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Technical and economic efficiency of microclimate parameters provision in greenhouse farming annual cycle

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Abstract. The use of solar energy in greenhouse farming allows us to reduce the consumption of organic and mineral fuel. Nowadays, the share of energy costs in the structure of production costs of indoor farms is up to 70%. It is connected with insufficiently effective use of electric and thermal energy in greenhouses, lack of optimization of energy processes in it. The paper also takes into account the thermophysical properties of soils necessary to determine the process of heat exchange during the year. Heat transfer in the soil is carried out mainly due to its conductive heat conduction, as well as moisture transfer and radiation. Therefore, when thermal processes are considered in the ground under the coefficient of heat conduction, some effective value is considered, taking into account the radiant and convective components and averaged over a sufficiently large volume compared to the size of the particles. The share of convective and radiant components under normal conditions does not exceed a few percent. The thermophysical properties of soils are determined by the experimentally established distribution of temperatures and heat fluxes in the soil. Creation and maintenance of design parameters of microclimate in greenhouses is most effective and economical through the integrated use of natural and artificial factors of formation of temperature, humidity and air regimes, combined in a complex system.

1 Introduction

Today, there is a widespread saving of raw material resources throughout the world. Scientists in many countries are trying to solve this problem through various methods, including the use of renewable and alternative energy sources [1-2]. These include such types as wind energy, solar energy, tidal energy, use of small rivers, sea waves, geysers and even industrial waste and household garbage [3-4]. And in this row, solar energy does not take the last place in the world economy [5-6]. Solar heating is based on the so-called greenhouse (greenhouse) effect. Solar rays penetrate through the translucent roof of protected ground structures and heat the walls there, the ground of which, in turn, heats the air [7-8]. Due to the use of accumulation of excessive daytime solar radiation during the day it is possible to get a significant saving of thermal energy for heating at night. But there is a problem of conserving the received energy. Consequently, the task is the

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need to determine the thermal potential of solar heat in annual and daily cycles and compare it with the heat storage capacity of the soil [9-10] in the construction of a greenhouse in Stavropol city.

2 Methods and materials

To calculate the surfaces of the greenhouse structures (Fig. 1), we take the following parameters as input data:

- size factor - a, m (size of the smallest side of the greenhouse);
- shape factor - f = b/a (the ratio of the greenhouse sides);
- greenhouse height - h, m.

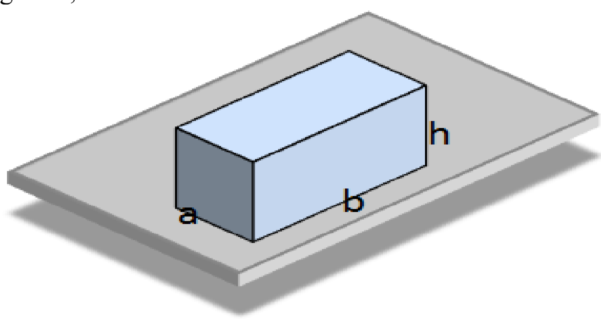

Fig. 1. Greenhouse dimensions

To calculate the disposable amount of solar energy supplied to an inclined surface, it is necessary to know the angles of incidence of the sun's rays on the inclined and horizontal surfaces at a given location. The position of some point A on the Earth's surface relative to the sun's rays at a given time is determined by three basic angles : the latitude of the location of the point φ; hour angle ω; declination of the Sun δ, taking into account n - the ordinal number of the day, calculated from January 1 (Table 1).

Table 1. Data for n and δ for an average day of months I-XII

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
n	17	47	75	105	135	162	198	228	258	288	318	344
δ	20.9	-13	-2.4	9.4	18.8	23.1	21.2	13.5	2.2	-9.6	18.9	-23

During the year, the parameters of the angles are constantly changing. This is due to the tilt angle of the Earth's axis. Therefore, for a more accurate calculation it is necessary to take into account these changes every day. Figure 2 shows how the tilt angle of the Earth's axis changes during the year.

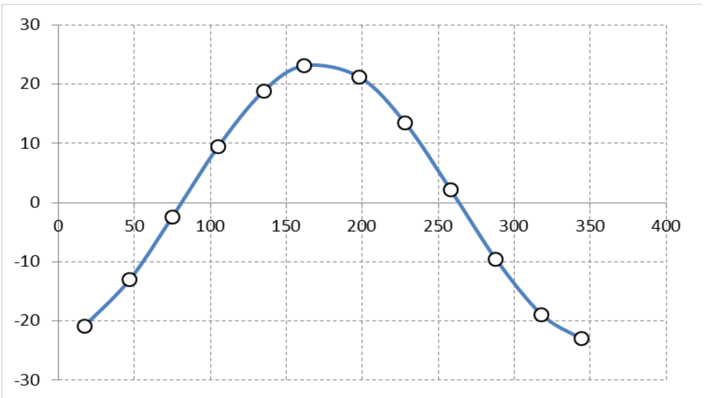

Fig. 2. Change in the tilt angle of the Earth's axis during the year

Table 2 shows the total (direct and diffuse) solar radiation to the horizontal surface under actual cloud cover conditions for Stavropol Krai, MJ/m^2**.**

Table 2. Total (direct and diffuse) solar radiation to a horizontal surface

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
134	205	272	406	523	553	574	486	364	243	130	105

To compare heat gains and heat losses of the greenhouse, we need to calculate the heat gains from solar radiation with respect to the whole greenhouse area (GJ/month) (Table 3).

