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SUMMARY

Heating systems with in-built heaters are used in situations with increased hygienic demands for heating systems and/or in combination with low temperature heat sources.

Low temperature heating systems have been previously studied in depth by such scientists as D. Pertaš, B. A. Missenars, W. Olesen, J. Babiak, R. Bean. The use of geothermal energy in Latvia, as well as the optimization of energy systems, have been previously studied by E. Dzelzītis, A. Freimanis, I. Gavēna, P. Šipkovs, A. Krēsliņš, I. Škapare. During this doctorate study, low temperature heating systems with heaters built into walls were examined and evaluated under real-world conditions. The results acquired will allow for the effective and practical use of this system, encouraging an improvement in the comfort level of the internal microclimate.

The goal of this doctorate study is to develop a method to calculate a constructive solution for heating systems with in-built heaters using low-temperature sources of heat.

In order to reach this goal, the following tasks were put forth: the current standard regulations for the installation of heaters built into walls was evaluated; a calculation method was prepared; during practical experiments, the suggested calculation method was tested; the practicality of an in-built heating system was supported economically; the system was compared with the traditional heating system, with several heat sources; the heat-pump system and geothermal energy were evaluated, as possible sources of heat in low temperature heating systems with in-built heaters.

Within this doctorate study, the research conducted is based on theoretical calculations and practical experimentation, performed on the experimental bench, in the SGUTI RTU climatic chamber, and on the experimental heater in the residential brick building. The study's scientific novelty is in the mathematical modelling of the parameters of heaters built into vertical surfaces, using experimentally acquired data, thus producing a calculation method that is precise and based on actual conditions. The studies conducted in this doctorate project and easy to use calculation method for heater parameters built into vertical surfaces, as well as the conclusions of the research, are practically applicable by planning organizations when planning technically and economically supported heating systems, and when building and modernizing current heating systems.

The results of this doctorate study have been announced times in international scientific conferences and have been reflected in publications. This doctorate study consists of 5 chapters and 99 pages. The project uses 100 references.

INTRODUCTION

Currently, there is great experience in installing heated floors in the sanitary and communal spaces of social buildings, as well as residential buildings. There is, however, insufficient experience in installing heaters into walls. To clearly understand the goal of this method, attention in the doctorate study was paid to current legislation in the field of internal climate. During the critical review, it was discovered that standard methods do not look into cases where heaters are built into dividing walls, which is one of the main aspects examined in the doctorate project. As well, the influence of wall materials on heat flow indicators are not appropriately reflected. These tasks were accomplished in the developed calculation method and, as a result, walls with in-built heaters and the correlations between their heating technical and constructive parameters allow for the evaluation of the system's efficiency. In practical experiments in the laboratory, concrete blocks of various density with in-built heaters were prepared were connected to the experimental bench; heaters covered in drywall were measured in the SGUTI RTU climatic chamber; an experimental heater was developed in the external wall of a residential brick building. Heater surfaces were measured, internal and external air temperatures, all of which allowed for the successful validation of the calculation method.

I propose that organizations involved in the planning of heating systems use this developed method. Also, recommendations for supplementation of standard documentation have been prepared. Opportunities to use low temperature heating systems with heaters built into walls in combination with such heat sources as: traditional furnace heating from natural gas; heat-pumps and geothermal systems, which use the heat within the depths of the earth in the geothermal anomaly zones of Latvia.

Goal of the doctorate study:

To develop constructive solutions for heating systems with low temperature heat sources.

Tasks:

1. To develop a calculation method for low temperature heating systems,
2. To validate experimentally the proposed heater calculation method,
3. To develop a calculation method for heater construction,
4. To evaluate the economic efficiency of low temperature heating systems.

Research method and materials

During the doctorate study, the current foundation of legislation and standard regulations was evaluated. The classification of source data necessary for calculations of heating systems was proposed, in relation to the determination of the level of thermal comfort. Supplementing current calculation techniques, a calculation program was developed, which can be used by the representative of the planning organization to determine heat flow from a vertical surface composed of various materials, and the heaters built within it, as well as to determine the angle factor coefficient and the temperature of the resulting radiation from surfaces in the room in locations allocated for periods of long-term rest. Within practical experiments in the laboratory, concrete blocks of various density with in-built heaters were prepared and connected to the experimental bench, while the surface temperature of heaters covered in drywall were measured in the SGUTI RTU climatic chamber, and an experimental heater was built into the external wall of a residential brick building. Heater surfaces were measured, as well as internal and external temperatures, which allowed for the successful validation of the method.

Scientific novelty of the project and main results

During the doctorate study, a method to calculate constructive solutions for heating systems with in-built heaters with low temperature heat sources was developed. The proposed method was validated experimentally.

Practical significance of the project

Over the course of this doctorate project, an easy, practically applicable calculation method for the parameters of heaters built into vertical surfaces was developed. The method developed is offered for practical application to planning organizations for the planning of optimal technically and economically sound heating systems.

The practicality and actual application of low temperature heating systems with heaters built into walls were examined and evaluated in real-world conditions. Correlations between the heating technical parameters of in-built heaters were determined, and the influence of data from wall elements on heat flow, surface temperature and the resulting heat radiation temperature indicators were determined. Following the method developed, the constructive solutions for various heaters were compared, and recommendations for practical applications in the formulation of constructive solutions for in-built heaters were suggested, as well as their possible application in periodic heating systems.

The economic viability of heating systems with heaters built into walls was tested with different heat sources, and the above-mentioned system was compared with heating systems using traditional heaters.

1. DEVELOPMENT OF CALCULATION METHODS FOR LOW TEMPERATURE HEATING SYSTEMS

Heating systems built into floor, ceiling or wall constructions are a type of central heating system that allows one to control the internal air parameters and to reach thermal comfort using conduction, convection and radiation.

