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Research Paper

DETERMINATION OF THE INSIDE AIR TEMPERATURE OF A GREENHOUSE WITH TOMATO CROP, UNDER HOT AND ARID CLIMATES

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Abstract: Up to now, few studies were devoted to the description of the energy balance components of a greenhouse located in the semi arid region of the southern Mediterranean basin, and no attention was paid to the prediction of the inside air temperature. In this study, experiments were undertaken to investigate the response of a greenhouse to the outside climate conditions considering a naturally ventilated Venlo glasshouse with a tomato crop. The measurements show that the difference between inside and outside air temperature is strongly linked to the incoming solar radiation as well as to the wind speed. From these results a simplified model was established to predict the greenhouse air temperature, knowing the greenhouse characteristics and the outside climate variables. The model is based on the energy balance of the greenhouse. Using a parameter identification technique, the model was calibrated against the experimental results. A sensivity analysis was conducted to assess the impact of several physical parameters such as solar radiation, wind speed and cover transmission on the evolution of the inside air temperature. This model appears to be suitable for predicting the greenhouse air temperature satisfactorily, at least during night.

Keywords: Greenhouse climate, semi-arid region, temperature, model

Nomenclature

a, b	constants
c_p	specific heat of the air (1004 J kg^{-1} K^{-1})
C_d	the discharge coefficient

C_w	the overall wind effect coefficient
g	gravitational acceleration (9.81 m s^{-2})
G	the ventilation rate (m^3 s^{-1})
h	the overall heat exchange coefficient (W m^2 K^{-1})
L	characteristic length of the solid surface (m)
Q	heat flux density (W m^{-2})
R	the solid (global) radiation flux outside the greenhouse (W m^{-2})
S	surface (m^2)
S_l	the equivalent area of leakage (m^2)
T	temperature (K)
U	velocity (m s^{-1})
v_o	the part of the ventilation rate not induced by the wind ($m^3 s^{-1}$)
W	constant

Greek letters

α, β, γ	coefficients
ε	the ratio of latent heat flux to net radiation
λ	the thermal conductivity (W m^{-1} K^{-1})
ρ	the density of the air (kg m^{-3})
τ	the greenhouse cover transmissivity to solar radiation

Subscripts

a	air
ai	internal air
ae	outer air
c	cover
e	exterior wind velocity
g	ground

Superscripts

evp	the part of heat used in the transpiration of the canopy
cov	the overall heat transfer at the cover surface
net	the incoming net radiation
sto	the heat storage in the greenhouse
sol	the incoming solar radiation
vent	heat loss by infiltration and ventilation

INTRODUCTION

During the last thirty years, greenhouses have expanded all over the world and in arid regions in particular [1]. In these warmer regions (arid and semi-arid regions) are characterized by high winter insulation [2]. However, the challenge concerns the control of the microclimate during the winter season, since the greenhouse cultivation is restricted by meteorological conditions at that season. The inside air temperature of the greenhouse is one of the key parameters that influences crop production. The prediction and the control of this parameter are therefore essential to maintain other parameters at acceptable levels, to prevent plant stress, and to improve economic heating system. Several studies of the inside air temperature of greenhouses have been conducted, mainly under temperate or Mediterranean conditions, and several works focussing on the modelling of this variable have been published. Kittas et al. [3] conducted an experimental study inside a tunnel greenhouse without crop; he could deduce a model to estimate the ventilation needs. Zhao et al. [4] performed an experimental study of the vertical distribution of temperature and humidity inside a closed and naturally ventilated greenhouse. Kittas et al. [5] developed a model to predict internal air temperature profiles in a shaded greenhouse with evaporative cooling under Mediterranean climatic conditions. For an unheated and naturally ventilated greenhouse and under Western European climatic conditions, Uchida Frausto et al. [6] investigated the climate variables to include into models to simulate the inside air temperature. Several studies provided empirical formulae inferred from in situ measurements to calculate the inside air temperature [3-5]. One limitation of these models however is the a priori specification of the greenhouse design, and climatic conditions corresponding to a given region. As a result, there is no general equation covering all greenhouse designs and all outside climatic conditions, and it is systematically required to estimate the parameters of the model from in situ measurement. To our knowledge, up to now, very few studies dealt with the estimation of the energy balance components of a greenhouse in the semi arid region of the southern Mediterranean basin [2], and of many trials, none had been carried out for a Venlo greenhouse with tomato crop. In the case of the area of Batna (a semi arid region of the southern Mediterranean basin, situated in the North-Eastern Algeria), greenhouses are generally closed or moderately ventilated during a large part of the growing season. Under these climatic conditions, Mesmoudi et al. [7] presented an analysis of the air temperature profiles observed inside a long plastic greenhouse. The thermal behaviour of the greenhouse was however not modelled at that time. Within this context, the scientific objective of the present work is to propose a simple model based on the energy balance of the greenhouse for the prediction of the inside air temperature and to proceed to calibration and validation against in situ measurements. An empirical formula is first derived to get the inside air temperature as a function of the outside measured climatic conditions. Secondly, the impact of solar radiation, wind velocity and greenhouse cover transmissivity on the inside air temperature is analysed into details.

