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Investigations on the external thermal radiation exchanges between glass-covered greenhouse surfaces and the sky

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1. Introduction, Knowledge, Objectives

During cold seasons, nighttime and daytime temperatures can sink below the biological optimum necessary for sustainable modern protected cultivation. This is predominant in Europe during winter seasons. Greenhouses are therefore heated in such cases to generate and maintain warmer climate within itself. This allows an extension of the cropping period (Tantau, 2013). Due to heating, temperature stands out as a critical variable influencing the radiation exchange of the surface with the sky, ground and other surrounding objects. Thermal radiation exchange is an essential component of the energy balance on the surface. Better understanding and accurate computation of thermal radiation exchanges between the external cover surfaces and the atmosphere is therefore critical. This study aims at modelling the thermal radiation exchanges between glass-covered greenhouse surfaces and the sky at representative test conditions. This will form a basis of checking the influence of thermal radiation on the overall heat transfer coefficient (U_{cs}-value). The results are necessary in improving the U_{cs}-value model.

2. Material and Methods

2.1 Greenhouse surface model

A developed greenhouse surface model (Fig. 1) inclined at an angle of 26.5^o was used to represent similar conditions of real greenhouses. The surface design measured 2 m long and 1.5 m wide. The surface of interest in this study was the top part of an empty box enclosure representing a dry greenhouse (with no plants). Heating elements (type 01.123: 800 W, Cr/Ni tubes, 6.9 mm diameter and 1.11 m length; type 02.251: 2000 W, Cr/Ni tubes, 8.5 mm diameter and 1.11 m length) were used to provide a heat distribution in the box and thus enabling U_{cs}-value measurements. Steel glazing bars usually used in reinforcing glass were incorporated on the external cover surface. The area under glass and glazing bars amounted to 86 % and 14 %, respectively.

The developed system was placed outdoors at the Biosystems Engineering Section, Institute of Horticultural Production Systems, Leibniz Universität Hannover (52.375^o N and 9.739^o E). This helps in understanding the influence of atmospheric conditions such as air temperature, wind speed and direction, relative humidity, cloudiness and rain on the thermal radiation exchanges.

Fig. 1. Greenhouse surface model for the thermal radiation exchange measurement.

2.2 Measurement of parameters

The temperatures were measured with precision temperature sensors (TS-NTC-104, Hygrosens, Germany). They had a wide temperature range of -60 to 150 ^{o}C with an accuracy of ±0.12 K at 25 ^{o}C. In the temperature range of -60 to 85 ^{o}C the maximum error was around ±0.5 K. Relative humidity was measured with a handheld psychrometer. Net radiation was measured using a CNR 4 net radiometer (Kipp & Zonen, Delft, The Netherlands) and four 240-8110 net radiometers (NovaLynx Corporation, California, USA). The CNR 4 design was such that both the upward facing and downward facing instruments measured the energy that was received from the whole hemisphere. The temperature sensors incorporated in the CNR 4's body near the pyrgeometer sensing element measured its temperature, which is taken into account in correcting the measured longwave irradiance (Kipp & Zonen, 2009). The atmospheric and radiation parameters were measured during the months of January and February 2014 at every 15 and 30 seconds, respectively. External surface inspection was done with a thermal camera (Varioscan 3022, Jenoptic Laser, Jena, Germany) with glass temperatures which were always higher than those of the glazing bars.

Cloudiness factors were integrated into the models by two different approaches: C_1-factors were obtained from cloudiness octa (eights) values given by the German Meteorological Service (www.dwd.de). They relied on hourly recorded values assigned by an experienced weather watcher. Secondly, hourly C_2-factors were estimated by a computer-based analysis of weather maps from Weather Online (www.wetteronline.de). For this, 12 weather maps per hour (interval of 5 minutes) were analyzed using a vision-based algorithm developed in Halcon 11.0 (HALCON Version 11.0.3, 2012). The simulated radiation exchange (using Equa. (3)) was compared with the average net radiation loss (negative net radiation) measured at the glass-covered surface.

2.3 Mathematical modelling of thermal radiation exchange

The equation for downwelling (from sky to glass surface) longwave radiation $LWRAD_d$ under all-sky conditions has the general form given by Eq. (1) (Choi et al., 2008; Duarte et al., 2006). According to Howard and Stull (2013), longwave radiation from the surrounding objects such as trees should not be neglected since it enhances the $LWRAD_d$ and this yields the total downwelling longwave radiation $LWRAD_{d,t}$ (Eq. (2)). This is specifically added for purposes of comparing the total simulated values with the measurements from the CNR 4 net radiometer.

