Selection of a heating system based on climatic conditions of Uzbekistan and on calculations of the technical and economic indicators of alternative systems: A case study of the solar greenhouse with a transformable building

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Abstract. This paper presents studies on the choice of a heating system based on calculations of economic efficiency and payback periods for alternative systems, a solar greenhouse with a transformable body. The purpose of the work is to carry out calculations to determine the consumption of fuel resources necessary to ensure the required amount of energy for the heating season: consumption of natural gas, solid fuel (coal) and electricity for heating a greenhouse with a transformable (adjustable) body. Analytical methods were used to determine the cost of materials and the main units of a greenhouse with a transformable (adjustable) body. Depending on the shape of the greenhouse, the total costs, economic efficiency and payback periods are determined. The research work carried out shows that, in terms of the cost of construction and consumption of materials, the developed greenhouse with transformable (adjustable) body are quite acceptable for its successful use among farmers and private households in the Republic of Uzbekistan. Calculation of economic efficiency and payback periods for greenhouses with a transformable housing allows you to choose the most acceptable heating system and technical characteristics of alternative systems acceptable for the climatic conditions of Uzbekistan.

1. Introduction

The geographical position of the Republic of Uzbekistan determines the presence of significant resources of renewable energy sources (RES), the main share of which is solar energy. The use of solar energy in agriculture and in everyday life allows, when calculating the cost of production or the cost of its production, to reduce the fuel component, and this, as a result, significantly increases the technical and economic efficiency of these areas. One of the promising directions in the use of inexhaustible resources of solar energy is its use in solar greenhouses.
Currently, solar greenhouses are widely used in many countries for growing vegetables, berries, tropical plants, greenery, flowers, etc. In some countries, along with greenhouses, photovoltaic plants are also used, which generate electricity to heat them [1, 2].

Due to the low agro-climatic potential and the short growing season observed in mountainous regions, agriculture has certain seasonality. In this connection, the solution of the problem of changing this factor for the most affordable food supply for the inhabitants of mountainous regions is very urgent today.

To reduce heat loss and increase the energy efficiency of greenhouses, we have developed a greenhouse with a transformable (adjustable) body. Adjustable mechanisms are installed on the greenhouse body, in racks. They allow you to change the height of the greenhouse body when the air temperature inside it changes [3].

In a number of fundamental studies, the issues of rational use of fuel and energy resources and analysis of energy efficiency and when heating greenhouses are widely covered [4-6].

We calculated by calculation the economic efficiency of greenhouses with a transformable body and the payback period, the calculations took into account the cost of heating by alternative systems [7-9].

2. Methods
Based on the analysis of research and development of heating systems and research of technical characteristics when calculating the economic efficiency of greenhouses, we have developed a block diagram of the choice of a heating system based on alternative systems.

![Block diagram of the choice of a heating system based on calculations of the economic efficiency of alternative systems](image-url)
According to the block diagram, the economic efficiency of greenhouses depends on the technical characteristics, thermal loads and the choice of the greenhouse heating system.

A greenhouse heating system can be implemented in two ways:

1. Solar heat supply;
2. Artificial heating system.

When calculating solar heat supply, it is necessary to determine the optimal amount of accumulated thermal energy. To calculate the amount of accumulated heat energy, the volume and geometrical dimensions of the accumulated installation are determined.

Calculation of the optimal accumulated thermal energy consists in determining the accumulating capacity of the stored volume of water or other type of liquid. In our calculation, antifreeze was used in the form of a duplicate liquid, as a coolant in the heating system - a modern alternative to water.

The storage capacity of water or antifreeze is characterized by the heat capacity, which for water at \( t = 20^\circ C \) is 4.19 kJ kg/°C and for antifreeze at \( t = 20^\circ C \) is 3.45 kJ kg/°C, which means that to heat one kilogram of water by 1 degree, it is necessary to supply an amount of heat equivalent to 4.187 kJ, which is the same, \( = 1 \text{ kcal} = 1.163 \text{ W\cdoth} \).

When calculating, we used a tank - a heat accumulator with a volume of 1000 liters (hereinafter, the mass of 1 liter of water or antifreeze equal to 1 kg is conventionally taken) and it heats up to 50 degrees, in this case it will accumulate thermal energy \( 1000 \cdot 50 = 50,000 \text{ kcal} = 0.05 \text{ Gcal} = 58 \text{ kW\cdoth} \).

When calculating the artificial heating system, the alternative systems most used in Uzbekistan are systems using electricity, natural gas and solid fuel (coal).

According to the block diagram of the presented sequential calculations in the field of renewable and unconventional energy [6], the economic efficiency from the use of new technology can be estimated by the formula (1):

\[
E = (V_m C \tau_m - V_p C \tau_p) - \left\{ \left[ \left( 3_p + A_p L_p \right)/ L_p \right) - \left( 3_m + A_m L_m \right)/ L_m \right] + \\
\left[ \left( M_m C_m - (M_p C_p) \right) \right],
\]

where, \( V_m \) and \( V_p \) - respectively the volumes (mass, quantity) of the consumed energy carrier (or the amount of energy) for a certain period (day) in the case of using the traditional and developed (new) type of greenhouse; \( C \) is the cost of a unit of energy carrier used to heat the greenhouse, \( \tau_m \) and \( \tau_p \) - respectively, the duration of energy consumption in a greenhouse with a traditional and developed greenhouse design; \( 3_p \) and \( 3_m \) - respectively, the costs of manufacturing and installation of traditional and developed greenhouse designs; \( A_p \) and \( A_m \) - respectively, depreciation deductions, operating costs of traditional and developed greenhouse designs; \( L_p \) and \( L_m \) - respectively, the payback periods of the traditional and developed greenhouse design.

