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Heat pumps and under floor heating as a heating system for Finnish low-rise residential buildings

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DESCRIPTION

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Heat pumps and under floor heating as a heating system for Finnish low-rise residential buildings

Abstract

In bachelor's thesis the study of under floor heating system with ground source heat pump for the heat transfers fluid heating is considered. The case study is low-rise residential building in Finland with under floor heating as a single heating system. The calculations of main parameters of under floor heating system and length of ground heat exchanger are conducted. As a result the conclusion about reasonable of using the studying system for low-rise residential building in Finnish climate and geological situation.

Subject headings, (keywords)
Ground source heat pump, under-floor heating, vertical ground heat exchanger, low-rise residential building

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CONTENTS

1. Introduction

Recently many people have tried to solve a problem of an economical use of energy. Engineers and scientists study modern ways to the most cost-effective and productive using of existing sources of energy, and also the possibility of using the maximum from natural renewable resources of energy. One of these ways is using heat pump for heating systems and hot water systems.

Now heat pumps are successfully used in many countries in the world. One of these countries is Finland. However, heat pumps are used generally in one family houses in Finland. It is known, the higher temperature of the low-temperature heat source (such as lake water, ground or air), the more heat pump can transfer heat to a heating system. But Finland is a Northern country, which means the temperature parameters of low grade heat source are not high. A solution is modern construction materials, which are used in buildings and which help to reduce greatly heat losses of buildings. Accordingly in this situation requirement of heat power for heating is reduced, and heat pump system can be used.

Generally, use of heat pumps in heating system is reasonable when temperature parameters of heat transfer fluid are low. Temperature of water in under floor heating system is 50 – 35 degrees. This temperature interval is satisfying of required for heat pump efficiency. In this situation combine an under floor heating with a heat pump is the most simple solution.

But what difficulties are there in heating system with heat pump applications and can we use this system for Finnish low-rise residential buildings? This bachelor’s thesis must answers on these questions.

The main aspects of topic are:

– The bigger building for heating, the more size of heating equipment in technical room. It is important to take into account for convenient situation inside the building;

– The cost of preparation and installation work is high;

– Speed and completeness renewal of potential of low-temperature environment (ground temperature) during summer time are not certain.

In this bachelor's thesis heating system with Ground Source Heat Pump (GSHP) and under floor heating system will be calculated for Finnish residential building. But we must remember each project is individual and it needs separate consideration. Many factors can influence the system. These factors can be both positive and negative.

Finally, the conclusion of bachelor thesis must be: "Is it real possible to use a heat pump and under-floor heating system for heating of Finnish low-rise residential buildings?"

Before the answer to the main question of bachelor's thesis will be got, the principle of heat pump work must be considered, the select of a heat pump for Finnish climate and geological situation of must be done.

Work objective is verification of feasibility and viability for heating system with heat pump in Finnish low-rise buildings.

2. Heat pump systems

2.1. Operating principle of heat pumps

Firstly, the questions “What is a Heat Pump?” and “How does it work?” must be answered.

We can find quite a few definitions of the Heat Pump in literature, but importance of these is same – it is cooling machine where low-temperature environment’s heat is delivered to high-temperature heat transfer fluid by means of using of energy on converting of machine’s working medium.

The heat pump is a refrigerator but conversely. It contains an evaporator, volumetric compressor, condenser and expansion valve. Refrigerant which is used in system as working substance can start boiling by subzero temperature. The schematic diagram of a heat pump is shown in Figure 1:

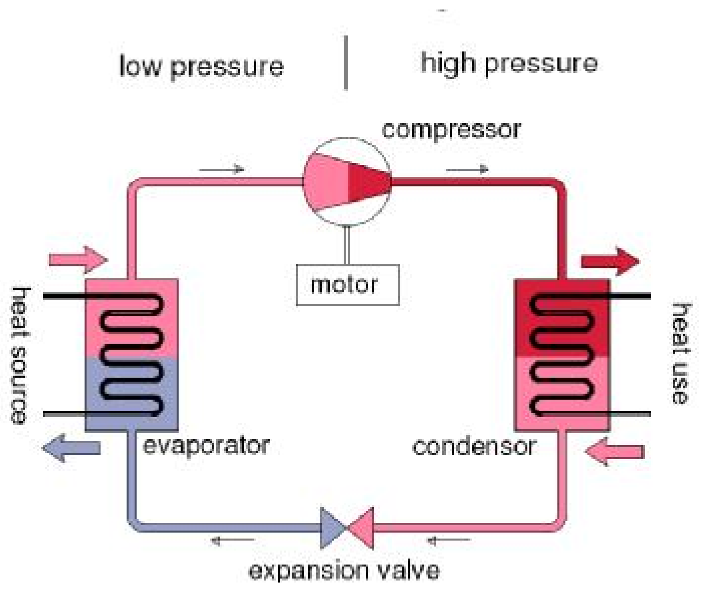


Figure 1 Schematic diagram of a compression heat pump /6, p. 6/

It should be noted that advantage of heat pump in comparison with other source of heat is the heat pump transfers the energy, but does not produce it. The heat pump changes energy from low-temperature to high-temperature and vice versa.

Sequence of process:

1) The Refrigerant resides in vapor state with low pressure and temperature on exit from the evaporator;

2) The Refrigerant in vapor state enters compressor. The Refrigerant pressure is raised to 1,52-2,53 MPa., the temperature is raised to 70-100 degrees inside the compressor;

3) After that this hot Refrigerant in vapor state is cooled and condensed inside the condenser. As result, the Refrigerant passes into liquid state. During this condensing process the heat from the hot Refrigerant is released to water or air, which are used for heating purposes;

4) The Refrigerant turns into liquid state with high pressure on exit from the condenser. In this state the liquid get into a flow control device which decompresses it quickly. During this part of the liquid is evaporating and passing into vapor state. Obtained vapor-liquid mixture enters evaporator. The Refrigerant gets heat from surrounding environment; during this the liquid is boiling inside the evaporator and turning into vapor state fully. Obtained superheated vapor exits from the evaporator;

5) The cycle will repeat.

In summary, the Refrigerant circulates over one cycle constantly and changes its phase state from liquid state to vapor state and vice versa.

The heat pump can work as heating or cooling machine, it change the direction of the Refrigerant transfer thought the evaporator and the condenser. The first case may be used in winter time for heating system, and the second case may be used in summer time for cooling system. The circulation system, which is working whole the year and generating both heat and cool in winter or summer seasons accordingly.

In this bachelor’s thesis the first case – the heat pump as heating machine for heating systems will be considered. For better productivity of system the temperature of low-temperature source (in our case it is ground temperature) must be as high as possible and the difference between this temperature and the temperature of transfer fluid inside the heating system should be minimum /2, p. 13/.

2.2. Classification of heat pumps

The heat pump gets heat from low-temperature source, such as air, water, ground or sewage. The type of the heat pump depends on type of low-temperature source and type of source for heating system. A heat transfer in heat pump system can be: from air to air, from air to water, from water to air, from water to water, from ground to air, from ground to water.

In terms of heat exchanger direction, systems subdivide on:

– System with horizontal network. Horizontal collectors require large areas free of rock or large boulders and a minimum soil depth of 1,5m. Multiple pipes can be laid in a single trench also. “The amount of trench required can also be reduced if the pipe is laid as a series of overlapping coils, placed vertically in a narrow trench or horizontally at the bottom of a wider trench” /4, p. 6/. Disadvantage of these systems is inapplicability for areas with pipes for building or other purposes. Vertical system is sown in Figure 2.

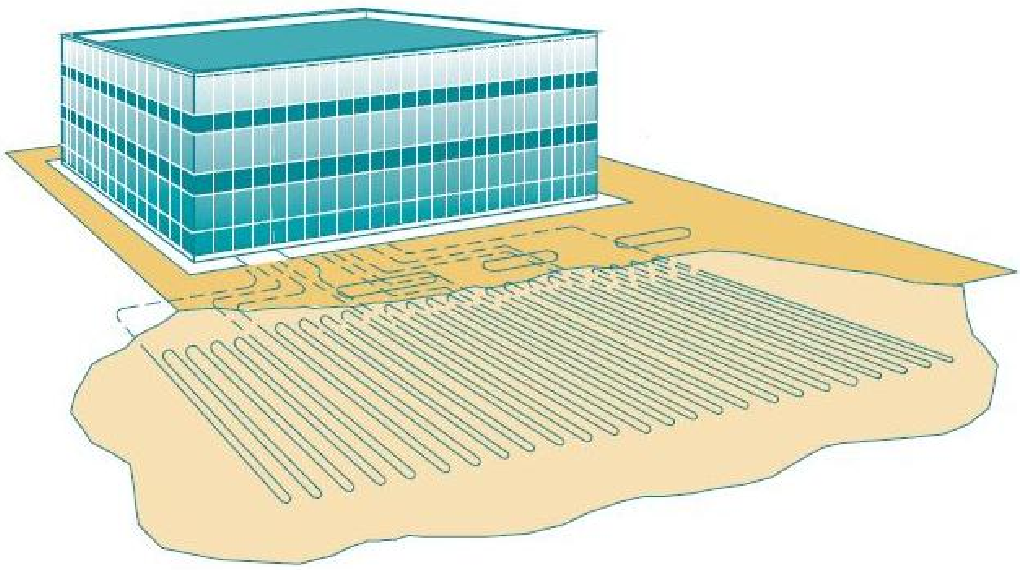


Figure 2 Horizontal Ground Heat Exchanger /5, p. 14/

– Systems with vertical boreholes. A Refrigerant is pumped through a series of vertical boreholes, “where heat is collected with a corresponding fluid temperature increase” /2, p. 13/. Vertical collectors often are used on places where land area is limited. They are inserted, for example, as U-tubes into boreholes generally 100 mm to 150 mm diameter and between 50 m and 150 m deep. Vertical systems are more expensive than horizontal systems but have high thermal efficiency and require less pipe and pumping energy. This system is causing low damage after installation than horizontal system /4, p. 6/. The system with vertical borehole heat exchangers is shown in Figure 3.

