

Kurasova Jelena


# Choosing a heating system according to the price and CO2 emissions

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## DESCRIPTION

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<b>Author(s)</b> Jelena Kurasova	<b>Degree programme and option</b> Building Services Engineering Double Degree programme	
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<b>Abstract</b>  <p>The aim of this work was to find a most suitable heating system according to the price and CO2 emissions for one family house in the Leningrad area. In this work the most widely used systems of heating are shown but also alternative energy sources such as heat pump. The choice of a system of heating for one family house is multifactorial task.</p> <p>When choosing a heating system many factors have to be considered such as cost of equipment, operational costs and the safety and environmental friendliness of equipment. The climatic features of the region also affect on the choice of the heating system.</p> <p>The role of this thesis is to find energy efficient and ecological heating system for one family house.</p>		
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<b>Tutor</b>  Jarmo Tuunanen	<b>Employer of the bachelor's thesis</b>	

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## **1. INTRODUCTION**

Power resources are in our time constantly becoming more expensive and tariffs are increasing. This issue is especially important in Europe. Alternative energy sources are one of the most topical issues in our contemporary society. The second of the most important issues are environment pollution and the emissions of carbon dioxide in the atmosphere. The increased concentration of carbon dioxide in the atmosphere is directly related not only with global warming, but it also has a direct impact on human health.

The selection of a heating system is a solution for decades. The choice of a system of heating in the house is not an easy task and it is multifactorial. There are no ideal systems of heating and hot-water supply. That is why, when choosing a heat-source equipment and a heating system in general, many factors have to be considered, analyzing and assessing the importance of each and the final result as a whole.

This work deals with such factors as the purchase price of equipment, operating costs on fuel and attendance (service), ease of use and the emissions of CO<sub>2</sub> in the atmosphere. These factors make the selection of a heating system more balanced. The analysis will be done by comparing the most widely used systems of heating.

## **2. CLASSIFICATION OF HEATING SYSTEMS**

### **2.1. Traditional heating boilers**

Heating boilers are land-type boilers that produce heat energy during combustion. This heat energy is transferred to a heating medium, which explains the other name - hot-water boilers. Heating boilers differ by type of fuel on which they work. There are electric, gas, solid fuel, diesel and multi-fired heating boilers.

Depending on functions, heating boilers are divided into a single-circuit, which serves only space heating and a dual-circuit heat exchanger, which is used for a space heating and for hot water supply. Dual-circuit heating boilers with low consumption and high capacity, help to avoid the installation of a boiler.

Besides, boilers vary in power and construction: heating boilers can be domestic and industrial, aspirated and supercharged, floor and wall make of steel and iron. Heating boilers may vary not only in operation principles, but also in dimensions. Besides there are heating boilers with a mounting burner (a built-in burner) and burners with a separate block. The use of one or another kind of a heating boiler depends on the available sources of energy, economic feasibility and working conditions of a boiler.

### **2.1.1. Electric heating boilers**

Electric heating boilers are compact, noiseless, they do not require additional maintenance and they are environmentally friendly. However electric heating boilers are expensive to operate, as electricity prices are constantly growing. Besides, electric heating boilers require a specific line voltage and they are not the most powerful.

### **2.1.2. Diesel heating boiler**

Diesel is by far the most experienced and versatile fuel that does not require the creation of a special collective infrastructures: gas pipelines, power substations and mains. The high cost of equipment and operating costs with current level of prices for a diesel fuel are also very high. Installation of a diesel heating boilers additionally requires a mounting of a capacity for 5-20 tons of fuel and that needs access roads for a fuel tanker.

During the work of a heating boiler certain things are necessary: an ignition system, a flame failure device and a fuel-feed pump. Even after a short-time power cutoff, the human intervention is required to reset the heating.

The presence of a sulfur in exhaust gases leads to the formation of a sulfuric acid that emits into the environment, and primarily, seriously disrupts a flue gas venting system, and also the nearest objects.

### **2.1.3. Gas heating boiler**

Boilers working on a gas are very popular in Russia. There are much more problems during it's application, than with any other heat medium.

Gas heating boilers are the most dangerous type of equipment because of the use of gas. This means that the installation requires the permission of the special services, as the installation works must be performed only by specialists that have the special work permit.

During the operation of equipment, it's necessary to strictly keep the safety standards. The gas heating boiler must be supplied with automatics, reacting to a gas leak and completely blocking the gas pipe, if the leakage happens. The gas heating boiler must be supplied with the automatic uninterrupted power supply system, it can be an accumulator with a large capacity, or the inverter station with the automatic switching-in system.

Gas heating requires a gas line installation and a separate specially prepared boiler room with a flue gas channel. Also engineering of a gas inlet project, wiring, and installation of a gas facility will be required. The gas line connection is prohibited without the approval and coordination of the project documentation with the special services. The permission of GazGorTekhnadzor must be obtained before the installation of a gas heating boiler.

The operating feature of the gas heating boilers is the necessity of precaution and control of burners, valves and automatics. These works must be done under the control of a licensed firms, otherwise there is a serious danger of a casualty-producing capacity.

#### **2.1.4. Solid fuel heating boilers**

Solid fuel heating boilers are especially popular because this is an off-line system. It works on the fuel woods, coal, peat or pellets - an eco-fuel made of the wood wastes. The solid fuel heating boiler is a suitable solution for non-gasified houses, districts with the power failures, but solid fuel heating boilers require the fixed maintenance labor.

The solid fuel heating boiler with a pyrolysis fuel combustion has a high efficiency: it uses not only fuel, but also the emitted gases during the combustion. Such boilers are expensive, but the price difference is compensated by the efficiency upgrading. When the heat transfer is up to 80%, this solution is convenient and economical.

### **2.1.5. Multi-fired heating boilers**

Multi-fired heating boilers are convenient, because different types of fuel can be used (diesel fuel and natural gas), depending on the type of a burner. The most convenient types of the multi-fired heating boilers are fuel woods-gas or diesel oil-natural gas, or fuel woods-diesel oil. They are made for burning several types of fuel. Having an additional electric heater is also convenient. Switching can be done semi-automatically, or changing of the fuel type can be done after installation of the appropriate burners, and settings combustion chambers.

Having the electric heating elements will protect a heating system from freezing in the case of emergency situation. The automatic system will provide additional heating of a heat carrier, if the combustion of fuel did not provide required heat power.

### **2.2. Heat pumps**

Heat pumps if calculations are correct is a system with the lowest operation costs.

To 1 kW of consumed energy, it produces from 2.5 to 5 and more kW of heat power. The heat pump uses received energy much more effectively than any other boilers, combusting fuel and using electric power. The operating costs of such pumps can be three times lower in comparison with other systems.

The work of a heat pump does not depend on organic fuel supplies and there is no necessity to install expensive heat or gas pipelines. The heat pump can be used in any climate conditions and in any location where electricity is available. If electricity is not available, the heat pump will work effectively complete with diesel generator.

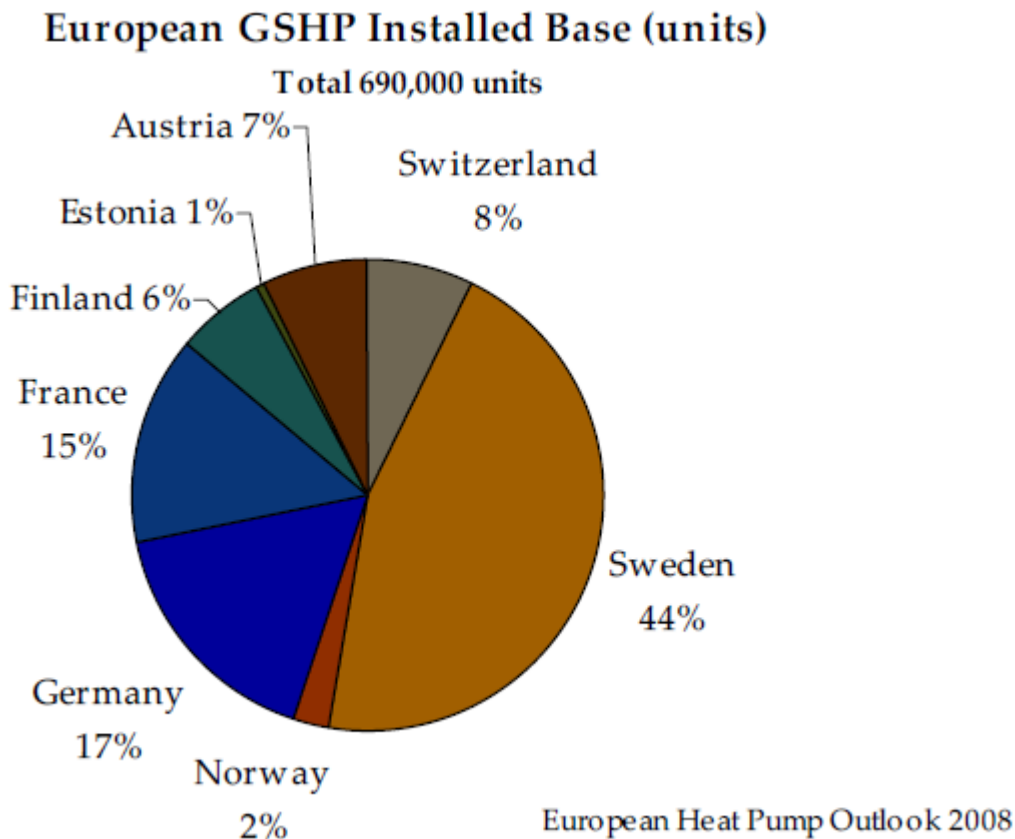
In comparison with electric boiler, heat pump at times reduces harmful emissions of CO, CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>2</sub>, PbO<sub>2</sub> in the atmosphere, leading to the desruption of the ozone layer, acid rains, there is no negative effect on your body.