MATERIALS AND METHODS

Basic theory

Inside a greenhouse, energy inputs equal the sum of the energy losses and greenhouse transient energy content. Usually, the greenhouse microclimate is represented by the climate in the middle of the enclosure, and five factors mainly affect the inside air temperature of the greenhouse: the heat gain, the ventilation losses (sensible and latent), the crop transpiration, the soil evaporation, and the heat loss coefficient of the cover. The energy balance equation combines these factors and can be written as follows under steady state conditions [8]:

$$Q^{sol} = Q^{\mathrm{cov}} + Q^{vent} + Q^{evp} + Q^{sto} \qquad (1)$$

Where Q^{sol} (W m-2) is the incoming solar radiation, Q^{cov} (W m-2) is the overall heat transfer at the cover surface (including convective and radiative losses); Q^{vent} (W m-2) is the heat loss by infiltration and ventilation (i.e. the sensible and latent heat exchanges by ventilation). Q^{sto} (Wm-2) is the heat storage in the greenhouse. As it is much smaller than the other fluxes during the diurnal phase, it can generally be neglected. Q^{cov} and Q^{vent} may be written as follows:

$$Q^{cov} = \frac{S_c h}{S_g}\left(T_{ai} - T_{ae}\right) \tag{2}$$

$$Q^{vent} = \frac{\rho C_p G}{S_g}(T_{ai} - T_{ae}) \tag{3}$$

With h, the overall heat exchange coefficient (W m^2 K^{-1}), S_c, the area of the cover, S_g, the area of the ground (m^2), T_{ai} the temperature of the inside air of the greenhouse, and T_{ae}, the temperature of the surrounding air (K). ρ *is* the density of the air (Kg m^{-3}), c_p, the specific heat of the air (J kg^{-1}), and G, the ventilation rate (m^3 s^{-1}). The other components of the energy balance may be expressed as:

$$Q^{sol} = \tau R \tag{4}$$

$$Q^{evp} = \varepsilon R^{net} \tag{5}$$

R is the solar (global) radiation flux outside the greenhouse (W m^{-2}) and τ is the greenhouse cover transmissivity to solar radiation. Q^{evp} is the part of heat used in the transpiration of the canopy (W m^{-2}), this heat takes part of the incoming net radiation R^{net}. ε is the ratio of latent heat flux to net radiation, this coefficient is an "evaporation coefficient", which estimates the fraction of total radiative load taken up by evaporation in the greenhouse. The range for this coefficient is assumed to be zero to one. Values closer to zero are recommended for sparse plants surrounded by dry soil in a humid climate, while values closer to one are recommended for lush vegetation in an arid region [9]. No further detail is given for the proper selection of ε, and standard examples [10] often use ε=0.5. Assuming that R^{net} is very close to the incoming radiation Q^{sol}, and neglecting the thermal inertia of the greenhouse, combining Eq. 2 to 5 with Eq. 1 yields:

$$\tau R(1-\varepsilon) - S_{cg} h(T_{ai} - T_{ae}) - \rho C_p G_g (T_{ai} - T_{ae}) = 0 \tag{6}$$

S_{cg} represents the ratio between the surface of the cover S_c and the ground surface S_g, and G_g represents the greenhouse ventilation rate (m^3 s^{-1} m^{-2}) per unit floor area (G/S_g). Generally, for a single-glazed greenhouse, the heat exchange coefficient of the greenhouse cover h is significantly affected by wind speed [11], and can be expressed as follows:

$$h = a + bU_e \tag{7}$$

where a and b are constants and U_e is the outside air speed (m s^{-1}). Combining Eq. (6) and (7), the temperature of the inside air of the greenhouse may be deduced:

$$T_{ai} = T_{ae} + \frac{\tau R(1-\varepsilon)}{aS_{cg} + bS_{cg}U_e + \rho C_p G_g} \tag{8}$$

When the greenhouse is opened (naturally ventilated), the air exchange is mainly due to ventilation and leakage. For wind speeds higher than 1-1.5 m s^{-1}, the stack effect (buoyancy effect) is small compared to the wind effect, and the ventilation rate is only a function of the wind [12, 20]. The calculation of the air exchange due to naturally ventilation can be expressed by Eq. (9) according to [13, 14].

$$G_g = \frac{WU_e + v_0}{S_g} \tag{9}$$

$$W = 0.5 S_l C_d C_w^{0.5} \tag{10}$$

Where W is a constant that depends on: S_l, the equivalent area of openings and leakage (m^2), C_d, the discharge coefficient and C_w, the overall wind effect coefficient. The parameter v_o in Eq. (9) represents the part of the ventilation rate not induced by the wind. Substituting G_g in Eq. (8) by the expression given by Eq. 9 yields:

$$(T_{ai} - T_{ae}) = \frac{\tau R \alpha}{\beta U_e + \gamma} \tag{11}$$

where

$$\alpha = (1 - \varepsilon) \tag{12}$$

$$\beta = (S_{cg} b + \rho C_p \frac{W}{S_g}) \tag{13}$$

$$\gamma = (a S_{cg} + \rho C_p \frac{v_0}{S_g}) \tag{14}$$

Eq. (11) represents a simplified version of the greenhouse energy balance, which can be used to estimate the inside air temperature T_{ai} of the greenhouses under similar climatic conditions. Eq. (11) must be calibrated to identify the constants α, β and γ.

