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Editors • Arthur Gibadullin, Ramazon Abdullozoda and Dmitry Morkovkin

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Theoretical Research of the Heat Exchange Processes of the Water Heated Floor System

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Abstract. Currently, the use of renewable solar energy in residential heat supply systems is one of the urgent issues. This article provides an overview of water-heated floor systems, their areas of application, advantages and disadvantages. Examples of calculations for evaluating the efficiency of a water-heated warm floor are given and procedures for calculating a warm floor are given. Heat exchange processes, heat carrier temperatures, thermal resistance of the heating panel were calculated in the water-heated warm floor system, and the consumption of the heat carrier according to the contour was determined.

INTRODUCTION

In our country, special attention is being paid to increasing energy efficiency in economic sectors and the social sphere by reducing energy consumption in all sectors of the economy, developing renewable energy. Construction of new modern energy-efficient heat supply systems is being carried out in order to provide residential buildings with heat energy stably in our republic, and certain results are being achieved in improving heat supply systems. In the development strategy of New Uzbekistan for 2022-2026, the important tasks of "...increasing the energy efficiency of buildings and structures, wide introduction of renewable energy sources in economic sectors, reducing the amount of harmful gases released into the atmosphere..." are defined. In the implementation of these tasks, it is an urgent task to increase the energy efficiency of heat supply systems of rural houses using renewable energy sources, and to optimize the main parameters of combined heat supply systems [1-3].

Nowadays, one of the important tasks is to improve the standard of living of the population, to use energy-efficient heating systems in the heating systems of production and industrial enterprises. It is known that it is necessary to create comfortable conditions for residents and service workers in industrial enterprises, especially in the winter season, to keep the temperature in the room at the same standard. To date, several systems for heating systems have been proposed and are being used effectively. However, the use of such systems causes difficulties during operation, the decrease in reliability of the system and the rapid failure require the introduction of new types of heating systems, which is one of the urgent issues of today. One of the solutions to this problem is the use of warm floor systems [4-13].

MATERIALS AND METHODS

Currently, various systems of water-based warm floors are used. Water heat concrete system of the floor. The concrete system of water-based warm floor is the most common today, concrete is poured into the contour of the warm floor pipes and there are no additional heat distributors.

The main purpose of the thermal insulation layer is to prevent low heat loss. The heat should only be transferred upwards to heat the room. Any heat-insulating material allowed for use in construction can be used as a heat-

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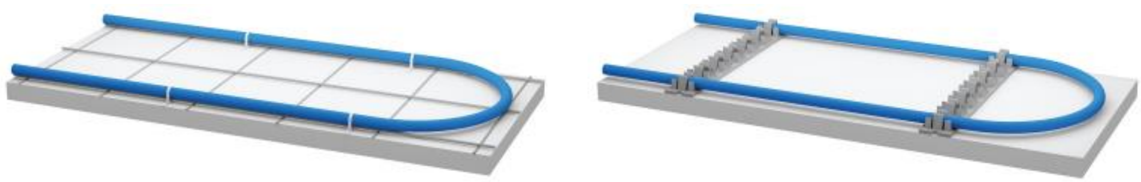
insulating material. It should be noted that the thermal resistance of the thermal insulation layer should be higher than the total resistance of the heating layer. The higher the heating load, the thicker the insulation layer. Also, the greater the thermal resistance of the clean coating, the greater the thickness of the insulation layer[14-15].

Fence with reinforcement. Rails. The step of the cell of the reinforcing bar and the diameter of the small pipe are selected based on the construction of the floor. In order to facilitate installation in standard structures, a grid with a cell size of 150x150 mm is used, the diameter of the pipe is 4-5 mm. Pipes are fixed to the grid using plastic clamps.

In order to provide additional strength to the screed, double reinforcement is made in several cases: the second layer of the reinforced grid is placed on the contour pipes of the warm floor. The pipes of the warm floor contours are placed according to the drawing. Before pouring concrete into the contours of the warm floor, the system is checked for tightness. System verification is carried out in accordance with national building codes. Also, the system is checked under a pressure of 3-4 bar for 24 hours.



a b

FIGURE 1. General view of the fence with reinforcement: a) General view of the fence with reinforcement without fastening b) General view of the fence with reinforcement and fastening.