The deficiency of fuel - gas, diesel oil, fuel woods - excludes the possibility of fires, explosions, and leakage of hazardous (dangerous) substances. Heat pumps are explosion-proof and fire-proof. No fuel, no open fires, and no dangerous gases or mixtures. There is

nothing that can explode here. So it is impossible to get gas-poisoning. None of the details of a heat pump is warmed to temperatures that can cause firing of inflammable materials.

There is no paperwork during the installation and operation and you don't need any approvals from the state licensing and supervising agencies.

The energetic applicability of the heat pumps as the heat generators is proved demonstratively by the results of a large number of researches and the operating experience of millions of heat pumps in the world's industrialized (developed) countries. According the European Heat pump outlook 2008, quantity of ground source heat pump installed in Europe is shown in Figure 1:



**Figure 1. European GSHP installed base (unit) /1.p.20/**

### 2.3. Conclusions by the chapter

Currently, in Russia the most profitable type of a heating boiler is a gas heating boiler. However, project engineering connection to a gas line, and getting a license from



GazGorTekhnadzor, may take more than just a few months, even years. When purchasing equipment, the electric heating boiler rightly can be called the most effective one, but in the maintenance it will be one of the most expensive ones. The diesel heating boiler, due to the combustion of fuel will throw a lot of harmful substances into the atmosphere.

According to the information mentioned above, the most effective and eco-friendly heating systems are a heat pump and a multi-fired heating boiler. With the multi-fired heating boiler, you can choose a fuel woods - natural gas, with a future possibility of the connection to a gas line.

### **3. A HEAT PUMP FOR ONE FAMILY HOUSE**

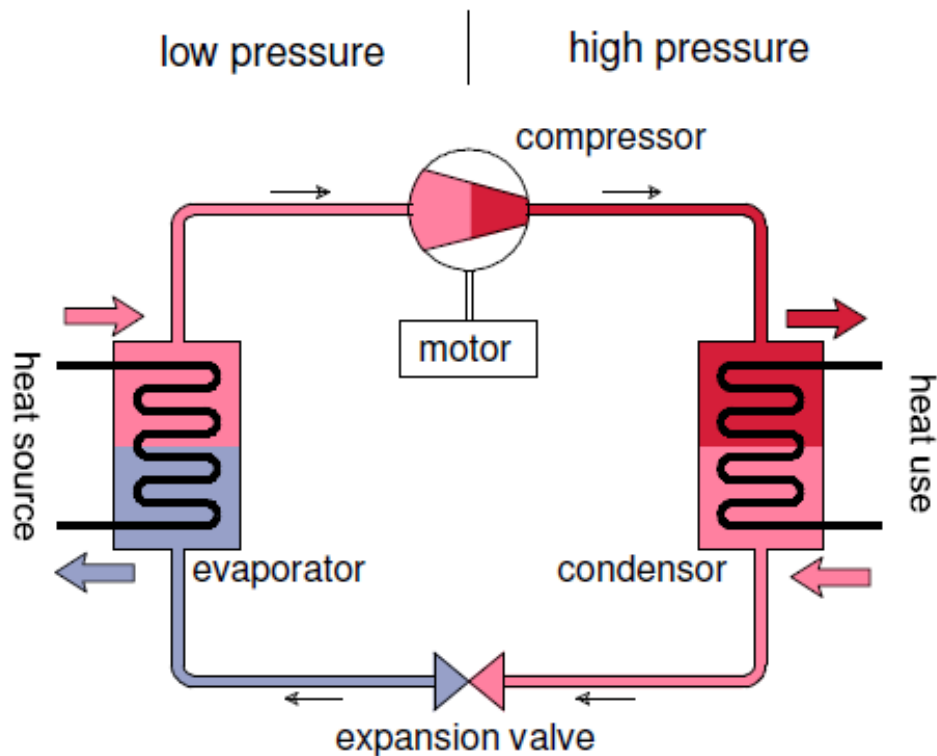
#### **3.1. Operation of a heat pump**

“Heat pump is a device which allows transport of heat from a lower temperature level to a higher one, by using external energy”/2.p.8/ Ground source heat pumps are used for the rational selection and the most efficient conversion of any low-grade heat such as ground, groundwater or outdoor air. This unit is capable simultaneously of covering the heat load on the heating, hot water supply, and air-conditioning.

Ground source heat pumps are used for the rational selection and the most efficient conversion of any low-grade heat such as ground, groundwater or outdoor air. This unit is capable simultaneously of covering the heat load on the heating, hot water supply and air-conditioning.

If dimensioning has been done right way then the heat of the soil surface layers of the earth is like a heat accumulator with unlimited capacity. Solar heat energy stored in the soil surface layers of the earth like water, ground and bedrock from first days of spring to the middle of autumn.

The compression heat pump is the most common type of a heat pump. The scheme of compression heat pump is shown in Figure 2:

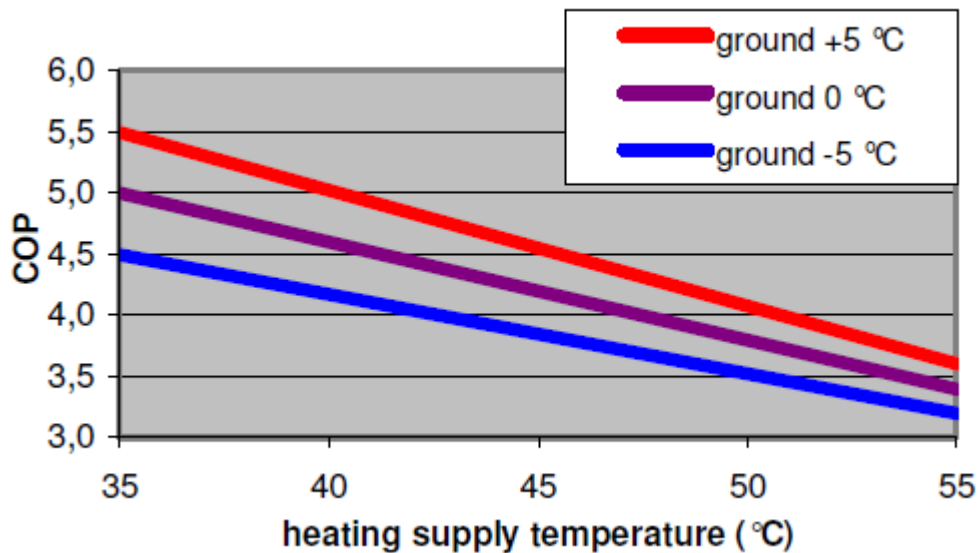


**Figure 2. Schematic of the compression heat pump** /2,p.6/

As we can see from Figure 2, heat source absorbs heat from the surrounding ground and delivers it to the evaporator. In the evaporator, refrigerant changes its aggregate state from the liquid to the gaseous state. The gas is compressed in the compressor. The compressor typically works by electric power of motor. According to the law of thermodynamics, the temperature increases as the pressure rises. So the hot gas after the compressor can be supplied for the heating system. After the heat exchange with a heating system the refrigerant is going to the expansion valve. In expansion valve the pressure decreases. The refrigerant come back to the ground source and the operation begins again. /2,p.6/

### 3.2. The efficiency of a heat pump

The efficiency of a heat pump is characterized by the coefficient of performance (COP). COP is the ratio between useful heat and electric power input of a heat pump. COP depends on the kind of compressor, heat exchangers, and on the temperature difference between the low potential source of heat (ground or groundwater) and high internal temperature inside the building. The efficiency of a heat pump is higher when low temperature radiators (max 50°C) are used in combination with underfloor heating (max 35°C). The figure 3 illustrates dependence of the COP from the temperature of the heating distribution system and ground temperature.



