) \]  \hspace{1cm} (4)

**Plant Canopy**

\[
M_p \ C_p \ \frac{dt}{d\theta} = \alpha_p \ G_p \ \ A_p - \ A_p \ Li \ h_{pgh} \ (t_p - t_{gh}) - \ A_p \ Li \ f \ (W_{sp} - W_{gh}) \ \lambda_p - \ A_p \\
\ h_{sp} \ (t_p - t_s) - \ A_p \ h_{r,pc} \ (t_p - t_{co}) - \ A_p \ h_{r,pgm} \ (t_p - t_{gm})
\]  \hspace{1cm} (5)

**Growing Media**

\[
M_{gm} \ C_{gm} \ (1 - \varepsilon_{gm}) \ \frac{dt}{d\theta} = \alpha_{gm} \ G_{gm} \ A_{gm} - \ A_{gm} \ h_{gmgh} \ (t_{gm} - t_{gh}) - \ A_{gm} \ (W_{sgm} - W_{gh}) \ \lambda_{gm} + \ A_{gm} \ h_{r,gmp} \ (t_p - t_{gm}) - \ A_{gm} \ h_{r,gmco} \ (t_{gm} - t_{co})
\]  \hspace{1cm} (6)

**Floor**

**Surface layer**

\[
M_s \ C_s \ (1 - \varepsilon_s) \ \frac{dt}{d\theta} = \alpha_s \ G_s \ A_s - \ A_s \ h_{sg} \ (t_{s(1)} - t_{gh}) - \ A_s \ h_{r,ps} \ (t_{s(1)} - t_p) - \ A_s \ h_{r,cos} \ (t_{s(1)} - t_{co})
\]  \hspace{1cm} (7)

**Subsequent soil layers (j=2,n)**

\[
M_s \ C_s \ (1 - \varepsilon_s) \ \frac{dt}{d\theta} = \alpha_s \ K_s \ \frac{dt}{dh}
\]  \hspace{1cm} (8)

**Relative Humidity of Greenhouse Air**

\[
\phi = \frac{W_{gh} \ P_{atm}}{[(0.622 + W_{gh}) \ P_{s,gh}]}
\]  \hspace{1cm} (9)
The absolute humidity of greenhouse air in equation (9) was computed as

\[ M_{gh} \frac{W_{gh}}{d\theta} = A_p L f (W_{sp} - W_{gh}) + A_{co} (h_{cog}/C_{gh}) (W_{sco} - W_{gh}) + A_{gm} (h_{gmgh}/C_{gh}) \]

\[ (W_{sgm} - W_{gh}) - E \]  (10)

Here, the mass transfer (E) due to natural ventilation (E_{nv}) and forced ventilation (E_{lv}) was calculated as given below

**Natural Ventilation**

\[ E_{nv} = Q \rho_a (W_{gh} - W_a) \]  (11)

In the above equation, Q for two natural ventilation methods was calculated similarly as calculated in equation (3).

**Forced Ventilation (Fan-Pad)**

\[ E_{lv} = m (W_{gh} - W_a) \]  (12)

The absolute humidity for saturation condition at cover, plant canopy, growing media and floor was computed as

\[ W_{s,co} = 0.622 \frac{P_{s,co}}{(P_{atm} - P_{s,co})} \]  (13)

\[ W_{s,p} = 0.622 \frac{P_{s,p}}{(P_{atm} - P_{s,p})} \]  (14)

\[ W_{s,gm} = 0.622 \frac{P_{s,gm}}{(P_{atm} - P_{s,gm})} \]  (15)

\[ W_{s,s} = 0.622 \frac{P_{s,s}}{(P_{atm} - P_{s,s})} \]  (16)
In above equations, the saturated vapor pressure at different components of greenhouse system was calculated as

\[ P_{s,co} = 6894.76 \exp[54.63 - (12301.69/ t_{R,co}) - 5.17 \ln (t_{R,co})] \] (17)  
\[ P_{s,gh} = 6894.76 \exp[54.63 - (12301.69/ t_{R,gh}) - 5.17 \ln (t_{R,gh})] \] (18)  
\[ P_{s,p} = 6894.76 \exp[54.63 - (12301.69/ t_{R,p}) - 5.17 \ln (t_{R,p})] \] (19)  
\[ P_{s,gm} = 6894.76 \exp[54.63 - (12301.69/ t_{R,gm}) - 5.17 \ln (t_{R,gm})] \] (20)  
\[ P_{s,s} = 6894.76 \exp[54.63 - (12301.69/ t_{R,s}) - 5.17 \ln (t_{R,s})] \] (21)  