Water-heated floor covering polystyrene system. This system is currently the simplest. The basis of the system is polystyrene with plates with grooves, on which aluminum heat distribution plates are placed.

a) A flat plate with a pitch of 250 mm.

b) A flat plate with a pitch of 300 mm.

c) A flat plate with a step of 150 mm.

d) A flat plate with a step of 150 mm.

e) Twisted plate with a pitch of 150 mm.

f) Twisted plate with a pitch of 150 mm.

g) A flat plate with two wedges with a pitch of 150 mm.

k) A flat plate with a pitch of 300 mm.

FIGURE 2. Installation steps for a water-based underfloor heating system with polystyrene.

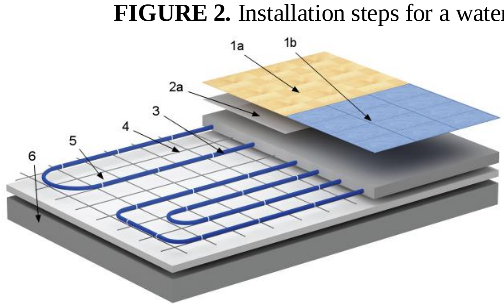


FIGURE 3. Water heat concrete system of the floor: 1a – clean coating (parquet, laminate); 1b – clean coating (tile); 2a – base; 3 – heat pipes; 4 – reinforced fence; 5 – compactor; 6 – base.

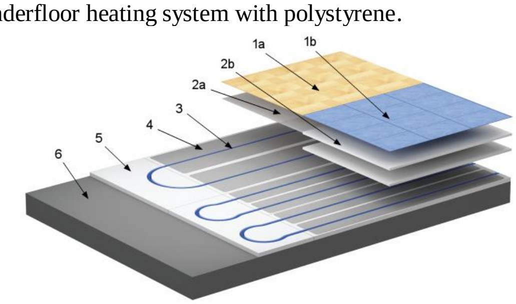


FIGURE 4. Polystyrene mat system of warm water floor. 1a - clean coating (parquet, laminate); 1b – clean coating (tile); 2a – bed; 2b - folding mattress; 3 – heat pipe; 4 – aluminum plate; 5 – wedged polystyrene elements; 6 – base.

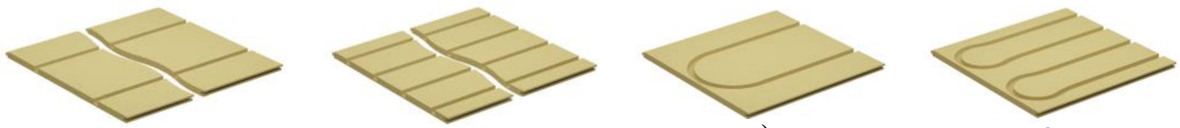
The foamed polystyrene system is made only with steps between 150 and 300 mm. Aluminum plates with a thickness of 0.4-0.5 mm are used as a heat transfer and distribution device.

Parquet or laminate can be placed directly on the polystyrene system. Elements of the polystyrene system [16-17].

RESULTS AND DISCUSSION

A wooden system of a modular type of warm water floor. The module of the system is made of chipboard with a thickness of 22 mm. The system is installed directly on the beam with a maximum step of 600 mm. A heat insulating layer is placed between the beams. All elements of the system are connected to each other using a special lock.

Elements of the wooden system

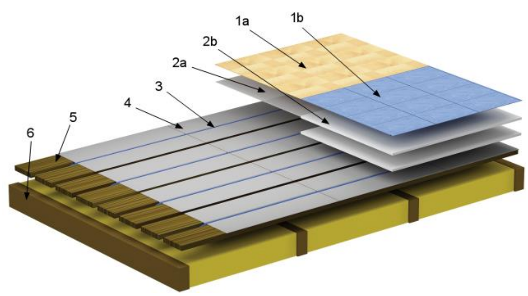


a)	b)	c)	d)
A flat plate with a pitch of 300 mm	A flat plate with a step of 150 mm	Twisted plate with a pitch of 300 mm.	Twisted plate with a pitch of 150 mm.

FIGURE 5. The arrangement of the elements of a wooden system.