It was determined that the use of low temperature heating systems in social buildings and residential buildings is limited to heated floors, due to the lack of sufficient experience in the installation of heaters in walls, and standard documents do not examine situations where heaters are built into dividing walls, and there is no easy practically applicable method for calculations for heating systems. This doctorate project proposes the source data classification necessary for heating system calculations, related to the determination of thermal comfort (criteria and indexes of the thermal environment) in a particular location.

There was no all-encompassing approach to calculation methods for heaters built into vertical surfaces. The heat flow of an in-built heater was calculated separately, but no attention was paid to the influence of the resulting heat radiation temperature and comfort zones in a room.

Developing the calculation program, which consists of three section, the planner has the opportunity to: calculate heat flow from the heater and to determine the necessary area of the in-built heater at the location (part 1); using the surface temperature calculation program, determine the comfort zone in the room and the resulting heat radiation temperature (parts 2 and 3). When planning for low temperature surface heating, it must be accepted that, depending on the location, surfaces have various heat capacity coefficients, acceptable surface temperatures, and heat capacity.

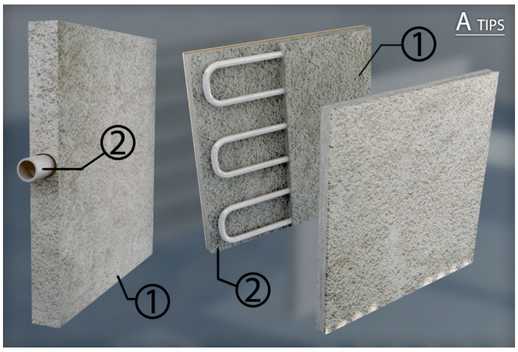
Low temperature heating systems are built via two methods:

A-type system: heating pipes build into a dispersing paved or concrete floor

This type of system with pipes, laid concrete or dispersing paved floors is the most common type of surface heating, used in many European countries. The pipes of the heating system are fully mounted within the concrete, and carry heat from the heat carrying agent to the radiating surface (Fig. 1.1).

B-type system: heating system pipes installed externally to the dispersing paved or concrete surface (for example, in the insulation layer)

Heat-carrying pipes are mounted into the heat insulation layer (Fig. 1.2). Horizontal heat transfer is limited by the system plate. To increase temperature diffusion, heat-guiding elements are used. Heat-guiding plates are effective if they are closely connected between pipes and heat-guiding appliances.



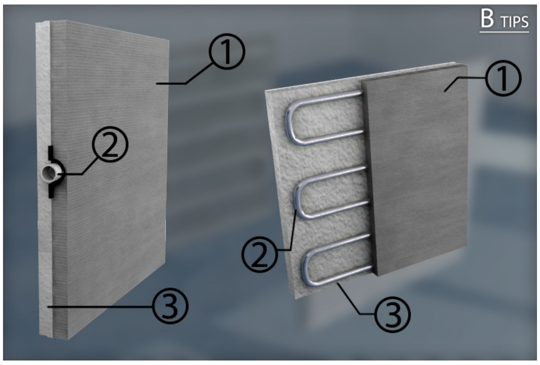


Fig. 1.1 A-type system: pipes built into the dispersing paving or concrete

Fig. 1.2 B-type system: pipes built external to dispersing paving or concrete (in insulating layer)

Using the first part of the developed planning calculation program, conclusions can be reached about the heater's constructive solutions, and the influence of wall materials on heat flow indicators. Selecting the **A-type system**, the heating system planner enters such data as thickness of wall surface layer, m (s_U); distance between pipe centers, m (T); and external diameter of pipes, m (D).

The density of heat flow from the heater is determined as follows:

$$q = B \cdot a_B \cdot a_T^{m_T} \cdot a_D^{m_D} \cdot a_U^{m_U} \cdot \Delta\theta_H \tag{1.1}$$

The values of resistance of surface coverage to heat conduction ($R_{\lambda,B}$), concrete heat conductivity (λ_E), external pipe diameter coefficient (a_D), pipe center distance coefficient (α_T), surface coverage coefficient (α_U) are dependent on resistance to heat conductivity and distance between pipe centers; the coefficients mentioned above are tabular data. The current calculation method did not account for the density indicators of various kinds of concrete. In the developed planning program, heat conductivity indicator tables were supplemented with heat conductivity data for concrete with densities of 1500kg/m^3 and 3700 kg/m^3, which, in turn, significantly influences the selection of coefficients and, as a result, influences heat flow indicators. Coefficient (B), W/(m^{2}K), corresponds to the system's vertical placement in the room.

Such parameters as the surface coverage coefficient (α_B); pipe interval coefficient (m_T); surface thickness factor (m_U) and the coefficient expressing pipe diameter (m_D) are calculated.

The surface coverage coefficient α_B, is determined using the formula:

$$\alpha_B = \frac{\frac{1}{\alpha} + \frac{S_{U,0}}{\lambda_{U,0}}}{\frac{1}{a} + \frac{S_{U,0}}{\lambda_E} + R_{\lambda,B}}. \tag{1.2}$$

Indicators such as the surface placement coefficient, W/m^{2}K (α); specific heat conductivity of wall external layer ($\lambda_{U,0}$); specific thickness of wall external layer, m ($S_{U,0}$); resistance of surface coverage to heat conductivity ($R_{\lambda,B}$) and concrete heat conductivity (λ_E) are tabular values.

