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Combined air conditioning for heating rooms and improving of indoor climate

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Abstract. Geothermal equipment consists of intake air pipes, vacuum wards and underground connecting pipes, placed near to a villa. The heat exchange ventilation equipment MENERGA 191191 used in ventilation systems makes air inside the device circulate. This patented equipment differs from the analogues of Germany, Japan, United States, etc. by the cooling exchange device. This device enables remarkable advantages in mounting and construction by decreasing the length, installation depth and number of air pipes, simplifying and reducing the maintenance and increasing the equipment durability. The geothermal equipment is meant for creating an environment with a constant temperature of 4 ºC and adjustable relative humidity in warehouses and basements. It is for improving an indoor climate in villas' basements, preheating, and air conditioning based on air heating as well. This equipment is indispensable when preheating greenhouses and cooling air in the hot season. The analysis of air climate parameters (temperature ϑ_k, relative humidity W_s, dew point ϑ_p, absolute humidity W_a, velocity v, oxygen content O_2, carbon dioxide content CO_2, positive light air ions n^+, negative light air ions n^-) passing through the geothermal equipment is presented in the article. Heat technical data (air specific heat capacity, characteristics of heat and cold exchange processes) are presented. This article summarises the research results of indoor climate qualities and presents data about energetic-economical efficiency of the geothermal equipment (air specific heat and gross capacities, return air flow specific heat and gross capacities, the economic effect of pre-heating the villa and the post-heating expenses were analysed).

Key words: geothermal, equipment, climate, environment.

INTRODUCTION

Ground heat is a great energy repository accumulated in the ground, stone surfaces and water. Utilisation of geothermal energy decreases pressure on the environment caused by energy production, reducing the dangers of pollution and health risks connected with operating chemical-based energy sources.

Usage of ground heat in ventilation and air heating systems has been practiced for about 150 years. In the patents of the United States of America, Germany and Japan (US-5131887, DE-3414973, JP 58095156 etc.) solutions for accumulating ground heat energy and for air filtration are described, essential for air heating systems.

A useful model EE00329 of an analogous solution is registered in Estonia under the names of Jüris, H. and Piigert, L, patent number 0104. The registered geothermal equipment is meant for pre-heating the incoming air (cold season), for cooling (warm season), for improving internal climate parameters and it differs from its predecessors by the application of a cold exchange device.

The aim of the research was to analyse the climate parameters of the air passing through the assembly of the working geothermal equipment, heat-technical parameters of the equipment's heat and cold exchange device and energy-economical data of the device, in order to make a prognoses about suitability of the device for house heating and establishing an internal climate. In order to attain the objectives the following tasks have been completed: 1) evaluation of the climate parameters of the working device; 2) analysis of the thermal-technical parameters of the working device; 3) defining and analysing the energy-economical data of the device.

OBJECT AND METHODS

The research object was geothermal equipment built into a house (Fig. 1), the climate parameters of the air input device of which (1...3), heat exchange device (5, ground source), air output device (6...13) and cold exchange device (14...20) were measured by a real time network. For this purpose diagnostic equipment DATA LOGGER ALMEMO 2690-8 with measuring sensors was used. Internal and external climate qualities of the air active in the geothermal heat exchange device were analysed on the basis of their basic characteristics (air temperature ϑ_k, air relative humidity W_s, dew point ϑ_p, air absolute humidity W_a, air movement speed ν, oxygen level in the air O_2, carbon dioxide level in the air CO_2, positively loaded light aeroions n^+, negatively loaded light aeroions n^-).

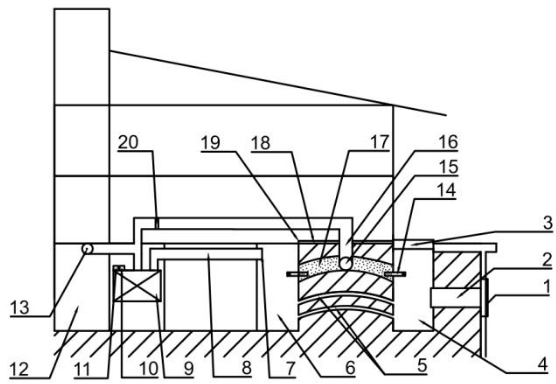

Figure 1. Graph of object with geothermal equipment and technical data: 1 – air input pipe lid; 2 – external air input pipe (Ø 250×6000 mm, 4 pieces); 3 – decompression chamber lid; 4 – decompression chamber (4400×1500×1900 mm)[2]; 5 – air pipes (Ø 162×7000 mm, 19 pieces); 6 – decompression chamber (4400×1500×1800 mm) (Fig. 2), 7 – air input nozzle; 8 – air input pipe (Ø 250 mm); 9 – heat exchanger Menerga 191101 (Fig. 3); 10 – internal air input; 11 – processed air output; 12 – chimney base; 13 – polluted air pipe; 14 – airing pipes (Ø 110 mm, 4 pieces); 15 – perforated pipe (Ø 160 mm); 16 – extracting pipe (Ø 160 mm); 17 – light weight aggregate (LWA) FIBO (7000×5000×400 mm); 18 – concrete floor; 19 – polyethylene film; 20 – ventilator.

