



Figure 1: General type of autonomous helio-greenhouse of the trench type.

In this work [18], for the first time, a mathematical model is proposed for studying the behavior of the dependence of the air temperature in a solar-fuel trench-type greenhouse. Since, at present, there is no thermal technical assessment of the microclimate of a solar-fuel trench-type greenhouse for the climatic conditions of the regions of Uzbekistan.

To check the reliability of the proposed mathematical model, experimental measurements of the air temperature inside the greenhouse were carried out, built on the experimental site of the Tashkent state technical university. The accuracy of the proposed mathematical model of a solar-fuel trench-type greenhouse was estimated using the methods of "standard deviation" and the square of the correlation coefficient. As the results show, the standard deviation is equal to 1,5 °C, the standard deviation in percent is equal to 7,2% and the correlation coefficient is 0,86.

2 MATERIALS AND METHODS

An autonomous photovoltaic plant of 3 kW was used as a source of electric and thermal energy. LED lamps were used at night to illuminate the greenhouse. For the heating of plants in the greenhouse used incandescent lamps of 150 W, with different spectrum of radiation, which were installed at a distance of 80-100 cm from the surface of the soil six sensors were installed to monitor the temperature of the soil outside its surface. The total power consumption of the lamps is 2,1 kW. The reserve emergency power source (Figure 2, 3) was a 3,5-kW electric boiler combined with a solar water heating system with forced hot water circulation in the greenhouse batteries, the average temperature of which was 60 °C.



Figure 2: General type of autonomous greenhouse electric heating system.

From Figure 3 it can be seen that the basic scheme of the combined system (electric boiler and solar water heater) consists of: 1 - solar heating water collector (SHWC); 2 - heat exchanger; 3, 7 - expansion tank; 4 - circulation pump; 5 - hot water battery; 6 - automatic mixing valve; 8 - emergency valve with manometers; 9 - electric boiler; CW and HW - cold and hot water; rad.1, rad.2, rad.3, rad.4 - heating radiators.

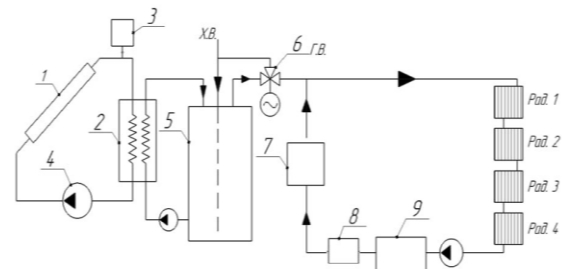


Figure 3: Principal scheme of two-circuit combined system (electric boiler and solar water heating system).

The experiments were carried out from 06.12. to 10.12.2022 at the beginning of the winter season. Daily values of solar radiation, ambient temperature, soil temperature, relative humidity outside and inside the room, indoor ambient temperature values, etc. were measured.

List of instruments used for measurement:

- 1) FLIR E5 - to measure the temperature on the surface of the radiators;
- 2) anemometer AS856 - for measurement of wind speed and air temperature;
- 3) pyranometer Solar Power Meter Di-LOG SL101 - for solar radiation;
- 4) pressure manometer - for water pressure;
- 5) thermometer with output sensor - for temperature measurements.

In particular, a multi-channel digital thermometer of the brand DS18B20 with portable temperature sensors, with a temperature range of -55°C to $+125^{\circ}\text{C}$, was used to measure the temperature of the air space of the autonomous helio-greenhouse of the trench type. The temperature measurement accuracy in the range from -10°C to $+85^{\circ}\text{C}$ is $\pm 0.5^{\circ}\text{C}$.

3 RESULTS AND DISCUSSIONS

On the basis of the experimental studies carried out in the autonomous helio-heating plant of the tranche type, graphs reflecting the daily values of the ambient temperature and airspace inside the helio-greenhouses are constructed. Figure 4 shows the daily thermograms of the outdoor air and the air environment inside the heliothermal plant. On the day of 6.12.2022 the weather was cloudy, clear clouds, during the night there was snow. The ambient temperature (Figure.4, curve 1) in the afternoon varied from -7°C to -4°C . The thickness of the snow on the roof of the transparent surface of the autonomic greenhouse was $4\div 6$ cm.