In above equations, the latent heat of vaporization at cover, plant canopy, greenhouse air, growing media and floor temperatures can be expressed as

\[ \lambda_{co} = 2500.78 - 2.3601 \ t_{co} \] (22)  
\[ \lambda_{gh} = 2500.78 - 2.3601 \ t_{gh} \] (23)  
\[ \lambda_{p} = 2500.78 - 2.3601 \ t_{p} \] (24)  
\[ \lambda_{gm} = 2500.78 - 2.3601 \ t_{gm} \] (25)  
\[ \lambda_{s} = 2500.78 - 2.3601 \ t_{s} \] (26)  

**Transpiration Rate**

The diurnal variation of transpiration rate was computed using the following relationship

\[ ET = f (W_{s,p} - W_{gh}) \] (27)  
Where the coefficient of transpiration (RT) was calculated as

\[ f = h_{pgh}/c_{gh} \] (28)  

The \( t_{gh}, t_{p}, t_{gm}, \phi \) and \( ET \) for clear and white washed glass coverings in combination with different cooling methods are then obtained by solving the above equations using a finite difference approach and considering the following boundary conditions.

\[ t_{co} (x,0) = t_{a}; \ t_{gh} (x,0) = t_{a}; \ t_{p} (x,0) = t_{a}; \ t_{gm} (x,0) = t_{a}; \ t_{s} (x,0) = t_{a}; \ W_{gh} (x,0) = W_{a}; \ ET(x,0) = 0; \]
The convective heat transfer coefficients, \( h_{pgh}, h_{gmg} \) and \( h_{sgh} \) were calculated using equations given in Papadakis et. al (1994) and \( h_{cog} \) was calculated according to Trigui et. al (2001). The radiative \( (h_{r,pc}, h_{r,coa}, h_{r,ps}, h_{r,gmp} \) and \( h_{r,gmco} \)) and wind related convective heat transfer coefficients were calculated by using the standard relations given in Duffie and Backman (1980). The conductive heat transfer coefficient between soil layers \( (h_{ss}) \) was calculated using the equations given in Wierenga and De (1970).

**RESULTS AND DISCUSSION**

By using the theoretical model presented above, the diurnal variation of \( t_{gh}, t_{p}, t_{gm}, \) RH and ET for different combinations of ventilation/cooling methods (RV,SRV and FP) and whitening was studied and performance was compared with the clear glass cover greenhouse and greenhouse without ventilation (NV).

*Effect on Greenhouse Temperatures*

For whitened glass cover, except for early morning hours (1.00 to 5.00h), all the three temperatures, \( t_{gh}, t_{p}, \) and \( t_{gm} \) were decreased significantly (Fig.3). The effect was found more prominent during peak sunshine hours. However, the inside temperatures were remain higher than the ambient temperature. The reduction due to whitening in maximum values of \( t_{gh}, t_{p} \) and \( t_{gm} \) were found as 9.35°C, 7.69°C and 6.83°C at 15.00h respectively. From figure 3 it can also be seen that whitewash also helped to improve the heat transfer between plant surface and surrounding air hence \( t_{gh} \) and \( t_{p} \) were identical.

