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Use of paraboloid solar concentrators to reduce heat consumption of residential buildings in the climatic conditions of Uzbekistan

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Abstract. This work examines the possibility of reducing the specific heat consumption of residential buildings for the climate of Toshkent and Navoi using a solar paraboloid concentrator and a heated floor system. Mathematical models of a living space, a paraboloid concentrator and a heated floor system are integrated, and the calculations are performed in the MathCAD programming environment and Python programming languages. As the results show, when using a paraboloid concentrator and a heated floor system, the annual specific heat consumption can be reduced to 26%, and the payback period is 18-22.5 years, depending on the level of thermal protection.

1 Introduction

Over the past few decades, changes in the global energy system have become increasingly significant [1]. Centralized gigawatt-scale systems are losing popularity in favor of small-scale renewable energy systems [2], which are driving significant market penetration of such energy sources [3].

In Uzbekistan, 40% of primary energy resources are spent on energy consumption of residential buildings [4], and the relative heat consumption of residential buildings is 2-4 times higher than in developed countries [5].

There are several ways to reduce the energy consumption of residential buildings [6], including increasing the efficiency of the traditional energy source and achieving minimal heat losses when delivering generated heat to the consumer [7], increasing the thermal protection of building walls [8], optimizing the geometric and thermal parameters of building elements [9] and the use of renewable energy sources [10].

A number of works are being carried out in Uzbekistan to increase the thermal efficiency of residential buildings or reduce specific heat consumption. In particular, in building codes and regulations, the maximum limit of specific heat consumption of residential buildings is gradually being reduced [11,12], the use of passive and active solar heating systems to reduce energy consumption [13,14], the use of phase change materials as thermal insulation [15], the use of nanofluids as a coolant in solar installations [16], as well as the use of solar

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paraboloid concentrators as an auxiliary heat source [17]. For Uzbekistan, using world experience, the concepts of "Passive House" and "Building with Zero Energy Consumption" are being developed.

This work is devoted to the issue of reducing energy consumption when heating residential buildings using solar paraboloid solar concentrators.

2 Mathematical model

To determine the thermal characteristics of the object under consideration, a static heat balance model was used. There is heat balance equations for a building below [6]:

$$Q_s + Q_f + Q_{he} = Q_{hl} \tag{1}$$

where Q_s is the heat input into the building from solar radiation; Q_{he} - household heat emissions (heat input from internal heat sources); Q_f- heat gain from the heated floor; Q_{hl}- heat losses from walls, windows, doors, floors, ceilings and through ventilation.

The heat input into the building from solar radiation is determined by the equation given in [18]. Heat gain from underfloor heating is described as [19]:

$$Q_{hl} = K_{hl} A_{hl} (T_{aw} - T_{ia}) \tag{2}$$

where K_{hl} is transfer coefficient of the heat from the water of the heated floor to the indoor air; A_{hl}- surface area of the heated floor; T_{aw}- average water temperature in the heated floor; T_{ia}- internal air temperature.

Heat transfer coefficient from underfloor heating water to indoor air [19]

$$K_{hl} = \left\{\frac{L}{2\pi\lambda_3}\left[ln\left(\frac{L}{\pi D_o}\right) + \frac{2\pi d_1}{L} + \sum_{i=1}^{\infty}\frac{G(i)}{i}\right] + \frac{L}{2\pi\lambda_p} ln\left(\frac{D_o}{D_i}\right) + \frac{1}{h_t}\right\}^{-1} \tag{3}$$

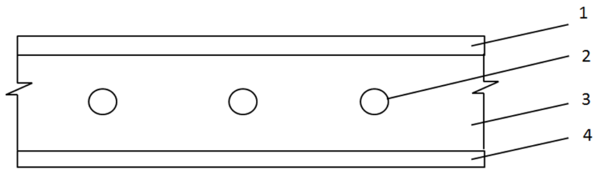

Fig 1. The scheme of warm floor: 1-layer of linoleum; 2-pipes; 3-concrete layer; 4-wood floor.

Calculations were made for the following 4 cases:

1. Standard 4-room residential building;
2. Standard 4-room residential building with a solar collector;
3. Standard 4-room residential building with a "warm floor" system;
4. Standard 4-room residential building with underfloor heating system and solar paraboloid concentrator.

Table 1. Thermophysical characteristics of a heated floor [17,19].

No.	Layer name	Thickness, mm	Thermal conductivity coefficient, W/(m·°C)
1.	Linoleum layer	3	0.2
2.	Pipes	2	0.042
3.	Concrete layer	10	1.4
4.	Wooden floor	40	0.15

Mathematical models of thermal processes occurring in the object under consideration have been studied in detail in the literature [4,5,8]. For example, a static mathematical model of a 4-room typical residential building was studied in the source [4], mathematical model of a solar paraboloid concentrator in the source [17], the mathematical model of the heated floor system was studied in the source [19].

