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Electric infrared heating panels as an alternative source of heating for greenhouses

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Abstract. The aim of this article is to show the possibilities of supplementary heating of greenhouses. There was used for this research an electric infrared heating panel ITA 700. The average total power was 630.8 W in laboratory measurements, of which 504.3 W has been transferred by the front part of the panel, of which 267.2 W has been transmitted by radiation. The total radiation efficiency of the front part was 42.4%. Similar measurements have been carried out in an experimental greenhouse (length 24 m, width 3.5 m). Approximately 448 W of average total power 603.7 W has been transferred by the front part of the panel, of which 159 W has been transferred by radiation. The total radiation efficiency of the front part was 26.3%. Differences between measured surface temperatures confirmed the influence of panel radiation on the flower bed. The average temperature in the soil (9 °C) shows that the influence of heating is mainly on the surface of the flower bed, where it could protect cultivated plants during the lowest temperature period. The obtained results can be useful for choosing suitable panel parameters for the placement in small horticultural or hobby greenhouse.

Key words: convection, heat transfer, low temperature, measurement, radiation, soil.

INTRODUCTION

The aim of this article is to show the possibilities of supplementary heating of greenhouses. Construction, calculation and design of heating systems in large scale greenhouses are well described and studied in special publications e.g. Has, 2004; Pokluda & Kobza, 2011. The heating systems (hot water, electricity or gas) recommended for large scale greenhouses are usually very sophisticated, but very expensive and they are supposed to be used permanently during the long period e.g. in the Czech Republic (autumn, winter and spring). Considerable attention is paid to the construction of greenhouses in terms of the use of progressive techniques (Avotins et al., 2018; Hart & Hartova, 2018).

There are also used some simple constructions of greenhouses (mostly made from plastics) used in many parts of the world. Constructions of these greenhouses are well described in (Cermeno, 2002). There is no supposed heating. Small greenhouses, which are used for growing seedlings, vegetables, flowers and other plants in the cold season unsuitable for growing in free garden, are usually without heating. These greenhouses, unlike large commercial greenhouses, are not equipped with a conventional overhead or underground heating system. A drop of outdoor air temperature and insufficient solar radiation e.g. in night, can cause plant destruction (spring frosts). That is the reason why some scientific publications are focused on this issue. E.g. (Anifantis et al., 2017) carried out an assessment of thermal energy with the use of small scale photovoltaic, hydrogen and geothermal stand-alone system for greenhouse heating.

The influence of heating systems on greenhouse microclimate for low-cost, plastic covered greenhouses is studied in (Tadj et al., 2014) as it greatly influences crop growth and development. It is focused on heating pipes and air heater. In conclusion, it is stated that precise evaluation of the behaviour of heating equipment in a greenhouse is necessary.

One of solutions for heating in the critical period is the use of electric infrared heating panels. Infrared emitters have considerable applications in many sectors (Bulgakov et al., 2014). Unlike conventional convection heating panels, which first heat the air and thus a lot of energy escapes (heat losses) through the surrounding walls, the electric infrared heating panels transfer part of energy from their surface in the form of radiation, i.e. directly on the plants and soil. This makes more efficient use of input power. The research work focused on the theory and construction of the electric heating panel is described in Greppi & Fabbri (2017). Unlike electric heating cables, which must be in the soil, these panels are easy to install.

This research is focused on the verification of the function of electrical infrared low-temperature panels in laboratory conditions and in an experimental greenhouse. The energy transfer and influence on the soil surface has been studied in real conditions.

MATERIALS AND METHODS

There was used for this research an electric infrared heating panel ITA 700 with rated power 680 to 730 W, which is recommended to install on the wall or ceiling. The front part of the panel which is the principal source of heat transmission has surface area $S_F = 0.75$ m^2 and the back part together with side parts ($S_O = 0.85$ m^2) are insulated and covered with the aim to reduce the heat transfer through these parts. The panel was set at an angle of 75° to the floor during the measurements.