The total area of the greenhouse, the entire outer surface of the greenhouse is 42.5 m². The calculations used four types of greenhouses (two-stack) of different shapes, but the same area.

3. Results and Discussions

The calculation results according to [2] on the consumption of gas, coal and electricity for the heating season are shown in Table 1.

Table 1 shows that the fuel consumption for the heating period, for the season, is determined depending on the type of fuel and the efficiency of the boilers. In the climatic conditions of Uzbekistan, the most acceptable fuel resource in terms of consumption and cost is natural gas and electricity in winter.

Based on the known overall dimensions of a greenhouse with a transformable (adjustable) body, we calculate the material costs for manufacturing and installation, and determine the cost of the main units [2].

The cost of materials and main units of a greenhouse with a transformable (adjustable) body are shown in Table 2.
Table 1. Cost, required amount and cost of purchasing fuel for the heating season by type of use

| Type of fuel | Efficiency boiler, % | Consumption for the heating period, season | Price, sum / $ | Heating costs per season, sum / $ |
|--------------|----------------------|---------------------------------------------|----------------|-----------------------------------|
| Accumulated energy: with working fluid: | 90 | 58 kW•h | The cost cubic meter of drinking water for the population - 1 400; for commercial consumers - 1000; - 1 liter - 20000 | - 81200 / 7.75 |
| - water; | | | | |
| - antifreeze; | | | | |
| Electricity | 99.5 | 1203.5 kWh | 450/0.027 per kW•h | 541 575 / 51.69 |
| Gas | 93 | 145.77 m³ | 380/0.23 за 1 м³ | 55392.6 / 5.29 |
| Coal | 77 | 1.6965 ton | 970 000/92.58 per ton | 1645605 / 157.07 |

Note: 1) when calculating the rate of 1 US dollar was 10477 soms, the cost of fuel is indicated as of 12.04. 2021; 2) the price of a cubic meter of natural gas supplied to the population in the presence of meters will be 380 soums; 3) the cost of 1 kW•h of electricity for household consumers increases from 250 to 295 soums, for other categories of consumers the tariff will be 450 soums.

Table 2. The cost of materials and main components of a greenhouse with a transformable (adjustable) body

| Name of materials | Unit the size | Number | Specific the cost сум/$ | Total costs, сум/$ |
|-------------------|---------------|--------|-------------------------|-------------------|
| Metal profile 4x4 | shoulder straps. meter | 66 | 14 000 / 1,34 | 924000 / 88.19 |
| Regulatory mechanisms | pieces | 4 | 200 000 / 19.09 | 800000 / 76.34 |
| Polyethylene film, thickness 150 microns | m² | 52 | 6000 / 0.57 | 312000/ 29.78 |
| Wire for holding mechanical loads, 1.8 mm thick | shoulder straps. meter | 40 | 8000 / 0.76 | 320000/ 30.54 |
| Total | | | | 2356000 / 224,87 |
| Other expenses | | | | 235600 / 22.49 |
| Total cost | | | | 2591600 / 247.36 |

Table 2 shows that in terms of material consumption and cost, the greenhouse developed by us with a transformable (adjustable) body is quite acceptable for construction on personal plots for individual use. The total cost of its construction will amount to 2591600 (two million five hundred ninety one thousand six hundred) soums or $ 247,36 (two hundred forty seven dollars and thirty six cents) US dollars.
The calculation results for various forms of greenhouses, the costs of manufacturing and installation, economic efficiency and payback periods of greenhouses are shown in Table 3.

Table 3. Name of the form, total costs, economic efficiency and payback periods for greenhouses when heating with natural gas

| Name of greenhouse shapes (two-stack) | Total costs, Sum / $ | Economic efficiency Sum / $ | Payback period, year |
|-------------------------------------|----------------------|----------------------------|---------------------|
| Rectangular.                        | 1740000 / 166,07     | 9024363,95 / 861,35        | 0,20                |
| Arched (rectangle and semicircle).  | 2000750 / 190,96     | 8999743 / 859,00          | 0,22                |
| With a transformable (adjustable) body. | 2591600 / 247,36   | 9302799,93 / 887,93       | 0,30                |

Table 3 shows that in terms of total costs, a rectangular greenhouse is the most acceptable in terms of price indicators. Its economic efficiency is 9,024,363.95 soums. Greenhouses with a rectangular and arched shape are stationary structures, and the construction of such structures in regions remote from the power grid and in mountainous regions creates certain difficulties and inconveniences, in addition, they require relatively large expenditures of fuel resources (see Table 1). The developed greenhouse with a transformable body differs from the existing greenhouses with a stationary attachment by the ability to regulate the thermal regime and save fuel resources. Thus, the block-diagram approach makes it possible to choose the most acceptable heating system and technical characteristics of alternative systems that are acceptable in climatic conditions in the regions of Uzbekistan.

4. Conclusions
Development of innovative types of greenhouses that do not depend on seasonality when growing agricultural products, will ensure food security in mountainous and remote regions. Calculation of economic efficiency and payback periods for greenhouses with a transformable body allows you to choose the most acceptable heating system and technical characteristics of alternative systems for the climatic conditions of Uzbekistan. Development of new types of greenhouses for mountainous regions of the republic, in spite of their low agro-climatic potential, adapted for year-round cultivation of agricultural products, will contribute in the future to improve food security in mountainous and rural remote regions of the republic.

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