$$LWRAD_d = \varepsilon_a \left(1 + bC^d\right)\sigma T_a^4 \tag{1}$$

$$LWRAD_{d,t} = LWRAD_d + \varepsilon_{gnd} F_{gnd}\, \sigma T_a^4 \tag{2}$$

$$Q_{lw} = \varepsilon_s \sigma \left\{\varepsilon_{sky} F_{sky} \left(T_s^4 - T_{sky}^4\right) + \varepsilon_a F_{air} \left(T_s^4 - T_a^4\right) + \varepsilon_a F_{gnd} \left(T_s^4 - T_{gnd}^4\right)\right\} \tag{3}$$

$$T_{sky} = \left[1.2T_o - 21.4 + C\left(20.6 - 0.26T_o\right)\right] + 273.15 \tag{4}$$

$$LWRAD_{u,t} = Q_{lw} + LWRAD_d + \left(1 - \varepsilon_s\right) LWRAD_d \tag{5}$$

ε_a : effective atmospheric emissivity [-]
ε_{gnd} : emissivity of surrounding objects [-]
ε_s : cover surface emissivity [-]
ε_{sky} : sky emissivity [-]
σ : Stefan-Boltzmann constant = 5.67×10^{-8} [$Wm^{-2}K^{-4}$]
a : splitting factor = $\{\cos^2(\beta/2)\}^{0.5}$ [-]
b, d : coefficients determined experimentally [-]
C : cloudiness factor [-]
F_{air} : view factor to the air = $(1-a)\cos^2(\beta/2)$ [-]
F_{gnd} : view factor to the ground = $\sin^2(\beta/2)$ [-]
F_{sky} : view factor to the sky = $a\cos^2(\beta/2)$ [-]
β : surface inclination angle [degree]
T_a : air temperature [K]
T_{gnd} : ground temperature [K]
T_o : outside air temperature [°C]
T_s : surface temperature [K]
T_{sky} : sky temperature [K]

The longwave radiation exchange between surfaces is dependent on the surface temperatures, spatial relationships between the surfaces and their surroundings, and relevant material properties (emissivity and absorptivity) of the surfaces. Considering the exterior surface and the view factors, the total thermal radiation exchange Q_{lw} is therefore the sum of components due to exchange with the sky, air and ground (Eq. (3)). For a non-horizontal surface (e.g. roof and wall), the view factor has to be used since this is less than one. This factor depends on the orientation of the surfaces and defines the proportion of thermal radiation exchange between these surfaces. A model by von Elsner (1982) was selected for calculating the sky temperature since it was developed within the same study location (Eq. (4)). The emitted longwave radiation by the cover surface plus the reflected $LWRAD_d$ from the sky gives the total upwelling (from glass surface to sky) longwave radiation $LWRAD_{u,t}$ as expressed in Eq. (5). The parameter $LWRAD_d$ is used in Eq. (5) since this is the specific sky radiation component and the Q_{lw} model (Eq. (3)) already captures the radiation exchange with the ground with its respective view factor.

3. Results

Fig. 2 shows a slight uneven distribution of surface temperatures resulted in variation of net radiation values captured by the five net radiometers. The simulated and measured values of downwelling and upwelling longwave radiation are compared in Fig. 3. The measured values were those specifically obtained from the CNR 4 net radiometer since the signal outputs allow the downwelling and upwelling longwave radiation components to be recorded separately.

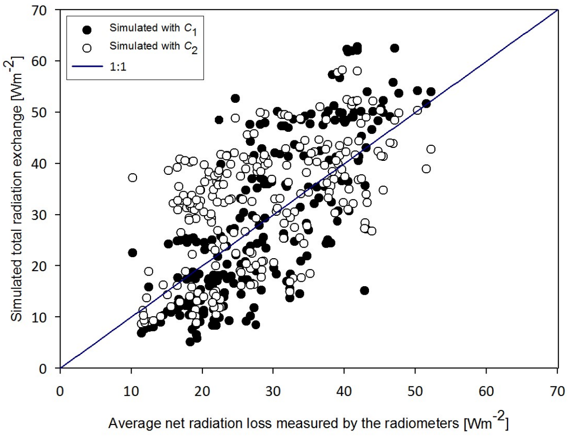

Fig. 2. Comparison of simulated radiation exchange and measured net radiation loss.