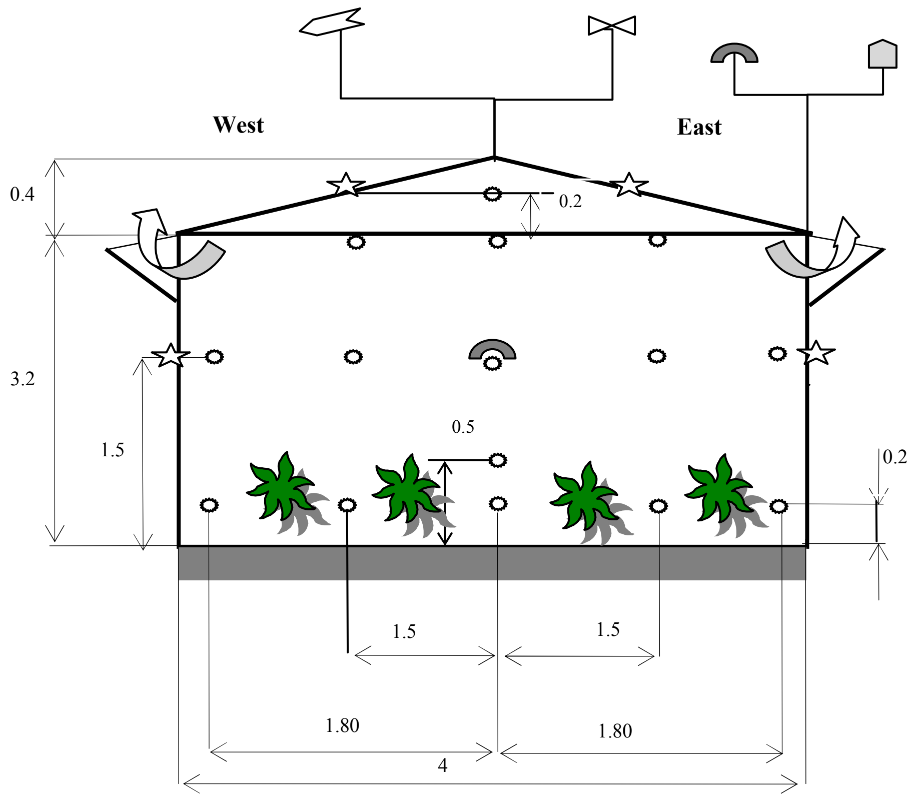
Site and greenhouse description

Experiments were conducted in a naturally ventilated Venlo glasshouse with four rows of tomato crop. This east-west oriented greenhouse was built with metallic frames, and covered with an horticultural glass of 4 mm thickness. It was located at the department of agronomy of the University of Batna (longitude: 6.11° E, latitude: 35.33° N, altitude: 900m) in North-East Algeria. The geometrical characteristics of the greenhouse were as follows (Fig. 1): ground area 32 m^2, height at eaves 3.2m, height at ridge 3.60m, total width 4m, total length 8 m, and total volume 108.8m^3. During the experiments, the side vents were opened and the greenhouse was naturally ventilated. The tomato crop grown in the greenhouse during the period of measurements had an average height of 0.8m, and the plant density was 2.5 plants m^{-2}. The plants were grown following local agricultural practices applied to four rows with an intra-row distance of 0.6m and an inter row distance of 0.7m.

Measurements

Measurements were performed over three periods, from January to March 2008 (25 January, 21 February, and 10 March) between 8 a.m. and 6 p.m. A schematic view of the experimental device is shown in Fig.1. Inside the greenhouse, the indoor temperature and relative humidity of the air were measured by two fast response sensors that cover a wide range (temperature -50° to 100°C with resolution better than 1°C, accuracy ±2%; humidity 0 to 100% with resolution 0.5%, accuracy ±3% up to 90%RH) and collected by means of a data logger (OAKTON Logger Plus). The probes were naturally ventilated and were protected from the influence of the direct solar radiation by a shelter box. Measurements were sampled at 5s intervals. The storage and the processing of data were carried out with the Micro Lab plus Software. Because of the heterogeneity of the inside air temperature distribution, the mean inside air temperature was deduced from temperatures measured at 15 points with 15 probes distributed along a cross-section at the centre of the greenhouse in the same vertical plane, and at different heights. The average value of these 15 points was considered as the temperature of the inside air at that time.

The incoming solar radiation was measured with a pyranometer (SP lite, Kipp & Zonen, Netherlands) placed inside the greenhouse at the centre and 1.5m above the ground. The cover surface temperatures of the greenhouse were measured on four positions distributed along the greenhouse sides and roof using stick on thermocouples secured to the cover with transparent adhesive tape. Additionally, the outside climatic data were measured with four sensors installed above the roof surface of the greenhouse at 1m height.



: Air temperature and humidity measurements by probe (Oakton log sensor).
: Platinum probe. : Wind vane. : Cup anemometer. : Pyranometer.
: Tomato crops . : Thermocouples.

Fig.1: Sketch of the experimental greenhouse showing the location of the sensors (all the distances are in linear meter).

External wind speed and direction were monitored by two cup anemometers (Model 100075, accuracy ±0.1ms^{-1}, Climatronic Corporation) and a wind vane (Model 100076, accuracy ±2°, Climatronic Corporation). The outside global solar radiation was measured with a pyranometer (SP lite, Kipp & Zonen, Netherlands). The outside air temperature and humidity were also measured using platinum probes in statically ventilated shelters (Model MP601A, accuracy± 0.2 % , Rotronic instrument crop) located at the same height as the outside pyranometer. . All the above mentioned measurements were collected on data logger system (Campbell Scientific Micro logger, CR3000, USA). All data were recorded every 2s and then averaged over 30min periods.

Calibration of the model

A number of 5400 data sets T_{ai}, T_{ae}, R, U_e was collected and analysed. A sensitivity analysis of the influence of the outside climate parameters $T_{ae}, R,$ and U_e on the inside-to-outside air temperature difference $\Delta T_{ai\text{-}ae}$ was undertaken. From Eq. 11, parameters α, β and γ can be identified. The estimation of these parameters was performed using the least-square method [15] and applying Eq. (11) on samples of 144 measurements corresponding to a range of rather broad variation of the measured variables. The following results were obtained with a fiducially limit relatively small for each parameter: $\alpha = 0.043 \pm 0.003$, $\beta = 0.612 \pm 0.06$ and $\gamma = 0.091 \pm 0.002$. The calibrated equation (Eq. 11) explains 83.67% of the variability of the dependent variable ΔT_{aiae}, and the small standard error of α, β and γ coefficients indicates that the results of the calibration are satisfactory.

