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On the determination of the Convection Heat Transfer Conductance at the Greenhouse Cover, Under Semi Arid Climatic Conditions

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AIM OF THE STUDY

Crop cultivation in greenhouses under semi-arid climatic conditions is subject to various stresses, in particular during the winter season at night, when the interior air is poorly controlled, leading to prolonged periods of low temperature. Because only sketch studies have been devoted to convective transfert in greenhouses under arid climates, the first aim here is to establish new correlations for the convective heat transfer coefficients and to make comparison with models available in the literature for other climatic conditions and greenhouse designs. The second aim of this work is to present a simple empirical method based on in situ measurements to get the heat transfer coefficients of the greenhouse cover. This method could be extended to other greenhouse designs under similar climatic conditions.

GOVERNING EQUATIONS

The convective heat transfer coefficients were determined from the energy balance of the greenhouse cover. The balance includes the radiative, convective and conductive contributions on both sides of the cover (Fig. 1). Assuming that natural convection prevails inside the greenhouse and forced convection outside, the expressions of the inside h_{ai-ci} and outside h_{ao-co} convective coefficients take the form $a(T_{ai}-T_{ci})^{0.33}$ and $b+cU_e^d$.

Inside cover energy balance $Q_{ci}^R + a(T_{ai}-T_{ci})^{1.33} - \frac{\lambda_c}{e}(T_{ci}-T_{co}) = 0$ (1)

Outside cover energy balance $Q_{co}^R + \frac{\lambda_c}{e}(T_{ci}-T_{co}) - b(T_{ao}-T_{co}) - c(T_{ao}-T_{co})U_e^d = 0$ (2)

a, b, c, and d were estimated by using the least-square method yielding :

$h_{ai-ci} = 3.68(T_{ai}-T_{ci})^{0.33}$ (3) and $h_{ao-co} = 2.56 + 2.34\,U_e^{0.69}$ (4)

Thermal heat flux;
Convective heat flux;
Conduction heat flux.
R_1, R_2, R_3, Radiative fluxes absorbed by the cover from the soil, roof and sky;
R_{ci} Radiative flux emitted by the inner surface of the cover;
R_{co} Radiative flux emitted by the outer surface of the cover;
R_{sky} Radiative flux emitted by the sky;
Q_{co-ao}^{cov} Convective heat flux between the outside cover surface and the surrounding air;
Q_{ci-ai}^{cov} Convective heat flux between the inside cover surface and the inside air of the greenhouse;
Q_{ci-co}^{cod} Conductive heat flux between the inside and the outside cover surfaces.

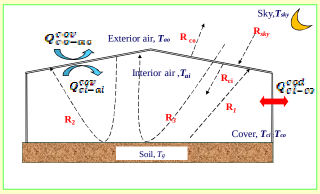

Fig. 1 Energy fluxes exchanged at the greenhouse cover.

Radiative fluxes may be estimated from theoretical considerations :

$Q_{ci}^R = R_1 + R_2 + R_3 - R_{ci}$ (5) $Q_{co}^R = R_{co} - R_{sky}\alpha_{co}$ (6)

with $R_1 = \frac{\varepsilon_s \sigma T_s^4 \alpha_{ci}}{1-\rho_s\rho_{ci}}$, $R_2 = \varepsilon_{ci}\sigma T_{ci}^4 \frac{\rho_s\alpha_{ci}}{1-\rho_s\rho_{ci}}$, $R_3 = \varepsilon_{sky}\sigma T_{sky}^4 \frac{\tau_c\rho_s\alpha_{ci}}{1-\rho_s\rho_{ci}}$,

$R_{ci} = \varepsilon_{ci}\sigma T_{ci}^4$, $R_{co} = \varepsilon_{co}\sigma T_{co}^4$ and $R_{sky} = \varepsilon_{sky}\sigma T_{sky}^4$

EXPERIMENTAL DEVICE AND MEASUREMENT TECHNIQUES

Experimental data were recorded over three periods of the winter season at night (from 6 pm to 6 am local time). The indoor temperature of the air, the cover surface temperatures of the greenhouse, and the ground temperature were measured. Simultaneously, the outside climatic data (external wind speed and direction, outside air temperature and humidity) were recorded with four sensors installed above the roof surface of the greenhouse at 1m height. A schematic view of the experimental device is shown in Fig. 2. All measurements were collected on a data logger system (Campbell Scientific Micro logger, CR3000), sampled at 2s intervals and then averaged over 30min periods.

Air temperature and humidity probe
Platinum probe
Wind vane
Cup anemometer
Thermocouple.

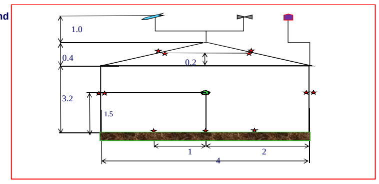

Fig. 2 Sketch of the experimental device

RESULTS

To check the validity of the developed method, the calculated values of the net radiation of the outside surface of the cover Q_{co}^R derived from from fundamental calculations (Eq. 6) were plotted against values estimated by the model (Eq. 2). The developed method showed fair agreement, with a high coefficient of determination r^2=0.84 (Fig. 3). Measured and predicted (Eq. 1) values of the inside air temperature T_{ai} were also compared (Fig. 4). Here again, a good agreement was obtained (r^2=0.91).

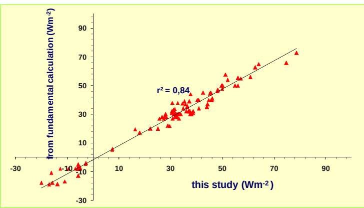

Fig. 3 Comparison between values of the net radiation of the outside surface of the cover obtained from fundamental calculation and estimated by the model of this study

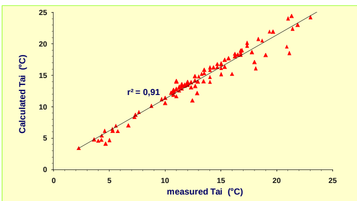

Fig. 4 Comparison between the measured and calculated temperatures of the inside air of the greenhouse

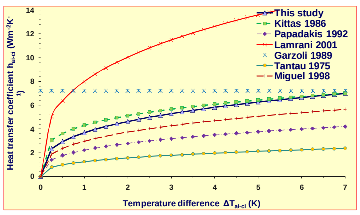

Fig. 5 Variation of h_{ai-ci} for the inside cover surface as a function of the temperature difference according to different authors

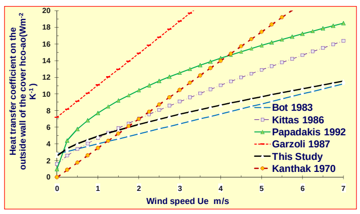

Fig. 6 Variation of h_{ao-co} for the outside cover surface as a function of the external wind speed according to different authors

Inside the greenhouse, the obtained values of the exchange coefficient (Eq. 3) were analysed against literature data (Fig. 5). The significant difference was due to the different conditions inside the greenhouse (heating and ventilation systems). Along the outside surface of the cover, the values of the convective coefficients (Eq. 4) were plotted as a function of the external wind speed (Fig. 6). The differences were due to the different geometries, cover materials, and climatic conditions considered.

CONCLUSIONS

New correlations for the heat transfer coefficients under semi-arid conditions were established in this study. They could be used to calculate the convective exchange heat transfer in closed Venlo type greenhouses under similar climatic conditions. Further experimental and modeling efforts however are still needed to establish suitable expressions for the convection heat transfer coefficients in greenhouses, for other geometry with different cover, in order to analyze the impact of the design on these coefficients under semi-arid climate conditions.