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ENERGY EFFECTS DURING USING THE GLASS WITH DIFFERENT PROPERTIES IN A HEATED GREENHOUSE

Sławomir Kurpaska

Institute of Agriculture Engineering and Informatics
University of Agriculture in Kraków

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Summary

The paper presents results of calculations conducted on a change of demand for thermal power in a greenhouse covered with standard garden glass and a low-emission glass. Changes of heat demand were also determined. Changes of the amount of fuel (fine coal size grade) as well as changes in the emission of pollutants to the atmosphere were estimated based on calculations. It was determined that covering a greenhouse with low-emission glass has a positive impact on decreasing heat demand.

Introduction

A whole year cultivation of plants in greenhouses requires ensuring optimal parameters of microclimate (temperature, concentration of steam, concentration of the CO_2, light availability) on the one hand and reduction of production cost on the other. Both these aims may be reached not only using a suitable technical equipment of facilities but it may be assumed that a casing of a facility is also essential. A casing (glass, plastic) by proper isolation positively influences on the reduction of heat consumption as well creating proper conditions of light availability of wave length at which physiological processes occur in cultivated plants. Correct physical and optic properties of glass (thermal conductivity, reaction of glass surface on rays getting through) influence reduction of fuel consumption what brings measurable financial effects and reduction of pollutants emission to the atmosphere and increased profitability of production. Currently, there are well-prepared production

Correspondence: Sławomir Kurpaska, Instytut Inżynierii Rolniczej i Informatyki, Uniwersytet Rolniczy im. Hugona Kołłątaja, ul. Balicka 116B, 30-149 Kraków, phone: 48 12 6624628, e-mail: rtkurpas@cyf-kr.edu.pl

