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PASSIVE HEATING SYSTEM OF A RESIDENTIAL BUILDING

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ПАССИВНАЯ ОТОПИТЕЛЬНАЯ СИСТЕМА ЖИЛОГО ЗДАНИЯ

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Abstract. In this article, we will talk about the passive heating system applied to residential buildings in rural areas. The air heating system is used as a heating surface in buildings with multi-channel structures in the fencing structures (external wall, floor and roof). In these cases, the author considers the issues of the first and second conditions of temperature comfort, taking into account the temperature of the heating surface.

Key words: passive heating, Trombe-Michel wall, solar-air heating scheme, room microclimate

Аннотация. В статье рассматривается пассивная система отопления, которая используется в жилых зданиях в сельской местности. Система воздушного отопления применяется в качестве поверхности нагрева в зданиях с использованием многоканальной структуры в ограждающих конструкциях (наружных стенах, полу и крыше). Рассмотрены вопросы первого и второго условий температурного комфорта с учетом температуры нагрева поверхностей.

Ключевые слова: пассивное отопление, стены Тромбе-Мишеля, схема солнечного воздушного отопления, микроклимат в помещении

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Introduction

The Republic of Tajikistan is located in the region of Central Asia, if there are 365–366 days in a year, and then almost 300 days are sunny. Therefore, the use of sunlight is beneficial for the needs of people. We can use active and passive solar heating devices to effectively use the thermal radiation of the sun to provide hot water and for heating systems.

Many scientists in the field of heat engineering physics, such as S. V. Zokoley, A. M. Shklover, B. F. Vasilyeva, F. V. Ushkova, Yu. Ya. Kuvshinova, A. G. Gagarina, V. I. Prokhorova, A. I. Anan'eva, V. K. Savina, V. P. Titova, Yu. A. Matrosova, E. G. Malyavina, E. K. Boronbaeva, W. Beckman, J. Duffy and other, studied the heat and mass transfer processes in various environments, tried to solve the problems of fuel consumption to ensure the correct microclimate of buildings, as well as the use of solar energy for heating [1, 2].

At the same time, in many available publications in the country and abroad, insufficient attention is paid to the peculiarities of applying methods for improving thermal properties when using local cheap heating materials for outdoor structures of rural residential buildings, which differ from other residential buildings. During the construction of public buildings, special attention should be paid to building materials and methods of construction, taking into account the microclimate of the region.

To do this, a thermal analysis of existing outdoor structures is carried out, a study of local heating materials, a search for options for their use, as well as ways to use solar energy to heat residential buildings.

In the conditions of high-mountain settlements, it is important to rationally supply heat by increasing the efficiency of heating and ventilation systems, using non-traditional types of fuel systems in the design, construction and operation of energy-efficient buildings.

In high mountain regions, under conditions of reduced barometric pressure, the temperature varies greatly during the day. The main problems of the use of gas are the transportation of fuel, the construction of heat supply lines. The required produced heat does not reach the consumers.

In this paper, for the first time, the potential of using the Trombe wall for rural residential buildings in the climatic conditions of Tajikistan is assessed. By calculation, it was found that due to the use of the Trombe wall in a building that belongs to the type of passive solar heating systems, the thermal loads of heating system are reduced. The studies were carried out for five characteristic climatic regions of Tajikistan [1, 3].

The supply of solid fuel to small consumers in villages, with relatively uneven building density, is accompanied by the high transport costs, only in the case of using high-calorie fuel (wood, dung and coal, etc.). The small fuel plants that warm dwellings inside pollute the atmosphere by burning fuel, all small (coal-fired) boilers with automatic exhausts do not clean their exhaust gases.

The solar heating system has become more popular than other heating systems in the world, especially two types of them can be considered: in the first place, passive systems, that use solar energy by the surrounding constructions of the building (walls, floor and roof) taking into account the properties of building materials according to the requirements of standards, secondly, active systems that use the heat carriers (water or air) and heat pump systems from non-renewable sources in practice.

In winter, you can use small devices to heat the room. For example, Trombe-Michel walls are used to store solar energy, the heat from which is moved inside the room by a fan, i.e. along the inner surface of the room. The cooled air is then returned through an opening at the bottom of the outer wall to the channel formed between the glazing and the heat array. As long as there is solar insolation (heat from the sun), this cycle of warm air repeats [2, 3, 4].

The use of energy, this is an additional cost, goes to the circulation of hot air, which is a flaw in this solution.

Object and methods of research

The article proposes a passive installation in the form of a protective wall with solar and air heating due to building envelopes or building elements for an effective Trombe-Michel wall.

The heating system consists of three main elements: a heat source, heat pipes and heat transfer devices to the space of the room. In the case under consideration, the Trombe-Michel wall plays the role of a heat source, and in our case, not only the outer wall, but also the inner walls, floor and roof of the house are equipped with building structures with channels. After all, the heat exchange ducts of the building's heat-producing surface can elevate the temperature of the room.