In comparison of no ventilation, the roof ventilation helped to reduce all the three temperatures, \( t_{gh}, t_{p}, \) and \( t_{gm} \) (Fig.4). The whitening helped to reduce temperatures further, particularly \( t_{p} \) and \( t_{gm} \) were found affected significantly. However, roof ventilation didn’t affect much \( t_{gh} \) under
whitened glazing. As compared to no ventilation greenhouse, low ventilation ($\beta=15^\circ$) in clear glass cover greenhouse helped to reduce maximum $t_{gh}$, $t_p$ and $t_{gm}$ about 3.1°C, 9.1°C and 9.0°C at 15.00h respectively whereas, for higher ventilation ($\beta=45^\circ$), reduction in above temperatures were found to be 7.14°C, 15.20°C and 15.0°C respectively. The combined effect of whitening and roof ventilation for $\beta=15^\circ$ (Fig. 4b) show that, as compared to clear glazing, about 4 to 6 °C reduction was occurred in $t_{gh}$, $t_p$ and $t_{gm}$ however, for $\beta=45^\circ$, the reduction in different temperatures was only 2 to 3 °C. $t_{gh}$ at given time. From figure, it can also be seen that whitening and higher ventilation rate helped to lower down $t_p$ and $t_{gm}$ below $t_{amb}$.

The influence of whitening for side and roof ventilated greenhouse with vent opening angles $\beta=15^\circ$ and 45° on diurnal variation of $t_{gh}$, $t_p$ and $t_{gm}$ is presented in Fig.5. From figures it can be seen that the trend of plots are similar as those observed for roof ventilation in Fig. 4(c) and (d). The figure shows that further decrease occurred in $t_{gh}$ and $t_p$ for whitewash coated glazing and higher $\beta$ as compared to only roof ventilation. The effect was found more prominent for whitening as compared to $\beta$. For comparison between RV and SRV, data presented in figures revealed that for $\beta=15^\circ$, reduction in maximum $t_{gh}$, $t_p$ and $t_{gm}$ were ranged between 2 to 4°C and 0.5 to 2°C for clear and whitened glass respectively. whereas for $\beta=45^\circ$ the corresponding decrements were 1 to 3 °C and 0.5 to 1.5 °C. Thus as compared to roof ventilation higher ventilation rate through side and roof ventilation, particularly for whitened glazing, has almost no influence on reduction of greenhouse temperatures.

The influence of fan-pad cooling system on diurnal variation of $t_{gh}$, $t_p$, and $t_{gm}$ for clear and whitened glazing is illustrated in Fig.6. Whitening in fan-pad cooling system helped to reduce 2 to 4 °C temperature of various greenhouse components as compared to clear glazing greenhouse. Comparing the performance with no ventilation and natural ventilation results,
trends show that whitening in forced cooling system helped to keep $t_{gh}$ within optimum temperature range of rose cultivation (18°C to 25°C) during the hottest period of the year. The data presented in figures show that as compared to no ventilation, the fan-pad system reduced maximum $t_{gh}$, $t_p$ and $t_{gm}$ about 23 °C, 24 °C and 23 °C for clear glazing and, 15 °C, 18 °C and 16 °C for whitened glazing respectively at 15.00h. The results also revealed that whitening has improved heat transfer coefficient between plant canopy and greenhouse air.

In all the above cases, the influence over $t_{gm}$ was affected least which is due to fact that growing media was partly covered by plant canopy and received only diffuse radiation equivalent to 0.115G, as well as it contains high amount of moisture.

Effect on Relative Humidity

Effect of different cooling/ventilation methods on inside relative humidity for clear and whitened glazing have been presented in Fig.7. Figure show that for all ventilation methods and both types of glazing, inside RH was found higher than ambient RH at given time. It can also be seen that for natural ventilation methods, RH decreased with increase in ventilation rate. Thus for both types of glazing, the RH was found to be lowest for SRV45 followed by RV45, SRV15 and RV15. The inside RH for fan-pad system at corresponding time was found to be higher than all four natural ventilation methods whereas for no-ventilation method it was found to be highest at given time because of no escape of moist air. The curves shows that for roof ventilation and fan-pad cooling methods, RH at 5.00h and 21.00h shoots up and then decreases for the next hour which may be because at 5.00h the ambient and greenhouse air temperature suddenly drops whereas at 21.00h it follows the ambient RH trend. The comparative results of clear and whitened glazing revealed that inside RH under whitened glazing was about 10-15% higher than clear glazing for different cooling methods because of whitening helped to reduce the dry bulb temperature of inside air.
**Effect on Transpiration rate**

