LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
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Environmental Energy Technology

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ENERGY SUPPLY OF DETEACHED HOUSES IN RUSSIA AND FINLAND

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D. Sc. (Tech.)

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ABSTRACT

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Keywords: Heating methods, electricity supply, detached houses, environment.

The problem of choosing the heating system is always relevant when building new houses. Type of energy source (solid fuel, liquid fuel, gas, electricity, alternative sources) is the main issue in choosing the heating system.

The work gives a comprehensive overview of heating methods, determines their advantages and disadvantages taking into account economical and ecological situations in Finland and Russia. Quantitative contribution of single Finnish and Russian detached houses in the overall level of carbon dioxide emissions is estimated when using each method. Comparison of Russian and Finnish energy markets and their impact on electricity pricing is made in the work. The influence of air pollution on environmental offsets according to Russian and Finnish legislative and normative acts is determined.

ACKNOWLEDGEMENTS

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Marina Shestakova

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NOMENCLATURE

Abbreviations

ATS	Administrator of Trading System
CDU	Central Dispatch Administration
CHP	Combined Heat and Power
DH	District Heating
EIA	Energy Information Administration
GDP	Gross Domestic Product
GHG	Greenhouse gases
IDC	Interregional Distribution Grid Companies
IEA	International Energy Agency
IEO	International Energy Outlook
MAC	Maximum Allowable Concentrations
PGC	Power Generation Company
R/P	The Reserves-to-Production Ratio
SO	System Operator
TGC	Territorial Generating Companies
toe	Ton of oil equivalent
U.S.	United States
UES	Unified Energy System

Symbols

c_i	Carbon dioxide emission factor of i-th fuel	[kgCO_2/MWh]
$C_{lim.i}$	Fee rate for the emission of 1 tonn of i-th pollutant within the prescribed limit	[RUB/t]
C_{ni}	Fee rate for the emission of 1 tonn of i-th pollutant within the allowable emission rates	[RUB/t]
CO	Carbon monoxide	
CO_2	Carbon dioxide	
E_{CO_2}	Carbon dioxide emissions from thermal power plants	[kgCO_2/MWh]
K	Inflation factor	
m_i	Actual mass of discharge of i-th pollutant	[t/a]
$m_{lim.i}$	Mass of discharge of i-th pollutant within the prescribed limit	[t/a]
m_{ni}	Maximum allowable emission mass of i-th pollutant	[t/a]
n_0	Duration of the heating period in days by the number of days with a stable average daily temperature is 8 ° c and below	[days]
$N_{lim.i}$	Fee norm for 1 ton emissions of i-th pollutant within the prescribed limit	[RUB/t]
N_{ni}	Fee norm for 1 ton emissions of i-th pollutant in an amount not exceeding the maximum allowable emission limits	[RUB/t]
NO	Nitric oxide	
NO_2	Nitrogen dioxide	
NO_x	Nitrogen oxides	
PM10	Particulate matter less than 10 µm	
P_n	Fees for pollutants emissions into the atmosphere at a rate not exceeding the maximum allowable emission limits	[RUB]

$Q_{0\,a}$	The annual consumption of heat for heating of residential and public buildings	[kcal]
$Q_{0\,av}$	Hourly average consumption of heat for the heating period	[kcal / h]
SO_x	Sulphur oxides	
δ_{atm}	Coefficient of the environmental situation and environmental significance of the atmosphere in the region	
∂_i	Share of fuel in the fuel balance	

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1. INTRODUCTION

Annual demand of energy in the world economy is estimated at 11.7 billion toe. Increased scale of economic activity and rapid growth of population in the world caused a manifold increase in aggregate demand for energy. Meanwhile, minerals and fuels, unlike other natural resources, belong to the non-renewable, non-reproducible. Mineral resources are finite. Despite the application of advanced energy-saving technologies, the increase in world production and consumption increases demand for energy, particularly in developing countries. The sharp rise in prices for fossil energy resources, political instability make us to use forest and agricultural wastes, helio- and geothermal resources in buildings heating and power generation. In this connection it is interesting to examine in more detail the heat-and-power engineering complex of Finland and Russia as two neighboring states, which have mutual interests in economic and political spheres of each other.

The purpose of this study is to determine the differences between Finnish and Russian solutions on the heating organization and electricity supply of detached houses and propose the best options for the future taking into account economical, ecological and technical aspects.

To achieve this goal the next objectives were set:

- to examine methods of buildings heating, such as district and decentralized heating. In the decentralized heating system to study in detail the sources of energy, which includes solid, liquid or gaseous fuels, solar energy, geothermal energy; to consider the principle of selecting of heat-generator;
- to make a review of the system of electricity obtaining from the grid in Finland and Russia and the market of electricity suppliers in both countries;
- to describe typical detached houses located in Russia and Finland and environment of their location;
- to compare heating methods in terms of cost of capital, payment for environmental pollution; to determine the best available technology in each country and compare them with each other;
- to evaluate the results and draw conclusions.

