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(Research Article)

Use of heat accumulators in greenhouse type passive solar heating systems

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Abstract

In the research work, a mathematical model of heat processes in the passive solar heating system of the Sunspace type was developed, and on this basis, the annual indicators of the considered system were determined. As the results obtained show, heat losses through the southern wall of an ordinary residential building during the heating season are 16-17 kWh/(m^2·year). The heat input through the southern wall in the heating season is about 125-130 kWh/(m^2·year), and the accumulated energy is 107-114 kWh/(m^2·year), in the presence of a heat accumulator.

Keywords: Solar energy; Heat accumulators; Passive solar heating systems; Heat conduction; Convection; radiation; Heat balance

1. Introduction

According to the International Energy Agency, residential energy consumption in Uzbekistan in 2020 amounted to 35.92% of the total final energy consumption of the Republic [1]. In developed countries this figure is 20-25%. As the dynamics of energy consumption in Uzbekistan shows, the situation is gradually improving year after year, for example in 2011, about 40% of total energy was consumed in the residential sector.

Today in the Republic, 40% of the electricity produced is used for heating and lighting, that is, the annual specific energy consumption for heating and lighting is 400 kWh, and in developed countries 170 kWh. As studies have shown, the annual specific energy consumption of rural residential buildings (a typical four-room residential building) for heating alone is 218 kWh/m^2 (for the first level of thermal protection) [2].

The amount of energy consumed by the construction sector in economic sectors is up to 40% of the total energy consumption, of which 50% is used to provide comfort in rooms [3]. The energy efficiency of individual residential buildings is very low, which in turn leads to a lot of energy loss and damage to the environment [4]. Active and passive solar heating systems are widely used together with a number of methods to improve energy efficiency in buildings [5].

Passive solar heating systems are characterized by low cost, ease of use and long-term use [6]. Passive solar heating systems are mainly divided into three types: direct gain, heat storage wall and Sunspace [7]. Sunspace is one of the basic types of passive solar heating systems, and has been actively used in recent years in scientific research on improving the energy efficiency of buildings. Studies on the use of Sunspace passive solar heating systems in many climates around the world have yielded positive results [3,8, 17–22, 9–16].

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2. Material and methods

Mathematical model. To develop a mathematical model, we used the mathematical model given in [23] and the equations of heat balances of differential type are written [24]. In writing the heat balance equations for each element of the living room [25] literature is used.

Heat balance equation for a heat accumulator

$$c_{ha}m_{ha}\frac{dT_{ha}}{dt} = h_{ha\_ra}F_{ha}(T_{ra} - T_{ha}) + U_bF_{ha}(T_e - T_{ha}) + (\tau\alpha)_{eff\_ha}F_{ha}I_T \quad .... \quad (1)$$

where c_{ha}, m_{ha}, T_{ha} - specific heat capacity, mass and temperature of the heat accumulator, respectively; h_{ha_ra} - coefficient of heat transfer from the heat accumulator to the room air; U_b - coefficient of heat transfer from the heat accumulator to the external environment through the base of the building; F_{ha} - the heat exchange surface of the heat accumulator; T_{ra} - room air temperature; T_e - soil temperature of a certain thickness; $(\tau\alpha)_{eff\_ha}$ - effective light absorption coefficient of the heat accumulator; I_T - solar radiation; t - time.

Heat balance equation for transparent layer

$$c_gm_g\frac{dT_g}{dt} = h_{g\_ra}F_g(T_{ra} - T_g) + h_{g\_a}F_g(T_a - T_g) + (\tau\alpha)_{eff\_g}F_gI_T \quad .... \quad (2)$$

where, c_g, m_g, T_g - respectively, specific heat capacity, mass and temperature of the transparent layer; h_{g_ra} - coefficient of heat transfer from the transparent layer to the room air; F_g - transparent layer surface; h_{g_a} - coefficient of heat transfer from the transparent layer to the environment; $(\tau\alpha)_{eff\_g}$ - effective light absorption coefficient of the transparent layer.

Heat balance equation for indoor air

$$c_{ra}m_{ra}\frac{dT_{ra}}{dt} = h_{ha\_ra}F_{ha}(T_{ha} - T_{ra}) + h_{g\_ra}F_g(T_g - T_{ra}) + h_{sw\_ra}F_{sw}(T_{sw} - T_{ra}) \quad .... (3)$$

where, c_{ra}, m_{ra} - specific heat capacity and mass of room air, respectively; h_{sw_ra} - heat exchange coefficient between the room air and the south wall; F_{sw}, T_{sw} - south wall surface and temperature, respectively.

The system of equations (1)-(3) together with the system of equations written for the building is solved by Gauss-Seidel iteration method using finite volume method. Calculations were performed in Python and MathCAD programming language and packages. Appropriate mathematical expressions for the heat transfer coefficients were obtained from [5]. As a boundary condition, the values of ambient temperature, solar radiation and wind speed for the Bukhara region were taken from [26].

