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Energy Conservation Potential of Inner Thermal Curtain in an Even Span Greenhouse

Ashish Shukla, G.N. Tiwari and M.S. Sodha
Centre for Energy Studies, Indian Institute of Technology Delhi, Hauz Khas,
New Delhi 110016, India

Abstract: In this study a thermal model has been developed to see the effect of inner thermal curtain on the thermal performance of an even span greenhouse for Srinagar (34.08° N), India. The analysis incorporates the study of thermal performance of three types of greenhouses (I) single zone greenhouse (without curtain) (ii) two zone greenhouse (with one curtain) and (iii) three zone greenhouse (with two curtain). The thermal performance of a greenhouse having one and two thermal curtain has been compared with greenhouse without thermal curtain. It is seen that the fluctuations in temperature in the vicinity of plants are more in greenhouse without any curtain in comparison to other two greenhouses; whereas temperature during night time in first zone of three zone greenhouse is significantly more with comparison to greenhouse without curtain and greenhouse with one curtain.

Key words: Thermal modeling, inner thermal curtain, greenhouse

Introduction

Proper temperature is an essential requirement for growth of plants. During cold winters the ambient air temperature falls very low (-2.3°C in case of Srinagar, India) (Tiwari, 2002) and this adversely affects the growth of plants. Hence heating of greenhouse is one of the most important activities during winter season (Tiwari, 2003). The heating of greenhouse may be acquired by (I) active and (ii) passive methods. In active heating ground collector, warm water, earth-air heat exchanger and under ground geothermal water may prove a better option for thermal improvement. Heating of greenhouse using active method has been studied by various researchers (Santamouris *et al*., 1996, Bargach *et al*., 2000, Jain and Tiwari, 2003). Active methods require a significant amount of electrical energy for greenhouse heating. In case of passive heating no or little electrical energy is required for the heating of greenhouse. Heating of greenhouse by passive methods (Bailey, 1981; Barral *et al*., 1999; Shukla *et al*., 2006) is getting importance. The passive heating may be due to water storage, rock bed storage and presence of north wall, mulching, phase changing material, movable insulation and thermal curtain.

Among passive heating modes a thermal curtain or thermal screen is one of the most practical and appropriate means for reducing the consumption of heat in greenhouse. Night curtain or thermal screens are drawn inside or outside greenhouse in night time during winter period to reduce heat losses to the ambient environment (Seginer *et al*., 1980). The curtain helps in retaining thermal energy near the plants and prevents the radiative heat losses to the cold night sky for maintaining better heat distribution inside greenhouse (Seginer *et al*., 1980). An external curtain is placed between the greenhouse cover and the surrounding atmosphere whereas an internal curtain is placed between the crop and structural cover of greenhouse. However thermal internal curtain is preferred to the external thermal curtain as the latter is exposed to outside weather causing early deterioration.

Corresponding Author: Ashish Shukla, Centre for Energy Studies, Indian Institute of Technology, Hauz Khas, New Delhi 110016, India Tel: +91-11-2659-1255 Fax: +91-11-2659-2208

Arinze *et al*. (1986) have studied the effects of movable internal curtain placed in between the glazing of double-layered structure. Basically curtain provides the additional thermal energy resistance that reduces the overall rate of heat transfer to the surroundings. Chandra and Albright (1980) have given a theoretical model to estimate the energy conservation potential of curtain during night time in greenhouse. Experimental results shown by Bailey (1981) and Roberts *et al*. (1981) and analytical findings of Seginer *et al*. (1980) and Chandra and Albright (1980) have recommended the use of thermal curtain for energy conservation.

Basic Principle

A thermal curtain works as a heat transfer barrier between plants in greenhouse and the surrounding atmosphere. Thermal curtains made of infrared absorbing low quality polythene are used to reduce night time losses significantly. Thermal curtain used to retain the thermal energy around the vicinity of plant mass and thus results in less loss. Thermal curtains are also used in inner sides of wall and roof. Here thermal curtains help in reducing the convective losses. The use of thermal curtain as ceiling further minimizes and thus a higher temperature is achieved during winter period. The use of these curtains cuts the convection currents in contact with the ground surface and reduces them to small zone near the plants. Another use of using these curtains is that excess energy received from the sun during daytime is absorbed and accumulated in the first zone of greenhouse. Thus energy stored during peak sunshine hours is released to plant mass during later part of day and during night. Thus it results in effective utilization of thermal energy stored in the ground. Thus with the help of thermal curtain increase of temperature inside greenhouse during day time has been restricted and release of stored energy during night time helps in making desirable temperature inside greenhouse. Thus thermal conditions inside greenhouse surroundings the plants have been improved significantly.