2 HEATING METHODS OF DETACHED HOUSES

The problem of heating is important for Russia and Finland as for countries with cold climate. Russia, as the coldest country in the world, has to spend 0.35 billion toe a year that forms a half of total annual fuel use [Danilov and Timofeeva, 2008].

State of energy industry in Russia is far from ideal. Depreciation of fixed capital stock in Russia on average is more than 50%; in remote rural areas it exceeds 75%. Most of the boiler houses need modernization [Rakitova et al. 2006, 5]. Finland, as a highly developed country, has a well-regulated heat and electricity supply system.

There are two methods of houses heating organization. They are district and decentralized heating. A decision on the choice of heating system type depends on the magnitude and spatial structure of settlement, the density of heat loads and location of subscribers, the type of fuel delivered, as well as the level of social, hygiene and sanitary requirements for the operating conditions and system operation.

2.1 District heating

It is believed that one of the main advantages of district heating (DH) system is low specific fuel consumption. DH is well developed in countries of the European North and has a strong position as the primary method of heating as the Finnish and Russian cities. The share of DH on the heating market of residential sector is shown in Figure 1.

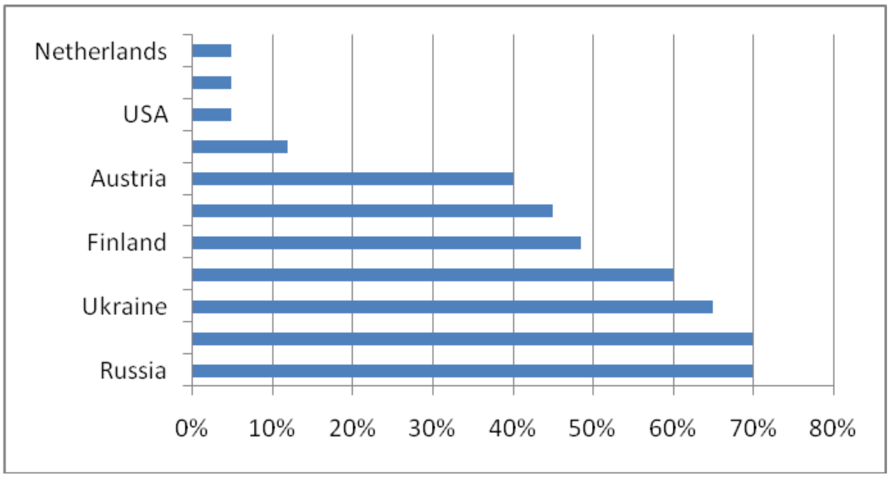

Figure 1. The share of district heating on the heating market of residential sector

As can be seen 48.5% of the buildings are heated with central heating in Finland [District Energiateollisuus, 2010] and 70 % in Russia [Danilov and Timofeeva, 2008].

In most countries, market relations are conducive to the further development of high-tech central heating. Thus, for example in Denmark the market share of DH increased from 30 to 60%, i.e. twice for the past 20 years (since 1985). In Russia, on the contrary, the share of sales systems of DH in most cases is steadily decreasing although still dominant among the heating methods. The heat losses in old pipelines in Russia make up 60% but in order to eliminate the critical wear of networks more than 120000 km of pipelines need to be replaced. In the heating season of 2003-2004 more than 300 thousand people stayed without heating in the middle of winter according to conservative estimates [Marketing Souz, 2005]. Why district heating in Russia is a “headache” of utilities and population but in developed European countries is a way to cheaply and efficiently deliver the heat where it is needed? Consider the advantages and disadvantages of centralized heating.

Advantages:

1. Centralized systems are more economical, since the unit cost of thermal power is lower than that of the decentralized item.
2. DH does not require additional space for installation of the boiler and fuel storage.
3. No need to constantly monitor the performance of its own heating system.
4. Most economical and environmentally friendly fuel and production manner can be used
5. Combined heat and power production derives the maximum amount of useful energy from the fuel burned
6. Efficient air-pollution control is possible
7. Different types of waste can be used for heat production in CHP plants.

The main disadvantages of DH systems include heat and power losses on the routes, but the application of new pipes and insulation, highly efficient pumping equipment can solve this problem and obtain an effective system of central heating.

Analysis of Russian district heating systems shows that:

- technical equipment and the level of technology in the construction of thermal networks correspond to the state 1960, while there was a transition to the new sizes of pipe diameters;
- metal quality of heat pipes, insulation, locking and adjusting valves, construction and laying of heat are considerably worse than European analogs, that leads to great losses of heat energy in the network;
- poor conditions of heat insulation and waterproofing networks have contributed to the increase of damageability of underground pipelines, that led to serious problems of equipment replacement of heating systems;
- Russian equipment of big thermal power station corresponds to the average European level of 1980 and now steam-turbine CHP characterized by a high accident rate;
- there is no cleaning system of flue gases from NO_x and SO_x at existing coal-fired CHP, and the efficiency of solid particulate capture often doesn't reach the required values;
- at this stage competitiveness of DH can only be achieved introducing a special new technical solutions, equipment, energy and heat networks;
- virtual absence of regulation of a heat supply for buildings heating in the transitional periods, when a particularly large influence on the thermal state of heated space has wind, solar radiation.