**Figure 3. Dependence of the COP from the temperature of the heating distribution system and the temperature of ground.** /2, p.6/

### Integral characteristic HDD

Heating Degree Days (HDD) are integral characteristics and commonly used to estimate the total local climatic features. The integral characteristics of the heating period are estimated according to the amount of the average daily temperature differences inside and outside during the heating period. Heating Degree Days is used to define the annual heat demand of the building, it is measured in °Cd, and it can be calculated by Formula 1.

$$D_d = (t_{in} - t_{out}) * T_h \quad (1)$$

where:

$t_{in}$  is the average indoor air temperature of the heating season, °C

$t_{out}$  is the average outdoor air temperature of the heating season, °C

$T_h$  the duration of the heating period, in days

Heat pumps available on the market of Russia are designed for Central European climatic conditions. The geological and climate conditions in many regions of Russia are substantially different from the average European ones. For example, the soil temperature at a depth of 10 m is 5.8 °C instead of 10.15 °C. The integral characteristics of the heating period are of 1.5-2 times more. The average value of this indicator in Russia is  $D_d = 5000$  °Cd. When compared

with similar indicators in other countries: Sweden Dd. = 4017 °Cd, Norway Dd. = 3600 °Cd, Germany Dd. = 3163 °Cd, Denmark Dd. = 2779 °Cd, U.S. Dd. = 2700 °Cd. /3/

According Construction Norms and Regulations 23-01-99 the heating season in Leningrad area lasts 220 days. The average indoor air temperature of the heating season ( $t_{in}$ ) ranges from 20 to 22 °C. The average outdoor air temperature of the heating season ( $t_{out}$ ) is -1,8°C. This value depends on the period with an average daily temperature of external air less than 8 °C. /4/

Thus, Heating Degree Days in St. Petersburg can be calculated:

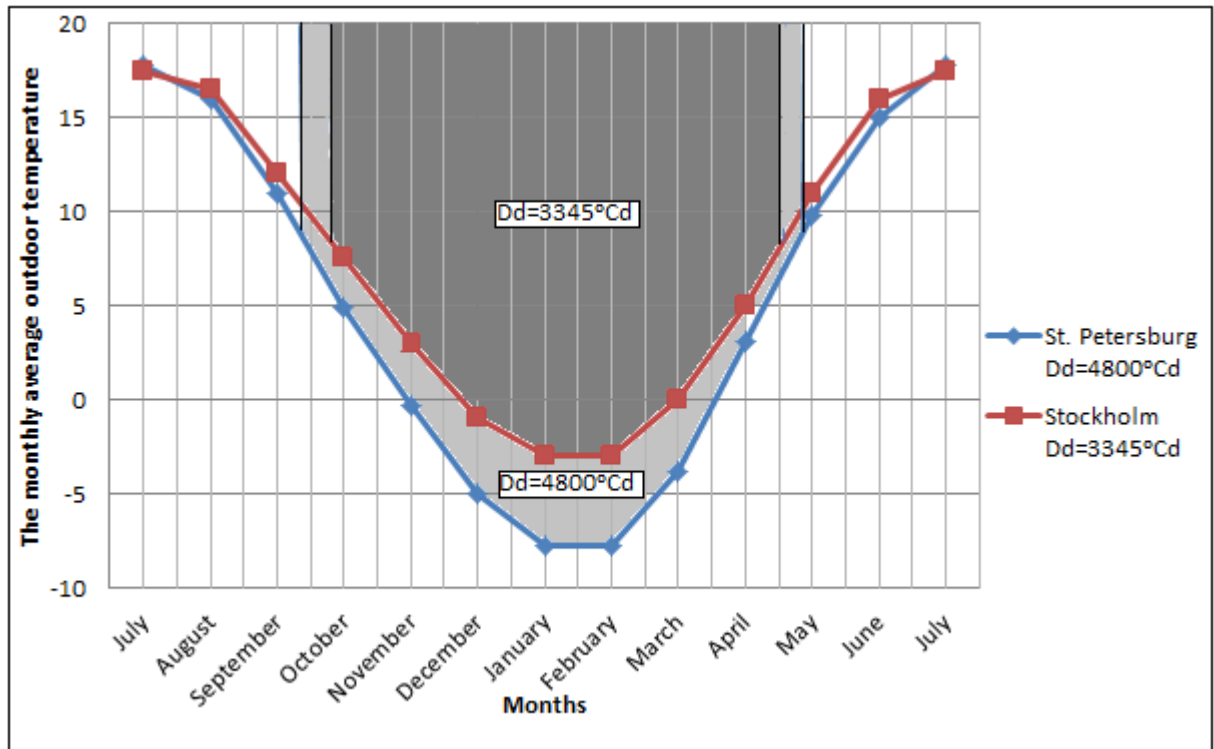
$$D_d = (20 - (-1,8)) \cdot 220 = 4800 \text{ °Cd}$$

When compared with the integral characteristics of St. Petersburg and Stockholm, which is the capital of Sweden, one of the most northern European countries. The monthly average outdoor temperatures are presented in the table 1.

**Table 1. The monthly average outdoor temperatures of St. Petersburg and Stockholm.**

The monthly average outdoor temperatures, °C		
	St. Petersburg	Stockholm
July	17,8	17,5
August	16	16,5
September	10,9	12
October	4,9	7,5
November	-0,3	3
December	-5	-1
January	-7,8	-3
February	-7,8	-3
March	-3,9	0
April	3,1	5
May	9,8	11
June	15	16

Graphically, integral characteristics are the area enclosed between the straight lines of indoor air temperature changes and the polylines of the average monthly outdoor temperature. The monthly average outdoor temperatures and integral characteristics of the heating period for cities St. Petersburg and Stockholm are shown graphically in Figure 4.



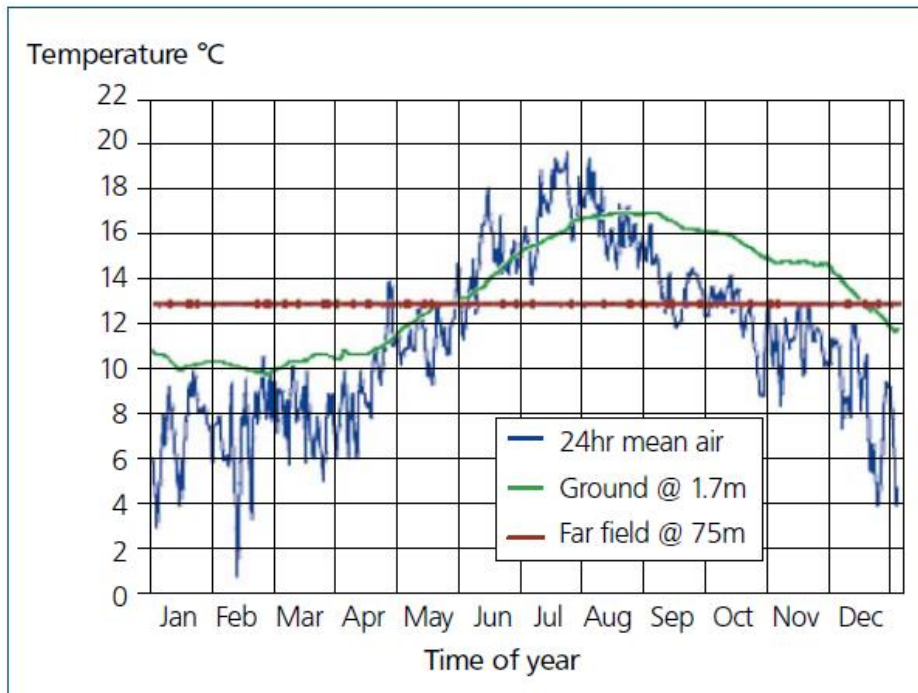
**Figure 4. The monthly average outdoor temperatures and integral characteristics of the heating period for St. Petersburg and Stockholm**

As we can see from Figure 4, the integral characteristics of St. Petersburg are more than the integral characteristics of Stockholm. Quantitatively, the integral characteristics of St. Petersburg are 1.4 times higher. It is obvious that for the same buildings, total annual heat output of the heating system in the climatic conditions of St. Petersburg should be more than 1.4 times higher than in the climatic conditions of Stockholm. Increased capacity requires increasing the set number of ground heat exchangers and the length per unit of area. As a result capital costs are also increased. The possibility of freezing of the soil near the groundwater collectors also increases, which leads to a significant reduction in heat transfer. All these factors lead to the decrease in the coefficient of performance of a heat pump.