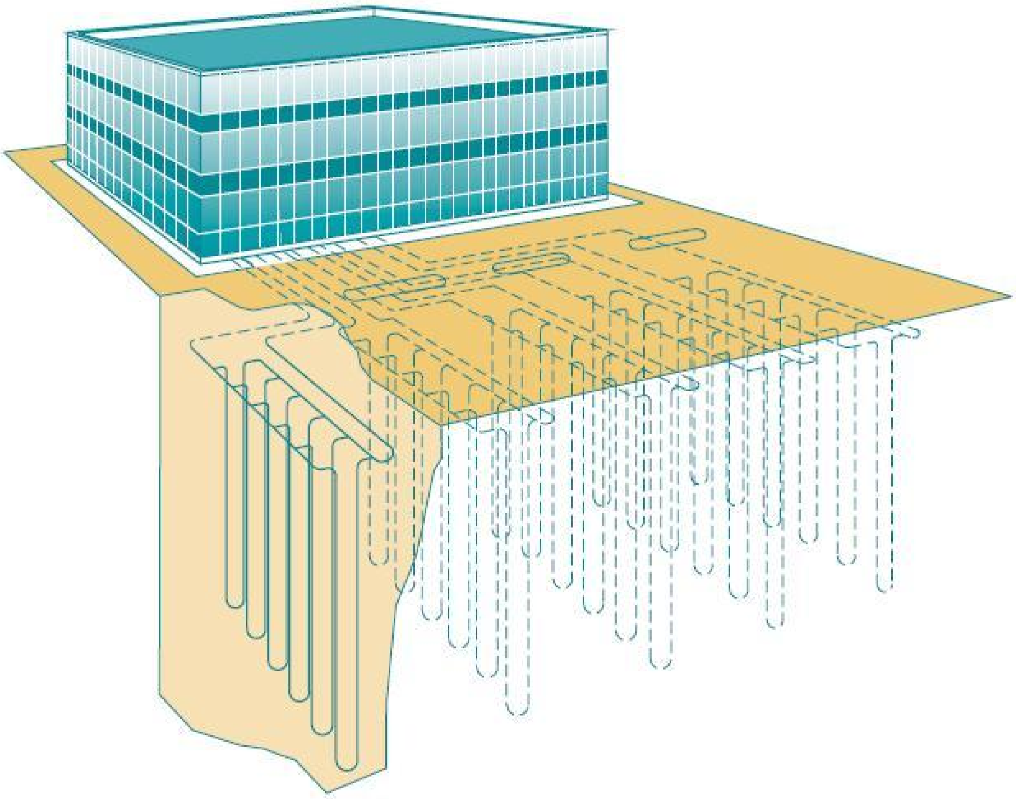


Figure 3 Vertical Ground Heat Exchanger /5, p. 13/

The choice between horizontal or vertical system depends on the area of ground available, ground parameters on this area, and excavation and drilling costs. Systems with vertical collectors are more expensive than horizontal systems, but they have high thermal efficiency and require less pipe and as result less pumping energy /4, p. 6/.

Pipe loops can also be laid under water (lake or pond), but efficiency of this system are lower than that of the systems with ground heat exchanger because of seasonal vary of the water temperature /4, p. 6/.

Different types of borehole heat exchangers for vertical systems are shown in Figure 4.

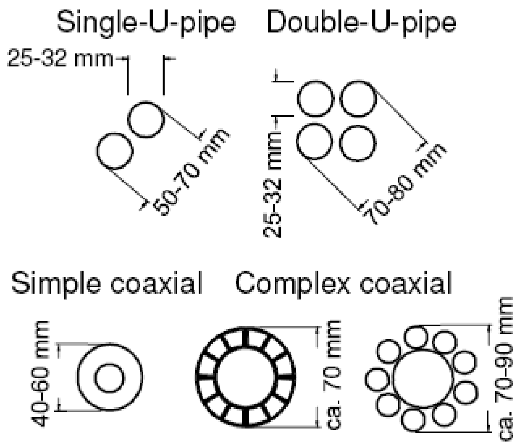


Figure 4 Different types of borehole heat exchangers /6, p. 10/

It is important that “careful consideration should be given to the pipe layout in order to keep the dynamic hydraulic pressure drop across the ground heat exchanger as small as possible to minimize the pumping power needed” /4, p. 7/.

Ground system description:

– Open-loop systems. Open-loop system uses a groundwater source. After the utilization this groundwater is returned back in the ground area. It is recognized that this technology is very cost efficient; as a result open-loop GSHP systems were the most widely until recently. The disadvantages are that water availability is limited, fouling and corrosion may be a problem depending on water quality and most importantly environmental regulations covering the use of groundwater are becoming increasingly restrictive. /4, p. 3/. The principle of open-loop system is shown in Figure 5:

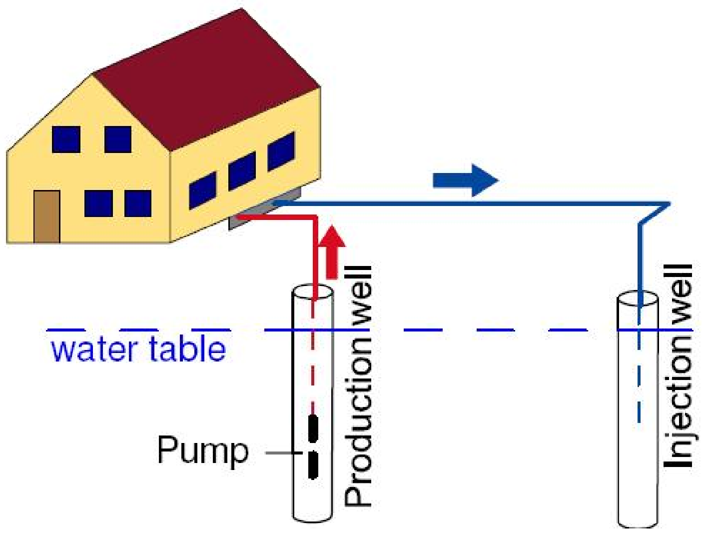


Figure 5 Open-loop systems /6, p. 8/

– Closed-loop systems (Ground Coupled systems). These are systems where the ground heat exchanger consists of a sealed loop of pipe buried either horizontally or vertically in the ground /4, p. 6/. Systems with closed-loop system are shown in Figure 6 and Figure 7.

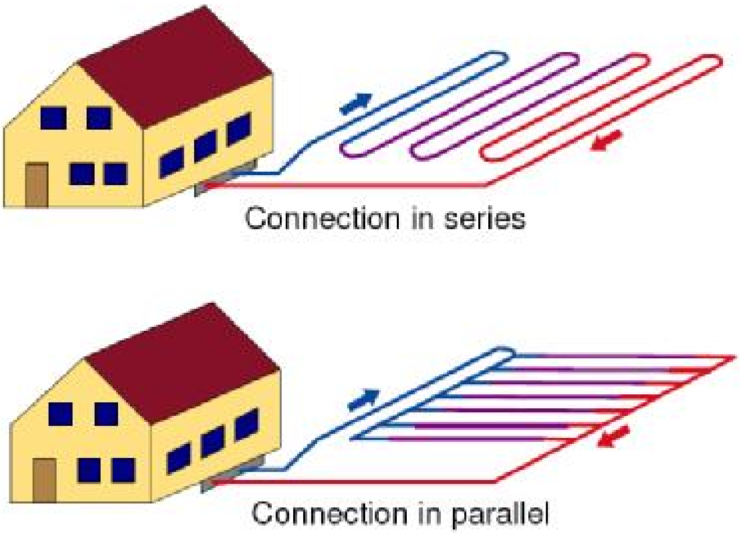


Figure 6 Horizontal closed-loop systems /6, p. 9/

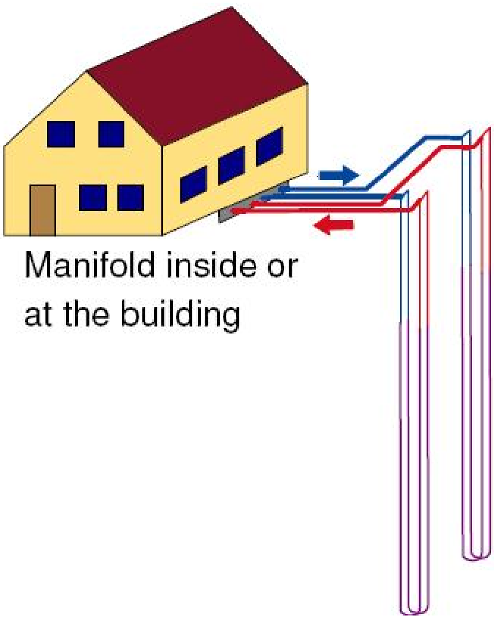


Figure 7 Vertical closed-loop systems /6, p. 9/

In the article "Domestic Ground Source Heat Pumps: Design and installation of closed-loop systems" /4, p. 12/ the following names have been adopted by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) to distinguish among the various types of earth connection systems:

– Ground-Coupled Heat Pumps (GCHPs) - use the ground as a heat source and sink, either with vertical or horizontal Ground Heat exchangers (GHXs);

– Groundwater Heat Pumps (GWHPs) - use underground (aquifer) water as a heat source and sink;

– Surface Water Heat Pumps (SWHPs) - use surface water bodies (lakes, ponds, etc.) as a heat source and sink;

– Ground Frost Heat Pump (GFHPs) - maintain sound structural fill in natural permafrost around foundations by extracting heat from the fill /4, p. 12/.

The Refrigerant circulates directly through the ground heat exchanger in a direct expansion system. But most commonly systems are indirect systems, where the liquid circulates through the ground loop and energy is transferred to or from the heat pump. In the indirect system the Refrigerant circuit via a ground heat exchanger /4, p. 3/.

As example about efficiency of direct and indirect ground source heat pump systems: For heat pump systems with ground heat exchanger, which used to supply low temperature water based heating systems (in our case it is under floor heating), seasonal efficiencies is between 300% and 400% for indirect systems and can be higher (from 350% to 500%) for direct systems /4, p. 4/.

2.3. Coefficient of performance

The efficiency of heat pumps is characterized with the transformation coefficient (the coefficient of performance COP). ”Transformation coefficient of heat pump is rate of useful heat to expending work in compressor’s gear. The most commonly encountered of transformation coefficient equals 3 and more” /8, p. 1/. It means that utilization of 1 kW of energy heat pump system can modify in 3 kW of heat energy.

The coefficient of performance (COP) and, as result, capacity of heat pumps depends on the fluid flow rate through heat exchanger, the temperature on the source and the heat load /2, p. 13/.

COP is dependent on the efficiency of heat exchangers, losses in compressor, and on the temperature difference between the low-temperature (for example, ground) side and the high-temperature (building) side /6, p. 6/.

2.4. The type of heat pumps for study in thesis

In this bachelor's thesis the Ground Source Heat Pump (GSHP) system with vertical closed-loop heat exchanger will be considered as case study.

This kind of system was chosen because three main aspects:

1) The land which belongs to each building has certain determination. It means that area of land which can be used for technical needs is in limited quantity. In case with using system with vertical heat exchanger the less square of land is needed than in case with horizontal system;

2) The rock with high thermal capacity is widespread on the territory of Finland. This kind of ground has good characteristics for heat pump work;

3) The using of electricity power in heat pump system is reducing CO_2 pollutions of atmosphere air /7, p. 2/. This assertion is more just for countries where electricity is got from power of the wind or water, for example. In this case oil or gas is not used. But for Finland, where electricity is result of oil and gas burning (in some cases), and because CO_2 pollutions not secretion in case with wood boilers the assertion about CO_2 pollutions must be corrected. The using of electricity power in heat pump system is reducing CO_2 pollutions of atmosphere air near residential buildings. CO_2 pollutions are reduced also because the electrical power for the heat pump system is lower than power of oil or gas boiler proportional to the COP. It is recognized that heating systems with GSHP systems have a lower environmental impact compared to traditional heating systems with radiators as heat emitters /1, p. 35/.

The GSHP system main components (the Figure 8):

- → Heat pump;
- → Earth connection (ground heat exchanger);
- → Heating distribution system.

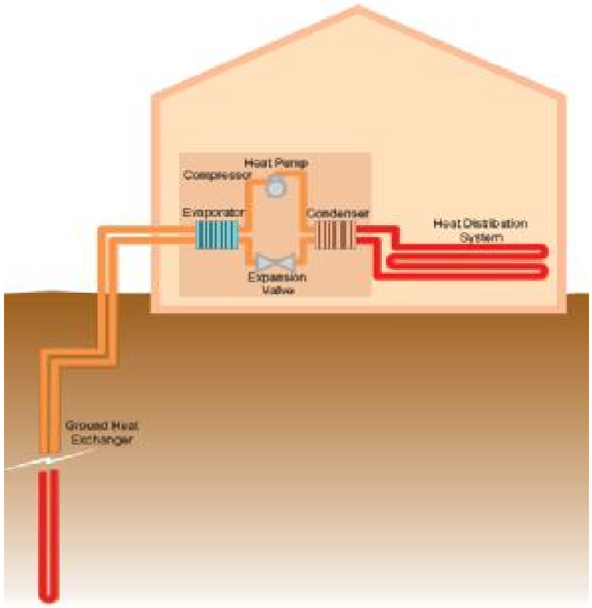


Figure 8 Three GSHP system major components /4, p. 1/

3. The main parameters for Ground Source Heat Pump effectiveness

When systems with Ground Source Heat Pump are considered it must be taken into account that the quality of heat pumps work and its productiveness and efficiency depends on many parameters. The primary and the main parameter which involve in principle of GSHP work is an energy potential of the soil.

The next parameters have influence on the energy potential of the soil: the geology of region; types of soils which are involved in the heat exchange process; the groundwater depth; the ground moisture/12/.

The ground moisture influences heat exchange of soil, because the water have large coefficient of heat conductivity. However, there is opinion in /4/ that the influence of groundwater on ground heat exchange in most cases is not very big, and the thermal conductivity of the ground is the main parameter for calculations. But a thermal conductivity of wet ground is bigger than a thermal conductivity of dry ground. In practice it means that soil with low thermal conductivity may require as much as 50% more collector loops than ground with high thermal conductivity /4, p. 7/.

The kind of soil has large importance too. Firstly, the each kind of soil has different importance of the heat capacity and the thermal resistance; secondly, the different technologies of drilling operations, their cost and used in process materials depend on types of soils or rock. “The most important difference between soil and rock is that rock has significantly higher values for thermal conductivity” /4, p. 7/.

It is important that before designing process the parameters of ground area such as: depth of soil cover, type of soil or rock, ground temperature is determined. A right evaluation of ground heat transfer cannot be calculated without importance of ground temperature and thermal conductivity.

When the ground on the area of drilling is soft soils or waterlogged sedimentary rocks it means that after drilling process the space between the vertical borehole wall and installed heat exchanger (plastic pipes) are filled with special grout (pumpable material) which has high conductivity. This grout is used for: structural reliability; facility of heat transfer from the working fluid or Refrigerant to the ground; protection of groundwater pollutions /2, p. 13/.

In the guide book "An action for the promotion and the dissemination of successful technologies in the ground source heat pump (GSHP) field" /6/ the following information about grout is presented: The borehole grouting and the walls of heat exchanger which can be summarized as borehole thermal resistance. Value for this parameter usually is on the order of 0,1 K/(W/m); for example, for 40 W/m heat extraction, this means a temperature loss of 4 K inside the borehole. “Thermally enhanced grouting materials have been developed to reduce these losses” /6, p. 10/.

On the areas where rock is main ground structure, for example in Scandinavia counties, vertical boreholes are kept open, and groundwater circulates between the pipes and the rock for good heat exchange /6, p. 9/.

The main parameter of effectiveness of ground low-temperature heat is the ground temperature and its change during the year.

It is recognized that the average temperature of ground on the certain depth is constant during the year and it equals 8-10 degrees. “The ground transports heat slowly and has a high heat capacity, its temperature changes slowly – on order of months or even years, depending on the depth of the measurements” /5, p. 6/. However, the temperature distribution in the ground depends on next factors: the ground structure; the existence of plant cover; the rainfall during the year; amount of solar radiation (46% of sun’s energy is absorbed by the earth); the thickness of snow cover /12/.

The effective borehole thermal resistance depends on: borehole diameter; pipe diameter; separating distance between pipes; grout thermal conductivity; ground thermal diffusivity; pipe thermal conductivity; fluid flow rate /2, p. 18/.