In addition, traditional modes of DH adopted in practice have the following disadvantages:

- fuel overrun and buildings overheating in the warm periods of the heating season;
- large heat losses during transportation (10%), for Russia is 20% according to Energy Strategy, 2009;
- irrational electricity consumption for transit of heat-transfer agent.

New energy efficient buildings and local heat production (increasingly more efficient heat pumps) are the main problems and competitors, faced by the DH in Finland in recent decades.

Is the DH more profitable than alternative sources of heat? Increasing share of DH systems in the market of many countries, it would seem, gives a positive answer to this question.

However, the profitability of such systems depends on the political, economic and technical conditions in the country and the region, and, of course, depends on the effectiveness of the company, providing DH.

2.2 Decentralized heating

Decentralized heating is more used in the case of houses remoteness from the central heating network. These systems provide a high level of thermal comfort create additional opportunities for energy savings.

Decentralized heating is a system consisting of a heat source and a consumer, heating, hot water supply, ventilation. Roof, built-in or adjoined boiler and boiler-column can be sources for an individual system. At the same time network is absent or has a local character. As a rule, the heat source operates a gaseous fuel in Russia and electric boilers are used in Finland. Liquid fuels and geothermal heat sources are also used.

Objective prerequisites for the introduction of decentralized systems of heating are:

- absence spare capacity at a central sources;
- case when a significant part of building falls on areas with poor engineering infrastructure;
- lower investments and the possibility of phase-coating of thermal loads;
- appearance on the market a large number of different modifications of the heat-generators of low power.

For Russia it is also an ability to maintain comfortable conditions in the house that is more attractive comparing with houses with DH, where the temperature depends on the policy decision about the beginning and end of the heating season.

The most common scheme of decentralized heating includes a single-or double-circuit boiler, circulation pumps for heating and hot water, check valves, closed expansion tanks, safety valves. Plate or capacitive heat exchanger is used in a single-circuit boiler for hot water preparation.

The advantages of decentralized heating are:

- no need to allocate land for heating networks and boiler-houses;
- a significant reduction in construction time;
- the absence of the need to build a chimney;
- low consumption of materials;
- reduction of heat losses due to the absence of external heating networks, water network loss reduction, decrease the cost of water treatment;
- saving electricity at pumping of heat-transfer agent;
- full automation of consumption modes.

Consider the different ways of energy obtaining.

2.2.1 Combustion in boilers

2.2.1.1 General information about energy and fuel balance in Russia and Finland

Energy fuel is combustible substances which can be economically effectively used for receiving of large amounts of heat for industrial goals. Its main categories are organic fuels such as peat, oil, shale, coal, natural gas, refined petroleum products.

Total geological reserves of mineral fuels on our planet exceed more than 12.5 trillion tons, of which more than 60% is coal, about 12% oil and 15% natural gas, the rest is shale, peat and other types of fuel [Zheltikov, 2001]. Fuel and energy balance of Russia and Finland are presented in Fig. 2 and 3 respectively.

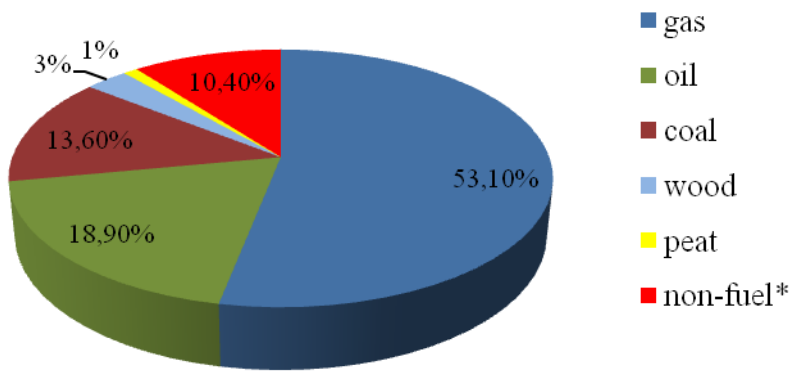

Figure 2. Fuel and energy balance of Russia [Energy Strategy, 2009]