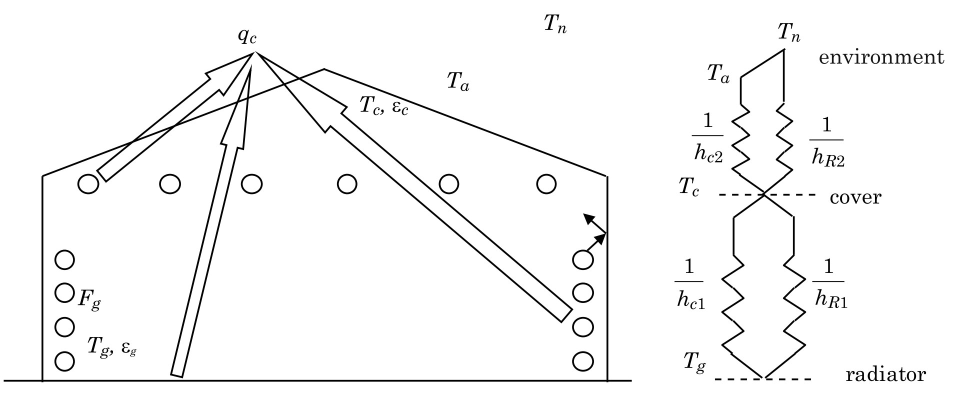
technologies and compiled methods of glass processing consisting in: modification of thermal properties as well optic parameters, which characterizes the flow of radiation of a suitable wave length (dusting metal coating or metal oxides on its surface), selective reflection of infrared radiation by application of low-emission glass, increasing a coefficient of light transmission by application of anti-reflexive glass. Estimation of potential benefits from using this type of processing or from using alternative (regarding glass) covering of a greenhouse is an essential challenge for science. This issue was the subject of the research. LEONIDOPOULOS (2000a, b) analysed energy issues in regard of a laboratory greenhouse covered with polymeric cover. As a result of the research, which he carried out and calculations he conducted, he determined daily kinetics of temperature change inside a facility for different levels of sun exposure. Moreover, he analysed the issue of thermo-dynamic balance as an effect of balancing of solar radiation energy with heat transmitted by a cover of the researched greenhouse in the process of its ventilation. AL-HELAL and ABDEL-GHANY (2011) determined quantitative heat fluxes used in a greenhouse (covered with PE foil) cooled with cooling mats divided into apparent heat and phase change. They divided solar radiation, which gets to a cover, into heat used in the processes occurring in a facility and into radiation reflected from the cover. TITEL et al. (2009) analysed heat consumption of a greenhouse (covered with PE foil) in which they installed a periodical heating system using warm air supplied to the inside with a system of perforated pipes. The authors found a relation between average temperature of leaves of the cultivated plants and temperature of their outer layer as well as a value of heat infiltration coefficient through a cover of a greenhouse for two cycles in its periodical heating. LI et al. (2009) compiled and verified a mechanistic model for prediction of air temperature in the system, in which warm water was stored between double foil covering the carcass of a greenhouse. It was concluded that the results obtained from the model give satisfactory comparison with intended values; co-participation of heat flux transmitted from the inside of a greenhouse to the outside was also determined. PISCIA et al. (2012) compiled a mathematical model (using CFD technology), which upon a verification procedure was used for simulation processes occurring on a casing of a greenhouse (a multi-nave tunnel covered with PE foil). The following issues were analysed: heat transfer by radiation from a tunnel casing to the surroundings, condensation of steam, plants transpiration and change of temperature of a casing during disappearance of solar radiation. It was concluded that a compiled model was useful for the analysis of fluctuations of air humidity inside a greenhouse. FIDAROS et al. (2010) worked out and verified a mathematical model for analysis of heat and mass transport phenomena in an air-conditioned greenhouse covered with PE foil. In a boundary condition (which includes a surface of a cover and a surrounding), they considered heat transfer through convection and radiation. After the analysis was carried out, it was determined that the suggested model may be used for simulation of processes which occur in a greenhouse. ABDEL-GHANY and KOZAI (2006) using analogy between heat transfer and electric current transfer, prepared a mathematical model of processes, which takes place in a greenhouse covered with standard garden glass. The model includes the processes of heat transfer through radiation, conductivity and convection between a casing and the surroundings as well as between a casing and a surface layer of soil and air inside a greenhouse. Additionally, processes of air-cooling were included (through fog dispersal and gravitational ventilation). Values of particular heat fluxes mentioned among the analysed surfaces were determined and in conclusion after conduction of model verification, it was determined that the prepared model may be used in a further analysis of processes occurring in a greenhouse with cultivated plants and for finding coefficients of transfer. STANGHELLINI et al. (2011) analysed issues of radiation of near infrared (NIR) in a greenhouse in which screens of a high coefficient of reflection were installed. In conclusion, it was stated that installation of such screens reduces heat demand from greenhouses of about 8%. Application of dyes, the properties of which were determined in the research, was recommended for covering sidewalls in commercial greenhouses. In KURPASKA'S paper (2003) heat demand of a foil tunnel equipped in reflective screens (mounted behind heaters) as well as heat screens were analysed. HEMMING et al. (2011) analysed usefulness of garden glass (standard and low iron content) for improving its optic properties. As a result of analysis, which was carried out, it was determined that more considerable efforts will be obtained at modification of composite glass. The analysis, which was carried out, proved that positive effects (at current prices) will be also obtained for single glass in the case where its layer will be covered with an anti-reflexive cover. SONNENVELD et al. (2007) presented results of analysis using a modified cover of PE foil as a cover of photovoltaic boards. Boards were located in a roof of a laboratory greenhouse. Covering the foil with material characterised with selective permeability (in regard of NIR waves) of solar waves was the most crucial point of modification.

Relevance of the issue of modification of garden glass optic properties results from the performed review of the selected papers. The main purpose of this paper will be to carry out such an analysis (limited to thermal issues).

Material and methods

The subject of the analysis was to determine energy effects in a greenhouse covered with standard garden glass as well as glass of modified optic properties. Use of glass by changed optic parameters consists on covering a glass layer with an additional layer of strongly anti-reflection parameters (the so-called low-emission glass). Theoretically, this layer should influence reduction of heat consumption by a heated facility through reduction of infrared radiation. The analysis of heat losses from the inside of a greenhouse was conducted for the stationary state and temperatures of a heater T_g and a glass T_c averaged for the whole surface. In view of considerable sizes of these surfaces, a one-dimensional direction of heat flow from surfaces of heaters to the surroundings through a layer of air and glass may be accepted.

Figure 1 presents a schematic representation of a greenhouse with a mechanism of heat losses.