System Description

The system consists of greenhouse in Srinagar, India. Thermal performance of three types of greenhouses has been carried out as given below:

- One zone greenhouse
- Two zone greenhouse and
- Three zone greenhouse.

One zone greenhouse is made of polythene sheet only, in two zone greenhouse no thermal curtain is used over plants only thermal curtain is used on ceiling and in three zone greenhouse thermal curtain over the plants is used along with thermal curtain on ceiling. Thus three zone greenhouse consists of zone I (plants under thermal blanket), zone II (space under ceiling covered with thermal curtain) and zone III (space between roof and ceiling), whereas two zone greenhouse consists of I (plants under thermal ceiling), zone II (space between roof and ceiling). The greenhouse used for the study is an even span greenhouse made up of wooden beams and polyethylene walls and roofs as shown in schematic diagram of three zone greenhouse in Fig. 1. The ceiling has also been covered with the curtain that is used permanently through out the winter season. Thermal curtains are made up of 50 μm transparent polyethylene sheets. The total decrease in solar radiation is about 25% inside the greenhouse and the level of solar radiation is still adequate for the growth of plants. Thermal blanket made up of transparent synthetic material is spread over the plant at the height of 1 m without making contact with them and is supported by the sticks. It remains permanently over the plants all through the

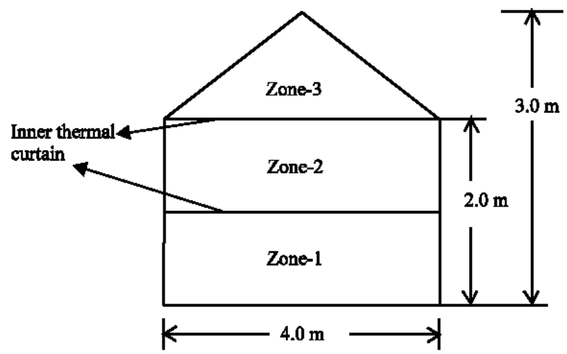

Fig. 1: Schematic diagram of an even span greenhouse with two curtains (three zone greenhouses)

winter period in three zone greenhouse. The blanket is light and transparent and it is only moved when horticultural work is necessary. After its movement, it can be slid back almost effortlessly along the supporting wire

Thermal Analysis

Following assumptions have been made while writing energy balance for different zones of greenhouse:

- Analysis is based on quasi-steady state condition.
- The heat transfer from floor to ground and inside ground is taken to be one dimensional.
- Radiative heat exchange between walls, roofs and plant mass is neglected due to smaller differences of temperature between them.
- Specific heat of plant in the greenhouse has been considered same as that of water mass due to high water content in the plant.
- Relative humidity inside the greenhouse does not vary with height due to small height of zone I.
- Heat capacity of air inside the greenhouse is neglected as compared to heat capacity of plant due to larger specific heat of water.

Energy balance for different greenhouses can be written as:

One Zone Greenhouse

Plant mass

$$(\alpha_P)(F_P)(\tau)\left\{\sum_{i=1}^{6}(A_iI_i)\right\} = h_P(T_{P1} - T_r)A_P + M_PC_P\frac{dT_{P1}}{dt} \tag{1}$$

Ground

$$\alpha_g(1-F_P)(\tau)\left\{\sum_{i=1}^{6}(A_iI_i)\right\} = h_1(T_g - T_r)A_g + h_{g\infty}(T_g - T_\infty)A_g \tag{2}$$

Greenhouse air

$$(1-\alpha_g)(1-F_P)(\tau)\left\{\sum_{i=1}^{6}(A_iI_i)\right\}+h_1(T_g-T_r)A_g+h_P(T_{P1}-T_r)A_P=h_2(T_r-T_a)A_s \quad (3)$$