Using the distance between pipes planned for in the system (T), external pipe diameter (D); the thickness of tiles above heating pipes (S_U) calculates the pipe interval coefficient, surface layer thickness factor and coefficient expressing pipe diameter:

$$m_T = 1 - \frac{T}{0.075} \quad (1.3)$$

$$m_U = 100(0.045 - S_U) \quad (1.4)$$

$$m_D = 250(D - 0.020) \quad (1.5)$$

In the determination of the heat carrying differential temperature ($\Delta\theta_H$), it is necessary to operate with such indicators as the forward average temperature, °C; (θ_V); reverse average temperature, °C; (θ_R); internal air operative temperature, °C, (θ_i).
For the heat carrier differential temperature, calculated as follows:

$$\Delta\theta_H = \left| \frac{\theta_V - \theta_R}{\ln \dfrac{\theta_V - \theta_i}{\theta_R - \theta_i}} \right| \quad (1.6)$$

Selecting the **B-type system**, the heat system planner enters such data as wall surface layer thickness, m (S_U); distance between pipe centers, m (T); and outside diameter of pipes, m (D); thickness of heat transfer device, m (S_{WL}).

Heat flow density from the heater was determined as follows:

$$q = B \cdot a_B \cdot a_T^{m_T} \cdot a_U \cdot a_{WL} \cdot a_K \cdot \Delta\theta_H \quad (1.7)$$

Such values as the surface placement coefficient, W/m^{2}K, (α); the specific thickness of the wall surface layer, m ($S_{U,0}$), the specific heat conductivity of the wall surface layer ($\lambda_{U,0}$); the coefficient for distance between pipes (α_T); the correction coefficient (α_K) are tabular data. The coefficient B = 6.7 W/(m^{2}K) corresponds to the system's vertical placement in the room.

Such parameters as the surface coverage coefficient (a_U); pipe internal coefficient (m_T); heat transmission coefficient (K_{WL}); the coefficient expressing pipe diameter (m_D) and the surface coverage coefficient (α_B); are calculated.

The surface coverage coefficient (a_U), is determined according to the formula:

$$\alpha_U = \frac{\dfrac{1}{\alpha} + \dfrac{S_{U,0}}{\lambda_{U,0}}}{\dfrac{1}{a} + \dfrac{S_U}{\lambda_E}} \quad (1.8.)$$

Such indicators as the surface placement coefficient, W/m^{2}K (α); the specific heat conductivity of the wall surface layer ($\lambda_{U,0}$); the specific thickness of the wall surface layer, m ($S_{U,0}$); the thickness of the wall surface layer, m (S_U) and the heat conductivity of concrete (λ_E) are tabular values.

The pipe interval coefficient (m_T) is determined using formula 1.3.

The coefficient of the heat transmission device ($K_{WL,}$) is determined according to the formula:

$$K_{WL} = \frac{S_{WL} * \lambda_{WL} + b_U * S_U * \lambda_E}{0.125} \quad (1.9)$$

The coefficient of the heat transmission device ($K_{WL,}$) contains such indicators as the thickness of the heat transmission device, m (S_{WL}), the heat conductivity of the heat transmission device, W/(m*K) (λ_{WL}), the coefficient (b_U), the thickness of the wall surface layer, m (S_U) and heat conductivity of concrete (λ_E) are tabular values.

The function of distance between pipe centers (T), occurs as follows:

$$f(T) = 1+0.44\sqrt{T} \quad (1.10)$$

The surface coverage coefficient α_B, is determined accoring to the formula:

$$a_B = \frac{1}{1 + B \cdot a_u \cdot a_T^{m_T} \cdot a_{WL} \cdot a_K \cdot R_{\lambda,B} \cdot f(T)} \quad (1.11)$$

Such indicators as the coefficient of system placement in the room(B) W/(m^{2}K) are proportional to the surface coverage coefficient (a_U), the coefficient of distance between pipes (α_T); the pipe interval coefficient (m_T); the heat transmission coefficient (α_{WL}); the correction coefficient (α_K); the resistance of the surface coverage to heat conductivity ($R_{\lambda,B}$); the function of distance between pipe centers (f(T)).

The coefficient of heat transmission (α_{WL}) is a tabular indicator, which is dependent on the diameter of heating pipes D and the value of the coefficient of the heat transmission device ($K_{WL,}$).

The differential temperature of the heat carrier ($\Delta\theta_H$) is calculated using formula 1.6.

Criteria for selecting a calculation method and limit conditions are shown in Table 1.1.

Table 1.1.

Criteria for selection of calculation method

Pipe position	System type	Limit conditions	Calculation method
Built into dispersing tiles or concrete	A	T ≥ 0.050 m S_U ≥ 0.01 m 0.008 ≤ d ≤ 0.03 $S_U / \lambda_u \geq 0.01$	Function of power unit $q = B \cdot a_B \cdot a_T^{m_T} \cdot a_D^{m_D} \cdot a_U^{m_U} \cdot \Delta\theta_H$
Built outside of dispersing tiles or concrete	B	0.05 ≤ T ≤ 0.045 m 0.014 ≤ d ≤ 0.022 $0.01 \leq S_U / \lambda_u \leq 0.18$	Function of power unit $q = B \cdot a_B \cdot a_T^{m_T} \cdot a_U \cdot a_{WL} \cdot a_K \cdot \Delta\theta_H$

To determine the room's comfort level, **part 3 of the calculation program for the resulting temperature of heat radiation** must be used, where through the determination of angle factors, the temperature of heat radiation in various zones of the room can be determined, taking into account a person's standing or sitting position and distance from the wall with in-built heater.

The current calculation method does not have a sample calculation for the determination of the surface temperature of a heater, as **proposed in the second part of the calculation method**. It is proposed that the principle of the construction's thermal resistance is directly proportional to its thickness and inversely proportional to the heat conductivity coefficient of its material to determine the surface temperature of the heater. By dividing the construction into layers and knowing their thickness and heat conductivity coefficient, the curve of temperature decrease can be determined.