F_g – area of the heaters [m^{-2}],
T_g – temperature heating system [K],
ε_g – heaters emission factor [–],
T_c – temperature of greenhouse cover [K],
ε_c – greenhouse cover emission [–];
h_{c1}, h_{c2} – equivalent heat transfer coefficient by convection to the inner side (h_{c1}) and external (h_{c2}) of the greenhouse cover [W · m^{-2} · K],
h_{R1} – radiative heat transfer coefficient to the inner side (h_{R1}) and external (h_{R1}) of the greenhouse cover [W · m^{-2} · K],
T_a – ambient temperature [K],
T_n – sky temperature [K].

Fig. 1. Mechanisms of heat losses through a greenhouse casing along with an equivalent schematic representation of thermal resistance connections

A product of a relative difference of temperature and a substitutive coefficient of heat transmission may express convective losses from a heater to a glass, whereas relations for a hollow of surface area F_g and surrounding it F_c surface may express radiative heat exchange. In a methodology presented further (symbols occurring in relations are marked in Fig. 1), all parameters, material properties as well as listed heat fluxes are expressed in the international system of units.

For the above assumptions, the following relation expresses a total heat flux transmitted from a heater to a casing of a greenhouse:

$$q_{g-c} = q_{c1} + q_{R1} = h_{c1}(T_g - T_c) + \frac{\sigma(T_g^4 - T_c^4)}{\frac{1}{\varepsilon_g} + \frac{F_g}{F_c}\left(\frac{1}{\varepsilon_{c-ef}} - 1\right)} \qquad (1)$$

where:
q_{c1} – heat flux transferred by convection, $W \cdot m^{-2}$,
q_{R1} – heat flux transferred by radiation, $W \cdot m^{-2}$;
σ – Stefan-Boltzman constant, $5.67 \cdot 10^{-8}\ W \cdot m^{-2} \cdot K^{-4}$,
ε_{c-ef} – stands for a weighted average of the emission coefficient (including glass surface area, cultivation surface area and their emissivity).

The same heat flux must be also diverted from a glass to the surroundings. Heat is conveyed through convection as well as emission to the sky. Thus, it may be expressed as follows:

$$q_{c-a} = q_{c2} + q_{R2} = h_{c2}(T_c - T_a) + \varepsilon_c\sigma(T_c^4 - T_n^4) \qquad (2)$$

Introduce the substitutive coefficient of heat transmission through radiation between a heater and glass in the following form:

$$h_{R1} = \frac{\sigma(T_g^4 + T_c^4)(T_g + T_c)}{\frac{1}{\varepsilon_g} + \frac{F_g}{F_c}\left(\frac{1}{\varepsilon_{c-ef}} - 1\right)} \qquad (3)$$

in addition, analogical for radiation between glass and the sky:

$$h_{R2} = \frac{\sigma\varepsilon_c(T_c^4 + T_n^4)}{T_c - T_a} \qquad (4)$$

temperature of the sky (T_n) was calculated out of relation [LIN et al. 2009]:

$$T_n = 0{,}0522 \cdot T_a^{1,5} \tag{5}$$

according to a schematic representation of thermal resistance (Fig. 1), we will receive the substitutive coefficient of heat losses through the surface of glazing as:

$$U_c = \frac{1}{\dfrac{1}{h_{c1} + h_{R1}} + \dfrac{1}{h_{c2} + h_{R2}}} \tag{6}$$

thus, relation for describing density of heat losses stream between a heater and the surroundings takes the following form:

$$q_c = U_c(T_g - T_a) \tag{7}$$

From presented methodology, it clearly results that in order to determine heat losses from a facility, knowledge of temperature of a coating is required (T_c). It may be determined only by an iterative method, where a final stage results from an assumed accuracy of calculations.

Analysis of heat consumption was carried out for a heating season (September-May) based on frequency of the surroundings temperature occurrence in a differentiable time d_t, the amount of heat was determined from the following formula:

$$Q_c = U_c \cdot F_c(T_g - T_a)\, d\tau \tag{8}$$

Thus, total heat consumption in a heating season was calculated from the following relation:

$$Q_{\text{tot}} = \int_{\tau_1}^{\tau_2} LF \cdot U_c \cdot F_c(T_g - T_{a\text{–min}})\, d\tau \tag{9}$$

where:
F_c – surface of the greenhouse cover [m^2],
LF – the seasonal coefficient utilization of the maximum heating power [–],
τ_1 and τ_2 – stands for the analysed time interval in a heating season.