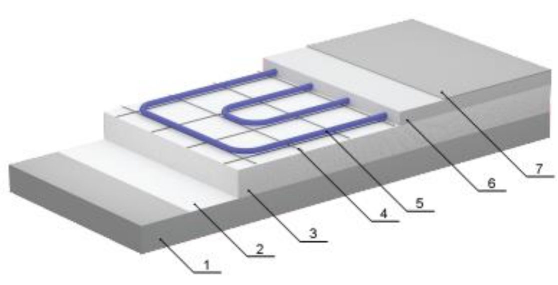
A wooden system of water-heated underfloor heating. Unlike the modular wooden system, this system does not use ready-made elements with wedges. The system is mounted directly on the beam, their maximum step is 600 mm. A heat insulating layer is placed between the beams.

Heat-distributing aluminum plates are used for steps of 150, 200 and 300 mm. 150 mm pitch plates are used in the zone with the greatest heat loss.



1a - clean coating (parquet, laminate); 1b – clean coating (tile); 2a – bed; 2b - folding mattress; 3 – heat pipe; 4 – aluminum plate; 5 – blackboard; 6 – beams with a step of 600 mm.

FIGURE 6. Wooden system of water-heated floor rekali type.



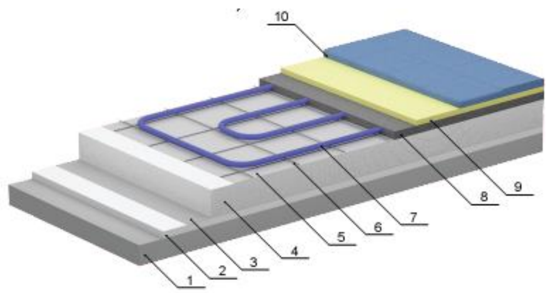
1 - reinforced concrete slab of the barrier; 2 – waterproof ceiling made of roll bitumen material; 3 – compactor; 4 – reinforced fence; 5 – heat pipe; 6 – leveling bracket; 7 – the base of the pitched ceiling

FIGURE 7. General view of the ceiling.

Application in warm water floor heating systems. Heating the ceiling in modern construction is not only a matter of saving resources and energy, but also reduces operating costs and increases the service life of the building.

In ceiling heating devices of this construction, the pipes of the snow melting systems are placed in a thermal insulation layer and installed on a cement-sand screed. The heat of the hot stove is transferred to the water insulating mat and heats the snow. In this construction of the ceiling heating, a slight slope is created, the melted snow falls down in a short time. Usually the slope is from 2% to 10%.

Ceiling for pedestrians. Such ceilings are usually used in modern architecture, they are mainly used when there is a shortage of pedestrian walkways. Corridor or ceramic tiles are used for them. The thickness of the sand-gravel layer should not be less than 30 mm. A ceiling heater is installed in this layer [18-19, 27].



1 - reinforced concrete structure of the fence; 2 – cement-sand screed forming a slope; 3 – waterproofing ceiling made of rolled bitumen material; 4 – compactor; 5 – filtering layer; 6 – reinforced fence; 7 – heat pipe; 8 - 10-20 mm pieces of gravel; 9 – sand; 10 – pavement tiles

FIGURE 8. Overview of the warm floor.

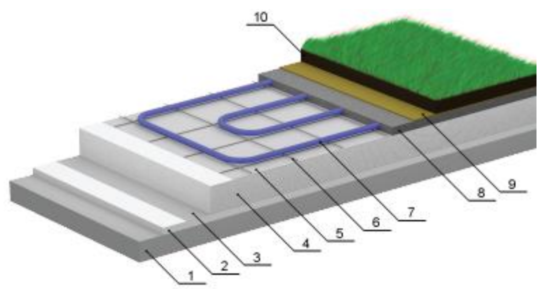
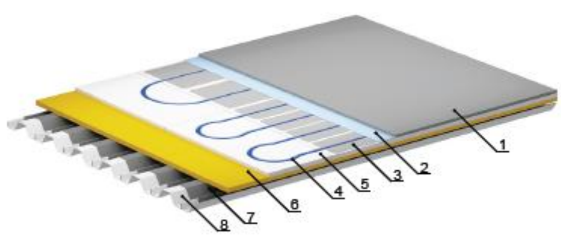


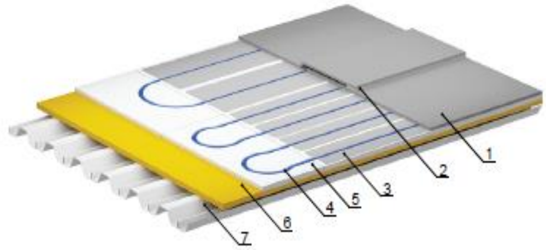
FIGURE 9. General view of the greened ceiling.