### 3.3. Thermal regime of the soil

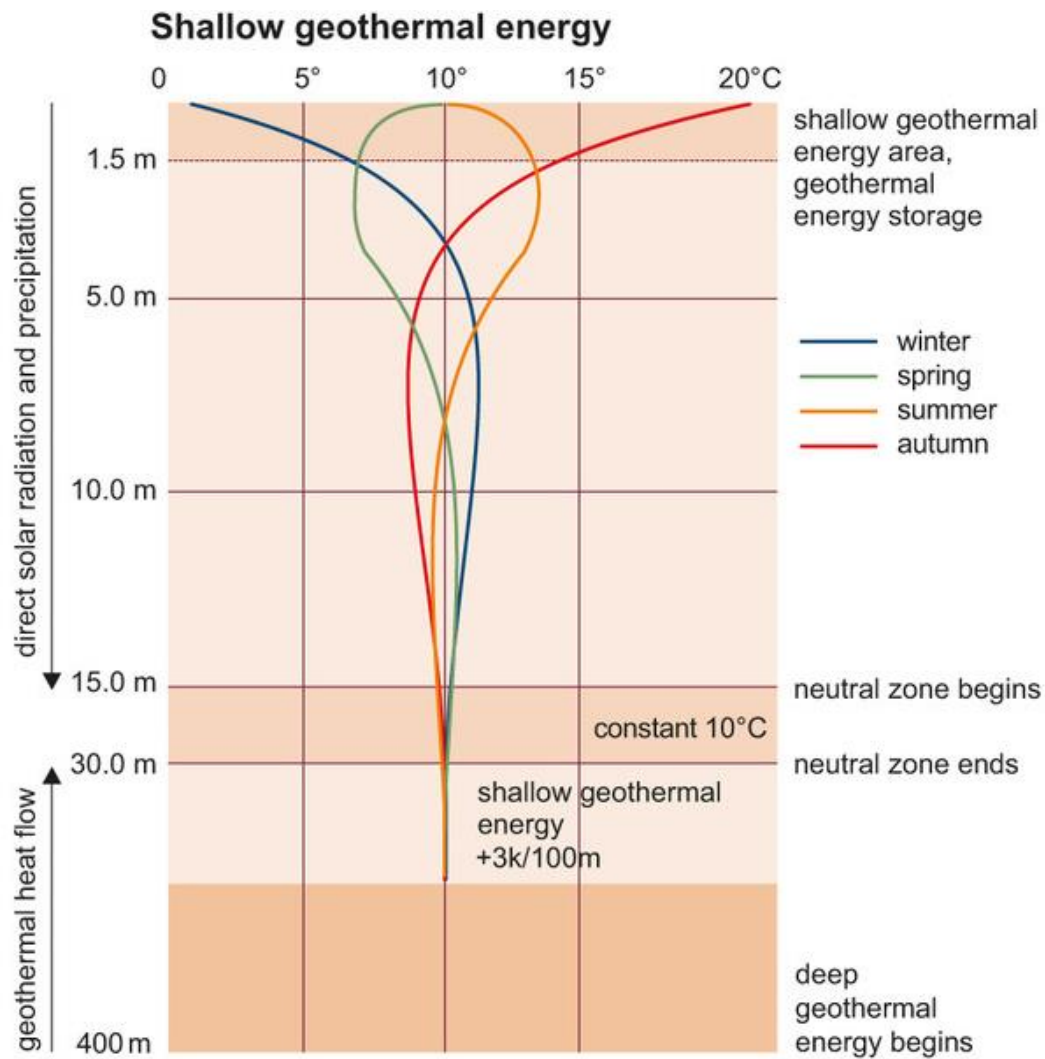
The thermal regime of the soil depends on the solar radiation incident on the surface and on the radiogenic heat of the earth which is released by the decay of radioactive elements, contained in the depths of the Earth.

The fluctuations in the temperature of the upper soil layers are formed due to seasonal and diurnal variations in the intensity of solar radiation and outside air temperature. The penetration depth of the daily temperature fluctuations of outside air depends on the specific soil and climatic conditions. In Figure 5 we can see the seasonal variation of ground temperatures according to the air temperature at the depth of 1.75m. /4/



**Figure 5. Air and ground temperatures, Falmouth 1994.** /5, p.8/

Further, with increasing depth, the temperature is constant at about 10°C. At this depth, the temperature is practically independent of seasonal and diurnal of parameter changes of the external climate. As we can see from the figure 6, the amplitude of seasonal temperature fluctuations of soil almost fades at a depth from 15 to 18 m. However, with increasing the depth of the ground temperature is also increased in accordance with the geothermal gradient (about 3° C per 100 m). /6/



**Figure 6. Underground temperatures depending on the depth. /7/**

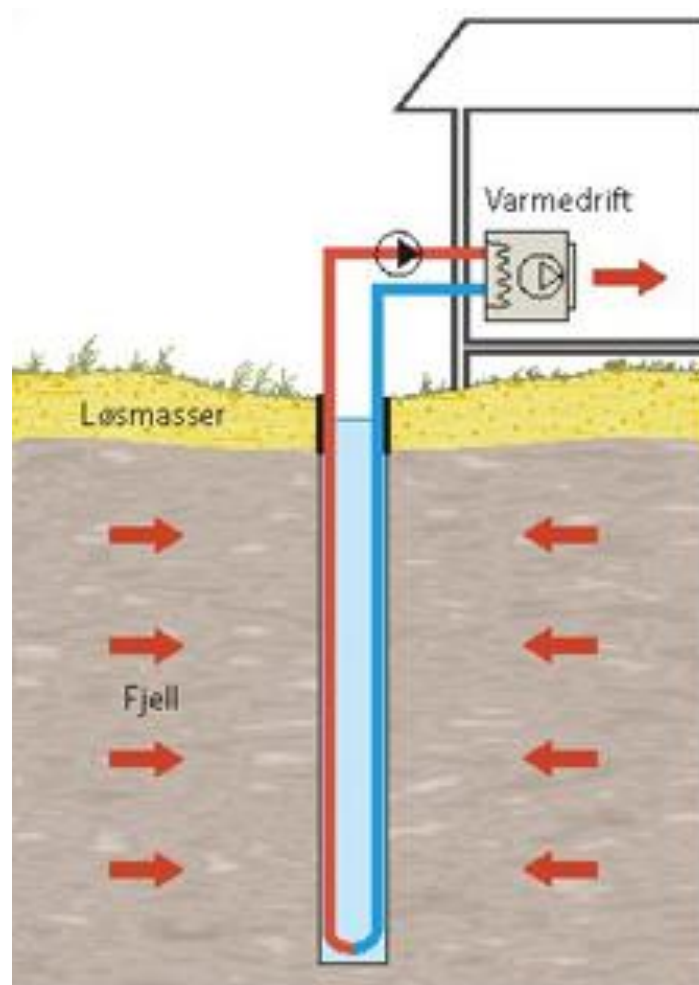
### 3.3. Geothermal heat exchangers

#### 3.3.1. Borehole heat exchangers

The energy of borehole heat exchangers should be adjusted to avoid frost collectors and they have to be easily recovered after the heating period. If the energy of borehole heat exchanger or geothermal probe is insufficient, this may lead to a technical installation issues and poor maintenance of the building.

Borehole heat exchangers don't require a lot of space. The temperature of soil is almost constant and doesn't depend on weather conditions. The borehole heat exchangers are usually set up in the form of vertical wells with a closed loop collector system. The principal scheme of a borehole heat exchanger with closed loop collector is shown in Figure 7. Inside the vertical

well are plastic tubes with antifreeze. Antifreeze circulates through the tubes, absorbs heat from the surrounding ground, and delivers heat to the heat pump.