Two Zone Greenhouse

Zone I

Plant mass

$$(\alpha_P)(F_P)(\tau_3)(\tau_2)\left\{\sum_{i=1}^{6}A_iI_i\right\}=h_P(T_{P2}-T_1)A_P+M_PC_P\frac{dT_{P2}}{dt} \quad (4)$$

Ground

$$(\alpha_g)(1-F_P)(\tau_3)(\tau_2)\left\{\sum_{i=1}^{6}A_iI_i\right\}=h_{g1}(T_g-T_1)A_g+h_{g\infty}(T_g-T_\infty)A_g \quad (5)$$

Greenhouse air

$$(1-\alpha_g)(1-F_P)(\tau_3)(\tau_2)\left\{\sum_{i=1}^{6}A_iI_i\right\}+h_{g1}(T_g-T_1)A_g+h_P(T_{P2}-T_1)A_P=h_{12}(T_1-T_2)A_g \quad (6)$$

Zone II

$$h_{12}(T_1-T_2)A_g=h_{2a}(T_2-T_a)A_r \quad (7)$$

Three Zone Greenhouse

Zone I

For plant mass

$$(\alpha_P)(F_P)(\tau_3)(\tau_2)(\tau_1)\left\{\sum_{i=1}^{6}A_iI_i\right\}=h_P(T_{P3}-T_1)A_P+M_PC_P\frac{dT_{P3}}{dt} \quad (8)$$

For ground

$$(\alpha_g)(1-F_P)(\tau_3)(\tau_2)(\tau_1)\left\{\sum_{i=1}^{6}A_iI_i\right\}=h_{g1}(T_g-T_1)A_g+h_{g\infty}(T_g-T_\infty)A_g \quad (9)$$

For green house air

$$(1-\alpha_g)(1-F_P)(\tau_3)(\tau_2)(\tau_1)\left\{\sum_{i=1}^{6}A_iI_i\right\}+h_{g1}(T_g-T_1)A_g+h_P(T_{P3}-T_1)A_P=h_{12}(T_1-T_2)A_g \quad (10)$$

Zone II

$$h_{12}(T_1-T_2)A_g=h_{23}(T_2-T_3)A_g \quad (11)$$

Zone III

$$h_{23}(T_2 - T_3)A_g = h_{3a}(T_3 - T_a)A_R \tag{12}$$

On solving Eq. (1-3) for T_r and writing in terms of T_{Pl} and T_a one gets

$$T_r = \frac{(IA)_{effA} + F_1(IA)_{effF} + (UA)_{a-r}T_a + h_P A_P T_{P1} + h_2 T_a A_g}{(UA)_{a-r} + h_P A_P + h_2 A_g} \tag{13}$$

where

$$(\alpha_P)(F_P)(\tau)\left\{\sum_{i=1}^{6}(A_i I_i)\right\} = (IA)_{effP};\ \alpha_g(1-F_P)(\tau)\left\{\sum_{i=1}^{6}(A_i I_i)\right\} = (IA)_{effG}$$

$$(1-\alpha_g)(1-F_P)(\tau)\left\{\sum_{i=1}^{6}(A_i I_i)\right\} = (IA)_{effA};\ F_1 = \left(\frac{h_1}{h_1 + h_{g\infty}}\right) \text{and} (UA)_{a-r} = \left(\frac{h_{g\infty}h_1 A_g}{h_1 + h_{g\infty}}\right)$$

Temperature at larger depth, $T_\infty = T_a$ (ambient air temperature).

Putting the value of T_r from Eq. 13 in Eq. 1 and after solving, the following first order differential equation is obtained

$$\frac{dT_{P1}}{dt} + aT_{P1} = B(t) \tag{14}$$

where

$$B(t) = \frac{z(IA)_{effP} + h_P A_P\{(IA)_{effA} + F_1(IA)_{effG} + (UA)_{a-r}T_a + h_2 T_a A_r\}}{zM_P C_P}$$

$$z = (UA)_{a-r} + h_P A_P + h_2 A_g$$

$$a = \frac{h_P A_P\{(UA)_{a-r} + h_2 A_g\}}{zM_P C_P}$$

Assuming the average solar intensity and average ambient as well as greenhouse air temperature for 0-t time interval, the solution of Eq. 14 can be written as

$$T_{P1} = \frac{\overline{B}(t)}{a}\left(1 - e^{-at}\right) + T_{P1o}e^{-at} \tag{15}$$