*atomic and other renewable

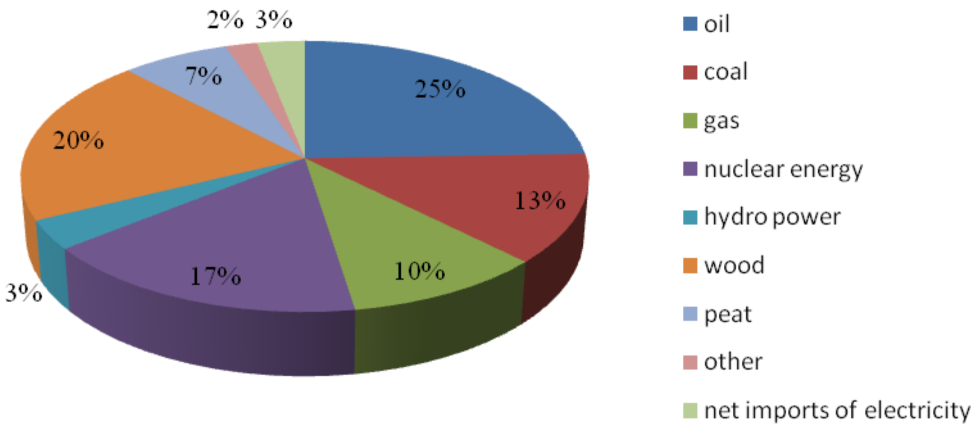

Figure 3. Fuel and energy balance of Finland [Statistics Finland, 2008]

Domestic consumption of fuel in the production of electricity and thermal energy is amounted to 693.7 million toe in Russia in 2008 [Energy Strategy, 2009]; 50.1 million toe in Finland [Statistics Finland, 2008].

BP estimates the current R/P ratio for natural gas at 67 years (Grote. 2007, 5). Natural gas resources are more evenly distributed than oil resources. Figure 4 presents the distribution of natural gas resources. Over the recent years, the projections for natural gas have varied. Natural gas is the fastest growing type of fuel. However, IEA WEO 2009 gives this designation to coal and states that the share of natural gas also rises, even though gas use grows less quickly than projected in earlier projections, due to higher prices.

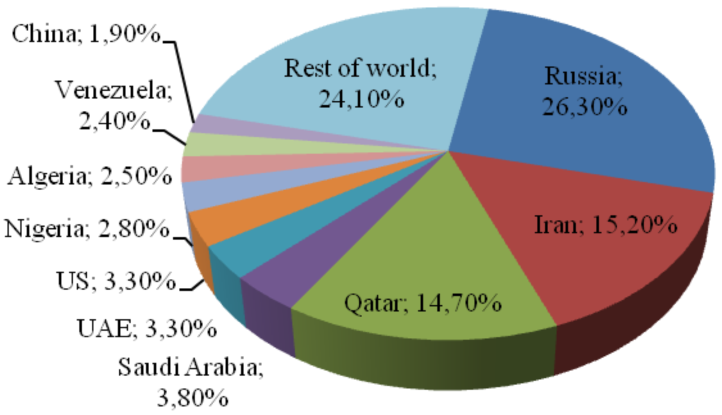

Figure 4. World natural gas reserves. [Nylund et al. 2008]

Coal is the most abundant fossil energy source in world with reserves of around 1 x 10^{12} tons (1 trillion tons) distributed in many countries. The largest coal reserves are found in the U.S., Russia, China, India and Australia (EIA IEO 2009). R/P for coal is 100 years at current demand. However, if utilization of coal is strongly increased with increasing demand in electricity and liquid fuels (e.g., in China), the reserve of coal begins to drop dramatically.

The total estimated amount of oil in an oil reservoir, including both producible and non-producible oil, is equal 1,292.6 billion barrels. The greatest oil reserves by countries are shown in Figure 5.

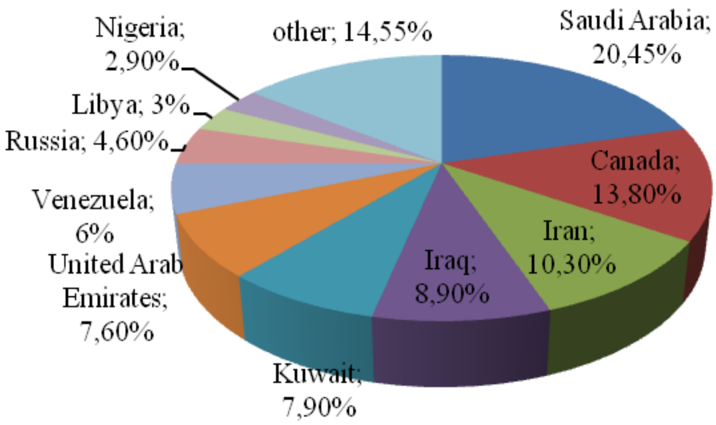

Figure 5. Greatest oil reserves by country [Infoplease, 2006]

Finland lacked petroleum, gas, and coal reserves, but at the same time Finland is the most forested country in Europe. Forests cover 86 percent of its land area [Forest.fi. 2010]. Finland's share of the world's total forest resources is about 0.5%, and of the world's coniferous forests is about 1%. Timber complex is well developed in Finland. Biomass-based fuels have traditionally included residues from the chemical and mechanical forest industry, and firewood used in heat and energy production. Finland leads in the use of bioenergy in Europe. The share of biofuels in Finland used for electricity and heating is equal to 27% (see Figure 3).