Green roofs. This system differs from the above systems in that they have plant root systems, which are used to protect the plant's root systems from heat and water isolation, and the regime in it is different from the standard system of snowing. Often, it is necessary to maintain the temperature of the soil of plants planted for landscaping, for this, special temperature adjustment sensors are installed[20].



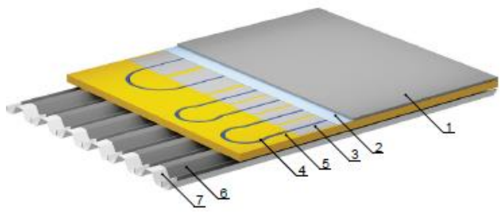
1 - waterproofing membrane - PVC, EPDM, TPO; 2 – separating filtering layer; 3 – aluminum plate; 4 – heat pipe; 5 – foam polystyrene plates; 6 – penoplex; 7 - vapor insulation; 8 – metal profiled bed

FIGURE 10. Profiled ceiling.



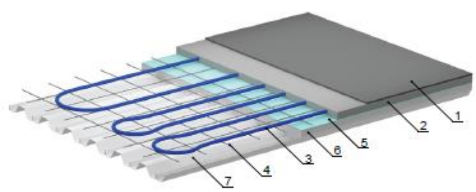
1 - waterproofing membrane - PVC, EPDM, TPO; 2 – weld; 3 – aluminum plate; 4 – heat pipe; 5 - expanded polystyrene plates; 6 – penoplex; 7 – metal profiled bed

FIGURE 11. Profiled ceiling.



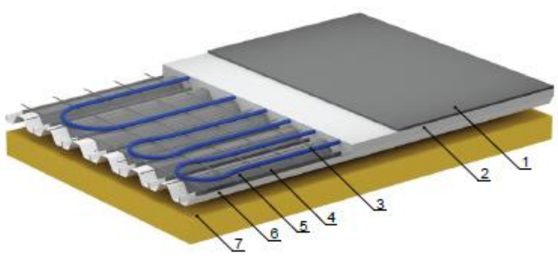
1 - waterproofing membrane - PVC, EPDM, TPO; 2 – separating filtering layer; 3 – aluminum plate; 4 – heat pipe; 5 – foam polystyrene plates; 6 – penoplex; 7 – metal profiled bed

FIGURE 12. Profiled ceiling.



1 – the second layer of technoelast; 2 – concrete foundation; 3 – heat pipe; 4 – reinforced fence; 5 - vapor insulation; 6 – foam concrete 250-350 kg/m^3; 7 - metal profiled bed

FIGURE 13. Profiled ceiling.



1 – the second layer of technoelast; 2 – foam concrete; 3 – heat pipe; 4 – reinforced fence; 5 - vapor insulation; 6 – metal profiled bed; 7 - mineral wool

FIGURE 14. Profiled ceiling.

Heat exchange processes in the water-heated warm floor system. The distribution and transmission of heat energy in the constructions of floor heating systems depends on the heat load, geometric and thermal physical parameters of the heating panels, the material and diameter of the pipe, and the material of the clean coating (fig. 13).

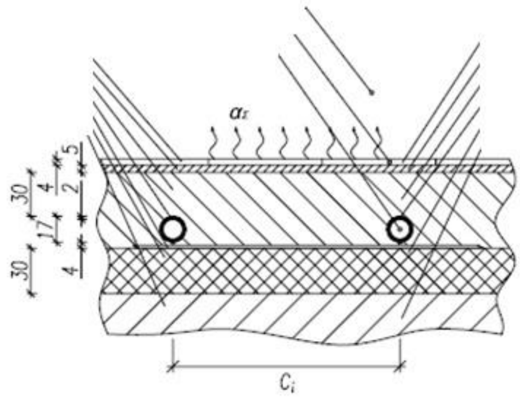


FIGURE 15. Shearing of a concrete type heating panel.