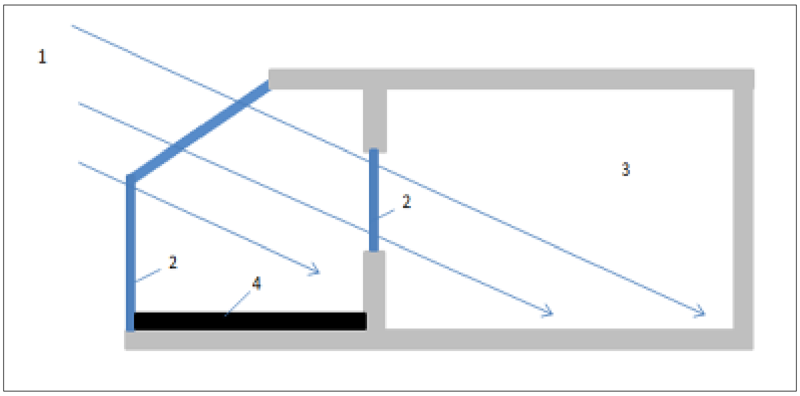

Figure 1 Schematic diagram of a passive solar heating system of the Solarium type (Greenhouse): 1-sun rays; 2-transparent barriers; 3-indoor air; 4- heat accumulator

3. Results and discussion

Relevant experimental studies were carried out for latitude 39.1°. Placing heat accumulators on the front of a passive solar heating system of the greenhouse type makes it possible to accumulate daytime excess heat, and the use of a thermal protective coating at night prevents a sharp drop in air temperature inside the greenhouse.

Based on the developed mathematical model, calculations were made to determine heat flows through the southern wall of a residential building with a passive solar heating system such as a greenhouse. As the results obtained show, heat losses through the southern wall of an ordinary residential building during the heating season are 16-17 kWh/(m²·year). The heat input through the southern wall in the heating season is about 125-130 kWh/(m²·year), and the accumulated energy is 107-114 kWh/(m²·year), in the presence of a heat accumulator. With an increase in the mass of the heat accumulator in the greenhouse part of a passive solar heating system, heat losses are reduced and heat input and the amount of accumulated heat increase. At the same time, thermal insulation of the outer part of the translucent fence at night and cloudy times plays an important role, reducing heat losses through the translucent fence.

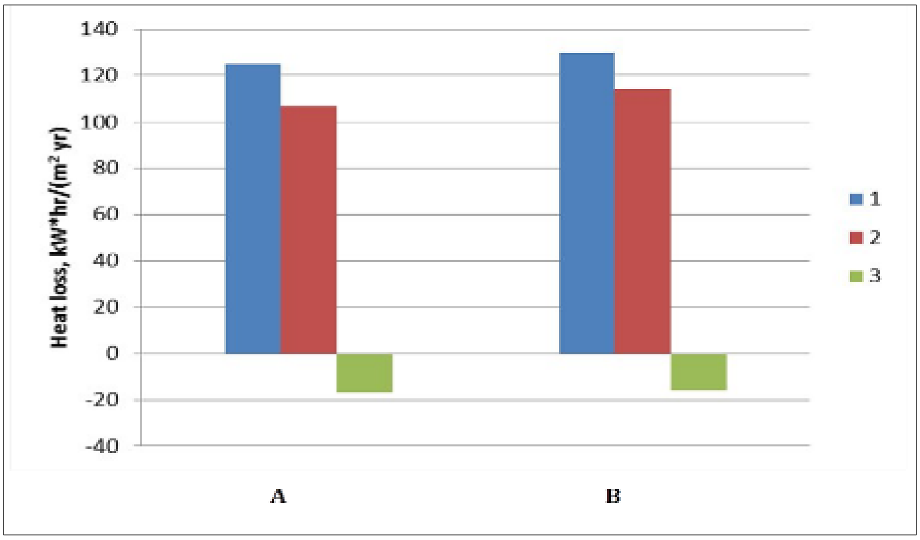

Figure 2 Heat balance through 1 m2 of area of the southern wall of a passive solar heating system of the "Sunspace (greenhouse)" type: A - without heat accumulator; B-with heat accumulator; 1-incoming heat flows; 2- storage energy; 3- heat losses

4. Conclusion

The main result of the presented research work is the mathematical model for the passive solar heating system of the Sunspace type, its validation and annual indicators. The mathematical model developed for the non-stationary process allows determining the hourly, monthly and annual heat indicators of the passive solar heating system of the Sunspace type based on the boundary conditions. The author determined and compared the heat input from passive solar heating systems of the Sunspace type with and without a heat accumulator. As the results obtained show, heat losses through the southern wall of an ordinary residential building during the heating season are 16-17 kWh/(m²·year). The heat input through the southern wall in the heating season is about 125-130 kWh/(m²·year), and the accumulated energy is 107-114 kWh/(m²·year), in the presence of a heat accumulator.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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