Production of wood pellets began in Finland in 1998. Today pellets produce more than 10 companies, the total capacity of about 240 thousand tons per year. The rapid development of bioenergy was reached by a national energy policy and stimulatory approach of local authorities. Increased use of biofuels has been supported by taxation, based on the CO_2

content of fuels. Tax on CO_2 was introduced already in 1990. Today the tax is 18.05 Euros per ton of CO_2 in the production of heat from fossil fuels, biofuels are released from it. Taxes for the peat are lower and manufacturers are exempt from tax with an annual production of heat less than 25 GWh. In addition, several incentive programs have been conducted; most of them are connected with regional development and employment. For example, a subsidy of up to 40% of investment cost can be obtained from some of the funds for renewable energy projects.

Peat deposits are extensive in Finland and equal 1100 Mtoe, peat lands cover 28% of the country. The share of peat in the energy balance, on average is 5 - 7%, with significant changes depending on weather conditions [Vares et al. 2005, 26, 27].

In Long-Term Climate and Energy Strategy of Finland, 2008 one of the purposes is the increase of renewable sources use to 30% by 2020.

The total area covered by forests in Russia occupies 45% of vast its territory. Russian forests are estimated to contain 776 million hectares of forestland, or nearly 23% of the total forestland in the world [Global Forest Watch, 2010]. 4.9 million hectares of land belong to Forest Fund of Russia in the Leningrad Region; wood reserves are estimated at 865 million m^3. About 6 million m^3 of wood and wood residues are used while from third to half of the waste is not used. The export of raw wood from Russia was 40 million m^3 in 2003. China (35%), Finland (33%), Japan (12%) and Sweden (7%) are the largest buyers of Russian raw wood. The import of forest products to Russia was about 2 billion EUR in 2003. [Heinimö and Alakangas 2006, 73]. In 2008, the share of peat in the energy balance of Russia amounted to less than 1%. In the Leningrad Region (including St. Petersburg) the share of biofuels in the energy balance was equal 2.7%. Biofuels are used in the 232 municipal boiler houses; some preparatory work has been done in 47 boilers for the biomass introduction. In recent years, 9 factories producing wood pellets with an annual capacity of more than 120 thousand tons started to work in the Leningrad Region [Vares et al. 2005, 28].

When combusting a fuel certain amount of sulfur ash and carbon dioxide is emitted. Indicators for different fuels are presented in Table 1.

Table 1. Typical emission factors

	Carbon dioxide		Sulphur dioxide		Ash
Fuel	**gCO_2/MJ**	**$kgCO_2/MWh$**	**$mgSO_2/MJ$**	**gSO_2/MWh**	**kg_{ash}/MWh_{fuel}**
Milled peat	105.9	381.6	200	720	10
Sod peat	102	367.6	180	650	8
Peat pellet	97	349.2	155	558	7
Wood	109.6*	394.2	25	90	4
Blend, milled peat 70% and wood 30%	74.1	266.8	139	500	8
Heavy fuel oil	78.8	283.76	464	1 670	0
Light fuel oil	74.1	266.8	85	306	0
Natural gas	55.0	198.0	0	0	0
Coal	94.6	340.6	705	2 538	14

* Carbon dioxide emissions of wood fuels are not calculated into greenhouse gas emissions, because their net emission effect is 0. Source: Statistics of Finland. 3 April 2006

According to the Energy Strategy of Russia, 2009 the following indicators must be achieved:

- increase the share of coal in the fuel consumption by thermal power plants from 26% to 34 - 36%;
- decline in the gas share in the domestic consumption of energy resources from 53% to 46 - 47%;
- decrease in the gas share in the fuel consumption by thermal power plants with 70% to 60 - 62%;
- increase in the relative volume of production and consumption of electrical energy using renewable energy sources (except hydropower installed capacity of more than 25 MW) from about 0.5% to 4.5%t;
- increase in the proportion of peat use in the energy balance of regions from 1 - 2% to at least 8 - 10%;
- increasing share of non-fuel energy from 11% to 13 - 14%.

2.2.1.2 Choice of heat-generator

A large choice of models of boilers and their modifications is offered on the market today. Modern boilers have to meet, first of all, the following requirements:

- high efficiency (90-92% for gas and liquid fuel boilers, 95 - 98% for electrical, not less than 80% for solid fuel);
- safety in the work;
- the standard period of service should be equal at least 20 years;
- a high level of automation of the heating complex;
- economical and environmentally friendly;
- required power;
- possible diversion of flue gases;
- functionality;
- investment, operating costs and profitability;
- boiler material (steel or cast iron).

All boilers are divided into single-circuit and double-circuit. Single-circuit boilers are designed only for house heating (hot water comes from a separate hot water heater); double-circuit boilers are designed for both heating and for hot water preparation.

The main types of boilers classification are given in Table 2.