**Figure 7. A borehole heat exchanger with closed loop collector. /8/**

Heat exchangers are set at the depths of 50 – 250 m. The depth of a vertical borehole influences on the cost and depends on the specific characteristic of the soil. According the German guideline VDI 4640 “Thermal use of the underground”, specific characteristics of the soil for borehole heat exchangers are shown in Table 2. Required probe/borehole depth using a heat pump with COP of 4 and performance 50w/m is shown in Table 3. /9 p.22/



**Table 2. Possible specific extraction values for borehole heat exchangers. /9 p.22/**

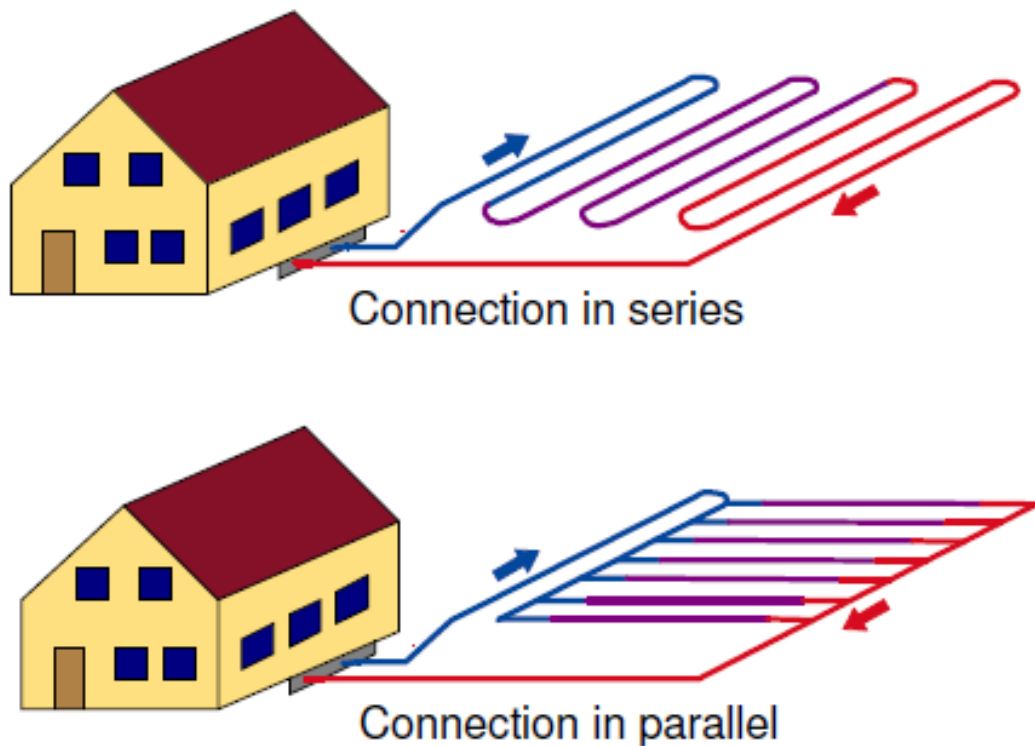
Operating hours	1800 h	2400 h
<b>Substrate</b>	<b>Specific extracted power in W/m probe</b>	
<b>General values:</b>		
Poor substrate (dry sediment) ( $\lambda < 1.5$ W/mK)	25	20
Normal bedrock substrate and water-saturated sediment ( $\lambda < 3.0$ W/mK)	60	50
Bedrock with high thermal conductance ( $\lambda < 3.0$ W/mK)	84	70
<b>Various types of stone:</b>		
Gravel, sand, dry	< 25	< 20
Gravel, sand, water-bearing	65 - 80	55 - 85
With strongly flowing ground water in gravel & sand, for individual systems	80 - 100	80 - 100
Clay, moist	35 - 50	30 - 40
Limestone (solid)	55 - 70	45 - 60
Sandstone	65 - 80	55 - 65
Acid magmatite (e.g. granite)	65 - 85	55 - 70
Alkaline magmatite (e.g. basalt)	40 - 65	35 - 55
Gneiss	70 - 85	60 - 70
(The values can vary widely due to stone formations such as cracks, layers or erosion.)		

**Table 3. Required probe depth using a heat pump with COP of 4 and performance 50W/m**

Required Heat Output [kW]	Evaporator Performance [kW]	Min. probe length [m]	Recommended no. of probes
4	3	60	1 probe at 60 m
6	4.5	90	2 probes at 50 m
8	6	120	2 probes at 60 m
10	7.5	150	2 probes at 80 m
12	9	180	2 probes at 90 m
14	10.5	210	3 probes at 70 m
16	12	240	3 probes at 80 m
18	13.5	270	3 probes at 90 m
20	15	300	3 probes at 100 m

### 3.3.2. Horizontal heat exchangers

A horizontal heat exchangers require a lot of space. There should be no capital buildings and trees on the surface which is used for a horizontal heat exchanger needs because their roots can damage the system. Horizontal heat exchangers are carried out at 0.2 m below the freezing point. Usually, pipes are buried at a depth of 1.0 to 2.0m. According to the German guideline VDI 4640 "Thermal use of the underground" the distance between pipes has to be 0.5-0.8m. The distance between multiple pipes is needed for reducing the thermal interference. The principal scheme of the horizontal heat exchanger with «closed loop» collector is shown in Figure 8.



**Figure 8. Horizontal heat exchanger. /2, p.9/**

The possible energy capacity of a heat pump will be 1,800 hours per year in the heating mode and 2400 hour per year in the heating mode plus hot water. Specific extracted power for horizontal heat exchangers is shown in the table 5. The Required surface area using a heat pump with COP of 4 is shown in the table 6. /9,p.20/

**Table 5. Specific extracted power for horizontal heat exchangers. /9,p.20/**

Substrate	Specific extracted power	
	at 1800 h	at 2400 h
Gravel, sand, dry	10 W/m <sup>2</sup>	8 W/m <sup>2</sup>
Clay, moist	20-30 W/m <sup>2</sup>	16-24 W/m <sup>2</sup>
Water-saturated soil	40 W/m <sup>2</sup>	32 W/m <sup>2</sup>

**Table 6. Required surface area using a heat pump with COP of 4. /9,p.20/**

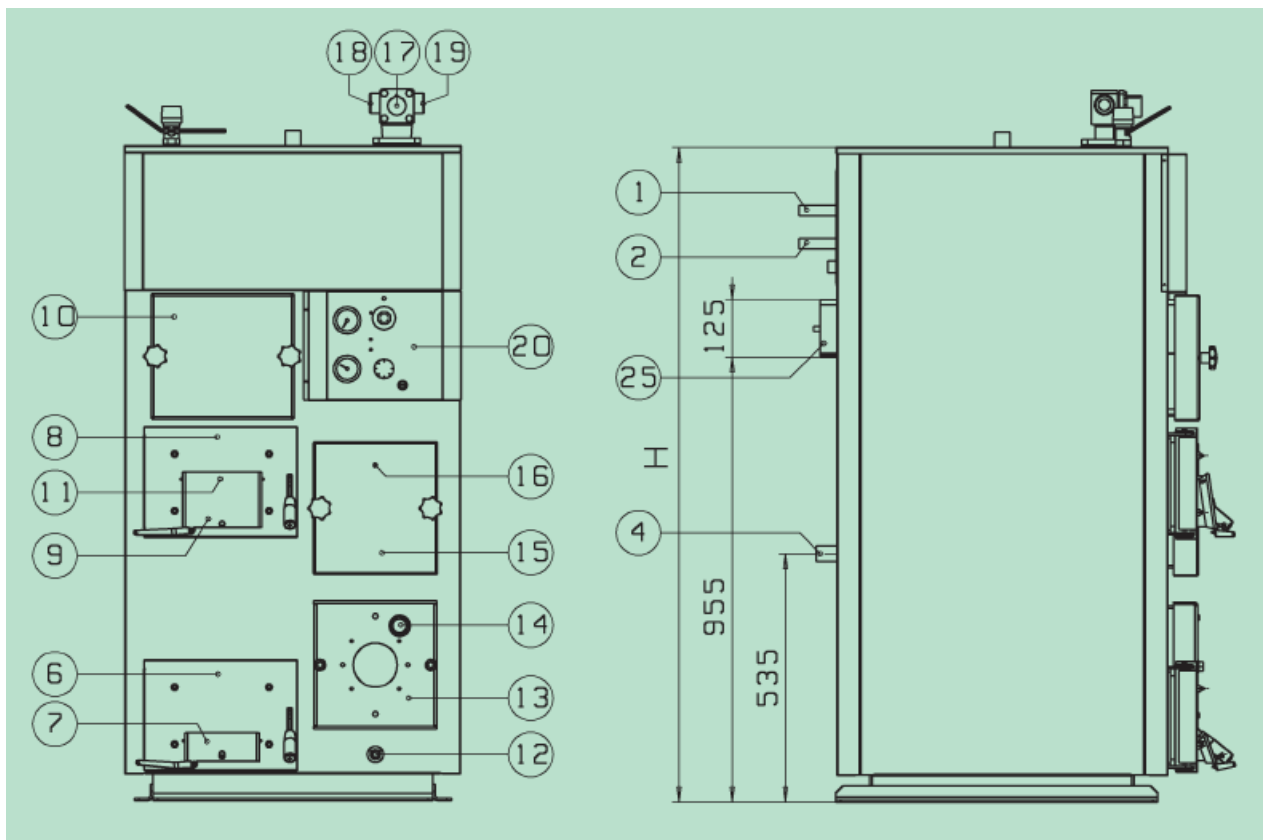
Required Heat Output [kW]	Evaporator Performance [kW]	Min Surface. Area [m <sup>2</sup> ]	Suggested RAUGE0 collect pipe [m]
4	3	120	200
6	4.5	180	300
8	6	240	400
10	7.5	300	500
12	9	360	600
14	10.5	420	700
16	12	480	800
18	13.5	540	900
20	15	600	1000