This paper includes the results of two types of experiments. There were carried out laboratory experiments inside the Faculty of Engineering, which enabled to install heating panel and all instruments together for long distance measurement on the floor. The aim was to find out properties of heating panel in protected laboratory conditions with average indoor temperature about 22 °C and relative humidity approximately 26%.

Similar measurements have been carried out in an experimental greenhouse (length 24 m, width 3.5 m and height 2.22 m) at outside air temperature about -2 °C, relative humidity approximately 65% and a solar radiation 520 W m^{-2}. This greenhouse is not equipped with any heating system.

Instrumentation

Air temperatures and relative humidity were measured by data loggers ZTH65 with registration at 1- minute intervals. Parameters of ZTH65 are: temperature operative range –30 to +70 °C with accuracy ± 0.4 °C and operative range of relative humidity 5–95% with accuracy ± 2.5%.

The surface temperatures of tested infrared heating panel were measured by special surface infra sensor FIA 260-MV with temperature operative range -18 to 260 °C with accuracy ± 0.1 K. The surface temperatures in some specific places were measured by special surface sensor S 106 9R (NiCr-Ni, with adapter G017R) connected to the instrument THERM 2253-2 (Ahlborn GmbH, Germany) for contact temperature measurement. This instrument was used also with sensor for air temperature measurement AMR TK 127 10R. This instrument and sensors can be used in operative range from –100 to 1,370 °C, with display resolution 0.1 °C and with accuracy ± 1% from the measured value.

There were installed during the measurements surface thermocouples NiCr-Ni (type K) in operative range from –50 to +200 °C, with display resolution 0.1 °C and with accuracy ± 1% from the measured value.

Temperatures of the soil in the greenhouse were measured by the thermocouples NiCr-Ni (type K) in operative range from –25 to +400 °C, with display resolution 0.1 °C and with accuracy ± 1% from the measured value, completed by the compensation line NiCr-Ni in operative range from –10 to +105 °C in the length installed according to the needs of measurements.

The heat flux density on the rear part of the panel was measured by special heat flux sensor FQA018C (Ahlborn GmbH, Germany) which has dimensions 120×120×1.5 mm. It is made from epoxy resin with the resistance to 80 °C and calibration constant 9.69 W m^{-2} mV^{-1} and relative measurement uncertainty 5%.

Temperature and humidity of surrounding air has been measured by sensor FHA 646–21 including temperature sensor NTC type N with operative range from –30 to +100 °C with accuracy ±0.1 °C, and air humidity by capacitive sensor with operative range from 5 to 98% with accuracy ±2%. All measured data were stored at 1-minute intervals to measuring instruments ALMEMO 2590-9 and ALMEMO 2690.

The measurement results were processed by Excel software and some of results were verified by statistical software Statistica 12 (*ANOVA* and *TUKEY HSD Test*).

Theory and modelling

To evaluate the function and efficiency of the panel, it is necessary to assess its energy balance (Eq. 1), expressing the total power consumption of panel P:

$$P = P_C + P_R \tag{1}$$

where P – total power consumption (W); P_C – power (heat) transmitted by convection (W); P_R – power (heat) transmitted by radiation (W).

Radiation heat transfer follows Newton-Richman law, Eq. (2). Basic principles and equations are described in many publications focusing on heat transfer, e.g. Sazima et al., 1989; Szekyova et al., 2006, which creates a theoretical background described in the next part of this article.

$$P_C = \alpha \cdot S \cdot \Delta t \tag{2}$$

where α – heat transfer coefficient (W m^{-2} K^{-1}); S – convective heat-transmitting surface (m^2); Δt – temperature difference between the panel surface and ambient air (K).

The heat transfer coefficient α depends on the Nusselt criterion *Nu* according to Eq. (3):

$$\alpha = \frac{Nu \cdot \lambda}{L} \tag{3}$$

where *Nu* – Nusselt number; λ – coefficient of thermal conductivity of air (W m^{-1} K^{-1}); *L* – characteristic dimension (height) of the panel (m).