Table 2. Classification of household heat-generators

By way of installation.	Hinged, floor
By type of energy source	Solid fuel, gas, liquid fuel, electric, multifuel
By way of preparation of hot water	Single-circuit with an external boiler, double-circuit with a built boiler, double-circuit with a flow-through water heater
By burner type	Atmospheric single-stage, two-stage, with smooth modulation, double; ventilation single-stage, two-stage, with smooth modulation.
By traction type	Natural, forced without air, forced with air (pipe in pipe).
By material of the main heat exchanger	Cast iron, steel, stainless steel, copper
By bundling	Full, partial, without a complete set
By electrical dependence	Electrical independent, electrical dependent without self-starting, electrical dependent with self-starting
By type of heat-transfer agent	Only water, water and antifreeze, air, direct electricity

Boilers of various designs can operate at one form of fuel, and can be multifuel. At present, almost all of Russian and most European firms produce boilers operating on gaseous and liquid fuels. There are universal boilers working for 4 types of fuel such as solid fuels, gas, diesel and electricity (boilers brand Ziosab-45 and CS-DVT-20E produced in Russia and the Finnish Jama and Jaspi). Electricity is used in emergency cases.

Currently a wide range of boilers types operating on biofuels is developed in Europe. Typical boilers power depends on the method of fuel combustion and is given in Table 3. Classification of boilers depending on its scope is shown in table 4.

Table 3. Typical boilers power with different fuel incineration methods [Vares et al. 2005, 78]

Combustion technology	**Minimal power, MW**	**Typical power, MW**
Furnace with a fixed grid	0,01	0,05 - 1
Mechanical grate-fired furnaces	0,8	2 – 15
Bubbling fluidized bed	1	>5
Circulating fluidized bed	7	>20
Gasification	0,3	2 - 15

Table 4. Classification of boilers depending on its scope

Scope	**Typical power**
Private houses	15 – 40 kW
Big buildings	40 – 400 kW
Central heating boilers	0,4 – 20 MW

Nominal thermal power of boiler is the main technical indicator, which determines the main consumer and operational qualities. Boilers produced in Russia are usually unpretentious to the gas pressure that is important for most of Russian gas networks, and relatively cheap. But they concede the Finnish those on their energy efficiency, environmental friendliness and ease of use. On the other hand, the Finnish equipment is not always adapted to the conditions of operation in Russia. Most Finnish burners meet the stated specification at a pressure of 180-200 mmH_2O that is not always possible in Russian natural gas network (for example, pressure of gas network is rarely rises to 100 mmH_2O in winter). As mentioned above (see table 2), heat-generators can be classified by heat-transfer agent. Let’s consider the difference between hot-water heating and air heating. In Russia the hot-water heating is the most common form of heating. The popularity of water heating is explained due to a number of advantages. They are:

- economical material consumption for water heating pipeline;
- high heat capacity of heat-transfer agent (e.g., heat capacity of water is to 4000 times more than heat capacity of air, heated to the same temperature);
- creating a comfortable temperature**.**

Scheme water heating of house works due to natural or forced water circulation. The water moves under the influence of hydrostatic head in the natural circulation arising due to difference in the density of the heated and chilled water. Movement of water occurs under the action of the circulation pumps in systems with forced circulation. Forced circulation is used in case of a considerable length of the pipeline. This system needs an uninterruptible electricity supply. Single pipe scheme is shown in Figure 6.

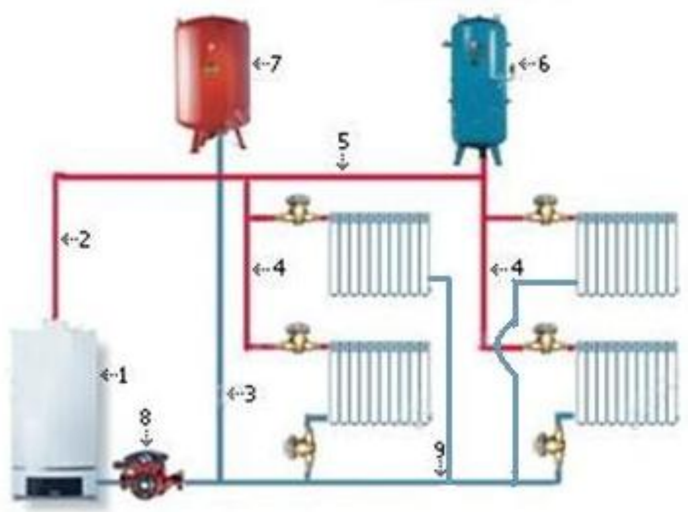

Figure 6. Single pipe hot water heating scheme. 1 – boiler; 2 – main riser; 3 – expansion pipe; 4 - return riser; 5 – overhead distribution; 6 – air collector; 7 – expansion tank; 8 – circulation pump; 9 – return line.

In single pipe scheme hot water given off heat on the top floor comes to the floor below with a temperature lower than at the outlet from the boiler. The temperature decreases with the passage of each subsequent floor. In single-tube circuit water velocity does not change, and the temperature is reduced after each floor.

Water temperature at the inlet to the radiator at all floors is equal, but the speed and pressure are different in double-pipe scheme (see Figure 7).