[2] length, width, height

In order to obtain reliable measured values, in accordance with experiment planning theory (Melnikov et al., 1980) probability $\alpha = 0.95$. To achieve the set-up reliability emanating from the technical data of equipment, measurement error of sensors $\varepsilon = \pm\, 0.4\sigma$, where σ is the standard deviation of arithmetic mean.

Functioning ability of heat and cold exchange device of the geothermal equipment was measured according to the following method:

1. In thermal-technical parameters of the equipment's heat exchange device it was considered that the ground is 7×5 m large land territory with unlimited depth. Air pipes (19 pieces) are placed in two rows, in chess positions up to 1.95 m deep in the ground. In light aggregate zone are placed 4 ventilation pipes (Fig. 4).
2. Considering the great thermal capacity of the ground (soil) c_p = 1,840 J (kg K)$^{-1}$ (Incropera & DeWitt, 1996) and unlimited depth, it can be considered as an unlimited heat repository.
3. The influence of diurnal temperature frequent variation is relatively irrelevant (Kabashnikov et al., 2002).
4. It is presumed (Kabashnikov et al., 2002) that ground temperature it 4–6 °C all-the-year-round.
5. There is proper thermal isolation under the floor of building socle/basement floor.
6. According to diagnosis data the medium temperature in March 2010 in the air input area was 11 °C.
7. The total length of the heat exchange area of air pipes is 63 m and air capacity 0.65 m^3.
8. Airflow average speed in air pipes was 0.12 m s^{-1}.

Figure 2. The decompression chamber.

Figure 3. The heat exchanger Menerga 191101.

Air volume and weight of consumption are calculated using formulas (Viljasoo et al., 2005)

$$\tilde{O}_e = v \cdot S_t \cdot n_t, \quad \tilde{O}_{ek} = v \cdot S_t \cdot n_t \cdot \rho, \qquad (1, 2)$$

where $\tilde{O}_e$ – air volume of consumption m^3 s^{-1}; v – air velocity in the air pipe m s^{-1}; S_t – cross-sectional area of the air pipe m^2; nt – number of air pipes; $\tilde{O}_{ek}$ – weight air consumption of air volume kg s^{-1}; ρ – density of moist air at normal conditions kg(m^3)$^{-1}$ (ρ = 1,293 (Liiske, 2002)).

In heat exchange of cold air indifferent capacity is calculated by the formula

$$Q_k = \tilde{O}_{ek} \cdot c_{n\tilde{o}} \cdot (\vartheta_1 - \vartheta_4) + Q_{ka}, \quad (3)$$

where Q_k – cold specific capacitance of air kW; $\tilde{O}_{ek}$ – air weight of consumption kg s^{-1}; $c_{n\tilde{o}}$ – moist air specific heat kJ (kg K)$^{-1}$, ($c_{n\tilde{o}}$ = 1.01); ϑ_1 – temperature of the air in the external environment K; ϑ_4 – average air temperature in the second chamber *K*; Q_{ka} – cold losses kW (average of 10%).

In the heat exchange part taken from the ground of different heat the number is calculated by the formula

$$q_s = S_s \cdot k \cdot \Delta\vartheta_k, \quad (4)$$

where q_s – from the ground of specific consumption of heat W; S_s – heating surface m^2; k – thermal efficiency of through W (m^2 · K)$^{-1}$, (k = 6); $\Delta\vartheta_k$ – the average temperature difference K.

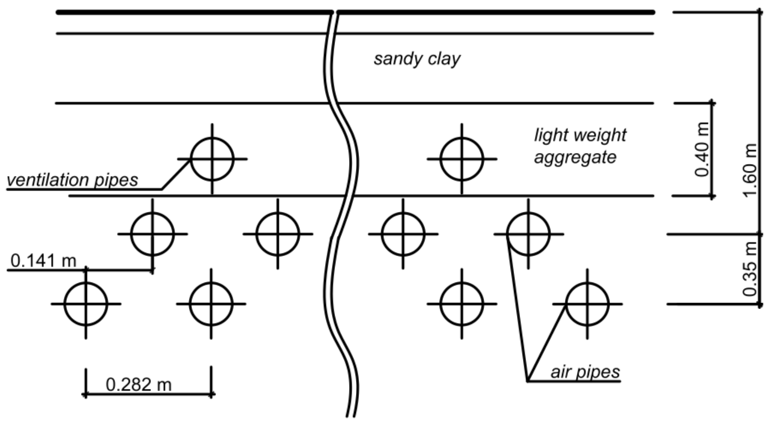

Figure 4. Placement of the pipes in case of limited building base area.

