LIGHTING CONDITIONS IN PHOTOVOLTAIC GREENHOUSES

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ABSTRACT. The cultivation of plants at extremely low temperatures is carried out in specialized greenhouses. They must provide very good thermal insulation with the environment, as heating costs will otherwise become disproportionately high. An example of such conditions is the climate of Mars or Antarctica. Unlike greenhouses built in temperate climates, where a polyethylene cover is sufficient to provide the necessary heat and transmit the necessary solar radiation to carry out photosynthesis, the greenhouses of the above type must be closed well-insulated rooms without windows. The required light will be generated by LED luminaires with a plant-optimized emission spectrum. The report analyzes the energy costs required for lighting. It is proposed to use photovoltaic panels to power the lighting. Options have been developed for powering greenhouses at different outdoor temperatures and levels of solar radiation.

Keywords: greenhouse, LED luminaries, photosynthesis, photovoltaic panels

СВЕТЛИННИ УСЛОВИЯ ВЪВ ФОТОВОЛТАИЧНИ ОРАНЖЕРИИ

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РЕЗЮМЕ. Отглеждането на растения при екстремно ниски температури се извършва в специализирани оранжерии. Те трябва да осигурят много добра топлоизолация с околната среда, тъй като разходите за отопление в противен случай ще станат несъразмерно високи. Пример за такива условия са климата на Марс или Антарктида. За разлика от оранжериите изграждани в умерените климатични пояси, където полиетиленова покривка е достатъчна да осигури нужната топлина и да пропуска необходимата слънчева радиация за осъществяване на фотосинтезата, то оранжериите от горния тип трябва да представляват затворени добре топлоизолирани помещения без прозорци. Необходимата светлина ще се генерира от светодиодни осветители с оптимизиран за растенията спектър на излъчване.
В доклада се прави анализ на необходимите енергийни разходи за осветление. Предлага се да се използват фотоволтаични панели за захранване на осветлението. Разработени са варианти за захранване на оранжериите при различна външна температура и ниво на слънчевата радиация.

Ключови думи: оранжерии, светодиодни осветители, фотосинтеза, фотоволтаични панели

Growing plants in greenhouses is practiced in the following cases:

- Use of waste heat from other productions and growing vegetables during the winter season in temperate latitudes.
- Growing crops that require special conditions - gas composition of the atmosphere, special soil, diet, lighting.
- Use of a closed volume to store scarce moisture (in desert areas).
- Growing of varietal seeds, where they should not be mixed with other crops. (this can only be done indoors).
- Intensive production with multi-storey plant placement.
- Getting food in extreme conditions - lack of suitable soil, extremely low temperatures or lack of suitable atmosphere.
- In all cases, except for the third option, additional artificial lighting will be required. The required amount and spectrum of light has already been discussed in [Velinova, 2019 and 2015, Blankenship R., 2014].

In this report, the subject of consideration is the last category of greenhouses - those operating in extreme conditions. An example of such conditions is the climate of Mars or Antarctica. Unlike greenhouses built in temperate climates, where a polyethylene cover is sufficient to provide the necessary heat and transmit the necessary solar radiation to carry out photosynthesis, the greenhouses of the above type must be closed, well-insulated rooms without windows. They must provide very good thermal insulation with the environment, as heating costs will otherwise become disproportionately high. The required light will be obtained from LED luminaires with a plant-optimized emission spectrum. The energy needed for heating and lighting can be generated in two ways - from a nuclear reactor or from photovoltaic panels. Technical capability also now. For example, the US Department of Energy has announced a tender for the creation of a small nuclear power supply system. The reactor must give not less than 10 KW of power, which must not be interrupted and be stable. According to the terms of this contract, the weight of the reactor must be no more than 3500 kg and it must be able to work autonomously for 10 years [kaldata.com].

At the same time, as early as 1990, Hyperion Power Generation, Inc. built a portable reactor with a thermal capacity of 10MW, which has a volume of about 3 cubic meters and can produce energy for 10 years. This reactor or rather nuclear battery was developed for the needs of the US military, and can be transported by truck and it is assumed that all permits for use have been obtained.