The proposed scheme of the passive installation is shown in fig. 1.

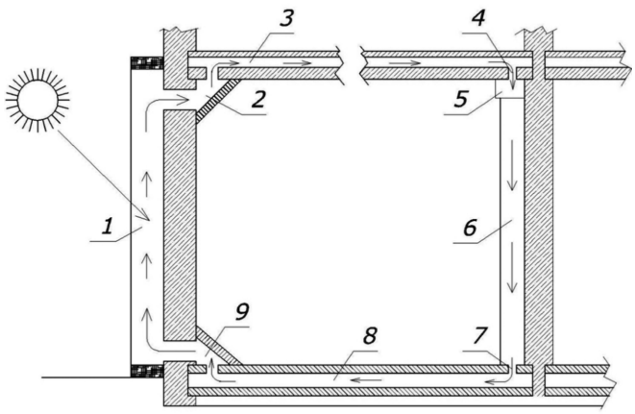

Fig.1. Passive heating system

The proposed solar-air heating scheme consists of a Trombe-Michel wall (solar radiation receiver) *(1)*, a transition pipe *(2)* connecting the receiver channel and the hollow ceiling channel *(3)* (voids, usually round in shape), a pipe *(4)* connecting through the collector *(5)* channels *(6)* on the inside partition and transition sections *(7)*, channel *(8)* and adapter *(9)*, closing the coolant with the heat sink.

In the proposed scheme, the heat source (solar heat receiver) is specially made in a row, and in the air channels in the ceiling, floor and walls are sterilized, which do not create natural pressure between the circulations of hot air. Basically, in the Trombe-Michel wall, the heat of the air is heated by the calculation of solar energy, then it gives its heat to the interior space of the room, and after the air cools, it returns to the lower part of the given wall by means of the channels placed in the constructions [1, 2, 5].

As the hot air cools, it passes through the channels. That is, this period is repeated from top to bottom.

When hot air moves in the channels of buildings surrounding the structure, it heats up and cools down and returns to the heat source. When the surface temperature of the insulation rises above the air temperature inside the house, the surface of these structures gives off heat to the room and heat losses are compensated.

According to the given criteria, the parameters of the microclimate of the room [3] in the entire area of their location should be determined among themselves, and it is necessary to control the location of the room without deviating from the established limits. Human activity is located in a certain part of the building according to the activity and services in all buildings. In the assignment, the heating system should be provided in one place according to the thermal resistance of the building according to the existing norms.

Comfortable conditions are conditions in which one does not feel hot or cold during work in service areas.

The room temperature is determined by: 1) thermal comfort in the room as a whole and 2) in the immediate vicinity of the heated or cooled surface.

The general temperature situation in the room should be such that if a person is in the middle of the room and feels all the factors inside the room, i.e. in the middle of the room there is no discomfort from heat and cold, in this case they are considered comfortable conditions.

Results

The heat sensation of a person is to a certain extent influenced by the radiation temperature t_R, air temperature t_{in}. The temperature t_R is determined by the formula:

$$t_R = \sum \varphi_{h-i} t_i , \quad (1)$$

where φ_{h-i} is the irradiance coefficients from a person to individual surfaces with a temperature t_i (the person is in the middle of the room).

The coefficients φ_{h-i} are determined by the method of light modeling [1].

Formula (1) is more accurate for indoor conditions, when the absolute temperatures and emissivity of individual surfaces are of the same order. A comfortable temperature regime in different rooms is possible with various combinations of t_{in} and t_R.

The equation of radiant convective heat transfer of a person has the form:

$$Q_h^{r+c} = F_h^r \propto_r \left(\tau_h - t_R\right) + F_r^c \propto_c \left(\tau_h - t_{in}\right), \quad (2)$$

where F_h^r, F_r^c are heat-releasing surfaces of the human body, respectively, for radiant and convective heat transfer; $\propto_r$, $\propto_c$ are the coefficients of radiant and convective heat transfer averaged over F_h^r and F_r^c; τ_h is the average surface temperature of a dressed person.

Equation (3) ensures the fulfillment of the first condition of temperature comfort in the room:

$$t_R = \frac{F_h^r \propto_c \tau_h + F_h^c \propto_c \tau_h - F_h^{r+c}}{F_h^r \propto_r} - \frac{F_r^c \propto_c}{F_h^r \propto_r} t_{in}. \quad (3)$$

For winter mode take: $\tau_h = 25\,°C$; $\propto_c = 2{,}3$, $\propto_r = 5{,}1$; $F_h^c = 1{,}9$; $F_h^r = 1{,}7$. Substitute the numerical values into equation (3) we obtain for the winter period:

$$t_R = \frac{326 - Q_h^{r+c}}{8{,}67} - 0{,}504 t_{in}. \quad (4)$$

For most premises of residential and public buildings, the apparent heat transfer of a person Q_h^{r+c} in the cold season can be taken as 87 W, therefore

$$t_R = 27{,}57 - 0{,}504 t_{in}. \quad (5)$$

This equation, obtained analytically, is in full agreement with the data of hygienic tests in a special chamber [2, 5].