The average temperature difference between the heat exchanges is calculated

$$\Delta\vartheta_k = \frac{(\vartheta_{mp} - \vartheta_4) - (\vartheta_{mk} - \vartheta_1)}{2{,}3\lg\dfrac{\vartheta_{mp} - \vartheta_4}{\vartheta_{mk} - \vartheta_1}}, \quad (5)$$

where $\Delta\vartheta_k$ – average temperature difference K; ϑ_{mp} – soil temperature K; ϑ_4 - average temperature in the second chamber K; ϑ_{mk} – average temperature of the air pipes above the soil K; ϑ_1 – average ambient temperature K.

Geothermal equipment performance to influence hygienic characteristics of unipolarity ions is determined by (Tšiževski, 1989)

$$q_n = \frac{n^+}{n^-}, \qquad (6)$$

where q_n – unipolarity factor of light ions; n^+ – positively loaded light air ions cm^{-3}; n^- – minus-loaded light air ions cm^3.

The relative freshness of the air is calculated by the formula (Viljasoo & Tomson, 2002)

$$V = 100 - \frac{q_t}{q_õ} \cdot 100, \qquad (7)$$

where V – the relative freshness of the air %; q_t – treated with air ions unipolarity factor in spaces; $q_õ$ – the maximum value of unipolarity factor ($q_õ = 1.3$) in indoor environment.

Considering the fact that there are many different methods to calculate the heat amount needed for heating the house, and the calculations' results are somewhat different, the following control calculations have hereby been conducted. In the first case the thermal unit capacity amount needed for heating the house was calculated using the formula

$$Q_s = q_{ot} \cdot V_e(\vartheta_{12} - \vartheta_1) \cdot \eta, \qquad (8)$$

where Q_s – thermal unit capacity necessary for heating the house W; q_{ot} – house specific thermal unit characteristic W $(m^3\,K)^{-1}$ ($q_{ot} = 0.87$ (Žabo et al., 1983)); V_e – house external cubature m^3 ($V_e = 500$); ϑ_{12} – air temperature in the house K; ϑ_1 – external air temperature K(ϑ_1 = -15 °C); η – correction factor depending on the quality of the house ($\eta = 0.6$ (Žabo et al., 1983)).

RESULTS AND DISCUSSION

Based on the diagnosis data the working parameters of the heat exchange device calculated according to the conditions stated in the research method are the following: considering air gravimetric unit expenditure the cold unit capacity of the air passing through the heat exchange device air pipes is 202.6–717.7 W (Table 1) in case of air flow medium speed 0.12 m s^{-1}. Thus the cold amount of air passing through air pipes depends mainly on external air temperature.

In connection with the fact that according to the data presented in literature (Incropera & DeWitt, 1996; Kabashnikov et al., 2002) the pipes are placed at the depth 2–6 m in order to ensure the environment with sufficient ground temperature (4–6 °C), in case of the object (Fig. 2) the possible temperature of the ground (clay-earth soil) surrounding the pipes placed at the depth of medium 1.4 m, is 4 °C.

Table 1. Work parameters of the heat exchange device of the geothermal equipment

Date, time	Equations, conditions	Unit	Heat specific volume q_s, W	Air specific consumption $\tilde{O}_e$
	1. $\tilde{O}_e = v \cdot S_t \cdot n_t$	m^3 s^{-1}		0.0235
	2. $\tilde{O}_{ek} = v \cdot S_t \cdot n_t \cdot \rho$	kg s^{-1}		0.0304
	3. $Q_k = \tilde{O}_{ek} \cdot c_{n\tilde{o}} \cdot (\vartheta_1 - \vartheta_4) + Q_{ka}$	kW		Q_k, kW
	3.1. $if \vartheta_1 = 11, \vartheta_4 = 4.9$	°C		0.2026
27.03.10	3.2. $if \vartheta_1 = -15, \vartheta_4 = 4.0$	°C		0.7177
27.03.10	4. $q_s = S \cdot k \cdot \Delta\vartheta_k$	W		*Source data*
	Provided	°C		v = 0.12 m s^{-1}
27.03.10	4.1. $if \Delta \vartheta_{k1} = 2.13$	K	447.3	S_1 = 0,0103 m^2
27.03.10	4.2. $if \Delta \vartheta_{k2} = 3.42$	K	717.7	ϑ_{mk} = 2°C