The resistance of heat yield is mainly dependent on external factors and from wall surface materials. Thermal resistance is dependent on the heat conductivity of wall materials and on wall structure. The construction's thermal resistance is directly proportional to its thickness and inversely proportional to the heat conductivity coefficient of its material.

$$R = R_1 + R_2 + R_3 + ...R_n = \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3} + ... + \frac{\delta_n}{\lambda_n} \qquad (1.12)$$

The current method recommends the use of graphs to determine that angle coefficient, and that attention is not paid separately and in detail to the radiating temperature, which is an important factor, and a reason for the development of the **3rd part** of the calculation program: **the resulting heat radiation temperature calculator**.

The heat flow of radiation, from the view of heat exchange between two internal surfaces, is influenced by the radiating angle factor between the heat radiating surface *i* and the surface/person *j* and the emission of surface *i* . The emission is dependent on such factors as temperature, angle of radiation and wavelength. The most often used surfaces radiating heat can reach an emission up to 0.95, which corresponds to long wavelength radiation between internal surfaces. The angle factor reflects the mutual relationship between geometric forms, size (area) and distance between two objects (person and surface). The sum of angle factors between a person and all surfaces of a room is equal to 1.

The angle factor between a sitting or standing person and room surfaces is calculated as follows:

$$F_{p-N} = F_{\max}(1 - e^{-(a/c)/\tau}) \cdot (1 - e^{-(h/c)/\gamma}) \quad (1.12)$$

$$\tau = A + B(a/c) \quad (1.13)$$

$$\gamma = C + D(b/c) + E(a/c) \quad (1.14)$$

$$t_{mr} = t_1^4 F_{p-1} + t_2^4 F_{p-2} + \ldots + t_N^4 F_{p-N} \quad (1.15)$$

where t_{mr} is the radiation temperature, °R (C°) ; t_N - surface temperature, °R (C°); F_{p-N} - the angle factor between the person and the surface; $F_{\max}$ - the maximum angle factor; a, b, c- distance from the person's position to surfaces, m; A, B, C, D, E – tabular coefficients.

2. EXPERIMENTAL VALIDATION OF PROPOSED CALCULATION METHOD FOR HEATERS

For a practical trial of theoretically calculated surface temperature data under real-world conditions, practical measurements were taken. During experimentation, measurements of surface temperature were planned: under laboratory conditions, prepared concrete blocks on the experimental bench, drywall slabs in the RTU IHGWT climatic chamber and a location where the heater of the heating system is built into the external wall. The heating and cooling times of heaters were evaluated. The surface temperature data acquired were used in the resulting temperature calculation program to determine the room's comfort zones. Within the experiment, three types of concrete blocks were prepared (0.6 x 0.6 x 0.05 m), into which the plastic pipe of the heating system was built (diameter 18 mm), with a distance between pipes of 300 mm. The system was connected to an electric water heater, with a forward temperature of 40ºC (Fig. 2.1).

Fig.2.1 Experimental blocks

Types of experimental block concrete mixtures: **1. normal weight concrete (NSB)**, traditionally used in construction. The usual composition of the mixture was selected: cement content 330 kg/m3, natural sand and dolomite fragments. **2. reduced weight concrete (ASB)**, where ceramsite was used as the basic component of reduced-weight concrete. Reduced heat conductivity and a lower value of heat capacity is characteristic of this type of concrete. **3. ultra-high-performance concrete (SSB)**, where mixture components are natural sand and waste elements of the metal processing industry (small steel rings), as component of increased weight. This type of concrete is characteristically with a higher heat conductivity value. All concrete mixtures were prepared in the laboratory. The function of each mixture was controlled and optimized with the use of a plastification agent.

Following the acquisition of measurement results, it was possible to validate the surface calculations developed in the doctorate study, and to use them in the program's 3rd part: the resulting temperature calculator.

In Figure 2.2, through the curve decreases of the graph, the processes of heating and cooling of concrete blocks of various composition are shown. The functional temperature of the blocks was reached in a time varying from 5 h 20 min to 9 h 5 min. The cooling process of block surfaces took place in a time varying from 60 h 45 min to 69 h 55 min. While summarizing the data, it can be concluded that the surface temperature of a functional NSB block is lower by 1 – 2ºC, ASB block lower by 5 – 6ºC that is lower than the SSB block – 28ºC.