RESULTS AND DISCUSSION

The influence of the outside solar radiation on the inside air temperature

The influence of the outside solar radiation on the inside air temperature is reported in Fig. 2, which provides the variation of the temperature difference $\Delta T_{ai\text{-}ae}$ versus the outside solar radiation R. From the linear regression analysis it can be seen that the corresponding coefficient of determination is relatively low (r^2 =0.61), showing the scattering of the data. From this result, it is concluded that $\Delta T_{ai\text{-}ae}$ is proportional to the outside solar radiation, and that the influence of the solar radiation is relatively important with respect to the inside air temperature changes. This is due to the predominant role played by solar radiation in the heat balance of the greenhouse. These results confirmed those obtained by [16, 17, and 18] for naturally ventilated greenhouses.

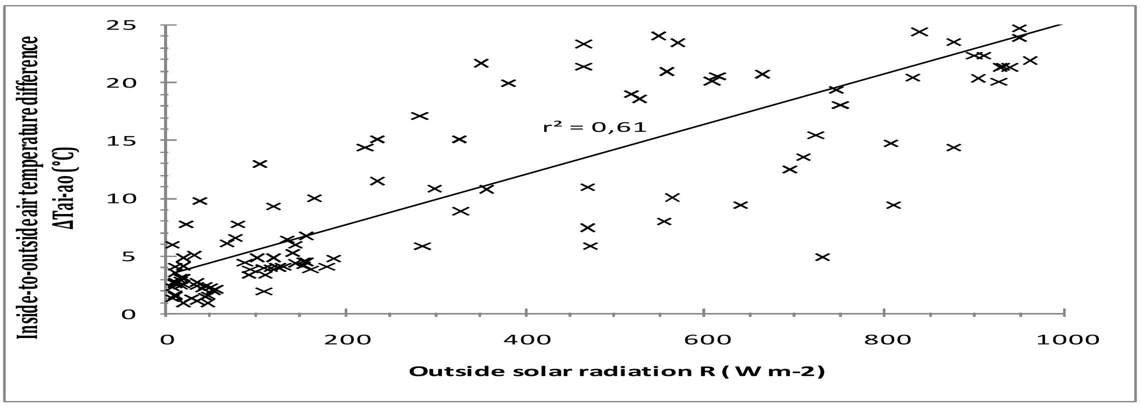


Fig. 2: Inside-to-outside air temperature difference $\Delta T_{ai\text{-}ae}$ (°C) as a function of the outside solar radiation R (W m^{-2})

The influence of the wind speed on the inside air temperature

The effect of the wind speed on the interior air temperature is displayed in Fig. 3. This figure shows the measured temperature difference $\Delta T_{ai\text{-}ae}$ as a function of wind speed, over the range of measured wind speeds, i.e. from 1 to 5 m s^{-1}. A clear influence of the wind speed on the inside air temperature is shown. It is observed that the values of $\Delta T_{ai\text{-}ae}$ decrease immediately with increasing wind speed but that the effect of the wind speed on $\Delta T_{ai\text{-}ae}$ is strongly nonlinear. The relatively low coefficient of determination observed (r^2 = 0.39) could probably be explained by the fact that the solar radiation overcomes the influence of the direct effect of the wind speed on the inside air temperature of the greenhouse under similar climatic conditions (a naturally ventilated greenhouse installed in a sunny area).

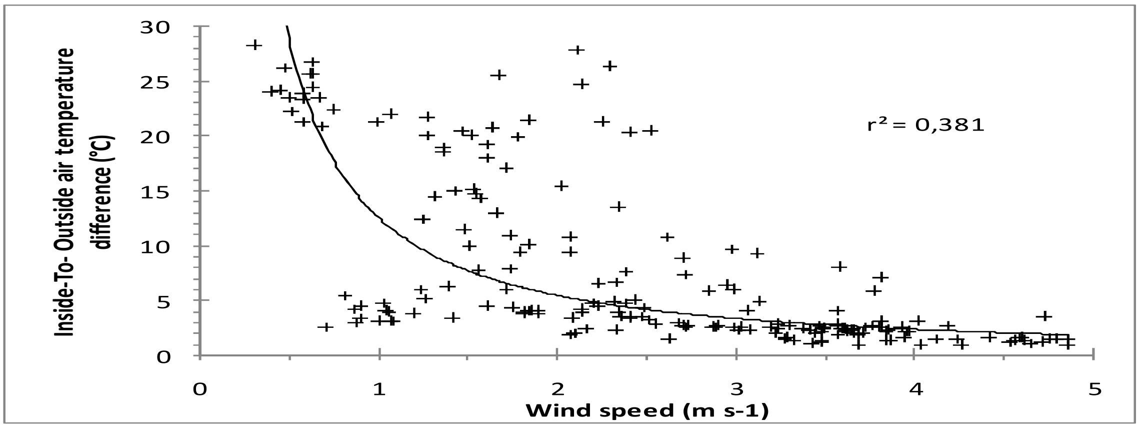


Fig. 3: Inside-to-outside air temperature difference $\Delta T_{ai\text{-}ae}$ (°C) as a function of the outside wind speed U_e (ms^{-1})

The comparison between measured and predicted values of the inside air temperature T_{ai} obtained by the Eq. 11 in the middle of the greenhouse is presented in Fig. 4. The agreement of the model with experimental data is satisfactory (r^2=0.97) for all measurements as shown by the proximity of dots with the bisecting line. In addition, to check the validity of the developed method, the measured values of the outside global radiation *R* and the calculated values of *R* derived from Eq. 11 were plotted in Fig. 5. The linear regression analysis of the measured values as a function of the values of the present study had a determination coefficient r^2=0.98. The global radiation calculated by the developed method thus showed fair agreement with measured values.