Hyperion Power Generation, Inc. is an American energy company in Santa Fe, New Mexico, USA, created for the purpose of implementation, construction and sale of several types of relatively small modular nuclear reactors (70 MW thermal, 25 MW electric), which have innate protection against accidents and do not provide the opportunity for the development of nuclear weapons. The reactor is the size of an oil tank and a diameter of 1.50 meters. [bg.oclifescience.com]

Another possibility for obtaining energy is the use of a photovoltaic plant. Under normal conditions for average latitudes, the incident solar radiation on a horizontal surface is from 1100 to 1400 kWh / year per sq.m. In the extreme conditions in which we want our greenhouses to operate, we can count on a much lower level of solar radiation.

What is the current state of technology and what part of this energy can be converted into electricity? The mass production of solar panels is produced on the basis of pure silicon. The technology is similar to that for the production of integrated circuits and the price of solar panels has dropped significantly. Currently, the price for deliveries of quality panels is about 0.2 € / Wp. For the last 10 years, the average annual increase in global cumulative production of PV capacity is about 30%. Applying the law of SWANSON (doubling the cumulative production leads to a reduction of prices by 24%), the price of the panels will fall below 0.1 € / Wp. Over the last 40 years, the prices of PV panels have decreased by more than 150 times. In places where there is high solar radiation (these are mostly desert places), tenders are held en masse for the construction of photovoltaic power plants according to the criterion of the lowest price of energy sold. An example of this is the recently won tender in Abu Dhabi for an energy price of $ 0.0135 per kWh or $ 13.5 / MWh (~ BGN 23 / MWh. For comparison, the price of the stock exchange in Bulgaria these days was about BGN 85 / MWh). Chinese solar developer Jinko Power and French energy giant EDF this year announced a new record low price for solar energy, which will be generated on a 1.5 GW Al Dhafra solar project in Abu Dhabi at a tariff price of 0.0135. $ / KWh. [*pv-magazine.com*].

In terms of solar energy utilization for silicon panels, there is still much to be desired. The efficiency of energy conversion is in the range of 13-15%. The latest panels with dimensions of 2x1m and power 500W, now have an efficiency of more than 20%. Is it possible to increase efficiency even more and is there a limit to this? According to the National Renewable Energy Laboratory of the USA, NREL in silicon cells without light concentration, results with 31% efficiency were obtained. Much higher efficiency results can be obtained with multilayer panels with light concentration. In this case, an efficiency of 47% is achieved for semiconductors with three or four P-N junctions. [*nrel.gov*]

In this report, an attempt is made to design a greenhouse for growing plants in extreme environmental conditions at a level of solar radiation of a maximum of 400 - 500 W / sq.m. In this case, all the energy for heating and plant growth will be obtained from external solar radiation.

An example of such a place is the planet Mars

The atmosphere on Mars is about 100 times less dense than on Earth. But the Martian atmosphere is dense enough to have clouds and winds. Huge sandstorms engulf the entire planet. Mars is a much colder planet than Earth. The temperature of the Martian surface varies from -125 °C near the poles in winter and reaches 20 °C at noon near the equator. The average temperature on Mars is about -60 °C. The atmosphere on Mars contains significantly less oxygen (O_2) than on Earth. The content of O_2 in the atmosphere of Mars is only 0.13%, while on Earth it is 21%. Carbon dioxide makes up 95.3% of the gases in Mars' atmosphere. The other gases are nitrogen (N_2) 2.7%, argon (Ar) 1.6% and water vapor (H_2O) 0.03%.

Winds on the surface of Mars are usually light, with a speed of about 10 km / h. Scientists have observed gusts of wind at a speed of 90 km / h. Martian winds have less strength due to the low density of the atmosphere.

Sandstorms

The biggest sandstorms can cover the entire surface of Mars. Storms of this size are rare, but can last for months. Such storms occurred in 1971 and 2001.

Sandstorms occur more often when Mars is closest to the sun. The reason for this is that the sun heats the atmosphere of Mars the most [solarsystem.valchev-bg.com].

The Insight spacecraft, which landed on Mars in November 2018, can count the time on Mars. [*nationalgeographic.bg*]

It is located near the Martian equator, 4 degrees north. According to the latest data, the temperature on Mars at five in the morning local time is minus 95 degrees Celsius. When the Sun warms the planet's surface, the maximum temperature reaches minus 5 degrees Celsius.

Another place with extreme conditions is Antarctica.