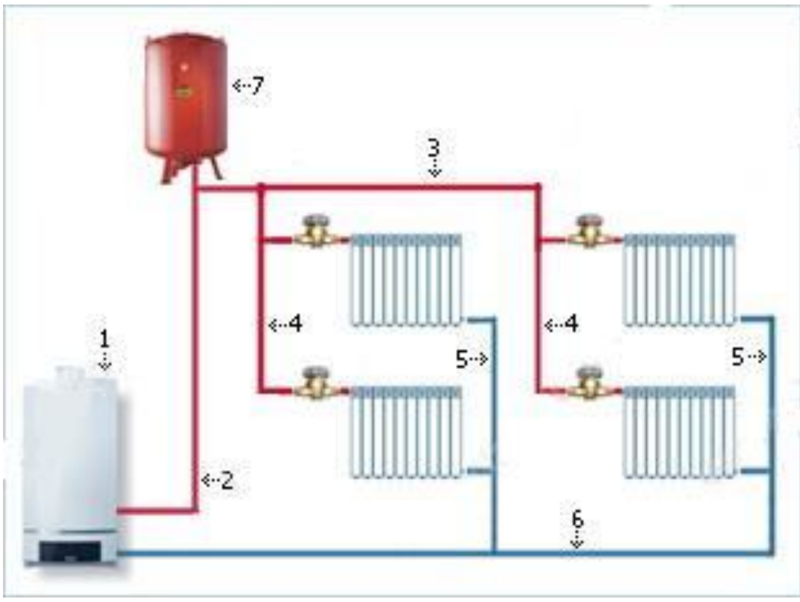

Figure 7. The overhead water distribution system. 1 – boiler; 2 – main riser; 3 – distribution pipe; 4 – hot risers; 5 – return risers; 6 – reverse pipeline; 7 – expansion tank**.**

As shown in Figure 7 the water is heated in the heating boiler, goes up the main riser in the expansion tank. Expansion tank is installed at the highest point of the system. Then water goes to the hot risers through distribution pipe. Hot risers and radiators are set on each floor. Chilled water passes through all floors in the reverse pipeline. The coolant returns back to the boiler for heating. The inlet valves are set at the entrance to the radiator heaters to balance the flow of hot water.

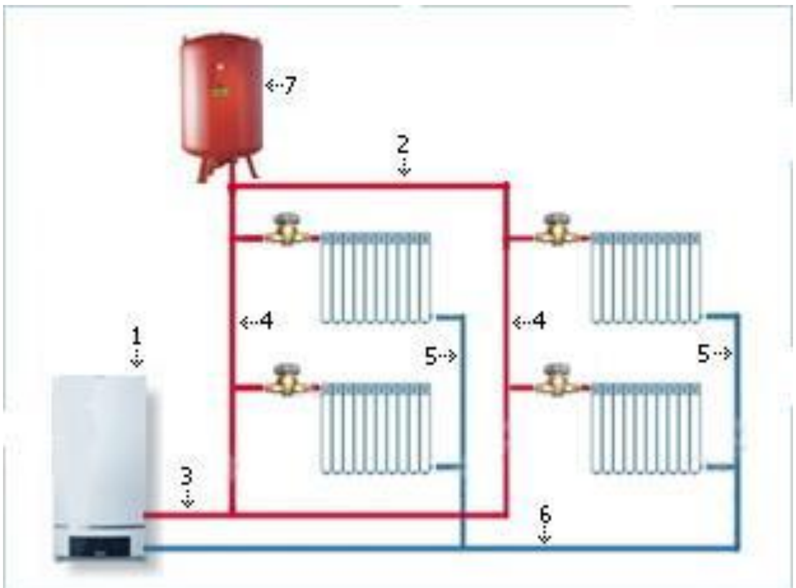

Figure 8. Lower water distribution system. 1 – boiler; 2 – air-line; 3 – distribution pipe; 4 – rising main; 5 – return risers; 6 – reverse pipeline; 7 – expansion tank**.**

The water rises through distributing pipelines and enters to radiators at the overhead and lower distribution systems (see Figure 8). It cools and becomes heavier. Then it flows to the reverse pipeline and enters the boiler. With high density, cold water displaces hot one up. In the given schemes, the pressure is created by the difference of the density of hot and cold water pillars.

In the scheme with the lower water distribution the delivery pipeline, which feeds the risers, is located below the living quarters. Inverse risers are connected to a common reverse pipeline, which is installed below. The air line at the top complements such water heating scheme. The air accumulating in the radiators is removed through the air line. It is released into the atmosphere through the expansion tank.

Air heating is a relatively new system. This system is a set of fans, which direct the warm air and, thus, heat an area. Air heating has several advantages over hot-water heating. They are:

- air heating system is fully automated;
- not need to conduct any additional pipes;
- air heating system allows to select any air (a cool, fresh from the street or wet).

Air heating system is shown in Figure 9.