The presented research work integrates mathematical models of a living space, a paraboloid concentrator and a heated floor system, and the calculations were performed in the MathCAD programming environment and Python programming languages.

The results of calculations using the mathematical model were compared and confirmed with the results given in the sources [4,5].

3 Calculation results and discussion

The calculation results show that the average annual heat consumption for the residential buildings under consideration in the climate of Tashkent is 220 kWh/m^2 with 1st level of thermal protection, and 204 kWh/m^2 when using solar heat collectors (-7.3%), and 182 kW·h/m^2 with using a heated floor system (-17.3%), 165 kW·h/m^2 when using a concentrator and a heated floor system (-25%). For the climate of Navoi, the annual specific heat consumption is 220 kWh/m^2 with 1st level of thermal protection, 210 kWh/m^2 when using solar collectors (-7.0%) and 187 kWh/m^2 when using heated floors (-17.0%), 168 kWh/m^2 when using a concentrator and a heated floor system (-26%).

Prices for devices and parts are taken from a single source [20]. Therefore, economic indicators are very close for the regions where the calculations were carried out. That is, the payback period for the 1st level of thermal protection is 17-18 years, the payback period for the 2nd level of thermal protection is 18.5-19.5 years, the payback period for the 3rd level of thermal protection is 21-22.5 years.

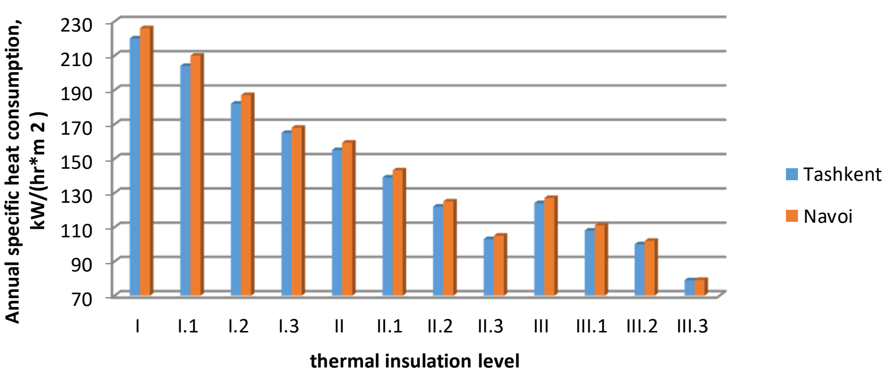

Fig 2. Specific heat consumption of the building: I - buildings with the first level of thermal protection; I .1 - buildings with the first level of thermal protection with a thermal collector; I .2 - buildings with the first level of thermal protection with heated floors; I .3 - buildings with the first level of thermal protection with heated floors and a paraboloid concentrator; II - buildings with the second level of thermal protection; III - buildings with the third level of thermal protection.

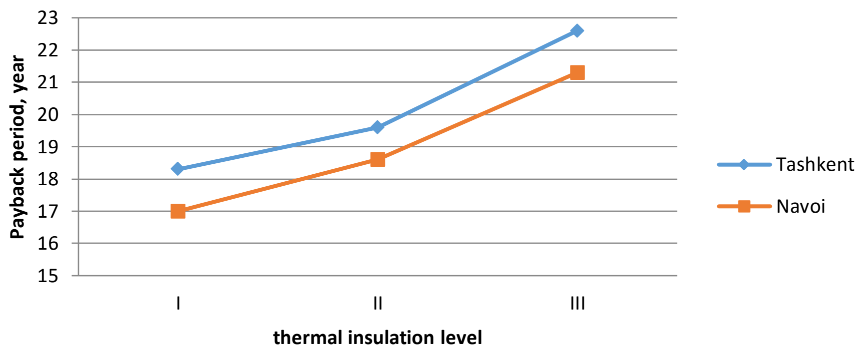

Fig 3. Payback period for a solar heating system with a concentrator: I - the first level of thermal protection; II - second level of thermal protection; III - third level of thermal protection.

4 Conclusion

The steady-state mathematical models developed for the 4-room residential building model, paraboloid solar concentrator and floor heating system were integrated, and a computer program was developed. Calculations were carried out for the climate of Tashkent and Navoi, the annual specific heat consumption of the type of residential building under consideration and the payback period were determined. According to it, when using a paraboloid concentrator and a heated floor system, the annual specific heat consumption can be reduced to 26%, and the payback period is 18-22.5 years, depending on the level of thermal protection.

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