4. Application of heat pumps in heating systems

The diagram of heating with heat pumps is shown on the Figure 9 /12/. The heat-transfer liquid for heating system is delivered by main-line pump CH in condensers K1 and K2 for warming. The condensers are working in two-level circuit and they are connected serial to the heating water (heat-transfer liquid). The water is warmed from the temperature t_2 to some intermediate temperature t_{np} inside the primary stage condenser K1. After that the water is directed in the second stage condenser K2 where it is warmed from the intermediate temperature t_{np} to the temperature t_1. The water with the temperature t_1 enters the heating system and transfers the heat to rooms (spaces). The water with the temperature t_2 returns through the main-line pump CH in the condenser K1.

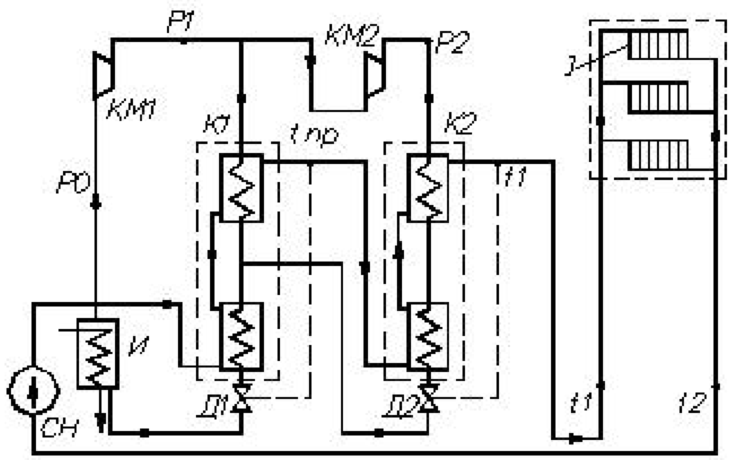


Figure 9 Principle diagram for heating system with heat pump /12/

The heat from ground source is transferred to the boiling Refrigerant inside the evaporator И. The Refrigerant vapor with the pressure P0 is directed from the evaporator И to the primary stage compressor KM1 where it is compressed to the pressure Pk_1. The Refrigerant is divided on two flows after the compressor KM1. First flow enters the condenser K1. Second flow enters compressor KM2 and is compressed to the pressure Pk_2. The Refrigerant vapor from the compressor KM2 enters the condenser K2 where the heat-transfer liquid is warmed from the intermediate temperature t_{np} to the temperature t_1. The Refrigerant in the liquid phase enters from condenser K2 to condenser K1 through the expansion valve Д2. The whole liquid

Refrigerant enters from the condenser K1 to the evaporator И through the expansion valve Д2.

The maximum temperature of the heat-transfer liquid for heating system which can be got with GSHP systems is 45-50 degrees. The heat-transfer liquid with such temperature interval can be used in two types of heating systems:

- The low-temperature radiator heating;
- The under floor heating.

In some cases it is good possibility to use the compatible system with under floor heating and low-temperature radiators.

But in this bachelor’s thesis under floor heating as sole heating system for low-rise multifamily building will be considered.

5. Using under floor heating in residential buildings

Under floor heating is a heating system where the floor surface is used as a heat emitter. The floor surface gets and transfers the heat from pipe system which is located inside floor construction. The process of heat transfer in under floor heating systems is combination of heat radiation and slow convective current.

In this Chapter the whole information about under floor heating from the guide book "Fundamentals of under floor heating" /9/. It is recognized that the most comfortable conditions for people are the floor surface temperature is 22-25 degrees and the air temperature on the head height is 19-20 degrees. According to the ISO 7730 the most comfortable floor surface temperature for people is 19-26 degrees. The difference between temperatures other parts of floor surface must be less than 5 degrees.

It must be taken into account the various floor surface materials have the different maximum temperature of floor surface for comfortable feeling of people (for example, the maximum floor temperature for parquet is 27 degrees) /9, p. 11/.

There are three main variable parameters in designing of the under floor heating: the heat losses of a room or a building; the temperature of water in system; the spacing of pipes.

The kind of material and the thickness of floor surface have influence on the intensity of radiation heat and the heat transfer. The floor construction also influences the response time. For buildings with the monolithic concrete floor the response time slow down because the concrete stores the heat during the heating period. For buildings with timber floor the response time is shorter because the wood has low heat capacity. The insulation and U-value of building also have influence on the quality of functioning of under floor heating system, because the less heat losses of building, the better quality of heat distribution inside building. It is important to have good insulation of floor construction because the heat losses down the floor must be as low as possible.

Often special metal paper material is used as upper insulating membrane for increasing of the heat transfer and the response time, decreasing the preheating time.

The water temperature in under floor heating system depends on the room temperature. The temperature difference between flow and return water is 5 degrees.

Principles of the water temperature regulation /9, p. 11-12/:

- The temperature of flow water is constant with the constant water flow rate;
- The temperature of return water is constant with the constant water flow rate;
- The change of the flow water temperature with the constant water flow rate depends on the inside room temperature;
- The change of the flow water temperature with the constant water flow rate depends on the outside temperature;
- The alternating flow rate with the constant flow water temperature;
- The temperature of floor surface is constant.

The main aspects in designing process:

- The type of under floor loop;
- The diameter of pipe;
- The spacing of pipe;
- The burial depth;
- The water flow rate.

The main types of under floor loops:

- The single pipe serpent;
- The flow and return pipes are parallel;
- The spiral of parallel flow and return pipes.

6. A case study

6.1. Heat losses of building

As case study the three-floored residential building is considered. The dimensions of building are 25m x 15m x 9m. For approximate estimate of building heat losses the specific heat load q can be used. The meaning of Φ for residential buildings in Finland is 15-20 W/m^3. In bachelor's thesis the specific heat load equals 20 W/m^3.

- The area of the building A is 360 m^2;
- The volume of the building V is 3240 m^3;
- The heat losses are H = 3240 m^3·20 W/m^3 = 64,8 kW.

With the meaning of the heat losses the main necessary parameters for under floor heating calculations and length of ground heat exchanger calculation can be done. The flow of the Refrigerant also can be calculated.

6.2. Determining of main parameters of under floor heating

The whole calculations of the under floor heating are executed in accordance with the guidebook "Fundamentals of under floor heating" /9/.

During the calculation process for under floor heating it is important to take into account that a quality of system work depends mainly on the specific heat load per 1 m^2 of floor area and the floor construction also.

For calculation of the under floor heating the specific heat load q_{floor} must be known:

$$q_{floor} = \frac{H}{A \cdot n} = \frac{64800}{360 \cdot 3} = 60\ (W/m^2), \tag{1}$$

where H is the heat losses of the building, W;

A is the area of a floor, m^2;

n is numbers of floors.

The situation when q_{floor} is 60 W/ m^2 is a good situation for using of under floor system. It means the under floor heating system as sole heating system will compensate all heat losses of the building.

Baseline datas for calculation:

– The room temperature t_{room} is 21 degrees;

– The specific heat load q_{floor} is 60 W/m^2;

– The temperature difference between flow and return water Δt is 5 K;

– The spacing of pipe is 300mm (the most commonly used meaning in Scandinavian countries);

– The material of floor covering is parquet.

The computing chain is:

1. Average temperature of the floor surface

$$\Delta T = t_{floor} - t_{room} = \frac{q_{floor}}{a} = \frac{60}{11} = 5{,}5\ ({}^{0}C)\,, \qquad (2)$$

where t_{floor} is the temperature of the floor surface, degrees;

t_{room} is the room temperature, degrees;

q_{floor} is the specific heat load is 60 W/m^2;

α is the coefficient of the floor heat transfer, α = 10-12 W/(m^2·˚C).

So, the temperature of the floor surface is:

$$t_{floor} = t_{room} + \Delta T = 21 + 5{,}5 = 26{,}5\ ({}^{0}C)\,. \qquad (3)$$

The comfortable temperature of the floor surface must be less than 27-29 degrees. It means that the specific heat load q_{floor} in the case with the parquet must be less than 66 W/m^2. For another material it can be less than 88 W/m^2.

2. Thermal transmittance of floor covering material

For the timber parquet the normative thermal conductivity λ is 0,12 W/(m·˚C) /10/. The thickness d of the parquet for calculations is 10 mm.