#### **4. PELLET BOILER FOR ONE FAMILY HOUSE.**

The pellet boiler Jaspi Pelletti 20 is one of the heating systems which can simultaneously operate on different types of fuels. The boiler has two furnaces which do not contaminate each other. One furnace is for wood, an other one is for pellets. Jaspi Pelletti 20 is environmentally friendly, economical, and reliable source for house heating.

The pellet boiler Jaspi Pelletti 20 is equipped with a 6 kW immersion electric heater. This power is provided in emergency cases. This is a huge plus for the rural areas where there is no

opportunity to refuel on time. The scheme of the pellet boiler Jaspi Pelletti 20 is shown in Figure 8.



1 - domestic hot water outlet, 2 - cold city water, 3 - boil connection (battery outlet), 4 - expansion connection (battery return), 5 - draft control connection, 6 - service hole, 7 - lower secondary air damper, 8 - filling port, 9 - upper primary air damper, 10 - cleaning port (solid fuel), 11 - flame monitoring port, 12 - drain connection, 13 - diesel/gas burner hole, 14 - flame monitor glass, 15 - cleaning hole (diesel/gas), 16 - flue gas analysis port, 17 - mixing valve, 18 - heating system outlet, 19 - heating system return, 20 - control panel, 21 - burner thermostat, 22 - tubular electric heater thermostat, 23 - thermometer, 24 - pressure gauge, 25 - flue connection, 26 - sensor connection.

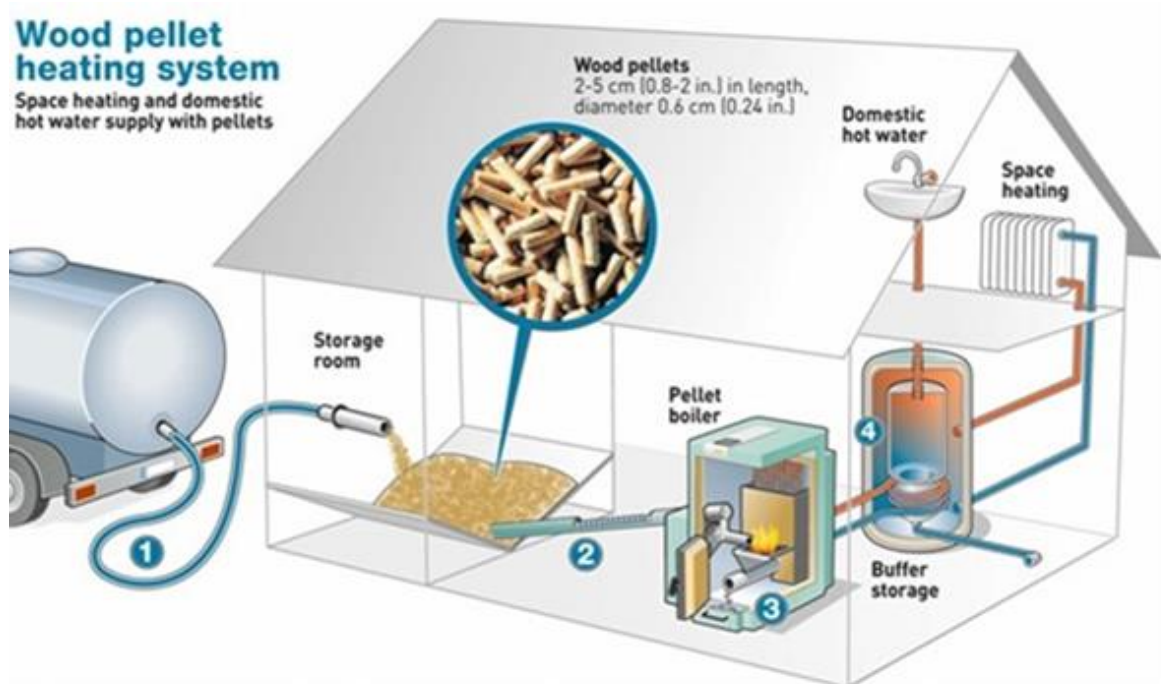
**Figure 9. Scheme of pellet boiler Jaspi Pelletti 20** /10, p.13/

Pellets are economical and environmentally friendly biofuels, with a sufficiently high calorific value (19 MJ / kg (4500 kcal / kg)). 1kg of wood pellets can give, in average, 5 kWh of thermal energy. The average cost of 1 ton of pellets is approximately 6000 rub.

The feeding and storage system of the pellet boiler plant can be performed in two ways. The choice of feeding and storage system depends on the quantity of free space in the house. So, if the house is not limited in space, it is advantageous to do a big storage room. The ideal shape of the storage room is oblong or rectangular. The storage room should have a width of not more than 2.0m and an useable volume have to be about 2/3 of the room volume. Inside there

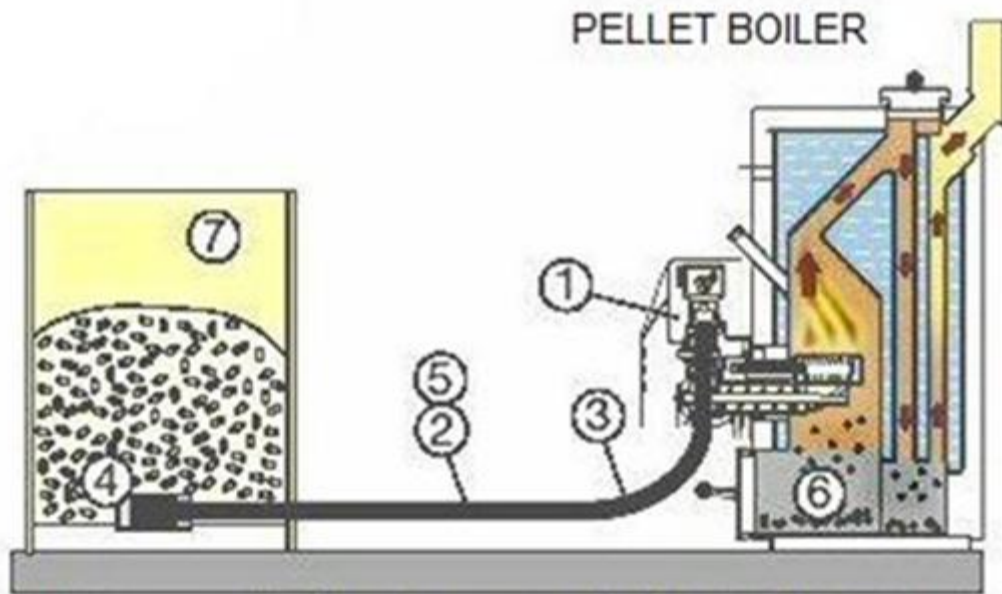
should be no electrical installations like sockets or light switches. The capacity of the big storage room is up to 3 tons of pellets.