Here: T_{air} – the required temperature of the air in the room, T_{floor} – the temperature of the floor surface; S – the area occupied by the floor heating panel; λ - thermal conductivity of the material involved in the heat transfer process. The heat transfer coefficient depends on the type of material, its thickness, and the physical and technical characteristics of the side.; δ - the thickness of the material involved in the heat transfer process; s – the distance between the pipes of the warm floor contours is determined by the heat load required for the system.

Distribution of thermal energy is carried out due to the movement of the boiling heat carrier along the pipe. But when calculating and designing a floor heating system, the uniform distribution of temperature over the surface of the heating panel depends on the distance between the pipes of the contours of the heating panels. The result of solving these problems depends on the step of placing the pipes in the contour of the warm floor[21].

Heat energy transfer in the heating system is mainly carried out by three methods: heat conduction, convection and radiation.

Thermal conductivity. Transfer of heat from a hot body to a cold body in solids. In our case, in the heating panel itself, the heat is transferred from the pipe of the floor contour to the concrete, and from the concrete to the clean coating. The efficiency of the process depends on the temperature of the heat carriers, the consumption of the heat carriers moving along the heating circuit, and the total thermal resistance of the materials involved in the heat transfer process.

Convection. Heat transfer in liquid and gaseous substances when the medium moves from hot to cold. In our case - heat transfer from the heating panel to the air heating the room. The main characteristic of the process is the heat transfer coefficient in convective heat exchange.

Radiation. Heat exchange with radiation is observed between two or more substances separated by a transparent body, heat exchange with radiation depends on the temperature of the body and the composition of its surface, as well as the optical properties of the media. In our case, heat transfer from the heating panel to the outside. The main characteristic of the process is the heat transfer coefficient in heat exchange by radiation.

All its surfaces, air flow and air in the room participate in the total heat exchange in the room. This process can be represented by many equations[22].

The total amount of heat transferred to the panel is equal to the sum of the amount of heat in radiation and convective heat exchange:

$$Q = \left(a_n \cdot \left(T_{floor} - T_{h.t}\right) + \alpha_k \cdot \left(T_{floor} - T_{air}\right)\right) S \tag{1}$$

Here$T_{h.t}$– the temperature of the heated surface of the structure.

According to the second condition of comfort, the coefficients are determined according to the graph:

$$\alpha_\Sigma = \alpha_n + \alpha_k = 4.9 \cdot 6.1 = 11 W / \left(m^2 \cdot {}^0 C\right) \tag{2}$$

Thus, half of the heat is transferred by convection and the other half by radiation. 61% and 49% respectively.

Calculation of the temperature on the floor surface. We will consider the heat calculation of a concrete type heating panel as an example.

Initial data is required for calculation. The main indicator of each heating device is heat load. If we consider a common room and a warm floor is considered a heating system for this room, then according to the heat balance equation, the heat load to the heating system is equal to the heat loss of this room[23].

In turn, heat technical calculations are performed to determine heat loss:

$$Q = \alpha_{\Sigma} S\left(T_{floor} - T_{air}\right) \tag{3}$$

It is known:

$$\Delta T = T_{floor} - T_{air} = 1°\text{C} \tag{4}$$

$$Q = \alpha_{\Sigma} S \Delta T = 11 \cdot 1 \cdot 1 = 11W \tag{5}$$

So, if the temperature difference between the temperature of the surface of the floor and the unheated air is equal to 1°C, the coefficient of heat transfer from 1 m^2 heated panel is 11 W.

There are three contours, each of them covers the following fields:

S_1=8.8 m^2, S_2=13.9 m^2, S_3=11.5 m^2

Lengths:

L_1=63 m, L_1=68 m, L_3=81 m

The set air temperature in all rooms is T_{air}=20^0C.