The thermal transmittance U is:

$$U = \frac{1}{R} = \frac{l}{d} = \frac{0{,}12}{0{,}01} = 12\ (W/(m^2\cdot{}^{0}\mathrm{C})), \qquad (4)$$

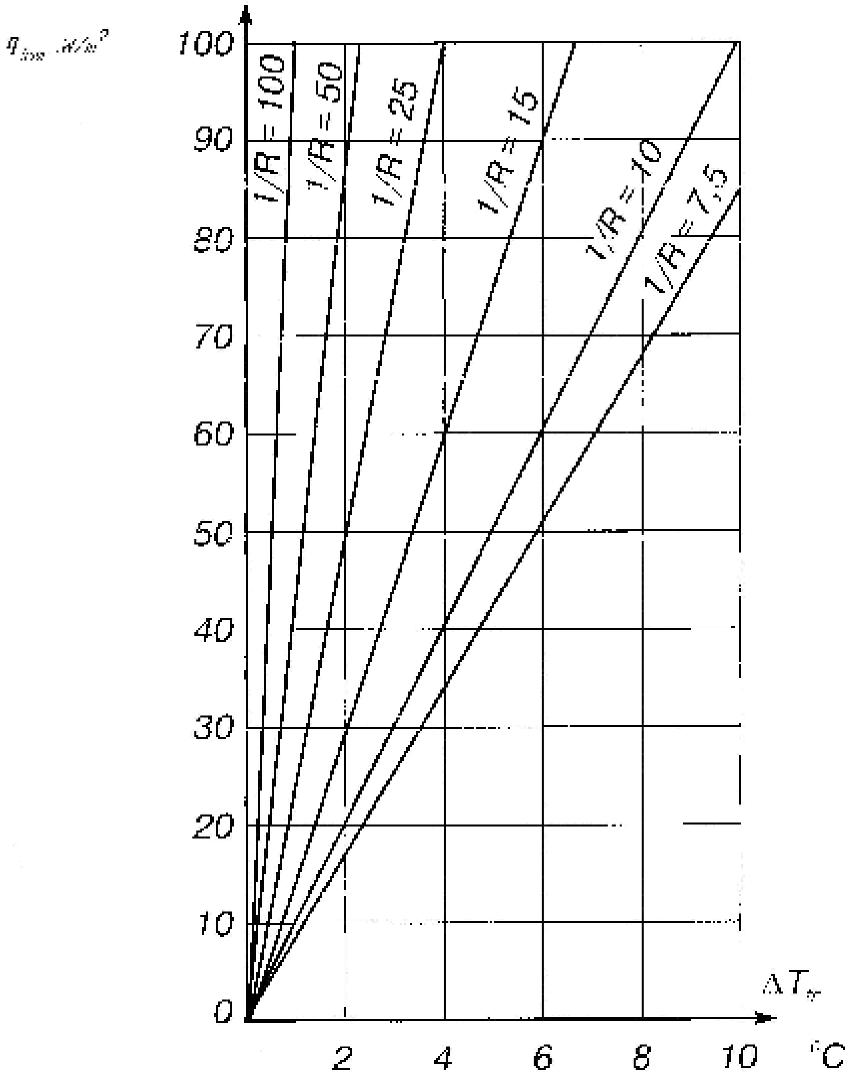
where R is the thermal resistance of the material, ˚C·m^2/W;

λ is the normative thermal conductivity, W/(m·˚C);

d is the thickness of the parquet, m.

3. Temperature drop through the floor covering

The meaning of the temperature drop through the floor covering is determining from the Graph 1:



Graph 1 Temperature drop through the floor covering /9, the graph 4.5.1/

$\Delta T_{fc} = 5{,}5\ (^0\mathrm{C})$.

4. Temperature drop through the floor construction

Calculations for two cases of the floor construction are done. The first case is a concrete floor (the Figure 10). The second case is a planked timber floor (the Figure 11). The temperature drops through the different floor constructions are determined with the Graph 2.

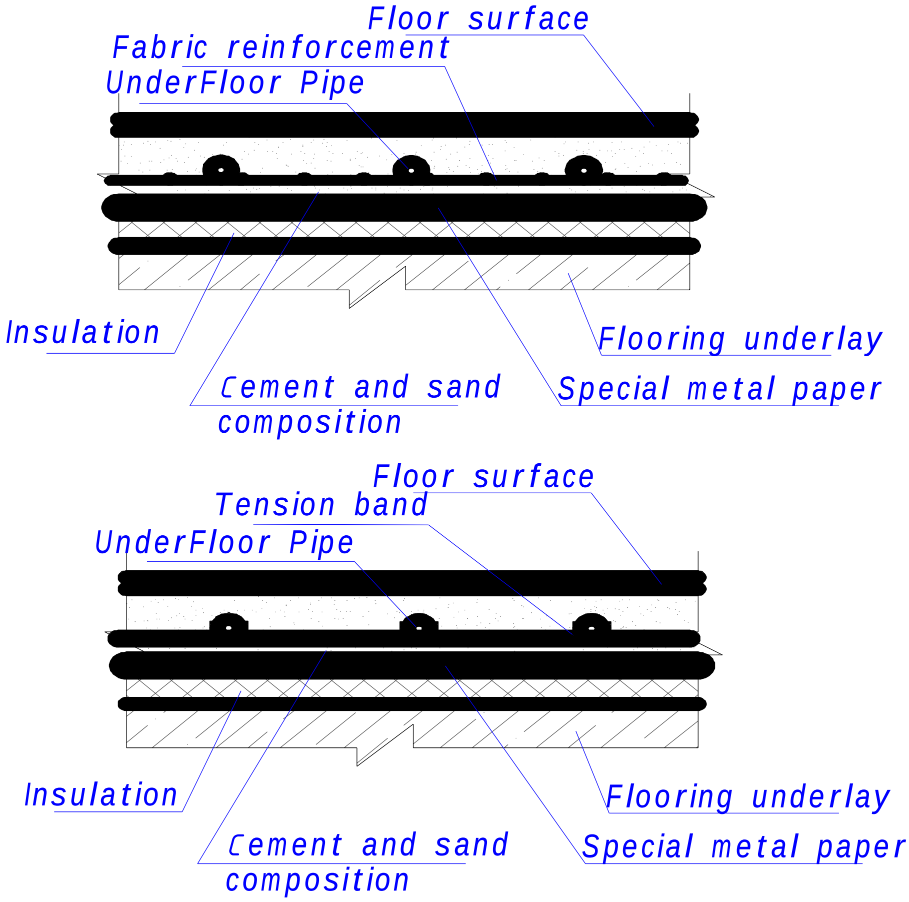


Figure 10 The floor construction with the concrete layout /9, p. 7, 8/

a. with the fabric reinforcement;

b. with the tension band.

For the case with the concrete floor the thickness of concrete above the pipes must be 40-70mm.

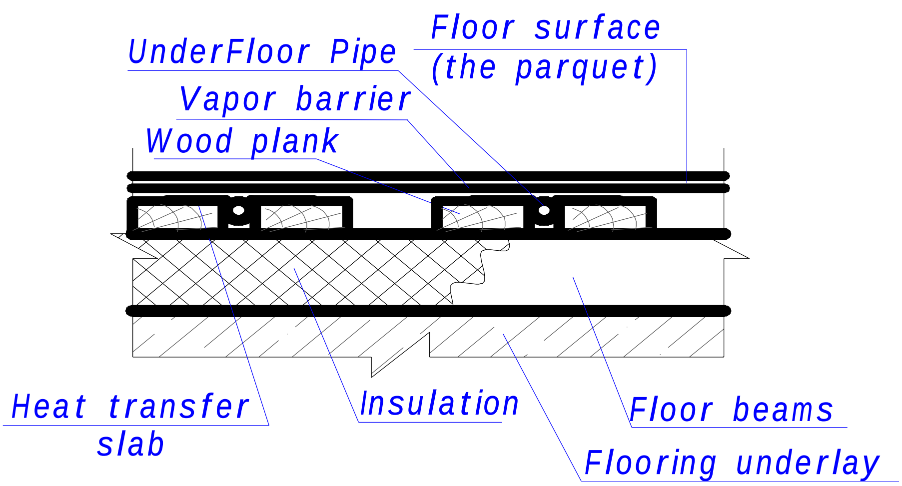
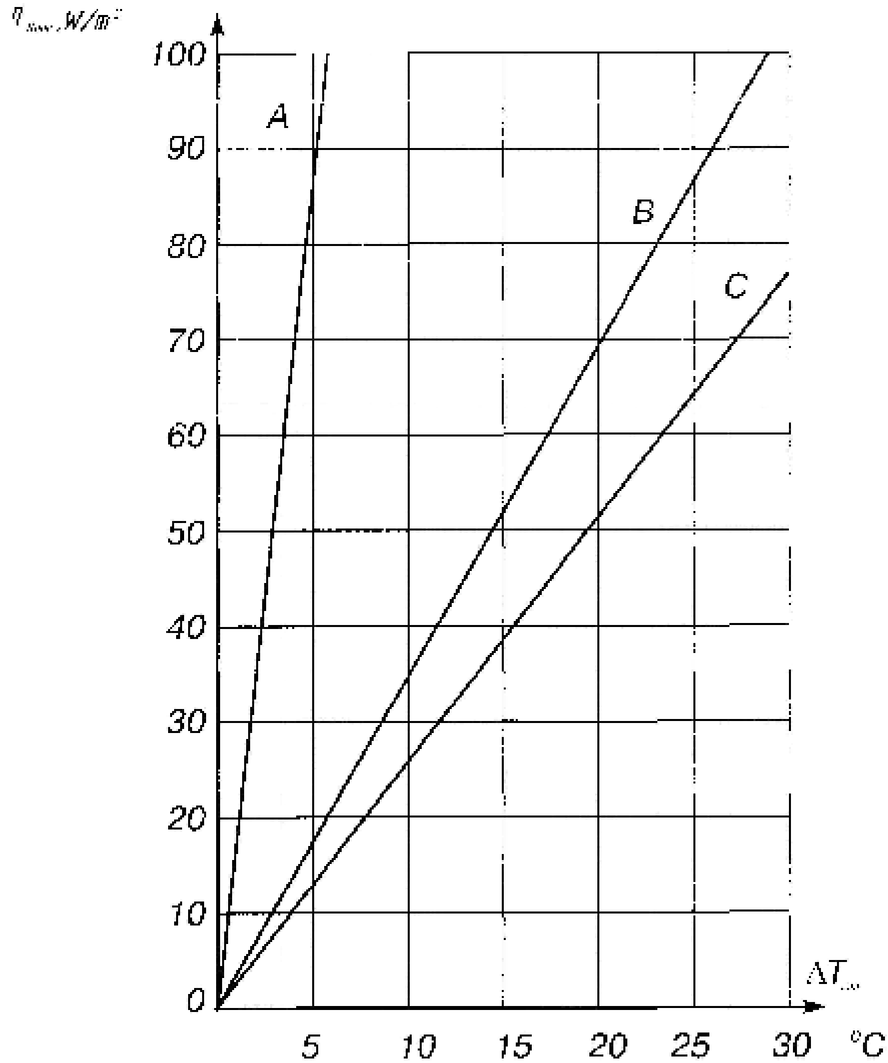