Similarly for two zone green house

$$T_1 = \frac{(AI)_{effA} + F_1(AI)_{effG} + (UA)_{a-1}T_a + (UA)_{1-a}T_a + h_P T_{P2} A_P}{(UA)_{1-a} + (UA)_{a-1} + A_P h_P} \tag{16}$$

$$T_{P2} = \frac{\bar{B}(t)}{a}\left(1 - e^{-at}\right) + T_{P2o}e^{-at} \tag{17}$$

where

$$B(t) = \frac{Z(AI)_{effP} + h_P A_P \left\{F_1 (AI)_{effG} + (AI)_{effA} + (UA)_{1-a} T_a + (UA)_{a-1} T_a\right\}}{ZM_P C_P}$$

$$Z = (UA)_{1-a} + (UA)_{a-1} + A_P h_P;\ a = \frac{h_P A_P}{ZM_P C_P}\left((UA)_{1-a} + (UA)_{a-1}\right)$$

$$(\alpha_P)(F_P)(\tau_3)(\tau_2)\left\{\sum_{i=1}^{6} A_i I_i\right\} = (AI)_{effP};$$

$$(\alpha_g)(1 - F_P)(\tau_3)(\tau_2)\left\{\sum_{i=1}^{6} A_i I_i\right\} = (AI)_{effG};\ (1 - \alpha_g)(1 - F_P)(\tau_3)(\tau_2)\left\{\sum_{i=1}^{6} A_i I_i\right\} = (AI)_{effA}$$

$$(UA)_{a-1} = \frac{h_{gl} h_{g\infty} A_g}{h_{gl} + h_{g\infty}};\ (UA)_{1-a} = \frac{h_{12} h_{2a} A_R A_g}{h_{12} A_g + h_{2a} A_R};\ F_1 = \left(\frac{h_{gl}}{h_{gl} + h_{g\infty}}\right)$$

for three zone green house

$$T_1 = \frac{(AI)_{effA} + F_1 (AI)_{effG} + (UA)_{a-1} T_a + (UA)_{1-a} T_a + h_P T_{P3} A_P}{(UA)_{1-a} + (UA)_{a-1} + A_P h_P} \tag{18}$$

$$T_{P3} = \frac{\bar{B}(t)}{a}\left(1 - e^{-at}\right) + T_{P3o}e^{-at} \tag{19}$$

$$B(t) = \frac{Z(AI)_{effP} + h_P A_P \left\{F_1 (AI)_{effG} + (AI)_{effA} + (UA)_{1-a} T_a + (UA)_{a-1} T_a\right\}}{ZM_P C_P}$$

$$Z = (UA)_{1-a} + (UA)_{a-1} + A_P h_P$$

$$a = \frac{h_P A_P}{ZM_P C_P}\left((UA)_{1-a} + (UA)_{a-1}\right);\ (\alpha_P)(F_P)(\tau_3)(\tau_2)(\tau_1)\left\{\sum_{i=1}^{6} A_i I_i\right\} = (AI)_{effP}$$

$$(\alpha_g)(1 - F_P)(\tau_3)(\tau_2)(\tau_1)\left\{\sum_{i=1}^{6} A_i I_i\right\} = (AI)_{effG};\ (1 - \alpha_g)(1 - F_P)(\tau_3)(\tau_2)(\tau_1)\left\{\sum_{i=1}^{6} A_i I_i\right\} = (AI)_{effA}$$

The values of plant temperature can be solved for one zone greenhouse (Eq. 15), two zone greenhouse (Eq. 17) and three zone greenhouse (Eq. 19). By using the plant temperature (Eq. 15, 17 and 19) the temperature of greenhouse without curtain (Eq. 13), temperature of zone one of two zone greenhouse (Eq. 16) and temperature of zone one of three zone greenhouse (Eq. 18) can be calculated and further these values are used to calculate the temperature in different zones of green house.