Table 3. Heat gain in the greenhouse from solar radiation, GJ/month

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
27	41	54	81	105	111	115	97	73	49	26	21

Heat loss was calculated using the heat transfer equation for a single-layer flat wall with the accepted thickness of polycarbonate 0.010 meters.

Optimal conditions of plant growth in the greenhouse corresponds to the daytime air temperature 24÷26ºC and nighttime air temperature 16÷18ºC. Daytime temperature is taken for calculation 25 ºC and the nighttime temperature 18 ºC which corresponds to the average daily internal air temperature.The outdoor air temperature is presented in Table 4, determined by normative data for Stavropol Krai.

Table 4. Average monthly outdoor air temperature

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
-4.2	-3	1.1	8.9	14.6	18.3	21.1	20.5	15.5	8.9	3.2	-1.4

Calculation of heat losses gave results by months of the year presented in Table 5.

Table 5. Heat consumption (GJ/month) to cover heat losses

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
-122	-116	-96	-60	-33	-15	-2	-5	-28	-60	-87	-108

3 Results

Below is a summary graph of heat gain and heat loss of the greenhouse (Fig. 3). The graph clearly shows that the extremes of heat gain and heat loss are very different by months of the year.

In winter months the heat inflow does not cover the heat losses of the greenhouse, and in summer months the heat inflow is maximum, but the heat losses are almost absent. In the spring and fall months, the heat gains are comparable to the heat losses of the greenhouse, but it should be taken into account that the heat gains are present only during the daylight hours, while the heat losses can be round-the-clock.

In order to fully utilize the solar heat during these periods of the year, a partial accumulation of daytime heat gains is necessary to compensate for nighttime heat losses.

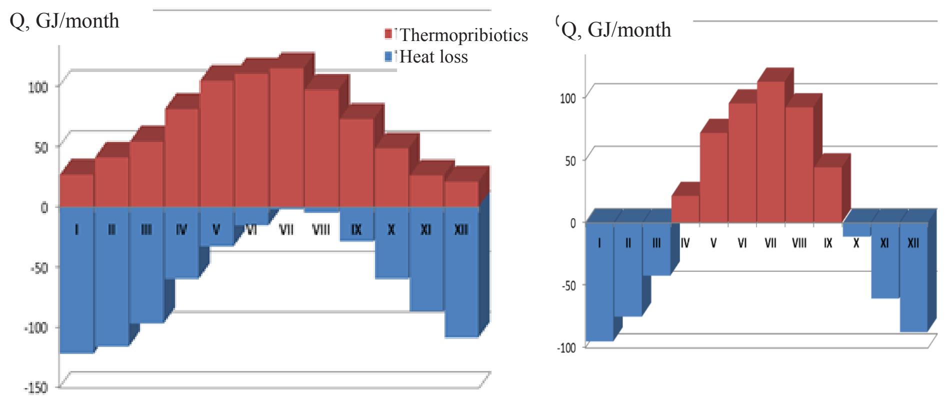

Fig. 3. Heat inflows and heat losses by months of the year (left); heat deficit and ash deficit by months of the year (right).

How much the heat inflows cover the heat losses of the greenhouse is determined by adding up the data of Tables 3 and 5 by months of the year (Table 6).

Table 6. Heat deficit and surplus, GJ/month

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
-92	-72	-40	24	74	98	115	95	47	-9	-58	-85

Adding separately the heat surpluses and deficits by months of the year (Fig. 4), we obtain these data in annual terms:

- heat surplus amounted to 439 GJ;
- heat deficit amounted to 370 GJ.

These data show that with proper organization of summer heat accumulation, it is possible to fully cover heat losses of the cold period of the year. However, it should be assumed that such a long (6 months) storage of a large amount of heat will require a high-tech organization of a heat accumulator. The size of the required heat accumulator for "preservation" of summer heat depends on the ground heating temperature.

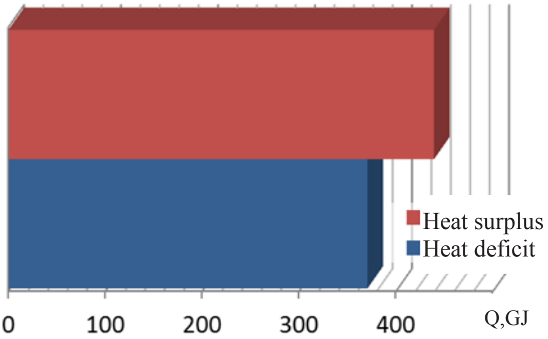

Fig. 4. Comparison of heat surplus and deficit in annual terms

The size of the required heat accumulator for "preservation" of summer heat depends on the ground heating temperature.