The diurnal variation of transpiration rate, ET for the different cooling / ventilation methods under clear and whitened coverings of greenhouse (Fig.8) shows that for both clear and whitened glazing during sunshine hours, the highest ET was occurred for SRV45 followed by RV45, SRV15, RV15, FP, and NV. The highest ET in case of SRV45 was due to high ventilation rate and wide gap between $t_{gh}$ and $t_p$ caused large canopy-to-air vapour pressure deficit whereas for NV, high RH and narrow gap between $t_{gh}$ and $t_p$ caused least ET. Except at peak sunshine hours, ET for SRV45 and RV45 as well as for RV15 and SRV15 was found almost similar while during peak sunshine hours the increase in temperature gap between $t_{gh}$ and $t_p$ caused higher ET. For whitened glazing, (Fig. 8(b)) ET at respective time was found lower than clear glazing for all cooling / ventilation methods. From data presented in above figures it was also found that for all cooling/ventilation methods and both clear and whitened glazing the maximum ET occurred between 15.00 and 16.00h and minimum at 2.00 h.

**CONCLUSIONS**

It may be concluded that whitened glass cover of greenhouse helped to reduce both inside air and plant canopy temperatures significantly for all methods of cooling/ventilation. However for high ventilation rate ($\beta=45^\circ$), $t_{gh}$ was found least affected. Moreover, the effect was found more prominent for plant temperature as compared to air temperature and during sunshine hours as compared to off-sunshine hours. Whitening has significant effect on all the three temperatures. For no ventilation and fan-pad cooling methods, whitening has no significant effect on inside RH. However, it has little effect on RH. The whitening reduced ET significantly at any given time for all cooling/ventilation methods.
REFERENCES


**NOMENCLATURE**

A  greenhouse floor area, m²
B  width of the greenhouse, m
C  specific heat, J/kg°C
dh, dl distance element, m
ET  transpiration rate, kg/hm²
f  coefficient of transpiration
G  solar radiation, W/m²
h  heat transfer coefficient, W/m²°C
k  thermal conductivity, W/m°C
Li  leaf area index
L  length of greenhouse, m
l  characteristics length of plant leaves, m
M  mass, kg
m  mass flow rate, kg/s
P  vapour pressure, kPa
Q  ventilation/infiltration/air flow rate, m³/s
T  temperature
V  volume, m³
v  wind velocity, m/s
W  humidity ratio

Subscripts
a  ambient
atm  atmospheric
c0  cover
fv  forced ventilation
gh  greenhouse
gm  growing media
(j)  number of layers
nv  natural ventilation
p  plant
r  radiative
R  rankine
s  soil / saturated
ss  soil-soil

Greek letters
ε  emissivity
λ  latent heat of vaporization, J/kg
σ  Stephan boltzmen constant
Δt  finite element of time
α  solar absorptance
ρ  density, kg/m³
θ  time, sec
Φ  relative humidity
ε  porosity
τ  solar transmittance
Fig.1 Schematic view of coefficients of heat transfer occurring at different components of the green house
Fig. 2  Weather input data for hottest summer day (06/20/2001) in Davis, CA
Fig. 3 Diurnal variation of temperatures ($t_{gh}$, $t_p$, $t_{amb}$, $t_{gm}$) in a no-ventilation greenhouse for clear and whitened glass covers.
Fig. 4 Diurnal variation of temperatures (--- $t_{ph}$, --- $t_p$, --- $t_{web}$, --- $t_{wm}$) in roof ventilation greenhouse for clear and whitened glass cover for different vent opening angles.
Fig. 5 Diurnal variation of temperatures (--- $t_{ph}$, - $t_p$, --- $t_{amb}$, - $t_{gm}$) in roof and side ventilated greenhouse for clear and whitened glass cover for different vent opening angles.
Fig. 6 Diurnal variation of temperatures ($t_{gh}$, $t_p$, $t_{amb}$, $t_{gm}$) in fan-pad cooling greenhouse for clear and whitened glass covers.
Fig. 7 Effect of different cooling methods (--- NV, ----- ambient, --- RV15, --- RV45, --- SRV15, ---- SRV45, ----- FP) on diurnal variation of RH for clear and whitened glass cover greenhouse.
Fig. 8 Effect of different cooling methods (--- NV --- RV15 --- RV45 --- SRV15 --- SRV45; --- FP) on diurnal variation of ET for clear and whitened glass cover greenhouse.