Figure 11 The floor construction with the planked timber floor /9, p. 8/



Graph 2 The temperature drop through the floor constructions

/9, the graph 4.6.1/

A - the floor construction with the concrete layout;

B - the floor construction with the laying floor;

C - the floor construction with the planked timber floor.

The importance of the temperature drops through the floor constructions:

– The concrete floor - $\Delta T_{con} = 3\ (^0\mathrm{C})$;

– The planked timber floor - $\Delta T_{con} = 17{,}5\ (^0\mathrm{C})$.

5. Calculation of flow and return water temperatures

The temperature of water in the pipes system depends on the room temperature which must be got for the certain specific heat load q_{floor}. The average water temperature for under floor heating is:

$$t_{aver} = t_{room} + \Delta T + \Delta T_{fc} + \Delta T_{con}, \tag{5}$$

where t_{room} is the room temperature, ˚C;

ΔT is the temperature difference between the room temperature and the surface temperature, ˚C;

ΔT_{fc} is the temperature drop through the floor covering, ˚C;

ΔT_{con} is the temperature drops through the floor constructions, ˚C.

The average water temperature is:

For the concrete floor: $t_{aver} = 21 + 5{,}5 + 5{,}5 + 3 = 35\ ({}^{0}C)$;

For the planked timber floor: $t_{aver} = 21 + 5{,}5 + 5{,}5 + 17{,}5 = 49{,}5\ ({}^{0}C)$.

The temperature difference between flow and return water is 5 ˚C. In this case the temperatures are:

For the concrete floor:

$t_{flow} = 35 + 2{,}5 = 37{,}5\ ({}^{0}C)$, $\quad t_{return} = 35 - 2{,}5 = 32{,}5\ ({}^{0}C)$;

For the planked timber floor:

$t_{flow} = 49{,}5 + 2{,}5 = 52\ ({}^{0}C)$, $\quad t_{return} = 49{,}5 - 2{,}5 = 47\ ({}^{0}C)$.

6. Requiring water volume flow

The volume flow q_v is determined as:

$$q_v = \frac{P}{r \cdot c \cdot \left(t_{flow} - t_{return}\right)} = \frac{64{,}8}{1 \cdot 4{,}187 \cdot 5} = 3{,}1\ (l/s), \tag{6}$$

where P is the heat losses of a building, kW;

ρ is the water density, 1 kg/cm^3;

c is the water capacity, 4,187 kJ/kg·˚C;

t_{flow} is the flow water temperature, ˚C;

t_{return} is the return water temperature, ˚C.

6.3. Determining of length of ground heat exchanger for the heat pump

6.3.1. The theory of calculation

Ground heat exchanger in heat pump systems usually is calculated for the worst conditions. “The ground heat exchanger needs to handle three next thermal pulses of various magnitude and duration: the yearly average ground load; the highest monthly ground load; the peak hourly load” /2, p. 13/.

The length of ground heat exchanger pipe required depends on heating load of building, parameters of soil temperature and thermal resistance, loop configuration, climate in building region and landscaping /4, p. 7/.

Two possibilities for calculation of the length of ground heat exchanger were found in the reading articles. In the first case the next formula for the total borehole length can be used /2, p. 14/:

$$L = \frac{q_y \cdot R_{20y} + q_m \cdot R_{1m} + q_h \cdot R_{6h}}{T_w - (T_g + T_p)}, \tag{7}$$

where q_y, q_m, q_h are the average ground load, the highest monthly ground load, the peak hourly load;

R_{20y}, R_{1m}, R_{6h} are the effective ground thermal resistances for 20 years, one month, and six hours, $m^2 \cdot {}^\circ C$ /W;

T_w is the borehole wall temperature, ˚C;

T_g is the ground temperature, ˚C;

T_p is the temperature penalty, ˚C.

However, the calculation with this formula is very difficult process, because the extensive dates are needed. The search of these parameters is not easy. In this situation it is better to use other formulas to calculation.

6.3.2. Chosen of heat pump for case study

Firstly, a heat pump with designing full heat power P must be chosen. It is important to pay attention to availability, abundance and of equipments from different manufactures. These equipments must answer to heat power requirement and have acceptable dimensions for practical using inside a building.

As it can be seen from the Table 1(Appendix 1), there are some companies, as example, which manufacture heat pumps equipment. Some heat pumps have sufficient heat power for heating system in study case; but if heat power is insufficient for designing heat power, parallel connection of heat pumps can be used.

The Table 1 (Appendix 1) is shown that search of heat pump with needing heat power is not difficult. There are heat pumps with big heat power in some companies which can be used for buildings with bigger heat losses than study case in this bachelor's thesis. But when designing of new building is determined, the dimensions of heat pump equipment must be taken into account.

In this bachelor's thesis the heat pump Vicotal 300 WW268 can be used. There are two needed flow temperatures for under floor heating in last calculations - $t_{flow} = 37{,}5$ (deg) and $t_{flow} = 52$ (deg).

Figure 12 The Ground Source Heat Pump Vicotal 300 /13, p. 1/

In Graph 3 work characteristics of calculating Heat pump are shown. The importances of characteristics are:

A is full heat power of the heat pump;

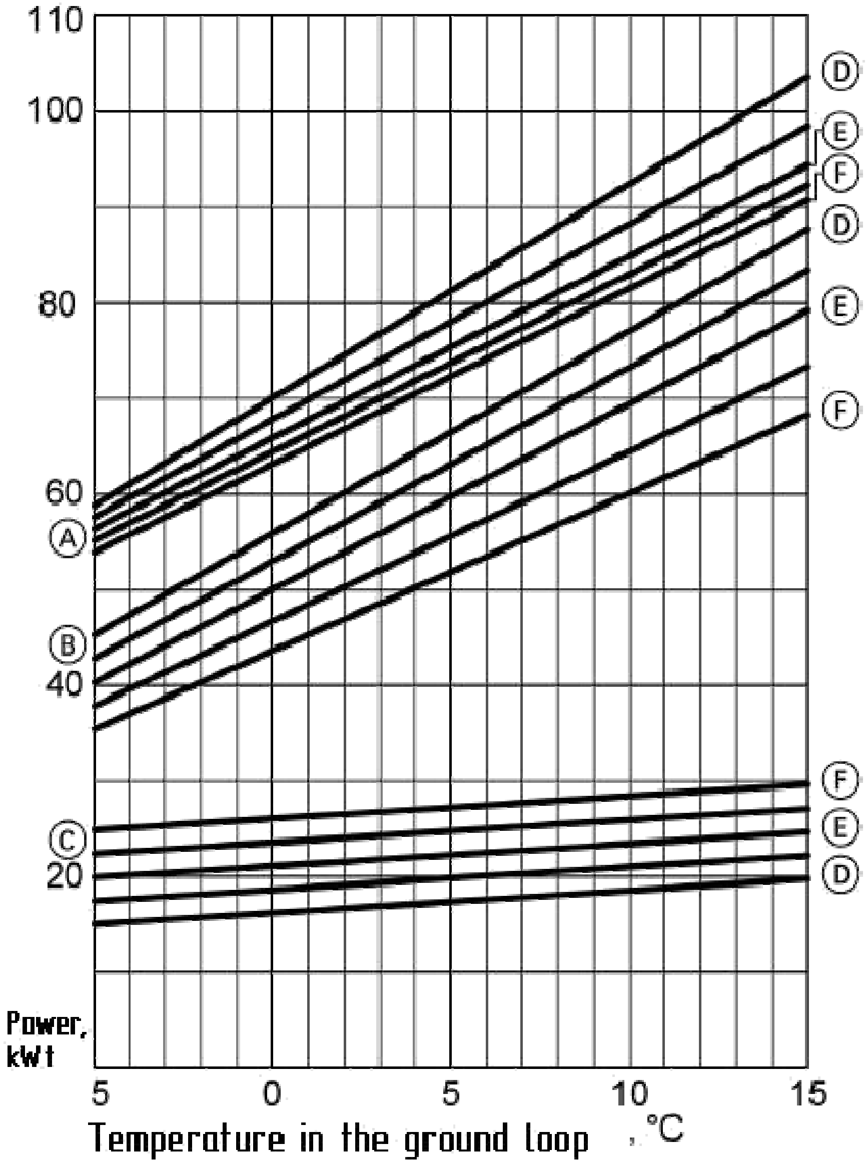
B is cooling power of the heat pump;

C is expending work in compressor's gear;

D is t_{flow} = 35 degrees;

E is t_{flow} = 45 degrees;

F is t_{flow} = 55 degrees.