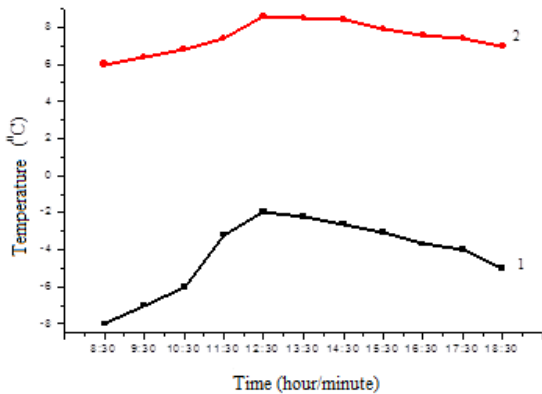


Figure 4: Daily thermo-grams of the outdoor air (curve 1) of the air environment inside the helio-greenhouse (curve 2) of the trunk type (06.12.2022).

The experiments continued on 10.12.2022 in the afternoon in clear weather. On the roof of the greenhouse until noon lay snow cover up to 1.2 cm thick. Environmental temperature values in the afternoon ranged from -10°C to -4°C (Figure. 5, curve 1).

From the graphs (curve 2) on Figure 4-5 it follows that the minimum values of the temperature of the air inside the greenhouse was reduced to 5°C and 6°C , while the outside air temperature varied from -10°C to -7°C (curve 1).

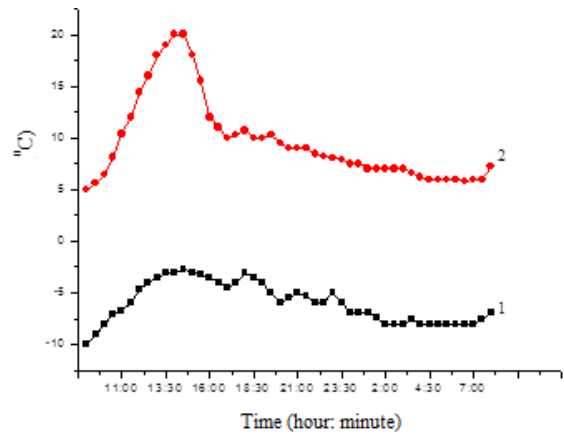


Figure 5: Daily thermograms of the outdoor air (curve 1) of the air environment inside the heliothermal plant (curve 2) of the trunk type (10.12.2022).

Figure 6 shows the dynamics of changes in solar radiation during the day. Analysis of the results of experiments indicate that with the increase of the snow thickness on the roof of the autonomous greenhouse, the transmittance coefficient of transparent multi-channel polycarbonate decreases, and vice versa, impedes the exchange of circulation processes of cold and warm air between the solid and air space.

The proportion of solar radiation (Figure. 6) taking into account the thickness of the snow cover $\sim 1,2$ cm and the consistent cloudiness inside the greenhouse is $7\div 30\%$ of the total value measured outside the research facility.

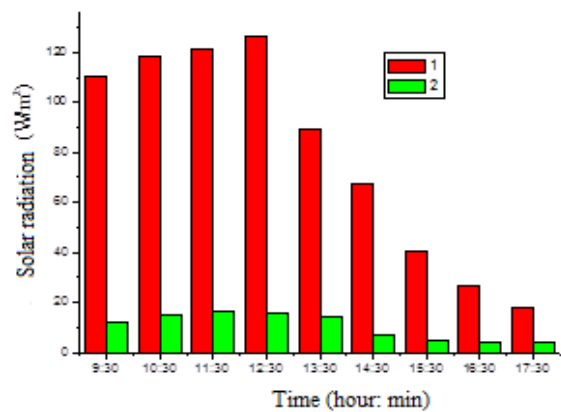


Figure 6: Dynamics of change of solar radiation during the day (1 - outside the greenhouse; 2 - inside the green house), (06.12.2022).

Figures 8-9 shows the results of experimental studies to determine the day and night changes in the temperature of the outdoor air and in the greenhouse

from 11 January to 14 January 2023 using a two-circuit combined system: an electric boiler with a solar water heating system.

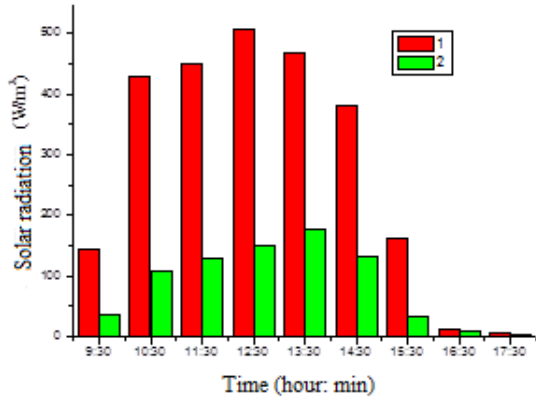


Figure 7: Dynamics of change of solar radiation during the day (1 - outside the greenhouse; 2 - inside the green house), (10.12.2022).