According to the second comfort condition, the intensity of heat transfer should be limited when a person is positioned near heated surfaces.

It can be a determining factor of the intensity of radiation heat transfer (equilibrium radiation in the most unfavorable and radiation-sensitive area of the human body). The surface of the head is exposed to more heat radiation. The radiation balance should be such that any elemental field inside the room affects the sensing area by 11,6 W/m^2 of radiation [1, 2, 6].

When the surface of the ceiling structure is heated, the unfavorable (and therefore calculated) position of the person will be directly below the center of the ceiling. When the enclosing construction (panel) is located on the walls, when calculating the heat comfort, the position of a person at a distance of 1 m from the enclosing construction, i.e. the heated surface, is taken into account. The radiation heat transfer equation for the elemental area of the human surface can be written as follows:

$$q_h^c = C\varphi b_{h-p}\left(\tau_h - \tau_p\right) + \\ + C\left(1-\varphi\right) b_{h-v.p}\left(\tau_h - \tau_{v.p}\right), \quad (6)$$

where C is the reduced emissivity taken for this case to be 4,65 W/m^2 K; φ is the irradiance coefficient from the side of the elementary area on the human surface towards the panel; $b_{h-v.p}$ is temperature coefficient, which for the winter regime at the surface temperature of the human head $\tau_h = 30\,°C$, $\tau_{v.p} = 18\,°C$ and the temperature of the panel about 40 °C take: $b_{h-p} = 1{,}15$ and $b_{h-v.p} = 1{,}05$.

Substituting numerical values into formula (6), we obtain an expression for q_h^c:

$$q_h^c = 5{,}3\varphi\left(30 - \tau_p\right) + 58\left(1 - \varphi\right).$$

Find the temperature of the heated surface of the panel τ_p:

$$\tau_p = 19{,}2 + \frac{58 - q_h^c}{5{,}3\varphi_{h-p}}. \quad (7)$$

With the minimum allowable heat transfer by radiation of 11,6 W/m^2, according to formula (7), we have the condition for the maximum allowable temperature of the heated surface in the room:

$$\tau_p^{ad} \leq 19,2 + 8,7 / \varphi_{h-p}. \quad (8)$$

Permissible temperatures of floor surface in the room τ_{pl} are given in [7]. They depend on the air temperature t_{in1} at a height of 1 m from the floor [8]:

$$\tau_{pl} = 55,7 - 1,63 t_{in1}.$$

The heat dissipation of the heater (centralized system) is determined by the formula:

$$Q_1 = K_1 \cdot F_1 \cdot \Delta t_1,$$

where K_1 is heat transfer coefficient, which determines the average rate of heat transfer along the entire heat transfer surface F_1.

Heat dissipation from solar air heating:

$$Q_2 = K_2 \cdot F_2 \cdot \Delta t_2,$$

where K_2 is heat transfer coefficient, which determines the average rate of heat transfer along the entire heat transfer surface F_2.

Let the thermal conductivity and thermal insulation of the constructions be equal to each other in two cases:

$$Q_1 = Q_2.$$

Heat transfer ratio of devices Q_1/Q_2, then it is:

$$1 = \frac{K_1 \cdot F_1 \cdot \Delta t_1}{K_2 \cdot F_2 \cdot \Delta t_2}.$$

From this we can determine what the difference in the sun's heat should be to heat the air inside the room:

$$\Delta t_2 = \Delta t_1 \cdot \frac{K_2 \cdot F_2}{K_1 \cdot F_1},$$

where Q_1 and Q_2 is the heat flow (amount of heat), F_1 and F_2 is the heat exchange surface, m^2; $K_1 - K_2$ – heat transfer coefficient, W/(m^2 K), Δt_1 and Δt_2 is the driving force of the heat transfer process.

Conclusions

From the analysis of the above evaluation example, it follows that for the transfer for the same amount of heat, the temperature difference Δt_1 must be much greater than with solar-air heating. That is, the temperature of the heat carrier in the heating device of the traditional system is 82,5 °C, and when using an unconventional source, the average temperature of the heat carrier is 24 °C.

Thus, the climatic conditions of the Republic of Tajikistan allow the passive use of solar energy, since the probability of sunlight is 2100–3166 hours per year.

Thus, it is shown that the use of solar radiation is useful for a passive heating system and it is advisable to use it in the conditions of the current economic crisis. It is proposed to design a solar heating system.

The results of the calculation show the acceptability of this solution, and thermophysical calculations regarding the solar heating system on sunny days are sufficient. As a result, we consider it's possible to use solar energy to heat a residential building, to use the surrounding structures or the main elements of the building for creating the Trombe-Michel walls, which have a lot of heat.

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