At the same time it is possible to assume that the temperature of the ground surrounding pipes placed at stated depth is 4 °C and even 5 °C. According to the stated temperature options (ϑ_{mp} = 4.0; 5.0 °C) and the results of calculations based on the diagnosis data the average thermal unit consumption acquired from the ground in the equipment's heat exchange device is 447.3–717.7 W. In Table 1 we can see that during period (27.03.10) the cold unit capacity of external air passing through the heat exchange air pipes was 202.6 W. At even colder times (-15 °C) the cold unit capacity of external air passing through the air pipes was on average 717.7 W and at the same date the average heat unit expenditure taken from the ground was 717.7 W, which also exceeds somewhat the external air cold unit capacity. Based on received calculations the functioning of the heat exchange device can be considered satisfactory.

Climate parameters (Table 2) of working geothermal equipment were diagnosed in rooms with processed air, accordingly and these were the following results: temperatures accordingly 22.27 and 20.51 °C, relative humidity 56.5 and 52.66%, air flow speed 0.12 and 0.13 m s^{-1}, air oxygen content 20.07 and 20.17%; air carbon dioxide content 0.05 and 0.08%.

The sanitary-hygienic conditions of the room can be judged and improved by defining and improving its electrostatic condition. The measuring results showed that in the room with processed air the unit quantity of negatively loaded light air ions (5,286 and 4,002 cm^{-3}). The amounts of positively loaded light air ions were accordingly 5,103 and 3,195 cm^{-3}. Thus in the room with processed air the air and room sanitary-hygienic condition was very good (q = 0.97 and 0.80) from the point of view of electro climate. To sum up, the climate parameters in the room with processed air were somewhat better than in the room with unprocessed air, which is characterised by an increase of 25.38 and 38.46% in relative air freshness in reference to the highest value of established norm (q = 1.3).

Table 2. Climatic characteristics of the geothermal equipment

N°	Characteristic	Unit	External climate	Decompression chamber	Cellar room	Living room	Bedroom
1.	ϑ	°C	11.10	4.88	18.86	22.27	20.51
2.	W_s	%	71.90	93.30	55.60	56.5	52.66
3.	ϑ_p	°C	5.80	4.90	7.33	9.4	7.85
4.	W_a	g kg^{-1}	6.12	3.80	9.56	13.2	10.50
5.	v	m s^{-1}	0.30	0.12	0.14	0.12	0.13
6.	O_2	%	20.17	20.72	19.87	20.07	20.17
7.	CO_2	%	0.08	0.12	0.10	0.05	0.08
8.	n^+	cm^{-3}	1,346	1,990	4,413	5,103	3,195
9.	n^-	cm^{-3}	2,298	2,412	5,318	5,286	4,002
10.	$\Sigma n^\pm$	cm^{-3}	3,644	4,402	9,731	10,389	7,197
11.	q		0.59	0.83	0.83	0.97	0.80
12.	S	%	54.62	36.15	36.15	25.38	38.46

The unit thermal capacity (Formula 8 (Žabo et al., 1983)) needed for heating the house is 9.4 kW and the total thermal capacity during the heating period (5,040 h) is 47.35 MWh. The total thermal capacity needed for heating the house during the heating period is 40.8 MWh, based on literature sources (Liiske, 2002). In connection that geothermal equipment was in winter conditions (external air temperature –15 °C) the air thermal unit capacity acquired with the help of geothermal equipment (Menerga 191101 only in ventilation mode) would be at temperature –15°...4 °C 4.96 kW and air total thermal capacity during the heating period would be 24.99 MWh. For after-heating the house from temperature 4–21 °C with a thermal exchange electrocalorifier the received unit thermal capacity is 4.44 kW and air total thermal capacity during the heating period 22.36 MWh. The returned heat unit thermal capacity from temperature 24–21 °C is 0.78 kW and total capacity during the heating period 3.95 MWh. The ground heat and the returned heat added unit capacity is 5.74 kW and total capacity during the heating period is 28.93 MWh.

The average total thermal capacity needed for heating the building is 47.35 MWh. The ground heat and the returned heat total capacity (28.93 MWh) during the heating period represent approximately 61.1% of this.

CONCLUSIONS

1. The functioning of cold and heat exchange devices of a working geothermal equipment with the cold exchange device may be considered satisfactory in conditions of stated air flow speed.

2. Climate parameters and the sanitary-hygienic conditions are comparatively better in the rooms (25.38…38.46%) with processed air.

3. The cold unit capacity of external air passing through the heat exchange air pipes was on average 717.7 W.

4. The average heat unit expenditure taken from the ground was 717.7 W.

5. Theoretically the unit thermal capacity achieved with help of geothermal equipment would be 0.717 kW and total thermal capacity during the heating period 3.62 MWh.

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