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Utilization of Geothermal Heat for Air-Conditioning of Different Small Buildings

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Abstract: The parts of the electronic equipment, the different electric units (amplifiers, rectifiers etc.) are installed in the containers deposed by the towers of telephone, broadcasting, TV and other short-wave relay stations. The operation of these units requires a suitable ambient temperature which is provided by conventional split air conditioners – however quite in an expensive way. The use of the novel solution and system as a result of the K+F project is absolutely economical; on the one hand, it saves some electric energy and, on the other hand, provides free available capacity as well; due to the reduction, the actual container and the relay station can be equipped with further instruments – the function can be improved without increasing the contingent capacity supplied by the mains (and its considerable cost also can be saved).
Key words: geothermal energy, air-conditioning, ground loop, heat-exchanger

INTRODUCTION

In the container-type control cabinets of the telephone, broadcasting, TV and other short-wave relay stations, the too low or too high temperature risks the reliable operation of the installed instruments and devices. It requires the removal of heat in summer so the room must be cooled by a suitable cooling device and; the ambience of instruments needs the air conditioning. The air conditioners are suitable for heating as well if necessary, through their reversible operation. Several thousand such devices are operated in Hungary. The national total of their energy consumption is already considerable. However, the equipment of the stations with reliable devices requires also a huge expenditure.

MATERIAL AND METHODS
(Conceptions of development)

Objective and tasks

The objective of the project was to develop a simple energy saving system and to adapt it to the relay stations.

Two versions have been preliminary elaborated:

(A) Application of **shallow-well (***ground loop)* **type (reversible) heat pumps** – from the soil layer at 5-to-10-m depth, adjacent to the containers.

The drive of pump is provided by the available electric supply. The factor COP of the pump is 3.5 to 4.5 so a reduction in electric-energy consumption can be achieved. Taking into consideration that the air-conditioner is required anyway, only the installation of the well ('probe') needs a new expenditure for the utilization of the geothermal energy. Taking this into consideration, according to the preliminary calculations, the return rate of the extra investment may be reduced to some years; in the case of a project subvention – to 1 to 2 years.

(B) The other version is even simpler – a design **without the compressor cycle.**

It can be applied in actual practice if a shallow but sizable collector can be installed in the adjacent area to the construction of station of which surface area is suitably large to fulfil the 'heating' in winter or the 'cooling' functions, by the heat absorbed from the soil.

The version (B) is simpler since only a pump and a fan required for the circulation of fluid and air has to be installed in the system; they are controlled by the thermometers mounted in the control cabinet of the station.

The collector is made of pipes of smaller diameter; the heat-transfer medium is a liquid which is driven by the circulating centrifugal pump through the soil collector as well as the air-fluid heat exchanger.

The conception of this device can be seen in Figure 1.

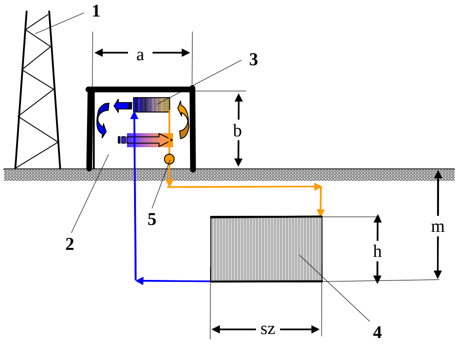

Figure 1. Schematic diagram of the heat-exchanger type system

1 – relay tower, 2 – container, 3 – fluid-air heat exchanger, 4 – fluid-soil heat exchanger, 5 – circulating pump
a – width of container, b – height of container, h – height of soil collector, sz – height of soil collector, m – bottommost point of collector in the soil

Theoretical fundamentals

The basic time unit is hour (h) used in the integral as well as the differential functions of the model calculation.