Heat load for each room according to heat technical calculation

Q_1=750 W, Q_2=1030 W, Q_3=780 W

We calculate the relative load of the heating system for each circuit:

$$Q_{comparision} = \frac{Q}{S} \tag{6}$$

$$Q_{comparison_1} \frac{750}{8.8} = 85\ \frac{W}{m^2},\ Q_{comparison_2} \frac{1030}{13.9} = 74\ \frac{W}{m^2},\ Q_{comparison_3} \frac{780}{11.5} = 68\ \frac{W}{m^2},$$

Temperature of floor surface by room:

$$T_{floor1} = Q_{comp1} / \alpha_{\Sigma} + T_{room} = 85/11 + 20 = 27.7^0 C$$

$$T_{floor2} = Q_{comp2} / \alpha_{\Sigma} + T_{room} = 74/11 + 20 = 26.7^0 C$$

$$T_{floor3} = Q_{comp3} / \alpha_{\Sigma} + T_{room} = 68/11 + 20 = 26.2^0 C$$

The obtained values are the temperature of the floor surface necessary to ensure the specified heat load.

Calculation of temperatures of heat carriers. The temperature of the heat carriers depends on the required temperature of the floor surface, which in turn depends on the heat load, the heat load is heat loss during heat transfer between different materials (from the heat carrier to the pipe wall of the warm floor circuit, from the pipe wall to concrete, from concrete to a clean coating) is calculated taking into account.

$$Q_{comp} = 1/R_{\Sigma}\left(T_{heat.c} - T_{floor}\right) \tag{7}$$

Here R_{Σ} - the total resistance of the materials participating in the heat transfer process.

So, the temperature of heat carriers for all heating panels is as follows:

$$T_{h..c} = Q_{comp}(R_{\Sigma} + 1/\alpha_{\Sigma}) + \Delta T/2(Q_{comp}(R_{\Sigma} + 1/\alpha_{\Sigma}) + \Delta T/2(S/L)) + T_{air} \tag{8}$$

$$T_{h.c} = (Q_{comp}(R_{\Sigma} + 1/\alpha_{\Sigma}) + \Delta T/2)(1 + S_h/L_h)) + T_{air} \tag{9}$$

$$T_{h.k} = (Q_{comp}(R_{\Sigma} + 1/\alpha_{\Sigma}) + \Delta T/2)K_T) + T_{air} \tag{10}$$

Here ΔT – a decrease in the temperature of the heat carriers between the transfer and return transfer pipes; K_T – coefficient that takes into account the uneven distribution of temperature in the heating panel

$$K_T=1+S_h/L_h \tag{11}$$

Calculation of the thermal resistance of the heating panel.

$$R_{\Sigma}=R_1+ R_2+ R_3+\ldots+R_n \tag{12}$$

$R_{1\ldots n}$ – thermal resistance of the specific material participating in the heat transfer process:

$$R_{1\ldots n} = \delta_{1\ldots n} / \lambda_{1\ldots. n} \tag{13}$$

For the three-room water-based underfloor heating system we're looking at, it's as follows:

- Contour of pipes made of 17x2 mm;
- 30 mm thick concrete is poured over the pipe above the contour of the warm floor;
- 4 mm thick clear coat and 4 mm thick tile;
- The temperature drop of heat carriers does not exceed 5^0C

Calculation:
Thermal resistance of the pipe:

$$\lambda_{pipe}=0{,}4\ W/(m\cdot{}^0C),\ \delta_{pipe}=0.002\ m,\ R_{pipe}=0.005\ (m^2\cdot{}^0C)/W$$

Thermal resistance of concrete:

$$\lambda_{concrete}=1{,}7\ W/(m\cdot{}^0C),\ \delta_{concrete}=0.03\ m,\ R_{concrete}=0.0176\ (m^2\cdot{}^0C)/W$$

Thermal resistance of glue:

$$\lambda_{glue}=1\ Vt/(m\cdot{}^0C),\ \delta_{glue}=0.005\ m,\ R_{glue}=0.005\ (m^2\cdot{}^0C)/W$$

Thermal resistance of the plate:

$$\lambda_{plate}=2\ W/(m\cdot{}^0C),\ \delta_{plate}=0.008\ m,\ R_{plate}=0.004\ (m^2\cdot{}^0C)/W$$