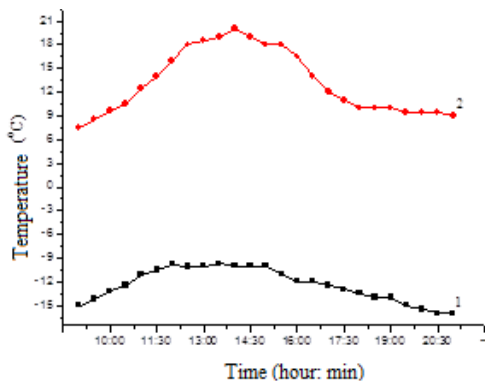


Figure 8: Daily thermograms of the outdoor air (curve 1) of the indoor air of the greenhouse (curve 2) of the tranche type (11.01.2023).

On 11.01.2023 the ambient temperature varied from -16 °C to -9,7 °C, and the intensity of solar radiation ranged from 6÷548 W/m². The transparent surface of the greenhouse was covered with snow, and its thickness was up to 10 cm. The average relative humidity in the greenhouse was 86%. The average temperature and humidity of the soil in the structure were ~16 °C and 76%, respectively.

As shown from the graphs on Figure 8 (curve 1, 2) the temperature in the greenhouse dropped to 10 °C at the outside air temperature -16 °C. When the ambient temperature dropped to -21 °C (Figure 9), the temperature inside the greenhouse was positive 8 - 9 °C. These abnormal frosts also include a lighting system based on a light bulb powered by a photovoltaic station.

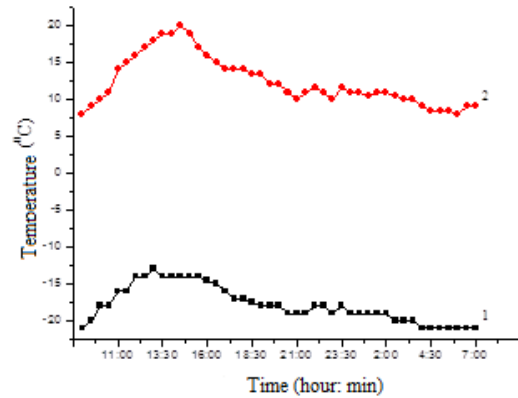


Figure 9: Daily thermograms of the outer air (curve 1) and the air environment inside the helio-greenhouse (curve 2) of the trunk type (13-14.01.2023).

Figures 10-11 shows the density of the flow of solar radiation during the day in Tashkent.

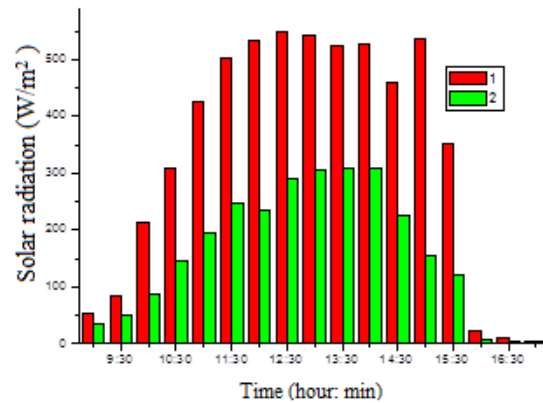


Figure 10: Dynamics of changes in solar radiation during the day (1.Outside the research facility, 2. Inside the research facility), (11.01.2023).

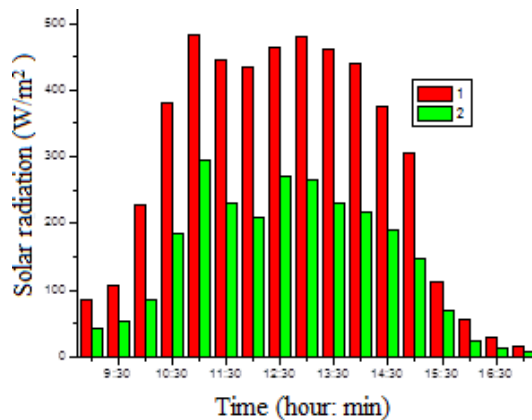


Figure 11: Dynamics of changes in solar radiation during the day (1.Outside the research facility, 2. Inside the research facility), (13.11.2023).

After analyzing Figures 11-12, it can be said that with a snow cover thickness of ~10 cm on the transparent surface of the autonomous greenhouse, the actual contribution to the maximum value of solar energy inside the structure is ~60% of the falling total solar radiation outside the object being studied.