Thermal Load Leveling

As the fluctuation of air temperature in the vicinity of plants play a vital role for their growth and development, these fluctuations in temperature have been quantified by a factor called thermal load leveling (TLL) and is expressed mathematically as

$$\text{Thermal load leveling } (\text{TLL}) = \frac{T_{r,max} - T_{r,min}}{T_{r,max} + T_{r,min}} \tag{20}$$

In winter lower values of TLL can be achieved by increasing the minimum temperature with the help of heating arrangements, resulting in the increase of $T_{r,max} + T_{r,min}$ as well as decrease of $T_{r,max}$ - $T_{r,min}$.

Results and Discussion

The values of plant temperature can be solved for one zone greenhouse, two zone greenhouse and three zone greenhouse by using Eq.15, 17, 19 and Table 1 having input parameters. By using the plant temperature the temperature of greenhouse without curtain, temperature of zone 1 of two zone greenhouse and temperature of zone 1 of three zone greenhouse can be calculated (by using Eq. 13, 16 and 18, respectively) and further these values are used to calculate the temperature in different zones of greenhouse. The total solar radiation on the greenhouse is solved by using the Liu and Jordan formula; results for total solar radiation on the greenhouse for different month, November, December, January and February are shown in Fig. 2. It can be seen that total solar radiation is coming maximum for February month whereas minimum for December month.

Variation of temperature of greenhouse without thermal curtain, with one thermal curtain (zone 1 and 2) and with two thermal curtains (zone 1, 2 and 3) for November month has been shown in Fig. 3. It is seen that temperature of greenhouse without thermal curtain is maximum during peak sunshine hours (10.3°C) whereas minimum during night time (3.6°C). During night time temperature of green house without curtain is 5.4°C more than ambient temperature, whereas this difference increases (7.0 to 8.8°C) during morning hours (8.00 to 10 h). It has been observed that maximum

Table 1: Input parameters used for computation

Parameter	Values
A_e	10 m^2
A_w	10 m^2
A_n	12 m^2
A_s	12 m^2
A_{nr}	13.4 m^2
A_{sr}	13.4 m^2
A_g	24 m^2
C_p	4190 J/kg°C
F_p	0.3
h_{12}	2.8 W m^{-2}°C
h_{23}	2.8 W m^{-2}°C
h_{3a}	9.5 W m^{-2}°C
h_{gl}	2.8 W m^{-2}°C
$h_{g\infty}$	0.52 W m^{-2}°C
h_t	65.31 W m^{-2}°C
h_p	27.35 W m^{-2}°C
M_p	190 kg
α_g	0.4
α_p	0.5
τ_1	0.8
τ_2	0.25
τ_3	0.25

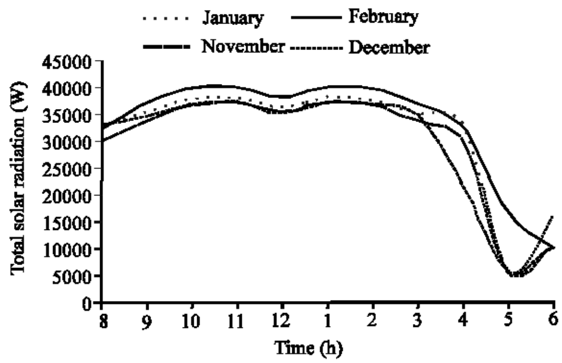

Fig. 2: Total solar radiation on greenhouse on a typical day in during November, December, January and February for Srinagar, India

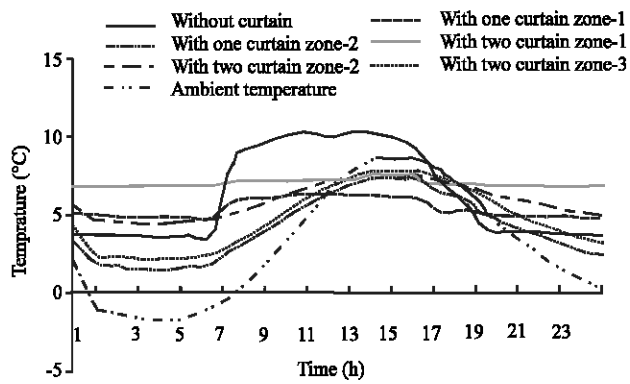

Fig. 3: Hourly variation of temperature in greenhouse without curtain, with one curtain and with two curtains during November month for Srinagar, India