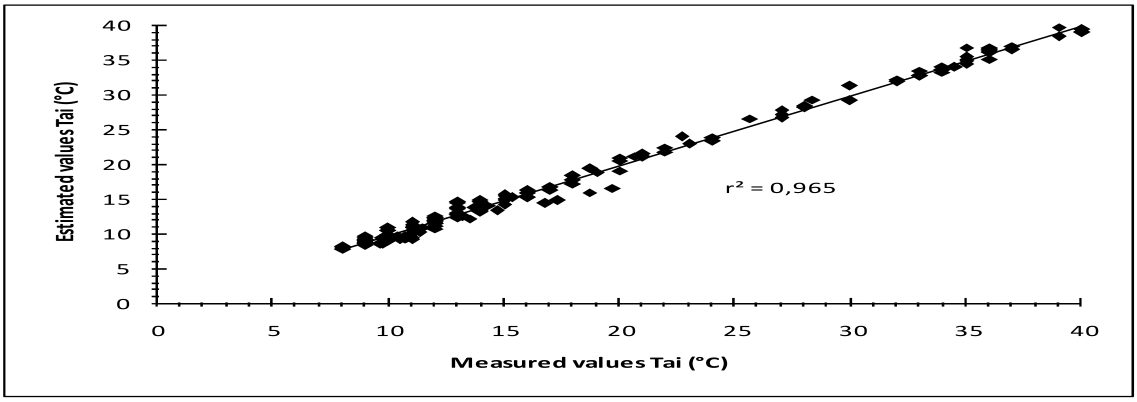


Fig. 4: Comparison between measured and the predicted inside air temperature

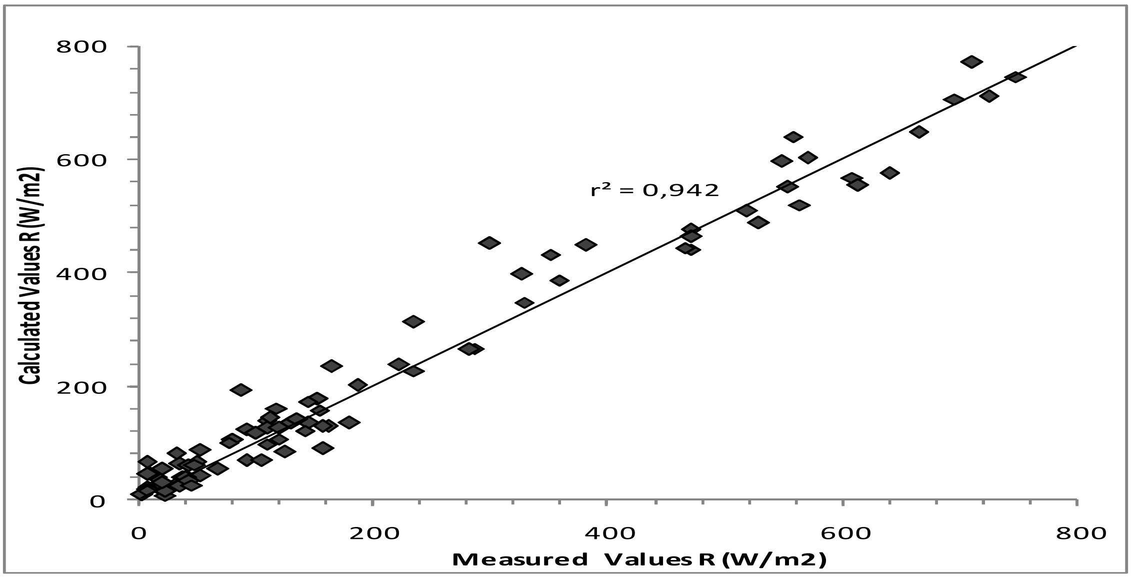


Fig. 5: Comparison between measured and predicted outside global solar radiation *R* (*W*m^{-2})

The dependence of the inside air temperature on several parameters such as solar radiation, wind speed, or greenhouse cover transmissivity to solar radiation τ was further investigated. In this prospect values of α, β and γ that were obtained from the experimental results were used in the model given by Eq. 11. The effects of the solar radiation on the inside air temperature are displayed in Fig. 6. This figure shows the calculated $\Delta T_{ai\text{-}ae}$ as a function of the outside solar radiation *R* for wind speeds within the range [0 - 7] m s^{-1}. An horticultural glass cover was considered for this particular case. It is predicted that $\Delta T_{ai\text{-}ae}$ increases with solar radiation. But for a given *R*, increasing the wind velocity strongly reduces $\Delta T_{ai\text{-}ae}$.

For the same greenhouse, Fig. 7 shows predicted values of $\Delta T_{ai\text{-}ae}$ as a function of wind speed for a set of solar radiations within the range [100 – 800] W m^{-2}. Here again, it can be seen that for a given radiation, the temperature difference $\Delta T_{ai\text{-}ae}$ decreases with increasing wind speed. This behaviour expresses the contribution of the wind to the ventilation process and to the sensible heat loss. It also shows that the dependence of the temperature difference on the radiation level decreases with increasing wind speed.