In the framework of the study, infrared images (Figures 12, 13, 14, 15) of panel radiators obtained by the device (FLIRE63900) installed on the fencing of the greenhouse compartment were studied. The number of heating panel radiators 4 pcs and has a single circuit consecutive connection in the heating system.

As the results of Figure10 show, the temperature of the water on the radiators with a single-circuit sequential connection will begin to decrease. In the last radiator the water temperature differs by 12 °C when compared to the first radiator.

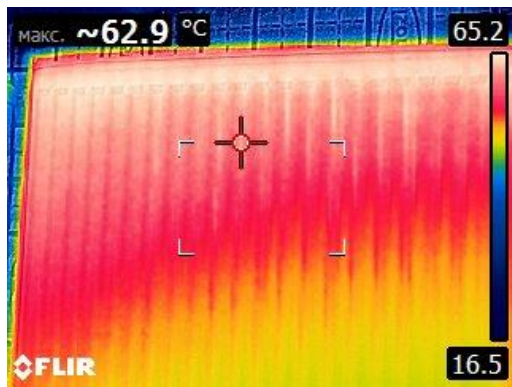


Figure 12: Dynamics of temperature change in greenhouse heating systems with sequential connection of radiators, Time: 14:00, Radiator №1, $T_{\text{radiat.}} \sim 62,9 \text{ }^{\circ}\text{C}$.

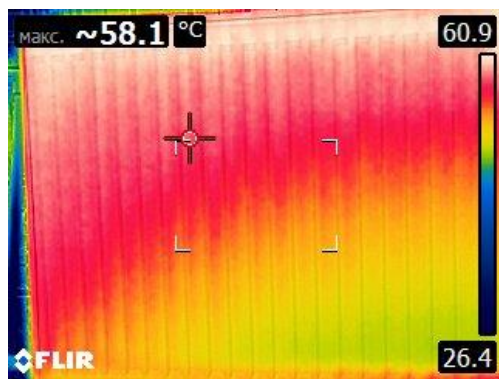


Figure 13: Dynamics of temperature change in greenhouse heating systems with sequential connection of radiators, Time: 14:01, Radiator №2, $T_{\text{radiat.}} \sim 58,1 \text{ }^{\circ}\text{C}$.

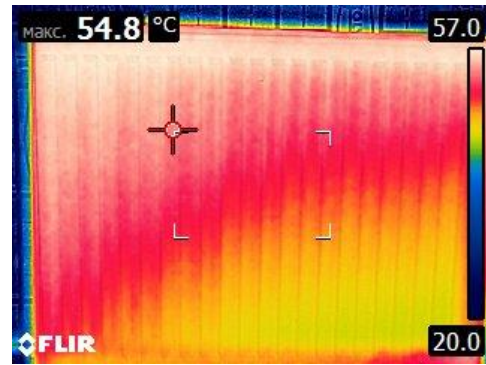


Figure 14: Dynamics of temperature change in greenhouse heating systems with sequential connection of radiators, Time: 14:02, Radiator №3, $T_{\text{radiat.}} \sim 54,8 \text{ }^{\circ}\text{C}$.

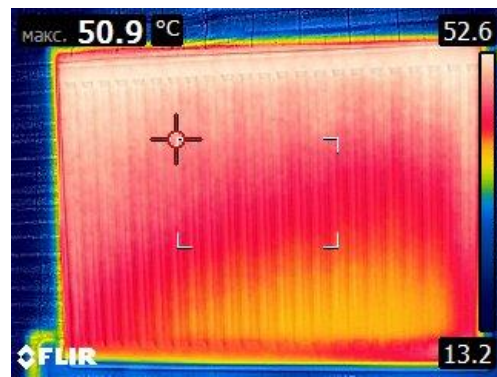


Figure 15: Dynamics of temperature change in greenhouse heating systems with sequential connection of radiators, Time: 14:03; Radiator №4, $T_{\text{radiato}} \sim 50,9 \text{ }^{\circ}\text{C}$.

4 CONCLUSIONS

The following conclusions can be drawn from the results of the studies:

- 1) during the winter heating season at ambient temperature up to $-10 \text{ }^{\circ}\text{C}$ and when using an autonomous photovoltaic system, the air temperature inside the autonomic heating facility dropped closer to $+5 \text{ }^{\circ}\text{C}$, and at an external temperature of more than $-10 \text{ }^{\circ}\text{C}$ it was necessary to turn on emergency heating sources;
- 2) a basic scheme of a two-circuit combined system based on an electric boiler and solar water heating system is proposed;
- 3) the actual share of solar energy within the greenhouse is determined when compared with the total solar radiation outside the object under investigation, taking into account the thickness of the transparent surface covered with snow.

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