temperature decreases during day time whereas increases during night time when thermal curtains are used (Fig. 3). For two zone greenhouse (greenhouse having one thermal curtain) the temperature of zone 1 varies from 4.8 to 6.3°C whereas in zone 2 temperature varies from 1.5 to 7.4°C (Fig. 3). It is seen that temperature is maximum in zone 1 of three zone greenhouse during night time with comparison to zone 1 and zone 2 greenhouse due to use of thermal curtains; as curtain reduces heat losses significantly during night time. It has been find out that temperature of zone 1 of three zone greenhouse is 3.2°C more than temperature of greenhouse without curtain and 2.1°C more than temperature of zone 1 of two zone greenhouse during night time (Fig. 3). It has been find out that temperature of zone 1 of three zone greenhouse is 8. 7°C more than ambient temperature during night time (Fig. 3).

Variation of temperature of greenhouse without curtain, with one curtain and with two curtain for the month of December, January and February months are shown in Fig. 4-6. It has been seen that in the three zone greenhouse (greenhouse with two curtains) temperature is more or less constant in all the months. For the month of December, January and February month it varies between 5.9 to 6.3°C. The temperature of zone 2 of three zone greenhouse varies between 3.8 to 6.9°C, 3.6 to 5.7°C and 4.1 to 6.7°C during December, January and February month (Fig. 4-6). The temperature in zone 3 of three zone greenhouse is low in night time due to more losses from canopy to ambient, whereas more during day time as it receives maximum radiation. Temperature of zone 2 of all type of greenhouses is in between the temperature of zone 1 and zone 3.

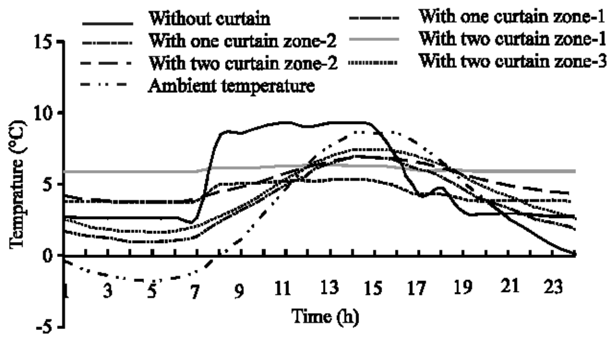

Fig. 4: Hourly variation of temperature in greenhouse without curtain, with one curtain and with two curtains during December month for Srinagar, India

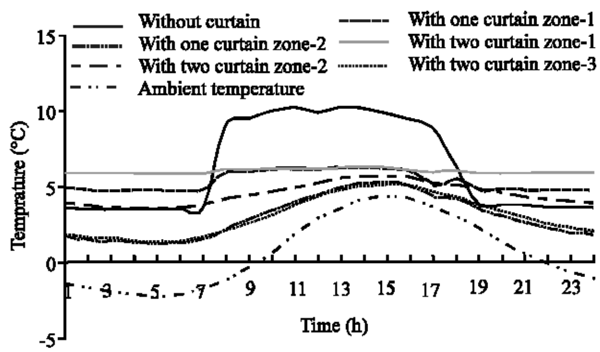

Fig. 5: Hourly variation of temperature in greenhouse without curtain, with one curtain and with two curtains during January month for Srinagar, India

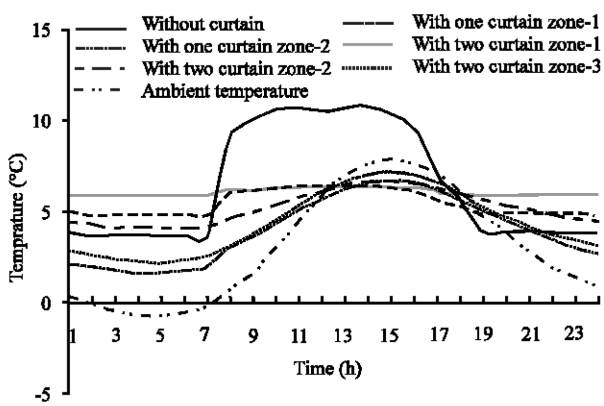

Fig. 6: Hourly variation of temperature in greenhouse without curtain, with one curtain and with two curtains during February month for Srinagar, India