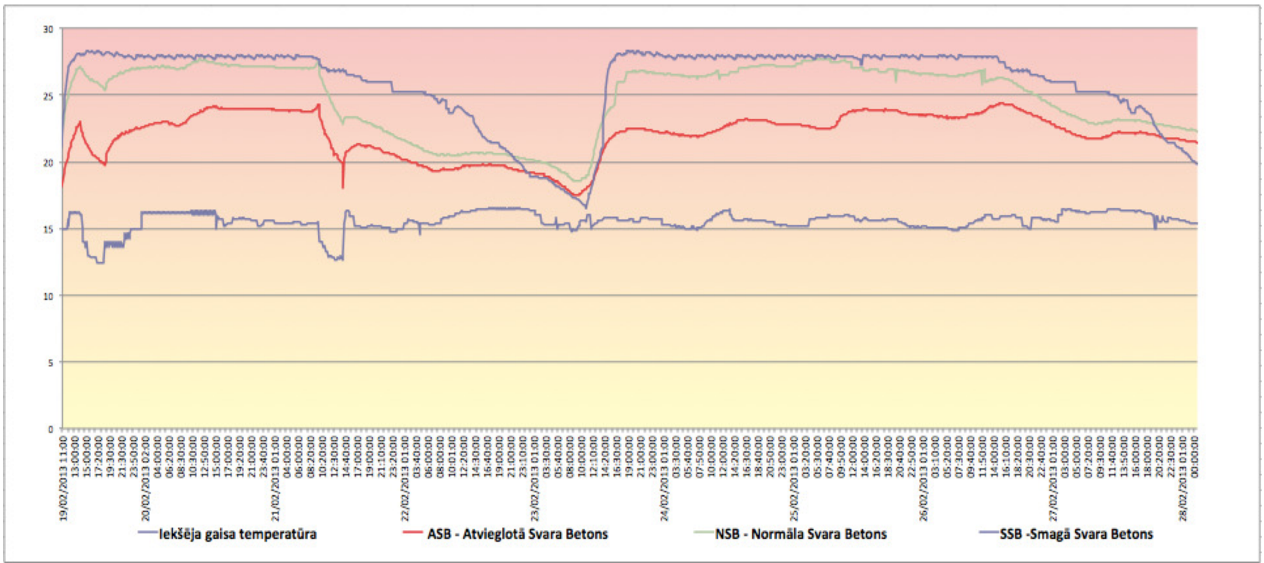


Fig. 2.2. Surface temperature data for various type of blocks

Iekšējā gaisa temperatūra	Internal air temperature
ASB – atvieglotā svara betons	ASB – reduced weight concrete
NSB – normāla svara betons	NSB – normal weight concrete
SSB – Smagā svara betons	SSB – ultra-high-performance concrete

Thermally durable and regular drywall slabs were heated to a functional temperature of 26ºC within 4 hours. Regular drywall heats up more evenly over the entire 4 hours (Fig. 2.3), compared to the thermally durable drywall. Both types of drywall showed a cooling time of 7 hours.

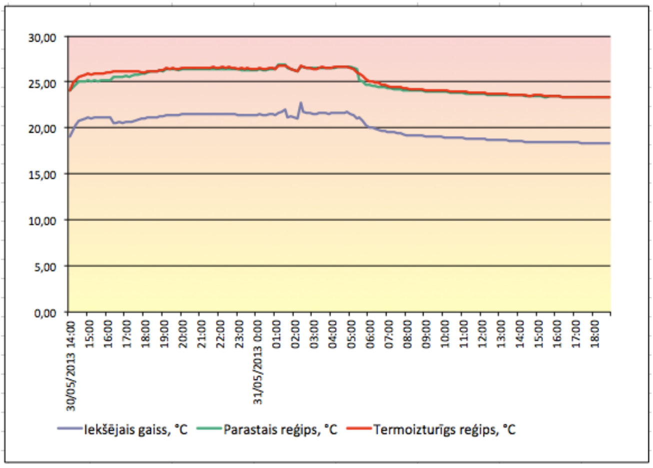


Fig. 2.3. Surface temperature data for different types of drywall

Iekšējāis gaiss	Internal air
Parastais reģipsis	Regular drywall
Termoizturīgs reģipsis	Thermally durable drywall

Within the insulation layer in the external wall, a low temperature heating system heater was placed with a surface layer of plaster, and the experimental trial took place in the five-storey residential brick building. A condensation-type combined gas furnace is the heat source in this system. The system provided is an A-type system, according to which theoretical calculations were made. Figures 2.4 and 2.5 show the location in photograph and thermograph. Figure 2.7 is a photograph of the wall with in-built low temperature heating system heater. While conducting the thermography (Fig. 2.8 and 2.9), the heater's pipes under working conditions at a heat carrier temperature of 40ºC can be seen.

Fig. 2.4: Photograph of residential building

Fig. 2.5: Thermograph of residential building

Fig. 2.6: Photograph of experimental heater

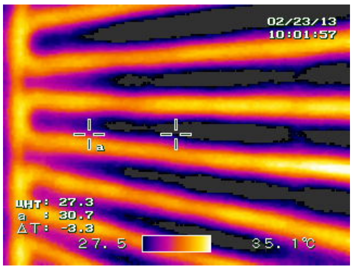


Fig. 2.7: Thermograph of experimental heater

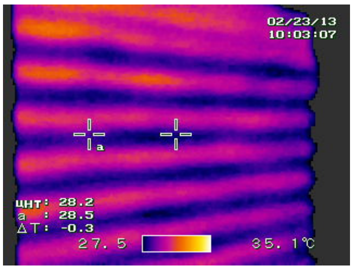


Fig. 2.8: Thermograph of experimental heater

To take surface temperature measurements and to record data, a 4-channel surface thermometer PCE-T390, type K/J/R/E/T/S, (calibration W13015557) was used. To obtain external temperature data, a humidity and temperature registrator KTH 300 A with a range of working temperatures from -25 to 70 °C was used. Thermographs were taken with the thermal camera MIKRON micro SHOT B with a range of working temperatures from -25 to +100 °C.

Data from measurements taken during the winter period were shown at various heights on the living room wall. With the surface temperature recorder, data about the wall surface temperature at various heights was collected, H = 0.8m – a sleeping person's zone, H = 1.6m – a sitting person's zone, H = 2.0m – the zone above a person's head. The time necessary for the system to heat up and heat the air temperature to a comfort level of those present is shown graphically. The time needed for the system to cool and for the internal temperature to become uncomfortable for those inside is also shown.