The overall thermal resistance of the structure:

$$R_{\Sigma}=R_{pipe}+ R_{concrete}+ R_{glue}+R_{plate}=0.005+0.018+0.005+0.008=0.0316\ (m^2\cdot{}^0C)/W$$

Temperatures of heat carriers in the circuit to heat the surface of the heating panel to the required temperature:

$$T_{heat\ carriert1}=(85(0.0316+1/11)+5.2)(1+8.8/63)+20=34.7^0C$$

$$T_{heat\ carrier2}=33.9^0C;\ T_{heat\ carrier3}=32.3^0C.$$

Determining the consumption of the heat carrier according to the contour. Consumption of the heat carrier in the i^{th} circuit:

$$G_i=Q/(1.163\Delta T) \tag{14}$$

Here Q – Calculation load on the n^{th} circuit, i – the circuit number being calculated; ΔT – a decrease in the temperature of the heat carriers between the transfer and return transfer pipes.

In our case:

$$G_1=0.075/(1.163\cdot 5)=0.129\ m^3/hour$$

$$G_2=0.177\ m^3/hour;\ G_3=0.134\ m^3/hour$$

The total consumption of heat carriers passing through the collector is equal to the consumption of heat carriers in all circuits:

$$G_{collector}=G_1+G_3+G_3+\ldots+G_n \tag{15}$$

Here G_i-is the consumption of the heat carrier on the i-th circuit; n- is the number of circuits in the collector.
In our case:

$$G_{kol}=G_1+G_3+G_3=0.129+0.177+0.134=0.44\ m^3/hour$$

Choosing the step of placing pipes of WHF contours. One of the main factors in the design of a water-heated floor is the step of laying pipes. This greatly affects the reliable operation of the system[24-26].

The most common pipe placement steps are 150, 200 and 300 mm. Laying pipes with a step of 150 mm is installed in rooms with a very high heat load.

Laying pipes with a step of 200 mm is mainly installed in industrial and production rooms, water parks and swimming pools. A pipe with a diameter of 20 mm is used as the contour of the warm floor.

The placement of pipes with a step of 300 mm is installed in the inner zones of the room and in rooms with an average heating load.

Let's consider the calculation of two contours with lengths of 80 m. In this case, the heating load on the heating panel is 65 W/m^2, but their steps are different, i.e. 300 and 150 mm.

We calculate the area occupied by each contour:

$$S_{contour300}=L_{contour}/(1000/300)=24\ m^2$$

$$S_{contour150}=L_{contour}/(1000/150)=12\ m^2$$

So the total heat load on these contours:

$$Q_{contour300}=S_{contour300}\cdot 65=1560\ W$$

$$Q_{contour150}=S_{contour150}\cdot 65=780\ W$$

It is not difficult to determine the amount of heat carriers flowing through these circuits to ensure the required load:

$$G_{contour300}=Q_{contour300}/(1.163(T_1-T_2))=1560/(1.163\cdot 5)=0.27\ m^3/hour$$

$$G_{contour150}=Q_{contour150}/(1.163(T_1-T_2))=780/(1.163\cdot 5)=0.134\ m^3/hour$$

In this case, the resistance of the circuit made of 17x2 mm pipe

$$\Delta P_{contour300}=L_{contour300}(G_{contour300}/K_V)^{1.78}=80(0.27/7.2)^{1.78}=23.2\ kPa$$

$$\Delta P_{contour150}=L_{contour150}(G_{contour150}/K_V)^{1.78}=80(0.134/7.2)^{1.78}=6.7\ kPa$$