For one-family house it is enough to have a completely filled storage room of 4.5 m<sup>2</sup>. The pellets are delivered in the house by a silo tanker once or twice per year. In the figure 10 the wood pellet heating system with big storage room is presented.



**Figure 10. Wood pellet heating system with big storage room. /11/**

The second way is to use the pellet tank. The volume of the pellet tank for one-family house is about 300-500 liters. In this case is needed to store pellets outdoors, because the pellet tank has to be filled every week. Anyway, outdoor storage of wood pellets does not require any capital investment. Pellets can be stored in any dry area or even on a street, on wooden pallets or boards. In the figure 11 pellet boiler with pellet tank is presented.



1 – pellet burner, 2 – flexible pipe, 3 – flexible pipe bend, 4 – flexible auger set, 5 – flex spiral for 8mm pellets, 6 – ash box, 7 – pellet storage 300 liters.

**Figure 11. Pellet boiler with pellet tank. /12/**

## 5. ENERGY CONSUMPTION OF ONE FAMILY

The initial data are taken in accordance with SNIP 23-02-2003 "Thermal protection of buildings" and SNIP 23-01-99 "Building climatology". /12, 13/

### Initial data

Object	one family house
The Area of one family house	200m <sup>2</sup>
Location of one family house	Leningrad region
Heat loss of the building	65 W/m <sup>2</sup> in accordance with SNIP 23-02-2003 "Thermal protection of buildings"
Design outdoor air temperature	-26°C
Average indoor air temperature	20°C
Average outdoor air temperature	-1,8°C
Duration of heating season	220 days
Heat source	electricity, pellets

The heat loss of the building has to be maximum 65 W/m<sup>2</sup> in accordance with SNIP 23-02-2003 "Thermal protection of buildings". The heating season in the Leningrad area lasts 220

days. So we can calculate the value of total heat losses through the building envelope can be calculated by Formula 2.

$$\Phi_T = q * A \quad (2)$$

where:

$\Phi_T$  total heat losses through the building envelope, kW

q is heat loss per  $1\text{m}^2$ ,  $\text{W}/\text{m}^2$

A is area of the building,  $\text{m}^2$

So, total heat losses through the building envelope area  $200\text{m}^2$  makes 13 kW. Assuming, that of hot water consumed, on average, 20% of the thermal energy, we can calculate how much heat energy required for heating and hot water supply by formula 3.

$$P_e = \Phi_T + 0,2\Phi_T \quad (3)$$

Where:

$P_e$  heat energy required for heating and hot water supply

So, heating and hot water demand is 15,6 kW. The power of the boiler has to be 16 kW. Power of the boiler plant has to be taken with a reserve. The boiler in the heating season operates about 12 hours. The annual energy consumption of one family house for heating and hot water supply can be calculated by Formula 4.

$$Q = \frac{D_d * \Phi_t * 24h/day}{(t_{in} - t_{out})} \quad (4)$$

Where:

Q the annual energy consumption of one family house for heating and hot water supply

Thus, the annual energy consumption of one family house for heating and hot water supply makes 39MWh.

## **6. ENERGY EFFICIENCY OF THE HEATING SYSTEM.**

For proving the efficiency of the heating system, it is necessary to conduct an economic analysis and to calculate the cost-effectiveness of the project. The economic efficiency of the project is one of the most important indicators of the success of the project.

An appraising the economic efficiency of the project, it is essential to solve the following three tasks:

- To do qualitative assessment of each heating system and prove its cost-benefit.
- Justify the use of a heating system
- Define non-energy benefits such as CO<sub>2</sub> emissions reducing

For the calculation Jaspri heating systems are used:

- Heat pump JAMA Star
- Jaspri Pelletti 20

### **6.1 Non-energy benefits such as CO<sub>2</sub> emissions**

During the combustion of fuel, there are a lot of harmful emissions of CO, CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>2</sub>, PbO<sub>2</sub> in the atmosphere, leading to the disruption of the ozone layer. The quantity of harmful emissions depends on kind of fuel. For the calculation COP of 4 is taken. The values of carbon dioxide depend on different types of fuel per unit of energy are shown in the table 6.

/14/

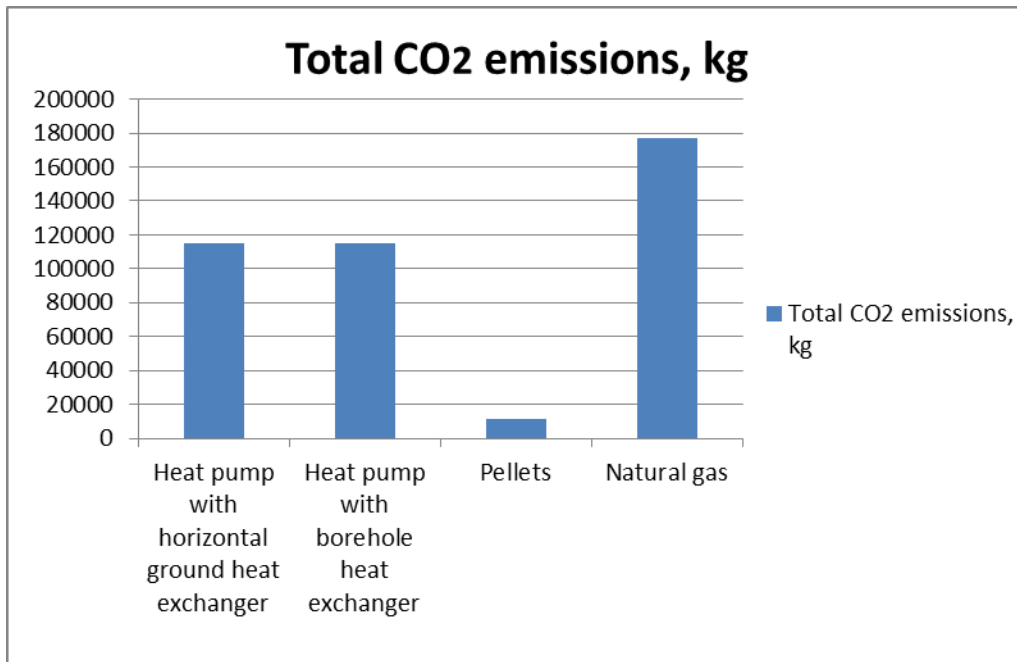


**Table 6. CO<sub>2</sub> emissions of different types of fuel /14/**

Fuel	CO <sub>2</sub> emissions (including production)	Annual total CO <sub>2</sub> emis- sions to heat one family house (39067kWh)	Total CO <sub>2</sub> emissions during 20 years
	kg/MWh	kg/year	kg/20year
Wood pellets	15	586	11720
Natural gas	227	8868	177364
Electricity	590	23050	460991
Heat pump with COP of 4	148	5762	115248

\* This calculation does not include CO<sub>2</sub> emissions from delivery of pellets

As we can see from the table 6, the most environmentally friendly fuel is pellets. Natural gas is in the middle. Production of electricity leads to big emissions of CO<sub>2</sub>. Using a heat pump helps to reduce harmful emissions up to 4-5 times. Total CO<sub>2</sub> emissions during 20 years are shown in Figure 12.

**Figure 12. Total CO<sub>2</sub> emissions during 20 years**

## 6.2. Evaluation of the project cost and payback period

For calculating the payback period of the heating system, it is necessary to know the following input data:

- Capacity of heating plant
- Cost of heating plant
- Maximum annual number of hours of work
- Fuel/electricity consumption per hour
- Cost of fuel
- Frequency of one service
- Price of one standard hour service
- Frequency of current repairs
- Electricity tariff
- heat tariff

Cost (C) of autonomous heating systems consists of the capital (C<sub>c</sub>) and operational (C<sub>o</sub>) costs. The capital costs include the price of the plant and the price of the installation. The operational costs per one year consist of maintenance and repairing cost, fuel cost, service cost and etc. The cost of 1 kWh of thermal energy depending on the fuel is shown in table 7. The cost of 1 kWh of each fuel is calculated in accordance with the efficiency of heating system. All prices are taken in accordance with the Federal Tariff Service of the Russian Federation. /15/.