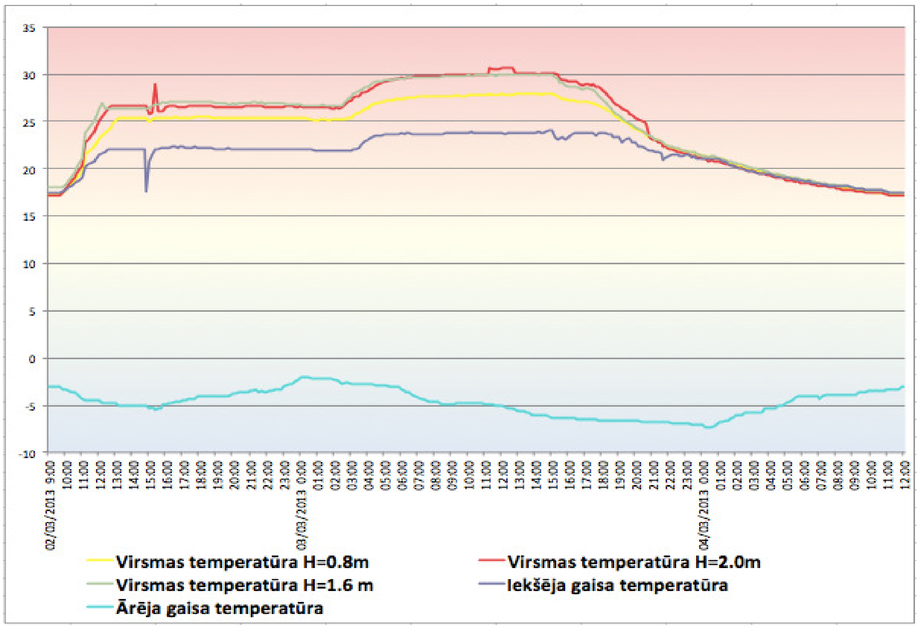


Fig. 2.6: Virsmas temperatūru dati eksperimentāla objektā

Virsmas temperatūra	Surface temperature
Ārējā gaisa temperatūra	External air temperature
Iekšējā gaisa temperatūra	Internal air temperature

During data summarization, it can be concluded that internal air is heated from 17°C to 22°C from the time the system is turned on, depending on the zone of activity of interest, within a timeframe from 3 h 30 min to 4 h 15 min. It can be noted that the surface temperature indicators increased from the minimum to a working temperature within a time from 3 h 30 min to 4 h 15 min. The system begins to cool, but air temperature indicators remain within the allowable comfort zone (up to 21°C) for 10 hours. The complete cooling of the system (until the initial indicator of 17°C, which is no longer comfortable to those inside) within 21 hours.

3. CALCULATION METHOD FOR HEATER CONSTRUCTIONS

Part 1 of the developed planning calculation program is geared towards the determination of heat flow from heaters built into vertical surfaces constructed from various kinds of concrete and covered with drywall slabs or plaster.

While processing various constructive solutions for heaters in **A-type systems (concrete blocks prepared experimentally**) within the heat flow calculation program, it was concluded that:

At identical output of the heat carrier of the heating system and return temperatures, identical temperatures of internal air and identical construction data, heat flow from normal weight concrete blocks is 21.9% higher than that of reduced weight concrete blocks. The heat flow from ultra-high-performance concrete blocks is 22.9% higher when compared to reduced weight concrete blocks. When increasing the difference in the system's forward and return temperatures from 5°C to 10°C, heat flow is reduced by 14%. When increasing the forward temperature of the heat carrier, with a temperature difference between forward and return temperatures of 5°C, heat flow increases to 26%. If the thickness of the wall's surface layer is reduced from 0.02 m to 0.01 m, heat flow is increased by 4%. Reducing the distance between pipe centers from 0.3 m to 0.15 m influences the system's coefficients and factors, as a result of which heat flow is increased by 50%.

In **B-type systems (with a heater covered by drywall, plaster)**, it was concluded that: At identical heat carrier output in the heating system and identical return temperatures, at similar internal air temperatures and identical construction data, heat flow from drywall walls is 12% higher compared to fire resistant drywall. The wall with a plaster covering had a heat flow, compared to fire resistant drywall, 16.9% larger. The reduction of distance between pipe centers from 0.3 m to 0.15 m influences system coefficients and factors, as a result heat flow is increased by 39%. If heater material is changed, as well as the material between the layer of insulation and the heating pipe, to a material with better heat conductivity parameters, heat flow can even be increased by 80%. This correlation can be used as necessary in separate areas in the room's zones. Changes the thickness of the wall's surface covering, decreasing it from 0.02 m to 0.01 m, heat flow is increased by 10.2%. Increasing the forward and return temperature difference in the heat carrier from 5°C to 10°C, heat flow is decreased by 10.2%. An increase in the system's heat carrier forward temperature, at a forward and return temperature difference of 5°C, heat flow is increased by 25%.

In the **calculation program for resulting heat radiation temperature**, the room's comfort conditions were calculated in zones and under various conditions. The table developed can be used in practical calculations. The calculation program allows for the determination of the angle factor coefficient and the resulting heat radiation of all room surfaces in planning a person's long-term area of rest. The representative of the planning organization can enter the room's dimensions into the calculation program, and one's long-term area of rest within it, as well as the predicted surface temperature of the room. The calculation program will calculate the angle factor for a specific object, and will show the radiating temperature, which can be used by the planner to plan work spaces or other necessary zones within the room (Fig. 3.1, 3.2).