In order to reduce the required heat storage volume, it is possible to increase the ground temperature, thus increasing the available temperature difference. In this case, the use of heat pumps will be required, and heat losses in the ground will also increase (Fig. 5).

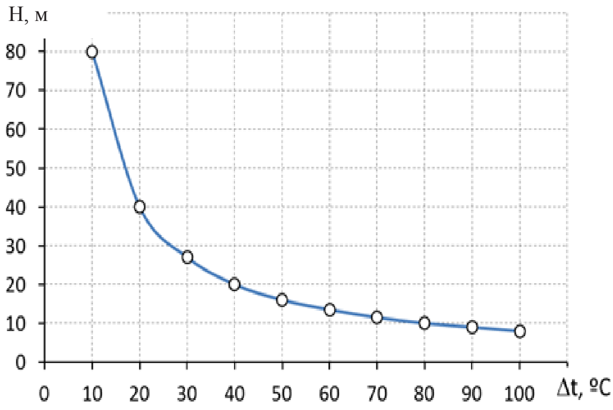

Fig. 5. Required depth of the heat accumulator (H) depending on the available temperature difference (Δt) in soil

Heat accumulator can be simpler in technical design and more efficient in terms of covering the daily heat deficit.

4 Discussion

At the geographical latitude of Stavropol Krai, annual heat gains from solar radiation can completely cover all annual heat losses of the greenhouse.

However, the maximums of heat gain and heat loss diverge significantly by seasons. The maximum heat gain occurs during the summer months, while the maximum heat loss occurs during the winter months. This significant time divergence makes it very difficult to conserve heat.

Heat gains and heat losses are also unevenly distributed during a single day. Daily irregularity can be successfully smoothed by accumulation of daytime excess heat from solar radiation in the ground.

Such accumulation of heat is most effective in the spring and fall period, which is about 6 months in duration.

In general, it turns out that only during three winter months of the year an external heating load is required, and nine out of twelve months the greenhouse can operate autonomously, without the need for energy for heating.

5 Conclusions

Determination of the useful effect of daily heat accumulation showed that in annual terms it is possible to save from 15 to 45% of energy spent on heating. And the greatest influence on the savings is the size of the greenhouse in plan. The larger the area occupied by the greenhouse, the greater is the useful effect of accumulation of daily excess heat.

References

1. Ovchinnikova S., Schneider E., Borovkov A., Lyamina, A. IOP Conference Series: Earth and Environmental Science **937(4),** 042049 (2021) doi.org/10.1088/1755-1315/937/4/042049
2. A. Sekisov, S Ovchinnikova, V. Grebneva and M. Chernyshova IOP Conf. Ser.: Mater. Sci. Eng. **913** 042035 (2020) doi.org/10.1088/1757-899X/913/4/042035
3. Ovchinnikova S., Abornev D., Kalinichenko M., Kalinichenko A., Sekisov A. Advances in Intelligent Systems and Computing **1259** AISC, 601–610 (2021) doi.org/10.1007/978-3-030-57453-6_57
4. Kalinichenko M.Y., Stojanov N.I., Abornev D.V., Ovchinnikova S.V. IOP Conference Series: Materials Science and Engineering **905(1)** 012034 (2020) .org/10.1088/1757-899X/905/1/012034
5. O. Takhumova, et.al., International Journal of Engineering and Advanced Technology (IJEAT) **9(1)** 1568-1571 (2019) doi.org/10.35940/ijeat.A1360.109119
6. G. Degtyarev, O. Takhumova IOP Conference Series: Earth and Environmental Science **395**. 012001 (2019). doi.org/10.1088/1755-1315/395/1/012001.
7. Bayramukov S.H., Dolaeva Z.N., Khezhev T.A. IOP Conference Series: Materials Science and Engineering, **698(2),** 022067 (2019) doi.org/10.1088/1757-899X/698/2/022067.
8. Bayramukov S., Dolaeva Z., Khezhev T. Lecture Notes in Civil Engineering **180**, 325–333 (2022) doi.org/10.1007/978-3-030-83917-8_30
9. Kozyrev B.A., Tsoraeva E.N., Zh Basieva L., Hugaeva L.M. IOP Conference Series: Earth and Environmental Science, **1010(1),** 012085 (2022) doi.org/10.1088/1755-1315/1010/1/012085
10. Tsoraeva E., Bekmurzov A., Kozyrev S., Khoziev A., Kozyrev A. E3S Web of Conferences **215**, 02003 (2020)doi.org/10.1051/e3sconf/202021502003