Fig. 8 shows the decay in ΔT_{aiae} as a function of the wind speed for two values of solar radiation (250 and 800 W m^{-2}), and three different types of greenhouse cover (horticultural glass HG τ=0.83, rigid polyethylene RP τ=0.72, and polyethylene film PF τ=0.68). When the coefficient of transmission of the cover τ is changed, the intensity of the incoming solar radiation is affected. Results indicate that $\Delta T_{ai\text{-}ae}$ decrease with decreasing τ and increasing wind speed. This is due to the fact that $\Delta T_{ai\text{-}ae}$ is directly proportional to τ and inversely proportional to U_e. [16, 19] obtained qualitatively similar results.

The values of ΔT_{aiae} obtained by the present study were compared with the values previously obtained by the model of Kittas et al. [3] (Eq. 15) for a closed unheated tunnel greenhouse without crop.

$$(T_{ai} - T_{ae}) = \frac{0.031R - 0.017\Delta R + 2.64}{1 + 0.085U_e^{0.8}} \qquad (15)$$

For both models, the variation of the calculated $\Delta T_{ai\text{-}ae}$ as a function of the outside solar radiation R for a fixed wind speed (U_e=2m s^{-1}) is reported in Fig. 9. The model developed in the present study and the model of Kittas et al. [3] provides similar results. The mean standard deviation between the two models (2.173°C) could be due to the following reasons: i) different shape of the greenhouse and different cover transmissivity to solar radiation; ii) the model of [3] included the temporal variation of the solar radiation ΔR (W m^{-2}) to take account of the thermal inertia of the greenhouse whereas in our case the experimental values were averaged over 30mn intervals to reduce fluctuations due to rapid changes in solar radiation; iii) the model of [3] was established for a tunnel greenhouse without crop and with a dry soil whereas in our case, the soil of the glasshouse was irrigated and covered with tomato crops and iv) in [3], the wind direction was supposed to be parallel to the greenhouse main axis and the effect of the wind was represented by $U_e^{0.8}$ (corresponding to forced and turbulent convective heat exchange on the greenhouse cover), whereas in our experiments, the average angle between the wind direction and the greenhouse ridge varied between 3° and 58°. Moreover, the Richardson number Ri (Gr/Re) was found to be superior to 0.1 on average for the 94 data considered. The general criterion for forced convection is Ri<0.1; and for free convection Ri >16 [11] which means that the flow was dominated by mixed convection in the present study.

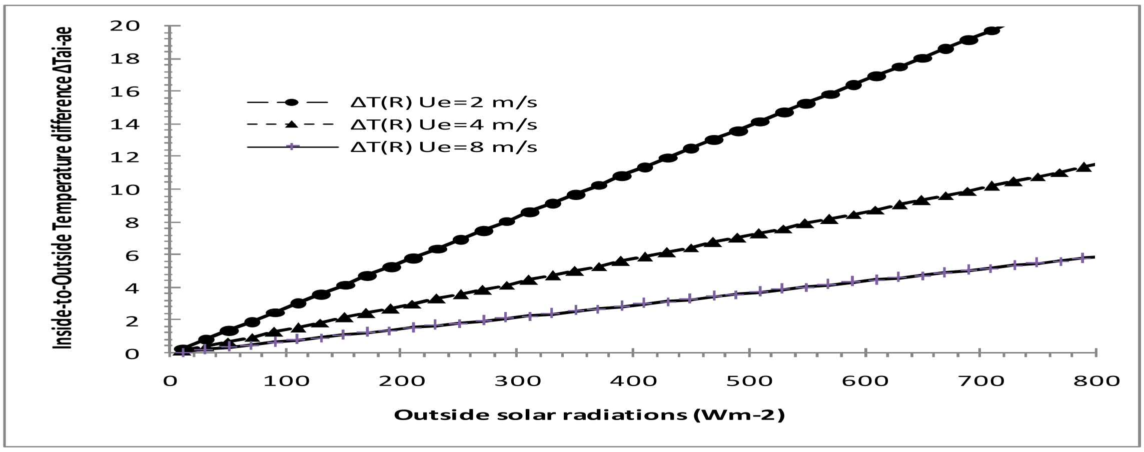


Fig. 6: Air temperature difference $\Delta T_{ai\text{-}ae}$ (°C) versus outside solar radiation R (Wm^{-2}) for four different wind speeds U_e (ms^{-1})

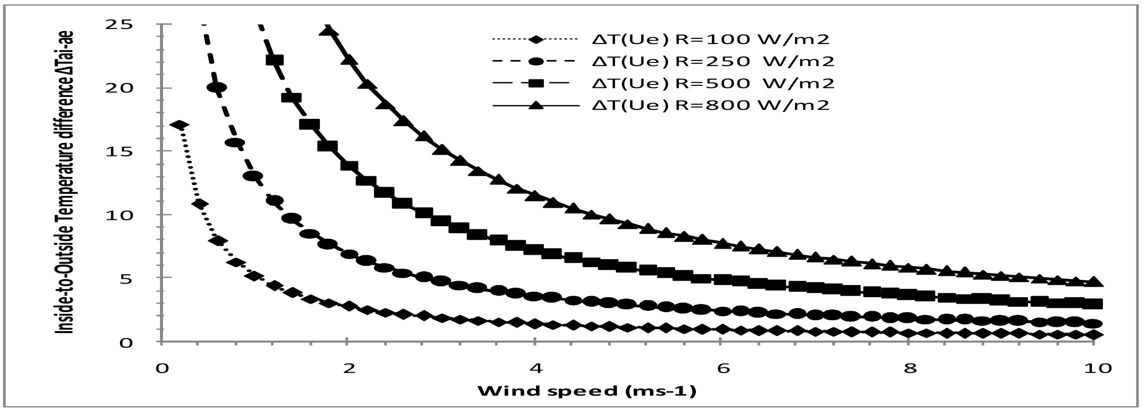


Fig. 7: Air temperature difference $\Delta T_{ai\text{-}ae}$(°C) as a function of the wind speed U_e(ms^{-1}) using Eq.(11), for four different values of the outside solar radiation R(Wm^{-2})