The ground of a greenhouse in both cases is covered with white foil PE of the emission coefficient equal to 0.8. Convective coefficients of heat transmission (h_{c1}, h_{c2}) were accepted according to an effective methodology (KURPASKA 2007).

Results and discussion

The analysis was carried out for a greenhouse of a usable area of 600 m^2, a casing index (surface area – usable area of a greenhouse ratio) equal to 2.0 and a cubic capacity of 3000 m^3. It was assumed that temperature in a greenhouse was 12°C, whereas its casing consists in a low-emission glass of a coefficient of long-wave radiation emission (NIR) on the level of $\varepsilon_{c1} = 0.18$, as well as alternatively standard glass of $\varepsilon_{c2} = 0.84$. Values of the final effective emission coefficient of a cover from the inside of a greenhouse were assumed as a weighted average (including a surface area of a cover and a usable area of a greenhouse) in calculations. Moreover, it was assumed that the surface area of heaters constitutes 35% of a usable area of a greenhouse, while an emission coefficient of heaters is $\varepsilon_g = 0.94$. Heat flux exchanged between the inside of a greenhouse and surroundings through infiltration was calculated in calculations regarding heat consumption using standard relations. Figure 2 presents impact of surroundings temperature on the value of the coefficient of heat transfer.

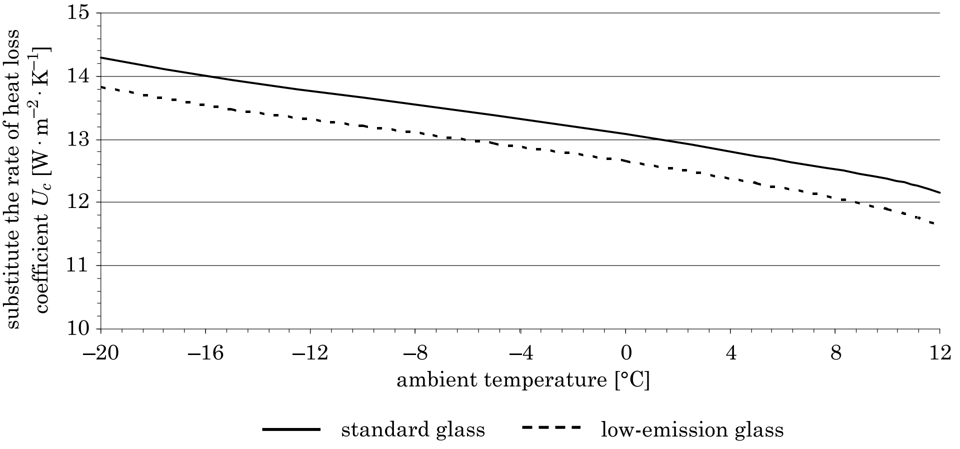


Fig. 2. Change of heat losses coefficient for the analysed casings

As it can be seen, glass of lower emission is characterised by a lower emission coefficient and by a lower value of the substitutive heat losses coefficient. For the analysed scopes of independent variables, this coefficient for the low-emission glass in comparison to glass of standard emission takes on average 3.5% of lower value.

Figure 3 presents the influence of independent variables (the coefficient of glass emission, temperature of heaters) on the change of a unitary heat demand for the researched greenhouse. A linear change of heaters temperature depends on the temperature of surroundings.