The momentary value of the enthalpy (*h_l*) of the air in the container can be calculated by the following equation:

$$h_l = c_{p_l}(t_l)\cdot(T_p - T_o) = c_{p_l}(t_l)\cdot t_{p_l} \left[\frac{\mathrm{kJ}}{\mathrm{kg}}\right] \qquad (1)$$

t_l = air temperature
c_{pl} = coefficient of specific heat of air
T_p = momentary temperature of air
T_0 = melting point of water-ice
t_{pl} = momentary temperature of air

The enthalpy of the air depends on several effects. The first one of these is the heat load – the heat production $\dot{q}_e$ (e.g. 2 to 5 kW) of the technical devices installed in the container. On the base of this and the equation (1), the following equation can be described:

$$t_l = t_l + \int_{i=0}^{\tau} \frac{\dot{q}_e}{\dot{m}_l \cdot c_p(t_l)} \left[{}^\circ\mathrm{C}\right] \qquad (2)$$

$\dot{m}_l$ = mass-flow rate of air

When calculating the temperature of the air, as the second step, the transmitted heat through the walls of the container – the amounts of the emitted or the absorbed heat (heating the internal air more) – has to be taken into consideration. Accordingly, the equation (2) can be improved as follows:

$$t_l = t_{l_0} + \left(\int_{i=0}^{\tau} \frac{\dot{q}_e}{c_p(t_l)} + \int_{i=0}^{\tau} \frac{\dot{q}_{kon}}{c_{p_l}(t_{l_p})} \right) \left[{}^\circ\mathrm{C}\right] \qquad (3a)$$

where the heat load *(q_{kon})* of the container on the air can be calculated in the following way:

$$\dot{q}_{kon} = \frac{\lambda_{kon}}{\delta_{kon}} \cdot A_{kon} \cdot dt \qquad (3b)$$

that is –

$$\dot{q}_{kon} = \frac{\lambda_{kon}}{\delta_{kon}} \cdot \left(2\cdot(l_h + l_{sz})\cdot l_m + (l_h \cdot l_{sz})\right)\cdot\left(t_{l_p} - t_{k\ddot{o}rny}\right)\cdot 0{,}001 \; [\mathrm{kW}]$$

A_{kon} = surface area of the container
l_h = length,
l_{sz} = width,
l_m = height,
$t_{körny}$ = temperature of the ambient temperature

With equation (3b), it was supposed that the motion of air along the walls of the container is negligible and that the floor insulation of the container is ideal so there is no heat transfer.

Of course, the sign of the right-side second term of the equation (3a), depending on the ambient temperature, can be negative or positive according that the internal space is heated (in summer) or cooled (in winter) from the external environment.

Obviously, the term $\dfrac{1}{c_{p_l}(t_{l_p})}$ cannot be put before the integral expression since the specific heat depends on the temperature but the temperature changes in every instant so it cannot be independent of the time consequently the coefficient of specific is not an independent factor of the time.

The third term influencing the temperature of the air is the high-performance heat exchanger installed in the container. The equation (3a) has to be modified again with this term and the equation (4a) will be given:

$$t_{l_p} = t_{l_0} + \left(\int_{i=0}^{\tau} \frac{\dot{q}_e}{c_{p_l}(t_{l_p})} + \int_{i=0}^{\tau} \frac{\dot{q}_{kon}}{c_{p_l}(t_{l_p})} + \int_{i=0}^{\tau} \frac{\dot{q}_{hocs}}{c_{p_l}(t_{l_p})} \right) \; [°\mathrm{C}] \quad (4a)$$

q_{hocs} = heat load of the heat exchanger
q_{kon} = heat load of the container

The heat load of the heat exchanger can be calculated as follows:

$$\dot{q}_{hocs} = \kappa_{hocs} \cdot A_{hocs} \cdot dt \quad (4b)$$

that is –

$$\dot{q}_{hocs} = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_{cső}}{\lambda_{cső}} + \frac{1}{\alpha_2}} \cdot A_{hocs} \cdot (t_l - t_{glikol}) \cdot 0{,}001 \; [\mathrm{kW}]$$

A_{hocs} = surface area of the heat exchanger

The above term – as it can be seen from the equation – also can be positive or negative according to that whether the air or the glycol is the warmer. So the heat exchanger operates as either a heating or a cooling panel.