For the vertical or inclined planar surface of the panel, *Nu* is determined by Eq. (4) depending on the Rayleigh's criterion *Ry*.

$$Nu = C \cdot Ry^{n} \tag{4}$$

where *C* – constant which depends on *Ry*; *Ry* – Rayleigh's criterion; n – exponent which depends on *Ry*.

The Rayleigh's criterion *Ry* is determined according to Eq. (5):

$$Ry = \frac{g \cdot \beta \cdot \Delta t \cdot L^{3}}{\nu \cdot a} \tag{5}$$

where g – gravitational acceleration (m s^{-2}); β – expansion coefficient (K^{-1}); ν – kinematic viscosity of air (m^2 s^{-1}); a – coefficient of thermal diffusivity of the air (m^2 s^{-1}).

The expansion coefficient β is expressed by Eq. (6):

$$\beta = t_m^{-1} \tag{6}$$

where t_m – characteristic temperature (K).

$$t_m = \frac{1}{2}\,(t_P - t_a) \tag{7}$$

where t_P – surface temperature (°C); t_a – air temperature (°C).

The total power transmitted by the panel can be divided into power P_F transferred by the front part of the panel and power P_O transferred by the other parts (back and side).

$$P = P_F + P_O \tag{8}$$

where P_F – power transferred by the front part of the panel (W); P_O – power transferred by the other parts of the panel (W).

The power transfer efficiency η_F of the front part of the panel is calculated according to Eq. (9):

$$\eta_F = \frac{P_F}{P} \cdot 100 \tag{9}$$

where η_F – power transfer efficiency of the front part of the panel (%).

The efficiency of power transfer by radiation of the front part η_{FR} is calculated according to Eq. (10):

$$\eta_{FR} = \frac{P_{FR}}{P} \cdot 100 \tag{10}$$

where η_{FR} – power transfer efficiency by radiation of the front part of the panel (%); P_{FR} – power transferred by radiation of the front part of the panel (W).

RESULTS AND DISCUSSION

Main parameters measured in laboratory and greenhouse experiments are given in Tables 1,2 and 3. The data are the mean values ± SD (standard deviation). Total power consumption P was lower than was the nominal information. As results of the surface insulation of back and side parts of the heating panel ($S_O = 0.85$ m^2) the power transferred through these parts $P_O = 126.5$ W is not too big and the power transfer efficiency of the front part ($S_F = 0.75$ m^2) of the panel is rather high, in the laboratory $\eta_F = 80\%$, in the greenhouse $P_O = 155.7$ W and $\eta_F = 74.2\%$.

Table 1. Results of power (W) and power transfer efficiency (%) (average and standard deviation) measured and calculated in the laboratory and experimental greenhouse

Experiments in	P ± SD	P_O ± SD	P_F ± SD	η_F ± SD
Laboratory	630.8 ± 1	126.5 ± 42.6	504.3 ± 42	80.0 ± 6.7
Greenhouse	603.7 ± 6	155.7 ± 20.5	448.0 ± 23.7	74.2 ± 3.4

SD – standard deviation.

Table 2 presents main results calculated for the power convection of the front part of the radiant heating panel. Final results of power calculation of the front part of the radiant heating panel in the laboratory and greenhouse experiments are presented in Table 3.

Table 2. Results of Nusselt criterion *Nu*, Rayleigh criterion *Ry* and heat transfer coefficient α (average and standard deviation) of the front part of the radiant heating panel calculated in the laboratory and greenhouse experiments

Experiments in	Ry ± SD	Nu ± SD	α ± SD
Laboratory	$7.83\times10^9 \pm 2.7\times10^9$	256.5 ± 45.1	5.57 ± 1
Greenhouse	$9.27\times10^9 \pm 1.1\times10^9$	278.1 ± 18.6	6.04 ± 0.4

SD – standard deviation.