Table 2 shows the thermal load leveling (Eq. 20) for greenhouse without curtain, greenhouse with one curtain (zone 1 and 2) and greenhouse with two curtain (zone 1-3). It has been find out that the thermal load leveling is minimum in the greenhouse having two curtains (three zone greenhouse) with

Table 2: Values of thermal load leveling for different months in one zone, two zone and three zone greenhouse

Month	With out curtain	With one curtain zone-1	With one curtain zone-2	With two curtain zone-1	With two curtain zone-2	With two curtain zone-3
November	0.4820	0.1351	0.6629	0.2816	0.2561	0.5643
December	0.5500	0.1739	0.7468	0.0327	0.2897	0.6304
January	0.4820	0.1351	0.5142	0.0327	0.2258	0.5522
February	0.4861	0.1428	0.5604	0.0327	0.2407	0.5217

comparison to all types under study. If we consider the zone 1 of all the greenhouses the value of thermal load leveling is maximum for greenhouse without curtain and minimum for greenhouse with two curtains. Minimum value of thermal load leveling means least fluctuations in temperature; this is due to use of thermal curtain. As the thermal curtain cuts the convection currents and reduces losses and it also helps in maintaining the temperature in the vicinity of plants by accumulating the energy surrounding the plants or ground during day time.

Conclusions

On the basis of present study following conclusions can be made,

- The maximum temperature during night time in the vicinity of plants is created in the three zone greenhouse (greenhouse with two thermal curtains).
- Fluctuations of temperature are minimum in the zone 1 of three zone greenhouse.
- The temperature of greenhouse without curtain is maximum during day time, whereas less during night time with comparison to greenhouse with one and two curtain.
- The temperature of greenhouse can be increased more if any auxiliary heating is made.
- Use of thermal curtain is a very good option for energy conservation in a greenhouse at very cold weather condition.

Nomenclature

A	Area (m^2)
C_a	Specific heat of air (J/kg °C)
C_P	Specific heat of plant (J/kg °C)
F_P	Fraction of incoming solar radiation falling on plants (dimensionless)
h_{gl}	Convective heat transfer coefficient from floor of greenhouse to air in zone I ($W\ m^{-2}$°C)
h_{12}	Convective heat transfer coefficient from air in zone I to zone II ($W\ m^{-2}$°C)
h_{23}	Convective heat transfer coefficient from air in zone II to zone III ($W\ m^{-2}$°C)
h_{3a}	Convective heat transfer coefficient from air in zone III to zone III to ambient air ($W\ m^{-2}$°C)
h_t	Convective heat transfer coefficient from flowing hot water to zone I ($W\ m^{-2}$°C)
h_p	Convective and evaporative heat transfer coefficient from plant mass to zone I ($W\ m^{-2}$°C)
$h_{g\infty}$	Heat transfer coefficient from ground to larger depth of ground ($W\ m^{-2}$°C)
$A_j\ I_j$	Solar radiation falling on different surfaces of greenhouse cover ($W\ m^{-2}$)
M_p	Total mass of plant (kg)
T	Temperature (°C)
T_o	Temperature inside ground (°C)
T_{p1}	Plant temperature in greenhouse without curtain (°C)
T_{p2}	Plant temperature in greenhouse with one curtain (two zone greenhouse) (°C)
T_{p3}	Plant temperature in greenhouse with two curtain (three zone greenhouse) (°C)

Greek Symbols

- α Absorptivity (dimensionless)
- τ_1 Transmissivity of thermal blanket (dimensionless)
- τ_2 Transmissivity of thermal curtain (dimensionless)
- τ_1 Transmissivity of greenhouse cover (dimensionless)
- ∞ Infinity (at larger depth)

Subscripts

- 1 Zone I in the greenhouse
- 2 Zone II in the greenhouse
- 3 Zone III in the greenhouse
- a Ambient
- g Ground of greenhouse
- i Different walls and roofs of greenhouse
- P Plant
- r Room

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