Graph 3 Work characteristics of the Heat Pump WW 268 /13, p. 9/

The main parameters of the chosen heat pump are presented in the Table 2 also /13, p. 9/:

Table 2

The work characteristics of the heat pump Vicotal 300 WW268

The "work point"	t_{flow} = 45 degrees	t_{flow} = 55 degrees
The full heat power, kW	71,6	68,8
The using electrical power (expending work), kW	20,5	23,7
COP	3,5	2,9

The needed flow temperatures can be provided by chosen heat pump, but next calculations will be done for the case with t_{flow} = 45 (degrees).

6.3.3. Calculation

Sequence of process is /11/:

1. Ground heat exchanger capacity

The heat capacity Q_0 which are got from the low-temperature heat source:

$$Q_0 = P - P_{el} = 71{,}6 - 20{,}5 = 51{,}1\ (kW), \tag{8}$$

where P is a full heat power of heat pump, W;

P_{el} is expending work in compressor's gear, W.

2. Length of ground heat exchanger (ground loops of pipes)

The length of ground heat exchanger (the total borehole length) L which can be got from the calculated heat capacity Q_0 from ground source:

$$L = \frac{Q_0}{q_{ground}}, \tag{9}$$

where q_{ground} is a specific heat removal per 1m of pipe loop, W/m.

The specific heat removal q_{ground} depends on type and moisture of soil. Meanings of average q_{ground} for several types of soil /11/:

- For dry sedimentary rocks q_{ground} is 20 W/m;
- For stony ground and waterlogged sedimentary rocks q_{ground} is 50 W/m;
- For rock with high heat thermal conductivity q_{ground} is 70 W/m;

– For under ground water q_{ground} is 80 W/m.

Two cases of soils can be taken into account for calculations with the formula 9: first case is a stony ground or waterlogged sedimentary rocks, and second case is a rock.

$$L_1 = \frac{Q_0}{q_{ground}} = \frac{51100}{50} = 1022\ (m);$$

$$L_2 = \frac{Q_0}{q_{ground}} = \frac{51100}{70} = 730\ (m).$$

3. Numbers of vertical boreholes

The length of a vertical borehole between 50 m and 150 m is usually used. In this situation numbers and length of boreholes can vary. It is important to remember that each borehole increase the cost of project, but the deep drilling work on rock soil is difficult too. In GSHP systems with vertical boreholes the depth and kind of soil have influence the project cost, because “it is more expensive and time consuming to drill through overburden than rock as the borehole has to be cased” /4, p. 6/.

It must be taken into account that cost of borehole drilling is generally higher than piping cost. It means that the heat extraction per unit length of vertical borehole must be maximized /4, p. 6/. So, inside each borehole two loops can be situated.

After calculation of two cases number of boreholes and these lengths are got:

L_1 = 1022 m it means 7 boreholes with 73m length each;
L_2 = 730 m it means 5 boreholes with 73m length each.

The distance between vertical boreholes must be “at least 3 m and preferably 5 m” /4, p. 7/.

4. Volume flow of the brine in the liquid phase

The parameters from the Table 1 are shown for some kind of solution. In calculation of a volume flow the 25% of glycol mixture is used.

$$q_v = \frac{Q_0}{r \cdot c \cdot \Delta t} = \frac{51{,}1}{1{,}05 \cdot 3{,}7 \cdot 5} = 2{,}63\ (l/s), \qquad (10)$$

where Q_0 is the heat capacity from ground source, kW;

ρ is the mixture density, 1,05 kg/m^3;

c is the specific heat capacity of the mixture, 3,7 kJ/kg·K;

Δt is the temperature difference between flow and return pipes, for vertical borehole Δt = 5 degrees.

But in the article /4, p. 7/ it is given other information about temperature difference Δt: “Typical heating only vertical collector systems would be designed assuming a mean ground loop fluid to far-field temperature difference of 10 K”.

6.4. Additional information about the system

6.4.1. Geological test

It must be taken into account that in each individual project the geological tests and extra works must be done. These tests let to get more information about ground parameters and under ground water level. It means design of under floor heating system with heat pump will de done more properly.

Value of thermal conductivity can be estimated from the type of area ground, but it can also be measured on the building site. One of them it is a thermal conductivity test which is called “Thermal Response Test”. During this Test the information about heat load and resulting rise of temperature is measured over at least 48 hours with a ground heat exchanger in vertical borehole. “The thermal conductivity than can be calculated using the slope of the temperature curve over logarithmic time” /6, p. 17/. The getting information also can be used for determination of borefield size and to select the borehole grout specification. The borehole which was used for test can be used later as working vertical borehole /1, p. 38/.

6.4.2. Pipe materials

Several words about pipe materials and diameter for ground heat exchangers must be said /4, p. 8/:

– For pipes in indirect systems high-density polyethylene is the most popular material. Diameter of pipes must make sure on the one hand the small pumping power and on the other hand turbulent flow for better heat transfers between the circulating fluid and borehole wall. Pipe diameters between 20 mm and 40 mm are usually used.

– For direct systems copper pipes with 12 mm and 15 mm diameter are usually used.

Depending on soil conditions, a plastic material may be necessary to prevent corrosion inside ground.

6.4.3. Installation and testing

The part of installation and testing it is one of the most important parts of a whole project. Mistakes in this part can nullify designer's work.

The installation time depends on: soil conditions; length of ground heat exchanger; equipment required; weather conditions; location of any buried utilities, drainage pipes, and other systems /4, p. 9/.

Installation of vertical heat exchangers requires highly specialist knowledge in drilling, joints, grouting fields.

The ground loop must be pressure tested before installation in the ground and again after installation. "The loop should be flushed and purged of all air before being charged with antifreeze and pressurized ready for connection to the heat pump". /4, p. 9/

6.4.4. Examples of buildings with GSHP system and under floor heating

From source /6/ the information about buildings with vertical heat pump system is presented. There is the head office of the German Air Traffic Control (Deutsche Flugsicherung) in Europe where 154 borehole heat exchangers each 70 m deep were installed. It is one of the highest numbers of boreholes for a single plant in Europe. The example of the largest single plant in the world is the Richard Stockton College in New Jersey where 400 boreholes each 130 m deep were installed.

There is complex of low-rise residential buildings in St. Petersburg where under floor heating system is used. This system compensates all heat losses of the complex.

These examples of buildings shown that buildings where GSHP system are using are really working projects; GSHP system with under floor heating system can be applied in low-rise residential building too.

The most popular uses of heat pump systems in the USA and Turkey because climate situation in these countries is the most suitable. The temperature during winter time is not low as in Northern countries. But in Northern countries temperature of low-temperature source is less than in above countries. May be the reason of low spreading of ground source heat pump systems in Finland depends on “habit” to traditional heating systems with radiators as heat emitters and 80-60 degrees temperature of heat transfer fluid and difficulties with drilling process for rock.

7. Temperature drop in soil

When heat is transferred from ground source temperature of the ground is dropping. The heat capacity of heat pump is bigger, the reduction of ground temperature is bigger. This reduction depends on: the average ground temperature; the temperature of the Refrigerant; the heat capacity of ground (different types of soil have different heat capacities); the thermal resistance of ground.

It is important the ground temperature must be higher than some importance which was used in the calculation for continuous operation of system. For the horizontal system this minimum ground temperature depends on depth of the loops and the average outdoor temperature during summer time. The main problem consists of in unknowing this minimum ground temperature without tests, measurements, and experimental observations /12/.

In Figure 13 it is shown that in some cases it is possible to calculate temperature drop in soil. More information about it can be found in the article “Experience with heat pumps for heating in the southern regions of Ukraine” /3/.