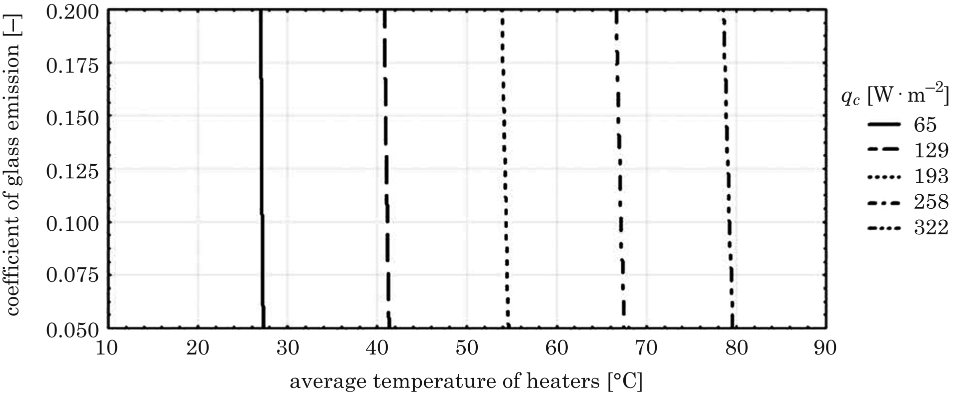


Fig. 3. Influence of heaters temperature and the coefficient of glass emission on unitary heat demand

It may be noted that the higher value of coefficient of emission is the higher unit demand for a heat flux. In the research scope of changes of the value of the heat emission coefficient (scope of changes within 0.05 to 0.2), a calculated variable (in regard to demand for a minimal value of emission) constitutes 1.9%.

A demand for thermal energy in the analysed greenhouse facility was calculated based on the relation, which presents frequency of the outside temperature for the sphere III (SZARGUT, ZIĘBIK 1995). Results of calculations were presented in Figure 4.

Because of similar courses of changes thermal loads for both analysed casings, (change a thermal load is a derivative of changes the value of heat losses coefficient) the course of loads was presented for a greenhouse covered with glass of standard value heat emission. A calculated value of *LF* coefficient is 0.26.

Thus, calculation results in the amount of heat necessary in the heating season for a greenhouse covered with the analysed casings were presented in Table 1.

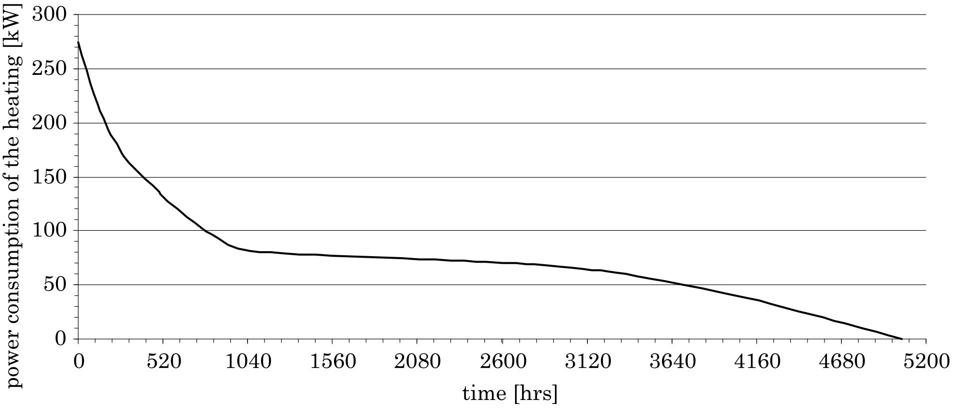


Fig. 4. An arranged diagram of thermal loads for the researched facility

Table 1

Amount of heat in the heating season

Type of casing	Heat demand [GJ · greenhouse^{-1} · a^{-1}]
Standard glass	1218.05
Low-emission glass	1171.85

Assuming that a greenhouse will be heated with fine coal size grade and assuming that total heat losses constitute 20% (transfer losses, losses in a boiler room) over 2.5 tons of fuel will be saved in the analysed greenhouse. Certainly, emission of pollutants to the atmosphere will be also reduced of CO_2 – 4264; CO – 47; SO_2 – 18; NO_x – 3.9 as well as dust of approx. 25 kg.

Conclusions

1. In the researched scope of independent variables, glass of lower emission in comparison to standard glass is characterised with the coefficient of heat losses, which is lower of 3.5%.
2. In the analysed facility, a unitary demand on heat decreases of approx. 2% along with the increase of the coefficient of glass emission (within the range of 0.05 to 0.2).
3. In the researched greenhouse, the use of low-emission glass leads to over 2.5 tons of fuel as well as reduction of pollutants emission to the atmosphere.

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