Accordingly, the temperature of the air can be modelled by the equation (4a) in which the hour-second conversion factor is to be written and, after a further simplifying operation, it can be described in the following way:

$$t_{l_p} = t_{l_0} + 3600 \cdot \int_{i=0}^{\tau} \left[\frac{1}{c_{p_l}(t_{l_p})} \cdot (\dot{q}_e + \dot{q}_{kon} + \dot{q}_{hocs}) \right] \cdot d\tau \; [°\mathrm{C}]$$

(5)

The similar principle to the air can be applied to the glycol. The enthalpy of the air is changed by two effects – on the one hand, the glycol delivers the heat transferred or absorbed by the air in the inner heat exchanger and, on the other hand, the glycol transfers or absorbs a certain quantity of heat in the heat exchanger in the soil. The amount of heat exchange for the glycol and the air alike is equal in the container cabin. This theoretical case provides the most advantageous facility concerning the calculations of design – when the heat load of the glycol is the maximum. In this way, the middle term on the right side of equation (4a) is also valid but its sign is just the opposite.

Accordingly, the following two relationships can be written down for the change in temperature of the glycol:

$$t_{glikol_p} = t_{glikol_0} + 3600 \cdot \int_{i=0}^{\tau} \left[\frac{1}{c_{p_{glikol}}(t_{glikol_p})} \cdot (-\dot{q}_{kon} + \dot{q}_{tal}) \right] \cdot d\tau \; [°\mathrm{C}] \quad (6a)$$

q_{tal} = heat load of the soil

The addition of heat into the soil can be calculated by the equation –

$$\dot{q}_{tal} = c_{tal} \cdot A_{csöv} \cdot \frac{1}{\sqrt{a_{tal} \cdot \tau_{ref} \cdot \pi}} dt \; [\mathrm{kW}] \quad (6b)$$

A_{csov} = surface of pipeline in collector

that:

$$a_{tal} = \frac{\lambda_{tal}}{\rho_{tal} \cdot c_{tal}} \left[\frac{m^2}{s} \right] \text{ and } \tau_{ref} = 180 \; [h].$$

In addition, always there is a vertical heat flow ($\dot{q}_{hömozgás}$) existing in the soil; its value is 0.2 W/m as an average in Hungary. This subsurface heat flow either increases or decreases the temperature of the actual soil layer in the way that the average soil temperature of 15 ºC shall be permanent. Accordingly, the temperature of the soil can be determined in the following way:

$$t_{tal_p} = t_{tal_0} + 3600 \cdot \int_{i=0}^{\tau} \left[\frac{1}{c_{p_{glikol}}(t_{glikol_p})} \cdot (\dot{q}_{tal} + \dot{q}_{hömozgás}) \right] \cdot d\tau \; [°\mathrm{C}]$$

The applied collector designed for soil-heat transmission

Design and installation

Figure 2. Assembled – ready for transport

Figure 3. Embedding in the soil

Figure 4. The designed and installed interior unit

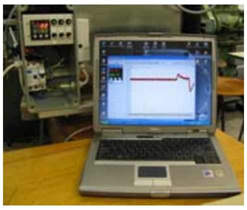

Figure 5. Programming of the interior unit

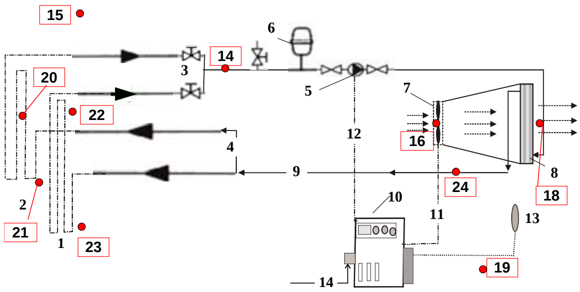

Figure 6. Schematic diagram of the system

1 and 2 – exterior collectors; 3 and 4 – shut-off cocks; 5 – fluid pump; 6 – compensator vessel; 7 – fan; 8 – water-air heat exchanger; 9 – return branch; 10 – control device; 11 – control of fan; 12 – control of pump; 13 – interior thermal sensor; 14 – power supply

