CHAPTER 4

OVERALL HEAT TRANSFER COEFFICIENT OF
GREENHOUSE
4.1 INTRODUCTION

Heat transfer is of great importance in modern greenhouse technology and therefore, understanding of its basic concept and practical application in evaluating the performance of a greenhouse under given climatic conditions becomes necessary. Heat may be transferred inside the greenhouse by thermal radiation, conduction, convection and evaporation. Based on these modes, computation of overall heat transfer coefficient ($U_t$) is a very important parameter for the thermal design of any greenhouse cooling or heating system. It is a direct function of the amount of heat lost by the greenhouse and has a very important role in calculating the amount of heat required for achieving the required temperature inside the greenhouse using different heating or cooling methods. Different conduction equations have been discussed in detail by (Duffie, 1991). Fundamental work related to convection heat transfer has been done by many researchers such as DeGrof et al. (1953), McAdams (1954), Duncle (1961) and Watmuff (1977) and developed many useful relations. Many relations of thermal radiation have been developed by scientists such as Swinbank (1963), Whiller (1967), Fernandez and Chargoys (1990) and Bansal (1990). Evaporative heat transfer has also been discussed by Jacob & Gupta (1954) and Tiwari & Goyal (1998).

Solar radiation, after transmission from the canopy cover, is partly absorbed by the plant and the floor receives the rest. After absorption of solar radiation, a small part is lost to the ground through conduction and the remaining part of the radiation is transferred to the greenhouse air by convection and evaporation. The enclosed room air is thus heated and then the various thermal losses occur, through canopy cover, ground, door, ventilation and infiltration etc. All these losses can be expressed in terms of an overall heat loss coefficient ($U_t$). The exact value of $U_t$ for the greenhouse helps in designing of any heating or cooling system for the greenhouse.

4.2 OUTSIDE HEAT TRANSFER

Heat transfer outside the greenhouse occurs from the roof, walls and door(s) of the greenhouse and is mainly governed by radiation, convection and conduction, which are independent of each other. Different greenhouse coefficients are shown below.

4.2.1 Outside Radiation Heat Transfer Coefficient

The temperature of the transparent canopy cover may be assumed to be uniform owing to its small thickness. The outside heat loss due to radiation per square meter from the canopy cover to atmosphere ($q_{ro}$) may be termed as

$$q_{ro} = h_{ro} (T_c - T_a)$$

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\[ h_{ro} = \frac{\varepsilon \times F_{c-a} \times \sigma ((T_c + 273)^4 - (T_{sky} + 273)^4)}{(T_c - T_a)} \]

\[ \varepsilon = \left[ \frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1 \right] \]

where

\[ T_{sky} = T_a - 6 \]  
(Swinbank, 1962)

### 4.2.2 Outside Convective Heat Transfer Coefficient

Outside heat loss due to convection per sq m from the canopy cover to atmosphere is

\[ q_{co} = h_{coc} (T_c - T_a) \]

where

\( h_{coc} \) may be determined as reported by Watmuff (1977) in which only convective heat transfer is considered

\[ h_{coc} = 2.8 + 3.0 \nu \]

The combined effect of radiation and convection from the canopy cover as reported by McAdams (1954) is also described as

\[ h_{coc} = 5.7 + 3.8 \nu \]

The Eqns. (4.2) and (4.4) are also valid for walls with the following modifications

\[ T_{sky} = T_a \]

\[ \nu = 0, \text{ for wind velocity perpendicular to the walls} \]

Therefore, total outside heat transfer coefficient \( h_o \) can be calculated by adding Eqn (4.2), and (Eqn. 4.4)

\[ h_o = h_{ro} + h_{coc} \]

### 4.2.3 Conductive Heat Transfer Coefficient

Heat is also transferred to or lost from the greenhouse ground due to conduction. The ground is assumed to be made of multi-layers. Thus bottom heat transfer coefficient \( h_b \) under steady state condition as suggested by Duffie (1991) can be written as

\[ h_b = \left[ \Sigma L_i / K_i \right]^{-1} \]

Average heat flux conducted into the ground may be taken as 8% of the inside solar radiation Garzoli (1973) using the following relation

\[ S = 0.08 A_g I_i \]
4.3 INSIDE HEAT TRANSFER

Inside heat transfer includes heat transfer due to radiation, convection and evaporation, which occurs from the floor, air and plants with in the greenhouse. Through these modes canopy cover receives heat from the floor as well as from the plants.