Table Nr. 3.2

Calculating radiating temperature

Temperature of wall with inbuilt heater ° C									
		23	24	25	26	27	28	29	30
	Distance from heated surface (m)	**Radiating temperature C°**							
Sitting person	0,50	20,36	20,88	21,43	22,00	22,59	23,19	23,82	24,46
	1,00	20,04	20,48	20,95	21,44	21,95	22,49	23,04	23,61
	1,50	19,77	20,15	20,54	20,97	21,41	21,88	22,37	22,87
	2,00	19,56	19,87	20,21	20,58	20,96	21,37	21,80	22,25
	2,50	19,39	19,66	19,95	20,26	20,60	20,96	21,33	21,73
	3,00	19,25	19,48	19,73	20,01	20,30	20,61	20,95	21,30
	3,50	19,14	19,34	19,56	19,80	20,06	20,33	20,63	20,94
	…	…	…	…	…	…	…	…	…

	7,50	18,52	18,60	18,70	18,80	18,91	19,03	19,17	19,32
Standing person	0,50	20,03	20,60	21,20	21,81	22,44	23,09	23,75	24,43
	1,00	19,58	20,08	20,60	21,15	21,72	22,30	22,90	23,52
	1,50	19,19	19,63	20,09	20,57	21,08	21,60	22,14	22,70
	2,00	18,71	19,07	19,45	19,86	20,29	20,73	21,20	21,69
	2,50	18,63	18,96	19,32	19,70	20,09	20,51	20,95	21,41
	3,00	18,29	18,56	18,85	19,16	19,50	19,85	20,22	20,61
	3,50	18,29	18,54	18,81	19,11	19,43	19,76	20,12	20,49
	…	…	…	…	…	…	…	…	…
	7,50	18,00	18,10	18,21	18,33	18,47	18,62	18,78	18,96

To create a calculation program for determining the heater's surface temperature, the construction is divided into layers, and the principles of direct proportionality of thermal resistance to layer thickness and inverse proportionality to the heat conductivity coefficient of the layer's material. Actual data from surface temperatures, taken from experimental data, are compared to theoretical calculations.

The representative of the planning organization may enter the heating system's data into the calculation program, as well as wall material and construction data, and air parameters, in order to gain the surface temperature of the in-built heater. The calculated surface temperature allows for the precise operation in the heat radiation temperature calculation program, which, in turn, aids in determining the zone of comfort. Table 3.3, which shows a sample surface temperature calculation, can be practically applied. Walls at five different heights were calculated, with an in-built heater with forward parameters of 35, 40 and 45°C, and with an internal temperature from 5°C to 18°C.

Table Nr. 3.3

Sample calculation of surface temperature

Surrounding air temperature	Ultra-high-performance concrete block			Normal weight concrete block			Reduced weight concrete block			Drywall			Plaster		
	Forward temperature of heater built into wall, C °			Forward temperature of heater built into wall, C °			Forward temperature of heater built into wall, C °			Forward temperature of heater built into wall, C °			Forward temperature of heater built into wall, C °		
	35	**40**	**45**	**35**	**40**	**45**	**35**	**40**	**45**	**35**	**40**	**45**	**35**	**40**	**45**
18	**25,25**	**27,16**	**29,06**	**25,11**	**26,99**	**28,86**	**23,27**	**24,65**	**26,04**	**21,76**	**22,75**	**23,74**	**23,51**	**24,97**	**26,42**

17	**25,01**	**26,92**	**28,83**	**24,86**	**26,74**	**28,61**	**22,82**	**24,21**	**25,59**	**21,16**	**22,15**	**23,14**	**23,09**	**24,55**	**26,00**
16	**24,78**	**26,68**	**28,59**	**24,61**	**26,48**	**28,36**	**22,38**	**23,76**	**25,15**	**20,55**	**21,54**	**22,53**	**22,68**	**24,13**	**25,58**
15	**24,54**	**26,45**	**28,35**	**24,36**	**26,45**	**28,11**	**21,93**	**23,32**	**24,70**	**19,95**	**20,94**	**21,93**	**22,26**	**23,71**	**25,16**
14	**24,30**	**26,21**	**28,12**	**24,11**	**25,98**	**27,85**	**21,49**	**22,87**	**24,26**	**19,34**	**20,33**	**21,32**	**21,84**	**23,29**	**24,74**
…	**….**	**….**	**…**	**…**	**…**	**…**	**….**	**…**	**….**	**….**	**….**	**….**	**….**	**…..**	**….**
5	**22,17**	**24,08**	**25,98**	**21,85**	**23,72**	**25,59**	**17,48**	**18,86**	**20,25**	**13,91**	**14,90**	**15,89**	**18,06**	**19,51**	**20,96**

As a result of the calculations performed, the step-wise gradient in surface radiation temperatures of various kinds of wall was determined. The gradient indicates a change in surface radiation temperatures when ambient temperature increases to 1°C. The gradient's value is linearly dependent on the heat conductivity coefficient of wall material. Coefficient values: for ultra-high-performance concrete – 0.24; for normal weight concrete – 0.25; for reduced weight concrete – 0.44; for regular drywall – 0.60; for plaster – 0.

4. CALCULATION OF THE ECONOMIC EFFICIENCY OF LOW TEMPERATURE HEATING SYSTEMS

As an example of calculating the cost-efficiency of the heating system, an office building with a required heat energy power of 40kW, and a total annual heat consumption for heating needs at 90 Mwh/year. To determine the effect of type of heater in the heating system and of the heat source on system efficiency, the following system variables were selected for the method: 1. heaters built into walls with heat-pump as heat source; 2. heaters built into walls with a gas condensation type furnace; 3. radiators with heat-pump as heat source; 4. radiators with gas condensation type furnace.

To model the operative parameters of the heat-pump, the specialized program VPW200, developed by the heat-pump company Junkers, was used. The basic data of the location must be entered into the table in order for the program to calculate the system's necessary parameters.