**Table 7. Cost of 1 kWh of thermal power depending on the fuel.**

Fuel			Specific heat of combustion		$\eta$ /COP	Cost
	Unit	rub	MJ	kWh		
Wood pellets	kg	6	17,86	4,96	0,92	1,21
Natural gas	m <sup>3</sup>	4,24	38,2	10,62	0,92	0,43
Electricity	kWh	3,4	3,6	1	1	3,40
Heat pump with COP of 4	kWh	3,4	3,6	1	4	0,85

Capital costs, operational costs per year and basic requirements of the boiler room for one family house are shown in the table 8.

**Table 8. Capital costs, operational costs per year and basic requirements of the boiler room for one family house**

Basic requirements of the boiler room for one family house, 200m <sup>2</sup>			
	Heat pump with horizontal ground heat exchanger	Heat pump with borehole heat exchanger	JaspiPelletti 20
	electricity	electricity	pelletes
Nominal heat output	16	16	20
Space requirements	400-500 m2, without any capital buildings	70-100 m2, without any capital buildings	no requirements
Requirements for individual heating units	2m <sup>2</sup>	2m <sup>2</sup>	Special room with ventilation
Capital costs, rub			
Design of heating system and boiler room	35000	35000	35000
Cost of equipment	325000	325000	150000
Cost of installation	110000	480000	0
Boiler room installation costs	40000	40000	40000
Cost of the gas project and the main connection	0	0	0
Total cost	510000	880000	225000
Operational costs per one year , rub			
Maintenance per year	3000	3000	5000
Costs for heating season	33206,95	33206,95	47258,47
*1m of borehole costs 2000rub, according the table 3 we need 3 probes at 80m ** On average, the cost of the land in Leningrad region is 3000 rub/m <sup>2</sup> . According the table 6 we need about 480m2 without any capital building. It is about 1 440 000 rub.			

To evaluate the effectiveness of the project costs in net present value should be calculated. Net Present Value (NPV) is the difference between the outflow and inflow of funds can be calculated using Formula 5. Net Present Value should be calculated taking into account the discount factor. /16/

$$NPV = \sum_{n=0}^N F_n \cdot a \quad (5)$$

where

- $F_n$  is the net cash flow in year  
 $a$  is annual discount rate,  
 $N$  is lifecycle of the investments, in years

The annual discount rate can be defined by Formula 6:

$$a = \frac{1}{(1 + d)^n} \quad (6)$$

where

- $d$  is discount rate, %  
 $n$  number of periods, year

As we can see from Formula 6, an annual discount rate depends on the discount rate. The discount rate depends on the time value of money, inflation, type of project and its activities, project participants (foreign or local investors), type of currency and etc. So in Russia the discount rate can be estimated as 5%. The beginning of the settlement period is the date when the first costs are accrued. The time of the settlement period is measured in years. Duration of settlement period is 20 years. Using Formula 6 the calculations of the annual discount rate ( $a$ ) are presented in the table 9.

**Table 9. Changing of the discount rate, depending on calculation period**

Discount rate, d=5% per year			
Number of periods, year, n	Annual discount factor, a	Number of periods, year, n	Annual discount factor, a
0	1	11	0,585
1	0,952	12	0,557
2	0,907	13	0,530
3	0,864	14	0,505
4	0,823	15	0,481
5	0,784	16	0,458
6	0,746	17	0,436
7	0,711	18	0,416
8	0,677	19	0,396
9	0,645	20	0,377
10	0,614		

Using Formula 5 and data from the table 9, the operational and maintenance costs can be calculated in the net present value. All results are presented in the table 10.

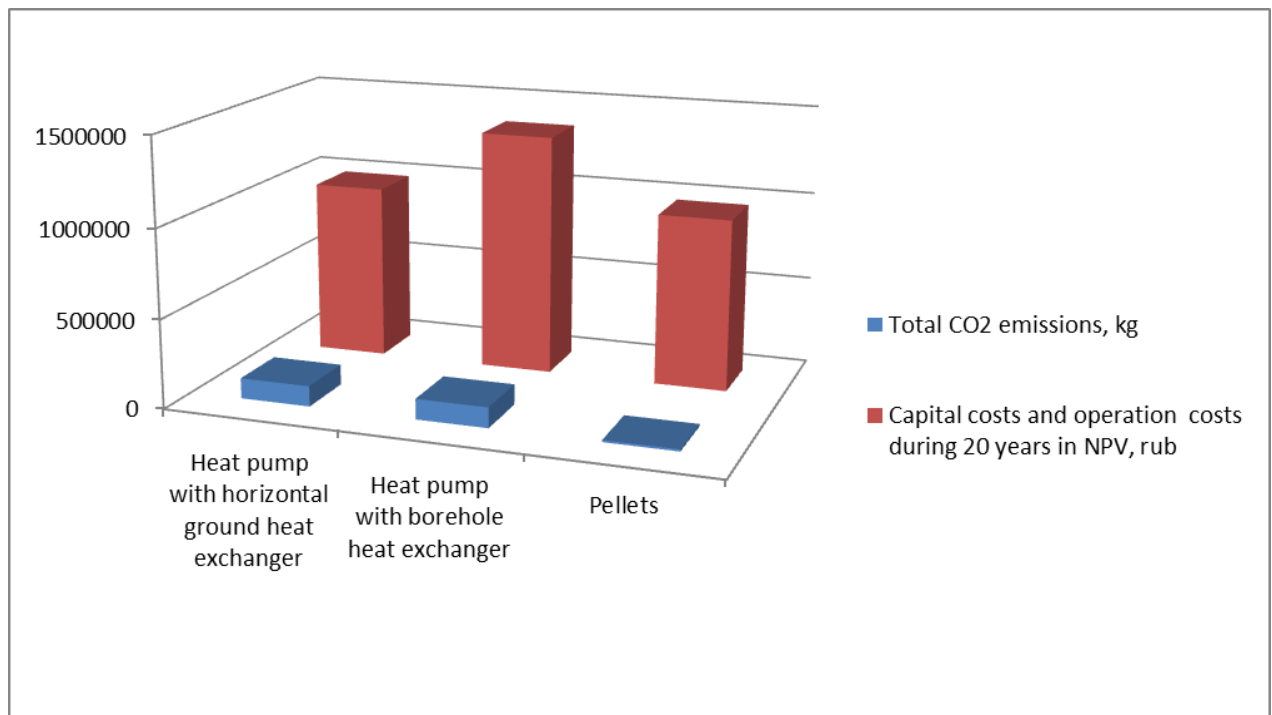
**Table 10. Capital costs and operational costs, taking into account the discount factor.**

Capital costs and operational costs, taking into account the discount factor. Discount rate, d=5%			
	Heat pump with horizontal ground heat exchanger	Heat pump with borehole heat exchanger	Pellet boiler
Capital costs, rub	510 000,00	880 000,00	225 000,00
Operation and maintenance costs during 20 years in NPV, rub	582 641,77	582 641,77	906 126,57
Total costs in NPV, rub	1 092 641,77	1 462 641,77	1 131 126,57
* Capital cost of heat pump with horizontal ground heat exchanger are calculated without cost of the land in Leningrad region			
* Operational costs are not include cost of renovation and refurbishment of equipment			

According the economical calculations and calculations of CO<sub>2</sub> emissions of each heating system, the following conclusions can be done:

As we can see from the table 10, quite similar by the price are heat pumps with horizontal heat exchanger and the pellet boiler but that's assuming that we have enough space and do not need to re-buy an extra piece of land. The most expensive is a heat pump with borehole heat ex-

changers. The pellet boiler is the most environmentally friendly but it is not so convenient to use. The total costs and total CO<sub>2</sub> emissions of the heating system during 20 years are presented in Figure 13.



**Figure 13. Total costs and CO<sub>2</sub> emissions during 20 years of the heating system.**

## 7. CONCLUSION

In the bachelor thesis capital and operating costs, CO<sub>2</sub> emissions of the following heating system were counted: a heat pump with horizontal ground heat exchanger, heat pump with borehole heat exchanger and pellet boiler. A comparative analysis of the integral characteristics of the heating season St. Petersburg and one of the most northern European countries Stockholm also performed.

The heat pump is the environmentally friendly and economical heating system when installed correctly. A heat pump with horizontal ground heat exchanger can be used only in the presence of vacant land. A heat pump with borehole heat exchanger is quite expensive but it can be more effectively used at high power thermal point. In general, this heating system is safe because it is explosion-proof and fire-proof.

The most eco-friendly heating system is a combo boiler on the pellets. The capital costs are quite small but the operational costs are the biggest. The operational costs will increase with

an increase in thermal capacity. Nevertheless, it is the best heating system in the ratio of price and environmental friendliness for one family house.

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