4.3.1 Inside Radiation Heat Transfer Coefficient

The rate of inside radiative heat transfer $q_r$ from the floor to the canopy cover is given by

$$q_r = e_{eff} \sigma F_{c-a} (T_f^4 - T_c^4)$$

Where

$$e_{eff} = \left[ \frac{1}{e_c} + \frac{1}{e_f} - 1 \right]^{-1}$$

4.3.2 Inside Convective Heat Transfer Coefficient

Convective heat transfer coeff from plant to inside air has been proposed by Bansal (1988)

$$h_{pa} = 2.38 (T_P - T_R)^{0.25} \quad \text{for} \ v = 1.0 \text{ m/s}$$

$$= 12.1 \sqrt{v} \quad \text{for} \ 1.0 < v < 2.6 \text{ m/s}$$

Convective heat transfer from inside air to canopy can be found by the same relation as given in Eqn. (4.4) assuming $v$ as 0 m/s.

$$h_p = 2.8 + 3.0 \nu$$

4.3.3 Inside Evaporative Heat Transfer Coefficient

Calculation of evaporative heat transfer coefficient as shown by Cooper (1973) without linearization is

$$h_{pr} = \frac{0.016 \times h_p [p(T_P) - \gamma p(T_R)]}{T_P - T_R}$$

and with linearization

$$h_{pr} = \frac{0.016 \times h_p \left[R_1(T_P - \gamma T_R) + R_2(1 - \gamma)\right]}{T_P - T_R}$$

The partial vapour pressures of plant and room air temperatures have been linearized as $p(T_p) = R_1 T_p + R_2$, and $p(T_R) = R_1 T_R + R_2$. $R_1$ and $R_2$ have been obtained by linear regression analysis for a given operating temperature range which varies with climatic conditions.
Now the total inside heat transfer coefficient can be obtained by combining the Eqns 4.11, 4.13, 4.14 and 4.16 as

\[ h_i = h_r + h_p + h_{pa} + h_{pr} \]

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4.4 OVERALL HEAT LOSS COEFFICIENT

Overall heat loss coefficient \( U_t \) for the greenhouse can now be calculated as

\[ U_t = \left[ \frac{1}{h_o} + \frac{1}{h_i} + \frac{1}{h_b} \right]^{-1} \]

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The above mentioned equation has been used to calculate \( U_t \) and the total heat required to be added or removed from the greenhouse depending upon the climatic conditions.

4.4.1 Total Heat Loss from the Greenhouse

Heat loss \( q \) from the greenhouse per unit area is thus given by

\[ q = U_t \times \Delta T \]

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where

\( \Delta T \) is the difference between the outside \( (T_a) \) and greenhouse room air temperature \( (T_R) \)

4.5 INFILTRATION/VENTILATION

Infiltration refers to admittance of outside air through door and/or ventilator openings and cracks, and interstices around the door and ventilators into the greenhouse controlled space.

The rate of infiltration losses due to ventilation/infiltration is given by Tiwari, 1998

\[ q_g = \rho_a c_a (T_R - T_a) \]

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\[ = (V_g/t) \rho_a c_a (T_R - T_a) \]

4.20

Substituting the values of \( c_a \), \( \rho_a \) and \( t = 3600/N \) are put in Eqn. 4.20 to obtain the infiltration loss through the greenhouse

\[ q_g = 0.33 N V_g (T_R - T_a) \]

4.21

where

\( N \) is the number of air changes per hour, \( V_g \) is the volume of greenhouse in m³