The average total power consumption was 630.8 W in laboratory measurements, of which 20% has been transferred by the rear part of the panel and the remaining 504.3 W has been transferred by the front part of the panel. It has been transmitted 237.1 W by convection to the ambient air and 267.2 W by radiation mainly to the floor.

Similar measurements carried out in an experimental greenhouse show that approximately 25.8% of average total power 603.7 W has been transferred by rear and side panel parts, and remaining 448 W has been transferred by the front part of the panel. It has been transferred by convection 289 W to ambient air and 159 W by radiation mainly to the soil surface.

Table 3. Results of power and power transfer efficiency (average and standard deviation) of the front part of the radiant heating panel calculated in laboratory and greenhouse experiments

Experiments in	P_{FC} ± SD	P_{FR} ± SD	η_{FR} ± SD
Laboratory	237.1 ± 94.3	267.2 ± 135.9	42.4 ± 21.6
Greenhouse	289 ± 42.5	159 ± 59.7	26.3 ± 9.7

SD – standard deviation.

The efficiency of power transfer by radiation of the front panel part are rather different (in the laboratory η_F = 42.4% and η_F = 26.3% in the greenhouse). It can be explained by bigger heat transfer coefficient α and higher percentage of the heat transferred by the convection in greenhouse.

Table 4 presents measured surface temperatures in 2 m, 4 m and 6 m distance from the installed heating panel in the laboratory as well as in the greenhouse experiment. The statistically significant differences between these temperatures are caused by increased distance from the panel.

Table 4. Results measurements of soil temperature at 5 cm deep in flower bed of greenhouse and surface temperatures 2 m, 4 m and 6 m distance from heating panel (average and standard deviation) measured in the laboratory and greenhouse experiments. Different letters (*a*, *b*, *c*) in the superscript are the sign of high significant difference (*ANOVA; Tukey HSD Test; P≤ 0.05*) between the surface temperatures of floor (laboratory) or soil surface in the greenhouse

Experiments in	t_{soil} ± SD	t_{s2} ± SD	t_{s4} ± SD	t_{s6} ± SD
Laboratory	-	23.0 ± 0.3^a	22.5 ± 0.1^b	22.3 ± 0.1^c
Greenhouse	8.9 ± 0.6	30.3 ± 4.6^a	28.1 ± 5.3^b	26.3 ± 3.6^c

SD – standard deviation.

The surface temperature of the floor in the laboratory measured at a distance of 2 m from the panel was 23.0 °C, at 4 m about 22.5 °C and at 6 m about 22.3 °C. The surface temperature of the soil in the greenhouse measured at a distance of 2 m from the panel was 30.3 °C, at 4 m about 28.1 °C and at 6 m about 26.3 °C. Higher surface temperatures in greenhouses than in the laboratory are caused by the influence of solar radiation (520 W m^{-2}) and greenhouse effect. The average soil temperature at 5 cm deep was 9 ºC.

CONCLUSIONS

The measurement results show the possibility of using a radiant low-temperature electric panel as a possible source of greenhouse heating, but the total output power was lower than nominal.

The total radiation efficiency of the panel front part was approximately 42.4% during the laboratory experiments. In similar measurements carried out in an experimental greenhouse total radiation efficiency of the panel front part was about 26.3%.

The energy transferred through the rear and side panels and the energy transferred by convection of the front panel part are also brought to the greenhouse and used to heat the indoor air. So, it has also positive impact on the indoor greenhouse conditions.

Differences between surface temperatures confirm the influence of panel radiation on the flower bed. The average temperature in the soil shows that the influence of heating is mainly on the surface of the flower bed, there it could protect cultivated plants, leaves and flowers during the lowest temperature period.

The obtained results can be useful for choosing suitable panel dimensions and parameters for the placement in small horticultural or hobby greenhouse. The future research could be focused on the long-time experiments and application in special greenhouses.

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