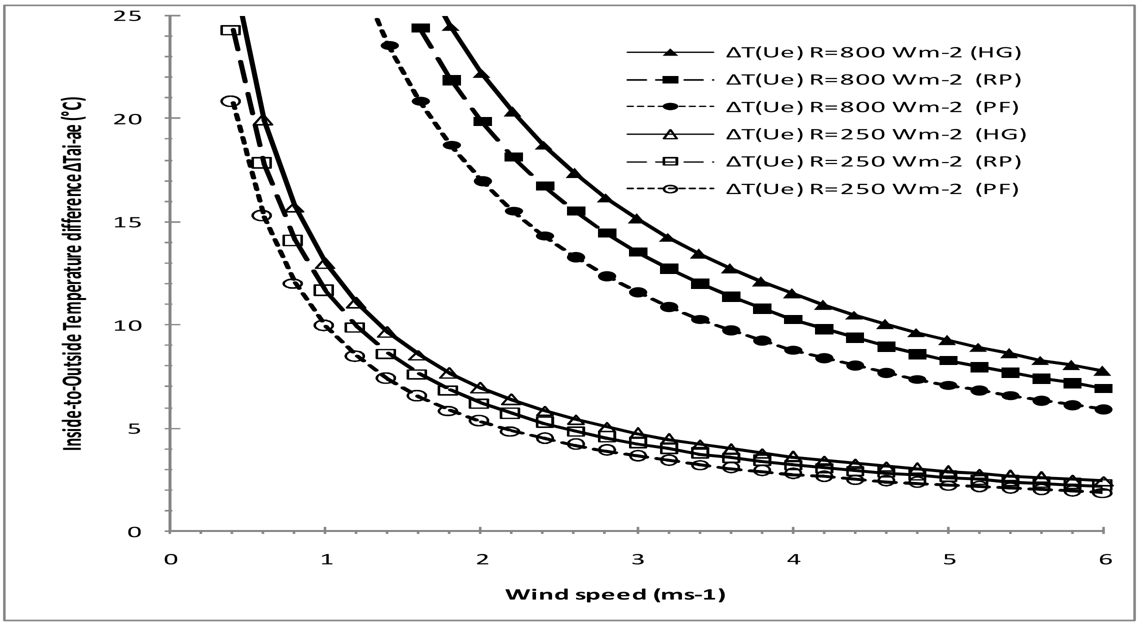


Fig. 8: Air temperature difference $\Delta T_{ai\text{-}ae}$(°C) as a function of the wind speed U_e (ms^{-1}) using Eq.(11), for two different values of the outside solar radiation R (Wm^{-2}), and for three different cover: horticultural glass (HG), rigid polyethylene (RP), and polyethylene film (PF)

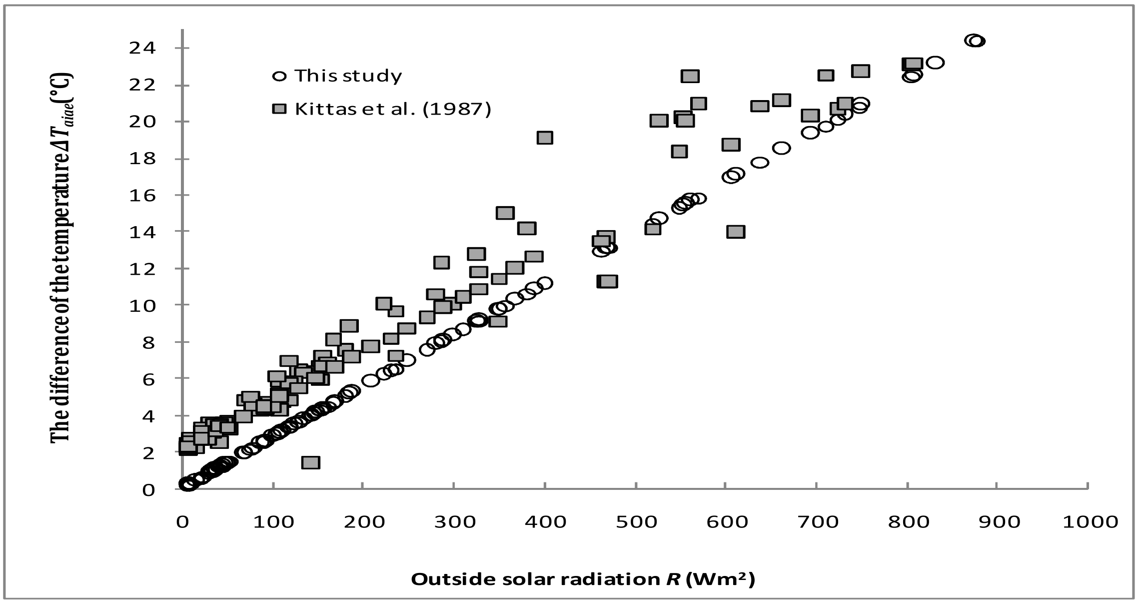


Fig. 9: Comparison between the model established by this study and the model proposed by [3]

CONCLUSIONS

A method has been developed to determine experimentally in situ the inside air temperature of a naturally ventilated Venlo greenhouse with a tomato crop. An equation that gives the inside air temperature T_{ai} as a function of the measured values of the outside global radiation, the surrounding air temperature and wind speed was established. The empirical formula derived was: $T_{ai} = T_{ae} + [(0.043\tau R)/(0.612U_e + 0.091)]$. The coefficient of determination obtained for the regression line between the estimated and measured values of T_{ai} was found to be r^2=0.965 showing a good agreement of the model with experimental data. The corresponding equation of the straight line (Fig. 5) was $y = 0.941x$. Apart from being a simple model for the estimation of the inside air temperature of the greenhouse, the approach developed in the present study provides a useful contribution to the understanding of the energetic behaviour of a greenhouse, as a function of the climatic conditions, greenhouse structure and shape.