Antarctica is the coldest place on Earth. The Japanese station in Antarctica on December 8, 2013 reported -91.2 °C. Winter temperatures reach minimum values - between -80 °C and -90 °C in the interior of the continent and maximum between 5 °C and 15 °C around the coast in summer. The snow surface reflects almost all the ultraviolet rays that fall on it. Almost the entire continent is covered with ice with an average thickness of 2.5 km. Stormy winds often descend from the polar plateau on the periphery of the continent. Inside, the wind is usually moderate. During the clear days of summer, more solar radiation reaches the surface than at the equator, due to the 24-hour glow

Under these thermal and light conditions, an attempt will be made to design an enclosed space in which to grow plants, all energy being obtained from solar radiation. A room with approximate dimensions 20x20x20 m will be built. Only existing technologies and materials will be used. As a thermal insulation material for the construction of the walls can be used some of the following materials shown in Table 1 and having the following coefficients of thermal conductivity (thermal conductivity), W / (m.K).

Table 1.

Material	The coefficient of thermal conductivity, W/m*K
Styrofoam	0,04
Polyurethane foam sheets	0,035
Polyurethane foam panels	0,025
Light foam	0,06
Perlite	0,05
Cotton wool mineral light	0,045
Mineral wool heavy	0,055
Expanded polystyrene - styrofoam	0,031
Mineral wool heavy	0,055

Most of these materials do not have good mechanical properties except for the foam glass, and you will need to build an external stable skeleton. Expanded polystyrene - styrofoam with a thermal conductivity coefficient of 0.031 W / mK will be used as thermal insulation material. If it is assumed that a temperature of 20 °C will be maintained inside the room and the outdoor temperature will be -80 °C, then the thermal difference will be ΔT = 100 °C

At a thickness of the thermal insulation panel of 20 cm, the power losses will be 15.5W / sq.m. Accordingly, with a wall thickness of 30 cm, power losses will be 10.3W / sq.m

With dimensions of the room 20x20x20 m, the outdoor area will be 6x20x20 = 2400 sq.m. The corresponding heat losses will be: 2400 sq.m x 15W / sq.m = 36kW. 864 kWh of electricity will be needed for one day to maintain the required temperature.

The effective area of the building for placement of PV panels is 1500 - 1800 sq.m. Panels with dimensions 2x1m and power 500 Wp will be used. It is assumed that the panels will be located only on the surface of the building. The average efficiency of using solar radiation for the months in spring, summer and autumn will be about 30%. With an effective number of panels - ~ 700 - 800 pcs. The peak power generated in the conditions of Antarctica for 30% efficiency of the system will reach - 700 pcs. x 0.5 kW x 0.3 = 105 kW. For the summer months, the effective operating time of the system will be about 16 hours, and for spring and autumn - an effective time of 8 hours. Respectively, in the summer 1680 kWh will be generated per day, and in the spring-autumn season - 840 kWh. This means that with modern technology, such a building can be heated by the energy received from the sun in the conditions of Antaktida for the months from September to April. As the solar radiation fluctuates around the clock during the transition months, it will be necessary to create a heat accumulator with a capacity of 1700 kWh (this provides heating power for two days). A water tank with a volume of 28-30 cubic meters can be used as such an accumulator. In fact, this is a cube with a wall size of 3 m. In hydroponic plant cultivation, such a tank will be needed to store the nutrient solution.

Is this power enough for plant photosynthesis? In this volume of the room - about 8000 cubic meters, shelves for hydroponic cultivation of plants with a total area of 4000 - 6000 sq.m can be located.

What luminous flux can be achieved at 105kW?

Modern LEDs have an efficiency of 180 - 200 lm / W. This means that with the available power a luminous flux of 19 to 21 million lm can be generated. With this luminous flux distributed over the effective area of 4000 to 6000 sq.m, irradiation from 3200 to 5200 lm / sq.m will be realized. This value is close to the lower limit for efficient photosynthesis, but is sufficient for the development of most plants.

The conditions on the planet Mars are similar to those in Antarctica. The advantage is the high content of carbon dioxide - 95%, which is useful for plants. The difference is that there the atmosphere is diluted and high-speed winds cannot cause the destruction of the structure. Sandstorms are dangerous. Due to their duration, there is a risk of the system shutting down. Nevertheless, building such an enclosed space is the only way for people on this planet to survive.

Conclusions and recommendations

1. The construction of modular heat-insulated greenhouses with a volume of 8000 cubic meters is possible with the current technological possibilities. In them it will be possible to grow plants for human consumption, and the necessary energy for lighting and heating will be obtained from photovoltaic panels.
2. It is recommended that the thickness of the thermal insulation be not less than 30 cm.

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