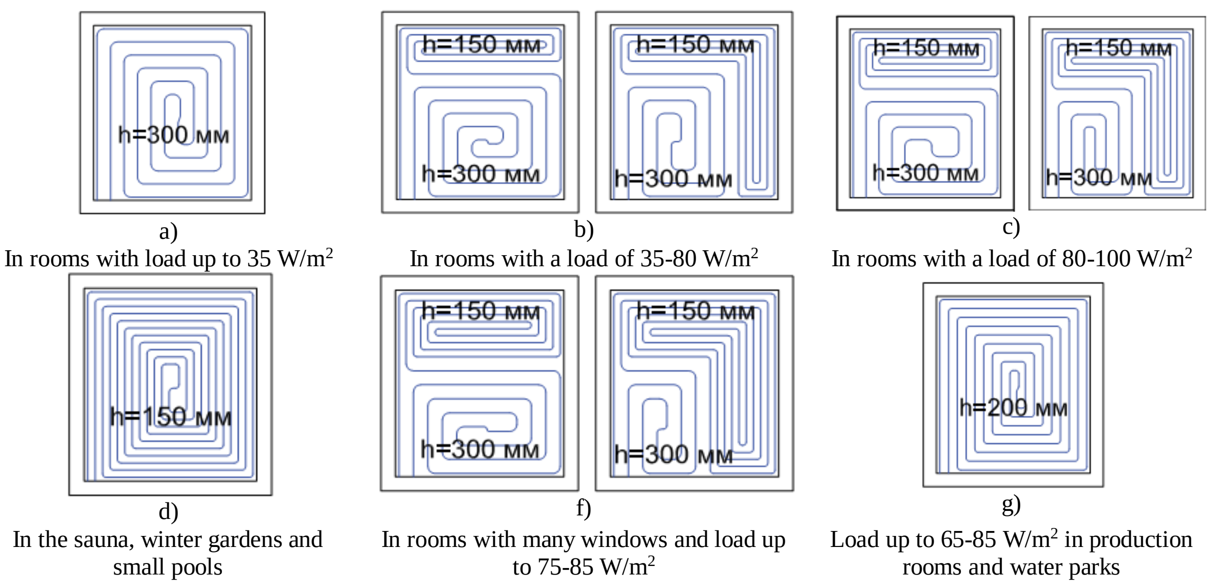
Comparison of the change of the load on the contour depending on the change of the step of laying the pipes.

TABLE 1. Comparison table of changes in the load on the contour depending on the change in the pipe spacing.

Deployment step	300	150
Contour length	80	80
Download comparison	65	65
The area occupied by the outline	24	12
Heat load	1560	780
Consumption	0.27	0.134
Pressure drop in the circuit	23.2	6.7

It is clear from the above calculation that for contours of the same length, as the placement step increases, the heating load on the contour increases, and the pressure loss on the contour doubles.

Piping options. Depending on the heat load in the room, there are options for placing pipes with a fixed and variable step. The following table lists the pipe placement options.



a) In rooms with load up to 35 W/m^2

b) In rooms with a load of 35-80 W/m^2

c) In rooms with a load of 80-100 W/m^2

d) In the sauna, winter gardens and small pools

f) In rooms with many windows and load up to 75-85 W/m^2

g) Load up to 65-85 W/m^2 in production rooms and water parks

FIGURE 16. Pipe layout options depending on the heat load in the room.

Heat lost from under the heating panel.

To determine the heat lost from under the heating panel, we perform the following calculation.

It is known from the practice of using a water warm floor that the temperature of the heat carrier transmitted to the heating system should not exceed 40 ^{0}C. We take the heat load in the room as 65 W/m^2 according to the norm.

It is known that when the heating load is 65 W/m^2, the percentage of loss through the floor should not exceed 12%, so

$$Q_{allowed}=65\cdot 0.12=7.8\ W/m^2$$

The temperature under the insulating layer should not be less than 20 ^{0}C.

It is common to use expanded polystyrene with a thermal conductivity of no more than 0,038 W$/(m\,^0C)$ as a heat insulating material for a water heating system.

According to the above equation

$$Q_{comp} = 1/R_{\Sigma}\left(T_{h.c} - T_p\right) \tag{16}$$

The thickness of the polystyrene thermal insulation for the heating panel:

$$\delta_{\text{polystyrene}} = 0.038/7.8(40\text{-}20) = 0.097\ m \approx 100\ mm$$

CONCLUSION

- General information about water-heated warm floor systems, their areas of application, advantages and disadvantages were fully considered. Examples of calculations for evaluating the efficiency of a water-heated warm floor are given and procedures for calculating a warm floor are given;
- The effective surface of the heater is 11 m^2, the heat consumption of the room is 440 W, the heating surface of the warm floor system when the temperature inside the room is 25^0C is F=10.4 m^2, the required length of the circuit is L=29.7 m and the mass of the water flow passing through the circuit It was determined that m=0.02263 kg/s.

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