Positions of the thermal sensors used during the measurements (bordered code numbers)

14 – temperature of inlet water; 15 – temperature of the exterior air (in shadow); 16 – inlet side of the air-water heat exchanger (tested with two versions – a heightened one and when the height was equal to the outlet opening); 18 – air temperature at the outlet of heat exchanger; 19 – interior or room temperature; 20 – ...; 21 – ...; 22 – ...; 23 – ... at 0,7-2,5-m depth; 24 – temperature of the return water after the heat exchanger

RESEARCH RESULTS

Technical conditions

At the bottom points of the collectors, the initial temperature was 18 to 19 ºC. After moistening the temperature decreased to 17 ºC; it proves the better heat conductivity of the wet soil and, at the same time, it is guiding principle for the installation.

At the top part of the collectors, the temperature was higher by 2.0 to 2.5 ºC but this difference decreased to 1.5 to 2.0 ºC in the warmer periods. Accordingly, it will be reasonable to decrease the height of collectors ('probes').

During the period before the start of operation, the temperature of the collectors decreased; the soil conducted the heat away from the ambience of the collector pipes. Then, after switching the system on, the temperature gradually increased – the difference grew to 0.2 to 0.4 ºC in 2 to 3 hours – and the increase continued up to the end of running of the system. There were considerable differences between these trends according to the actual times of day – the change in the heat load or the temperature in the interior space.

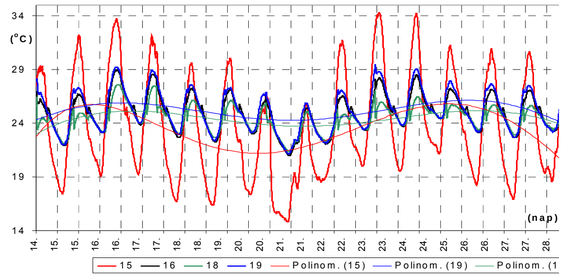

Figure 7. Values and trends gained from the measurements; comparison between the ambient and the interior temperatures

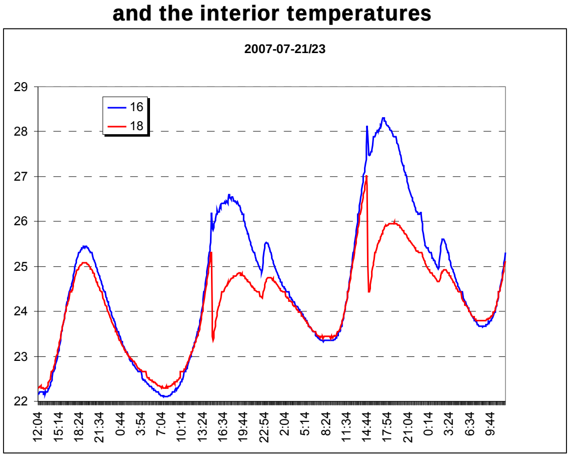

Figure 8. Temperature pattern of the inlet and outlet sides of the water-air heat exchanger

The rotary speed of the fan adapted to the system was changed in 10 steps; however, only the upper 30 % of the available control range of air delivery was utilizable.

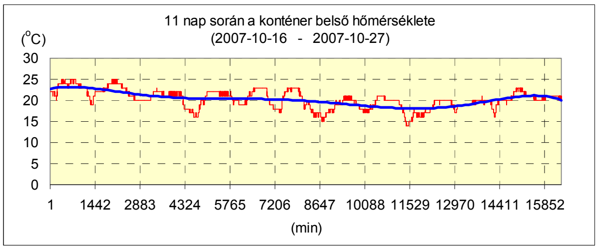

Figure 9. Course of the interior temperature in the container

It can be established from the test series that the surface area of the collector and the characters of the interior heat exchangers were technically in a good accordance with each other. It is expected that the air-delivery performance of the fan of the air-water heat exchanger should be increased by one size-class by which an air delivery 180 to 200 m^3/h can be achieved in comparison with the present value between 80 and 120 m^3/h.