Evaluation of financial cost-efficiency

The system's financial efficiency can be determined using the following instruments: payment rate (ARR); payment period (AP). The payment rate is the average annual savings against capital investments. $\sum_{t-1}^{N} CF_t$ total expenses; $\sum_{t-1}^{N} A_t$ - heat energy consumption

$$ARR = \frac{\sum_{t-1}^{N} CF_t}{N} - \frac{\sum_{t-1}^{N} A_t}{N} \quad (4.1)$$

Evaluating and comparing kinds of low temperature heating systems (situations 1 and 3) using the payment rate method, the system with heat-pump as heat source is 32% more effective than the low temperature heating system with a gas condensation type furnace as heat source.

The payment period is the time period necessary for the total net savings (IE) before losing value becomes equal to capital investments (K).

$$AP = \frac{K}{IE} \ , \quad (4.2)$$

During the economic analysis, it was concluded that situation 1 is the most cost-effective, even though capital investments are msot significant. In terms of heat energy costs, it is the economically most feasible solution. Situation 1 has a payment period half as long, while situation 3 has a greater payment period related to energy resource costs.

CONCLUSIONS

It was determined that the use of low temperature heating systems in social and residential buildings is limited to heated floors only, due to the lack of experience in the installation of heaters in walls. The experimental validation of the developed calculation method was conducted on heaters in concrete blocks of three different densities; and with heaters covered by drywall slabs and a layer of plaster. When compiling data, it can be concluded that the surface temperature, under working conditions, for NSB block is lower by 1 – 2ºC and ASB block lower by 5 – 6ºC that is lower than the SSB block – 28ºC. The time to heat the surface of these concrete blocks of various density from the minimal temperature to the working temperature was in the range from 5 to 9 hours; the cooling period from the working temperature to the minimal temperature was from 60 to 72 hours long. During compilation of data from the experimental location, the surface heating period from the minimal temperature to the working temperature was in a time range from 3 h 30 min to 4 h 15 min; the cooling period from working temperature to the minimal temperature was in a time range of 10 to 20 hours. The data mentioned above can be used for periodic heating systems.

Based on the experimentally validated method, a easy and practical calculation method, program and tables, is presented to planning organizations. Using this method's calculation examples, it can be seen that in B-type systems (heater covered by drywall, plaster): reduction of distance between pipe centers from 0.3 m to 0.15 m influences heat flow by increasing it by 39%; changing the materials of the heating device can increase heat flow up to 80%. For A-type systems (concrete blocks prepared experimentally), it was concluded that: normal weight concrete blocks have a 21.9% higher heat flow than reduced weight concrete blocks; the heat flow of ultra-high-performance concrete blocks is 22.9% higher than that of reduced weight concrete blocks; changing the thickness of the wall surface covering from 0.02 m to 0.01 m can increase heat flow by 4%; reducing distance between pipe centers from 0.3 m to 0.15 m can influence system coefficients and factors, increasing heat flow by 50% as a result.

While calculating the cost-effectiveness of heating systems, it was concluded that heaters built into walls with heat-pump as heat source are 32% more effective compared to low temperature heating systems with a gas condensation type furnace as heat source, and the payment period is two times shorter.

As a prospective resource, geothermal energy was reviewed, because the geological study of territorial sedimentary deposits and the crystalline bedrock has yielded data on their potential. For the development of the branch of geothermal energy, it is essential to develop a national development strategy for the utilization of geothermal energy.

List of Publications:

1) Psenichnaja J., Kreslins A. The potential of geothermal energy usage for district heating in Latvia // Proceedings of 10th REHVA World Congress „CLIMA 2010", Antalya, Turkey, 9 – 12 May 2010. – 1 – 5 lpp.

2) Psenichnaja J., Kreslins A., Ikaunieks A. The Energy Efficient Heat Pump System for Office Building in Baltic Region // Proceedings of the 12th International Conference of Indoor Air Quality and Climate "Indoor Air 2011", US, Austin, Texas, 5-10 June 2011. - 1 – 6 lpp.

3) Psenichnaja J., Kreslins A. The potential of geothermal energy usage for district heating in Latvia // Proceedings of the 12th International Conference of Indoor Air Quality and Climate "Indoor Air 2011", US, Austin, Texas 5-10 June 2011. - 1–6 lpp.

4) Krēsliņš A., Pšeņičnaja J., Gaujēna B. "Evaluation of working parameters of radiant heating systmes" // Proceedings of 2nd WTA International PhD Symposium, Brno, Čehija, 06.-07.October 2011 "Building Materials and building Technology to preserve the Built Heritage – 196-205 lpp.

5) Pšeņičnaja J., Gaujēna B. Evaluation of parameters of radiant heating systems // Raksts ir apstiprināts publicēšanai RTU Zinātnisko rakstu krājumā „Būvzinātne" Sējums. Nr. 13, 2012. – 41. – 46. lpp.

6) Ikaunieks A., Ivancovs D., Pšeņičnaja J. „Ceiling panels radiant heating systems"// RTU Zinātnisko rakstu krājumā "Būvzinātne" 2012. 1 – 6 lpp. (Akceptēts publicēšanai)

7) Pšeņičnaja J., „Evaluation of parameters of radiant heating systems"// Proceedings of International Scientific Conference "Renewable energy and energy efficiency", Jelgava, Latvia, 28.-30.May 2012. - 212.lpp.

8) Krēsliņš A., Pšeņičnaja J., "Geothermal heat in Latvia" // Book of abstracts 3rd European Geothermal PhD Day, Pisa, Italia, 29.March 2012.- 19lpp.

9) Pshenichnaya Y., Borodiņecs A., Zemītis J., Krēsliņš A. The potential of geothermal energy usage in Latvia // World Renewable Energy Forum, United States of America, Denver, 13 - 17 May 2012. - pp 1-4.

10) Krēsliņš A., Pšeņičnaja J., Gaujēna B. „Radiant heating systems" // Healthy Building 2012 10th International Conference 08-12.July 2012 Brisbane, Australia pp 1-6.