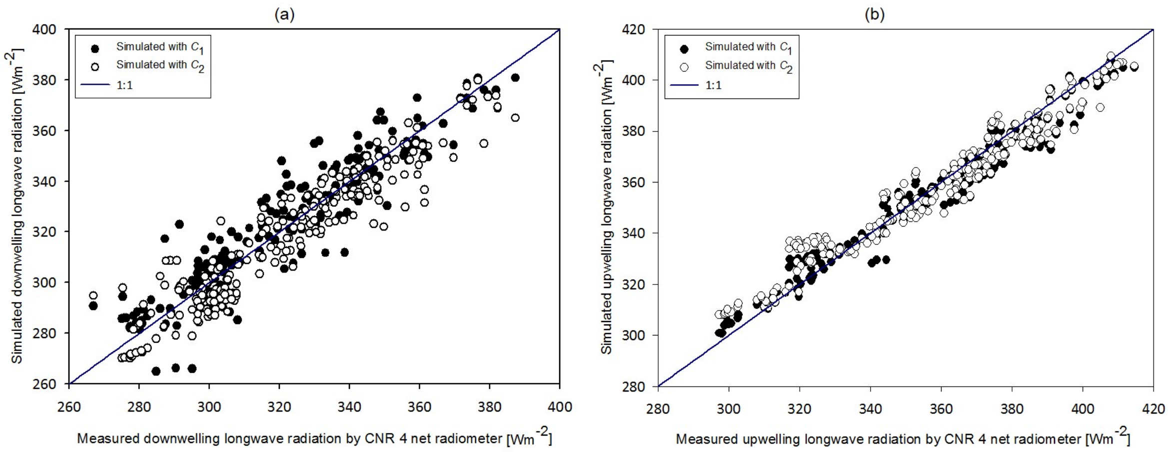

Fig. 3. Comparison of simulated and measured downwelling (a) and upwelling (b) longwave radiation.

This shows that cloud cover is a critical parameter in radiation exchanges and the two approaches (C_1 and C_2) can be utilized to improve the performance of the longwave radiation models. The octa-based C_1 and map-based C_2 cloudiness factors showed non-significant differences ($p > 0.05$) in the simulations of the longwave radiation.

4. Discussion

The thermal radiation exchange between two surfaces is dependent predominantly on their surface temperatures, surface properties and their relative positions. At night, the external cover surface exchanges longwave radiation with the sky, air and ground. The view factor between the surfaces is important in the thermal radiation exchange Q_{lw} model. This effect has been successfully applied by Howard and Stull (2013) in the case of downwelling longwave radiation over a groomed ski run. The Q_{lw} model includes all the relevant parameters and the trend (Fig. 2) indicates how it compares well with the measured net radiation loss. The presence of clouds increases atmospheric irradiance received at the surface. This could be attributed to the fact that radiation from water vapour and carbon dioxide in the lower atmosphere gets supplemented by emission from clouds in the waveband which the gaseous emission lacks (Iziomon et al., 2003). For simulation under all-sky conditions cloudiness factors are needed and the two approaches used (C_1 from octa values and C_2 from analyzed weather maps) gave promising results.

5. Conclusions

The findings of this study have demonstrated that prediction models provide a more realistic understanding of thermal radiation exchange between the cover surfaces and the sky if cloudiness factors are used in the simulations. The radiation exchange between the cover surface and the sky depends on the surface orientation which could be represented by view factors. The generated model explains the relationships between specific exterior thermal performance of the cover, atmospheric conditions and energy consumption. Considering all the model parameters, there is a possibility to determine the significance of the thermal radiation in the U_{cs}-value model. Therefore the knowledge is useful for enhancing efficient greenhouse production throughout the year.

6. Literature

Choi, M., Jacobs, J.M. and Kustas, W.P. (2008). Assessment of clear and cloudy sky parameterizations for daily downwelling longwave radiation over different land surfaces in Florida, USA. *Geophysical Research Letters*, 35, L20402.

Duarte, H.F., Dias, N.L. and Maggiotto, S.R. (2006). Assessing daytime downward longwave radiation estimates for clear and cloudy skies in southern Brazil. *Agricultural and Forest Meteorology*, 139: 171-181.

German Meteorological Service (Deutscher Wetterdienst, DWD). WebWerdis. http://werdis.www.dwd.de. Accessed on 9th July 2013.

HALCON Version 11.0.3 (2012). HALCON/HDevelop Reference Manual. MVTec Software GmbH, München, Germany.

Howard, R. and Stull, R. (2013). Modeling the downwelling longwave radiation over a groomed ski run under clear skies. *Journal of Applied Meteorology and Climatology*, 52(7): 1540-1553. DOI: 10.1175/JAMC-D-12-0245.1.

Iziomon, M.G., Mayer, H. and Matzarakis, A. (2003). Downward atmospheric longwave irradiance under clear and cloudy skies: Measurement and parameterization. *Journal of Atmospheric and Solar-Terrestrial Physics*, 65: 1107-1116.

Kipp & Zonen (2009). Instruction manual, CNR 4 net radiometer. Manual version 1107. Delft, The Netherlands.

Tantau, H.-J. (2013). Heat requirement of greenhouse including latent heat flux. *Landtechnik*, 68(1): 43-49.

Von Elsner, B. (1982). Das Kleinklima und der Wärmeverbrauch von geschlossenen Gewächshäusern: Ein Simulationsmodell zur gartenbautechnischen Bewertung unter Berücksichtigung des Einflusses von Standortklima, Pflanzenbestand und Gewächshauskonstruktion. PhD Thesis, Leibniz Universität Hannover, Germany.

Weather Online. Weather maps - clouds, rain and snow at a glance. http://www.wetteronline.de. Accessed on 9th July 2013.