Concerning these aspects the following conclusions may be drawn, at least for naturally ventilated Venlo greenhouse set in a semi arid region as follows. The results of the study show that the inside air temperature of the greenhouse is strongly dependent on the incoming solar radiation as well as on the wind speed. Nevertheless, the solar radiation overcomes the influence of the wind speed on the inside air temperature of the greenhouse. The calibration of the model gives satisfactory results and shows that it could be incorporated into algorithms used for greenhouse climate control in Venlo greenhouses with tomato crops. The model proposed in the present study could be used as a practical tool for the rational dimensioning of heating and ventilation systems in greenhouses with standard transpiring crops (tomato crops) under similar climatic conditions. The empirical method (based on in situ measurements) presented in this paper to get the inside air temperature of a greenhouse could be adapted to other specific greenhouse designs under similar climatic conditions. The model can be used in energy balance studies of greenhouses, comparing their expected performance for different greenhouse designs, operation modes, and weather conditions.

References

1. Baille, A., Lopez, J.C., Bonachela, S., Gonzalez-Real, M.M., Montero, J.I., 2006, Night energy balance in a heated low-cost plastic greenhouse, Agricultural and Forest Meteorology, 137: 107-118.
2. Mesmoudi, K., Soudani, A., Serir, L., 2008, Modèle de Bilan Energétique d'une Serre en Verre Sans Couvert Végétale, Revue des Energies Renouvelables, 1 (11) : 51-64.
3. Kittas, C., Chiapale, J.P., De Villele, O., Aries, F., 1987, Paramètres significatifs du déterminisme de la température de l'air de la serre, Agricultural and Forest Meteorology, 40 : 265-277.
4. Zhao, Y., Teitel, M., Barak, M., 2001, Vertical temperature and humidity gradient in a naturally ventilated greenhouse, Journal of Agricultural Engineering Research, 78(4): 431-436.
5. Kittas, C., Bartzanas, T., Jaffrin, A., 2003, Temperature gradients in partially shaded large greenhouse equipped with evaporative cooling pads, Biosystems Engineering., 85(1): 87-94.
6. Uchida Frausto, H., Pieters, J.G., Deltour, J.M., 2003, Modeling greenhouse temperature by means of auto regressive models, Biosystems Engineering, 84 (2): 147-157.
7. Mesmoudi, K., Adjroudi, R., Soudani, A., Bougoul, S., 2007, Etude de la distribution de la température de l'air à l'intérieur d'une serre en plastique sans couvert végétal dans la région des Aurès, Etude Expérimentale. Proc. International Conferences of Renewable Energy and Sustainable Development (ICRESD_07), Tlemcen May 2007.
8. Boulard, T., Wang, S., 2000, "Greenhouse crop transpiration simulation from external climatic conditions, Agricultural and Forest Meteorology, 100: 25-34.
9. Seginer, I ., 1997, Alternative design formulae for the ventilation rate of greenhouses., Journal of Agricultural Engineering Research, 68: 355-365.
10. Albright, L.D., 1990, Environment control for animals and plants 453p. ASAE, St. Joseph, MI.
11. Roy, J.C., Boulard, T., Kittas, C., Wang, S., 2002, Convective and ventilation transfers in greenhouse, Part I, Biosystems Engineering, 83: 1-20.

12. Baptista, F.J., Bailey, B.J., Randall, J.M., Menesses, J.F., 1999, Greenhouse ventilation rate: theory and measurements with tracer gas techniques, Journal of Agricultural Engineering Research, 72: 363-374.
13. Kittas, C., Draoui, B., Boulard, T., 1995, Quantification du taux d'aération d'une serre à o uvrant continu en toiture, Agricultural and Forest Meteorology, 77 : 95-111.
14. Joliet, O., Danoly, L., Gay, J.P., Munday, G.L., Reist, A., 1991, HRTICERN: an improved static model for predicting the energy consumption o f a greenhouse, Agricultural and Forest Meteorology, 55, 265-294.
15. Gourdin, A., Boumahrat, M., 1991, Méthodes numériques appliquées, Office des publications universitaires, Alger.
16. Teitel, M., Tanny, J., 1999, Natural ventilation of greenhouses: experiments and model, Agricultural and Forest Meteorology, 96: 59-70.
17. Litago, J., Baptista, F.J., Meneses, J.F., Navas, L.M., Bailey, B.J., 2005, Statistical modelling of the microclimate in a naturally ventilated greenhouse, Biosystems Engineering., 92 (3), 365-381.
18. Montero, J.I., Anton, A., Kamaruddin, R., Bailey, B.J., 2001, Analysis of thermally driven ventilation in tunnel greenhouses using small scale models, Agricultural Engineering Research, 79 (2): 213-222.
19. Kittas, C., Karamanis, M., Katsoulas, N., 2005, Air temperature in a forced ventilated greenhouse with rose crop, Energy and Building, 37: 807-812.
20. Ould Khaoua, S.A., Bournet, P.E., Migeon, C., Boulard, T., Chassériaux, G., 2006, Analysis of greenhouse ventilation efficiency based on computational fluid dynamics, Biosystems Engineering, 95 (1): 8398.

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