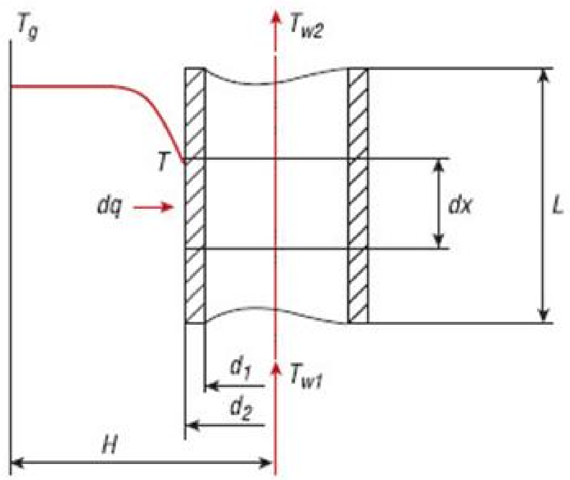


Figure 13 Heat transfer from ground to the brine /3/

However, for vertical systems this reduction is not so large. In case with vertical systems ground is accumulating heat from more deep soil layers. These layers deliver heat flow from center the Earth to top layers.

8. Conclusion

At this time in Finland heat pump systems are usually used in one-family house. But if these systems can work in those types of building, they can work in low-rise multifamily residential buildings too.

In bachelor's thesis the combination of ground source heat pump (GSHP) system and under floor heating was studied. Using the under floor heating system with heat pump for heating the heat transfer fluid is the most optimal case, because the less is temperature of heat transfer fluid, the higher is the coefficient of performance (COP) of heat pump when it works. Quality, thermal characteristics, and energy saving parameters of modern building envelopes and materials are so good that the total heat demand of a building can be compensated with just under floor heating system. There are opinions that this type of heating systems is more comfortable and useful for people.

Under floor heating system is a good solution for buildings with specific heat load 40-70 W/m^2. However, this importance may vary with verification of floor surface temperature. This temperature cannot be more than some maximum meaning of temperature, which is difficult for different types of surface materials.

It must be taken into account that variation of floor surface material during operating time can give occasion to change heat transfer from system. It means that people who will be living in building where this system is used must know about types of materials which could be used in flats during the life-cycle of the building.

Ground source heat pump systems are more efficient in comparison with systems which are worked on air or water low-energy, because the temperature of ground is higher than air or water temperature in Scandinavia countries; ground temperature is also almost constant during the whole year.

One of the main characteristics of Finland is rock (granite) as a base ground level on the greater part of country area. On the one hand, properties of rock are the positive factors for GSHP system because:

- The granite have high thermal capacity;
- Grouting of boreholes is not needing;

– Borehole casing is not used.

However, on the other hand, drilling works for rock material are difficult, more expensive and need more time than drilling in soil.

In case with soft soil it is important to have wet soil and availability of groundwater level, because the thermal capacity of wet soil in several times is more than the thermal capacity of dry soil.

Design engineer must remember well that each borehole adds cost to a building project. In this situation designer must maximize efficiency of heat pump system and minimize installation costs. It means that the optimal compromise between lengths of pipes in ground heat exchanger for reducing of heat pump energy consumption as much as possible must be found /2, p. 13/. And the next aspect is “costs for trenching and drilling are generally higher than piping costs it is important to maximize the heat extraction per unit length of trench/borehole /4, p. 6/”.

It is necessary to turn attention to drilling process. In some cases it may to be needed to get permission to drilling from the special environment agency. The need of this permission depends on where the area for future building and drilling are situated, and does under ground water lavel on this area, what importance of this water-bearing layer. Normally, the permission for closed-loop GSHP systems is not requires. But in some cases the special departments “can provide comment on proposed schemes with a view to reducing the risk of groundwater pollution or derogation that might result /4, p. 5/”.

The main questions of the special environment agency are /4, p. 5/:

– Risk of the underground pipes/boreholes creating undesirable hydraulic connections between different water bearing strata;

– Undesirable temperature changes in the aquifer that may result from the operation of a GSHP;

– Pollution of groundwater that might occur from leakage of additive chemicals used in the system.

It is important to pay attention on comfortable and fast choice of equipments and materials for installing the under floor heating with ground source heat pump. The companies which manufactures ground source heat pump are different, as it looks from the Appendix 1. These differences are: country of execution; dimensions of equipments and heat power. It means that design engineer can choice the most suitable heat pump for each individual case. Finnish companies suggest the wide assortment of pipes and control valves for under floor heating. The dimensions of equipment are important parameter also for useful place the heat pump in technical room inside the building.

The important aspects about the heat pump which is working on electrical power in comparison with other systems on fuel are: on the one hand, the consumption of electrical power for building is increasing, but on another hand, the CO_2 pollution of air is decreasing in comparison with boiler on gas or oil fuel. For Finland, where electricity is result of oil and gas burning (in some cases, but not water of wind power), the using of electricity power in heat pump system is reducing CO_2 pollutions of atmosphere air near residential buildings. CO_2 pollutions are reduced also because the electrical power for the heat pump system is lower than power of oil or gas boiler proportional to the COP.

In comparison with district heating, the length of piping network is decreasing.

As a final the conclusion can be done: the use of heat pump and under floor heating as a heating system for low-rise residential building is really possible. This system permits: using the good characteristics of ground (in the most cases is rock) of Finland; decrease the CO_2 pollution of air; expulsion district heating in case of unreasonable situation.

List of definitions

1) A **ground loop**. This is comprised of lengths of pipe buried in the ground, either in a borehole or a horizontal trench. The pipe is usually a closed circuit and is filled with a mixture of water and antifreeze, which is pumped round the pipe absorbing heat from the ground;

2) **A heat pump** it is cooling machine where low-temperature environment's heat is delivered to high-temperature heat transfer fluid by means of using of energy on converting of machine's working medium; or

A heat pump is an electric unit that cools the house during hot weather by absorbing heat from inside and discharging it to the outside. In cold weather, it absorbs heat from outside and discharges it inside;

A **heat pump** has fore main parts:

§ **the evaporator** - device in which liquid is changed to the vapor state by the addition of heat (takes the heat from the water in the ground loop);

§ **the compressor** - the part of heat pump unit that compresses the refrigerant gas so that it can absorb heat;

§ **the condenser** - (the hot part at the back of fridge) gives up heat to a hot water tank which feeds the distribution system;

§ **the expansion valve –** a valve in which fluid flows under falling pressure and increasing volume;

3) **Heat distribution system** is consisting of under floor heating or heat emitters (for examples radiators, convectors, heating pipes) for space heating and, in some cases, water storage for hot water supply;

4) **The coefficient of performance (COP).** This is the ratio of units of heat output for each unit of electricity used to drive the compressor and pump for the ground loop;

COP (Coefficient of Performance) is the heating capacity of the unit divided by its electrical input at standard (ARI/ISO 13256-1) conditions /8, p. 1/;

5) **R-value (thermal resistance), m^2·K/W)** - the ability of a material to resist the flow of heat;

6) **U-value (thermal transmittance, W/m^2·K) –** thermal transmittance indicates the heat flow density which permeates a building component in steady-state when the temperature difference between the environment on different sides of the building component is the unit of temperature;

7) **λ (thermal conductivity, W/m·K)** - thermal conductivity indicates the density of heat flow in steady-state through a layer of homogenous material with a thickness of a unit of length when the temperature difference between the surfaces of the material layer is a unit of temperature;

8) **Under floor heating** is heating system where a floor surface is used as heat emitter;

9) **Closed loop –** antifreeze mixture water, or another heat-transfer fluid is circulated from the heat pump, around the tubing, and back to the heat pump;

10) **Open loop –** earth connection draw water from a well or a body of water transfer heat to or from the water, and return than it to the ground or the body of water;

11) **Refrigerant** is a substance used to provide cooling either as the working substance or a refrigerator or by direct absorption of heat; or

Refrigerant is a compound used in a heat cycle that reversibly undergoes a phase change from a gas to a liquid.

12) **Grout** is special pumpable material which has high conductivity and is used for: structural reliability; facility of heat transfer from the working fluid or Refrigerant to the ground; protection of groundwater pollutions.

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APPENDIX 1

Table 1

Manufactures, heat power and dimensions of heat pumps which can be used for the case study / characteristics from the source 14/

№	Company	Country	Model	Heat power, kW	Using electrical power, kW	Dimensions (H x W x D), mm
1	“Burgerus”	Germany	Logafix WPW920IP	91,2	16,97	830 x 1480 x 890
2	“FHP”	USA	WP210	69,4	18,6	813 x 1168 x 711
3	“FHP”	USA	WP240	93,9	18,6	1626 x 1168 x 711
4	“Mammoth”	USA	MSR-L270WHC	82,5	20,12	1248 x 1336 x 1175
5	“Mammoth”	USA	MWH O25CB	95	22	1144 x 1053 x 1850
6	“Matrixclima”	Italy	WPW-GEO	till 153,5		
7	“Thermia”	Sweden	Robust 38 VIM	38,2	14,0	
8	“Viessmann”	Germany	Vicotal 300 WW268	90,2	16,2	1505 x 1200 x 760