The delivery capacity of the pump can be changed in 3 stages; the short tests showed that the pump should be operated with the top speed (stage 3) when the pump delivery was 4 m^3/h and the turbulence of the fluid flow was approximately four times greater than the required minimum value.

In cold nights (the exterior temperature decreased below 10 ºC), it was managed to test the system in similar conditions to that in the cold season; in this case, the collector cooled the soil therefore the temperature of the soil layer was lower next day – it improved the efficiency.

Economy

With conventional air conditioners in containers, the installed power is usually 6 kW of which annual capacity factor is between 0.3 and 0.4. Here the annual energy consumption is 15,768 kWh; with 35 HUF/kWh energy price, the energy cost adds up to 551,000 HUF/year. The electric power of the novel air-conditioning device is 0.2 kW. With a 50-% capacity factor, the annual energy consumption is 876 kWh – equivalent to 35,600 HUF/year energy cost. The winter emergency heating requires an additional energy amount of 800 kWh with the cost of 28,000 HUF/year. Altogether, the cost of the new system is 58,000 HUF.

The initial cost of the conventional air conditioner (with a suitable, stable, reliable construction), together with the installation, is 3,000,000 HUF. Calculating with a 15-year life, its annual depreciation cost is 200,000 HUF. Including the energy cost, the total cost of use is 751,000 HUF.

The initial cost of the new system, including the cost of installation of the soil collector, is 4,500,000 HUF. In the case of a 25-year life, the annual depreciation is 150,000 HUF and, adding the annual operating cost to it, the total annual cost is 238,600 HUF. In conclusion, the difference of the initial costs is 1,500,000 HUF; dividing it by the annual saved cost, the return rate of the new system is 2.9 or 3.0 year.

DISCUSSION AND SUGGESTIONS

(1) It is reasonable to position the bottom points of the collectors to the depth 2.5 to 3.0 m and, instead of the collector height of 1.1 m, 0.5 to 0.6 m should be chosen; the length of the collector should be increased in the ratio to the reduction. It is advisable to fit collectors on both sidewalls of the dug trench in the soil accordingly two branches with opposite flow directions are placed in one trench which are connected in series to the collectors in the adjacent trench at a distance of at least 2 m. The pipes leading to the building (container) should be embedded in the bottom depth range of the collector; the heat loss or the absorption of heat can be reduced in this way.

The design of the interior heat exchanger and the control unit has to be modified (Figure 10) – such as changing the heights of the inlet and outlet points or placing a baffle before the outlet opening by which the air can be enforced to circulate inside the room; thereby the efficiency of heat transfer increases.

(2) The use of the system is absolutely economical; it saves a certain amount of electric energy and, at the same time, frees a capacity as well; due to the reduction, the actual container and the relay station can be equipped with further instruments – the function can be improved without increasing the contingent capacity supplied by the mains (and its considerable cost also can be saved).

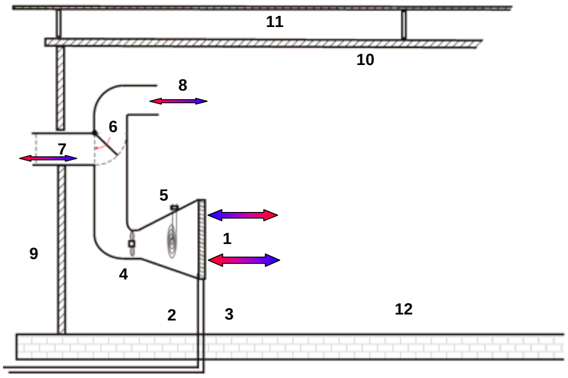

Figure 10. The suggested constructional design
1 – air-water heat exchanger, 2 – inlet from the soil collector, 3 – outlet towards the soil collector, 4 – reversible fan of variable rotary speed, 5 – auxiliary heater, 6 – changeover air flap; 7 – inlet / outlet opening of external air, 8 – inlet / outlet opening of internal air, 9 – insulated side wall of the container, 10 – insulated ceiling of the container, 11 – shade from the sun

(3) Due to the lower energy consumption, the device is ecologically beneficial since an emission of CO_2 of 7500 kg/year can be avoided by its application.

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