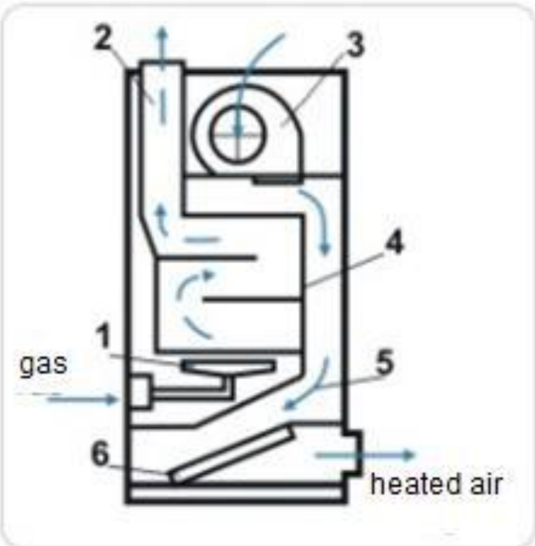

Figure 9. Air heating system. 1 – gas burner; 2 – chimney; 3 – fan; 4 – air-gas heat exchanger; 5 – heating conduits; 6 – air filter.

The main element of the cottage air heating is air heater. It works on gas or diesel fuel. Heat obtained by burning gas or diesel fuel is transferred to the air which is injected by fan. After cleaning in the filter the hot air flows into the heated space by means of air ducts. Combustion gases are removed into the atmosphere through the chimney. Air ducts are linked to the heater. Fence of cold air from the premises provides a return air ducts system for its subsequent heating in a furnace. Thus, recycling of indoor air is achieved. If necessary, a part of air can be taken from the street by means of the opening of special chokes. This provides ventilation. Such system can be used in heating and ventilation mode. Floor-gas-air heater or diesel-gas-air heater is most applicable as a heat-generator. Installed diesel burner is easily replaceable on the gas one.

Modular boiler plants can be attributed to **decentralized heating systems** one of those is shown in Figure 10.

Figure 10. Modular boiler plant

They represent a container made of prefabricated elements. Protecting designs are made of construction materials such as "sandwich" which meet the requirements for fire safety and climatic conditions. Boilers, heat exchangers, pumps, electricity, gas and water supply are mounted inside the container. Typically, automatized boiler plants of container type are produced in the factory and delivered to customers in fully finished form. It only remains to connect it to external networks of electricity, gas and water supply and heating system of the buildings. The undeniable advantage of prefabricated boiler plants is their mobility and the ability to heat small settlements. The main types of classification of modular boiler plants are given in Table 5.

Table 5. Classification of modular boiler plants

By installation type	stand-alone boiler plants, attachable boiler plants, roof boiler-plants
By fuel type	gas, diesel, mazut, biofuel; multifuel boiler plants: oil-gas boiler plants, gas-diesel boiler plants
By type of production	steam boiler plants and hot-water boiler plants

2.2.2 Solar

One promising solution to the problem of rational use of natural resources and environmentally friendly fuel is to use renewable solar energy for heat supply of innovative energy-efficient buildings. The efficiency of energy conservation of buildings with using solar energy depends on technical solutions, climatic conditions and the radiation regime of the territory.

Every year about $5 \cdot 10^{24}$J of energy comes to the Earth with solar radiation. Energy flux density is equal 1360 W/m^2 within the Earth's atmosphere. Economically viable area of application of such systems is the regions located below the 50 degrees north latitude [Polonskiy et al. 2006, 50].

Solar collectors of various types can receive heat energy, which is primarily used for hot water preparation, which is especially important during the summer season. Moreover the heat from solar collectors can be used in various heating systems at the construction of combined boiler plants during periods of transition in areas of high solar activity.

All solar collectors are conventionally divided into flat plate collectors and evacuated tube collectors.

Flat plate collectors shown in Figure 11 represent the absorber, the element that absorbs solar radiation and connected with the heat-conducting system.

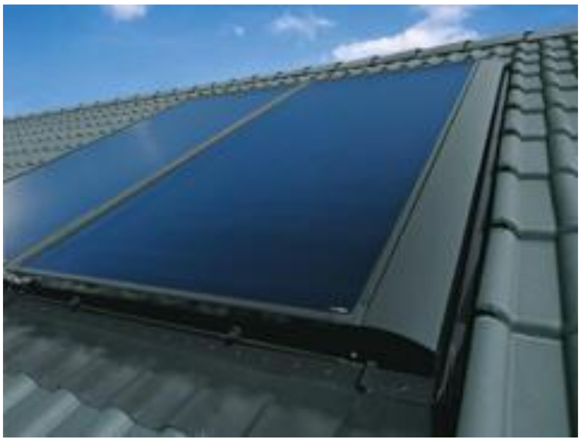

Figure 11. Flat plate solar collector

The element is covered with a layer of transparent material from outside. Most of the coating is made of special tempered glass with the minimum metal content. The reverse side is covered with heat insulator to reduce heat losses. If the heat is not transferred to external consumers, a flat plate collector is in a position to heat the intermediate coolant up to 140 ^{0}C. Currently special optical covering is being developed and implemented. As copper has the highest thermal conductivity, it has become the main raw material for the production of the absorber.

The main part of evacuated tube collectors which is shown in Figure 12 is a special vacuum tube covered with darkening for heating.

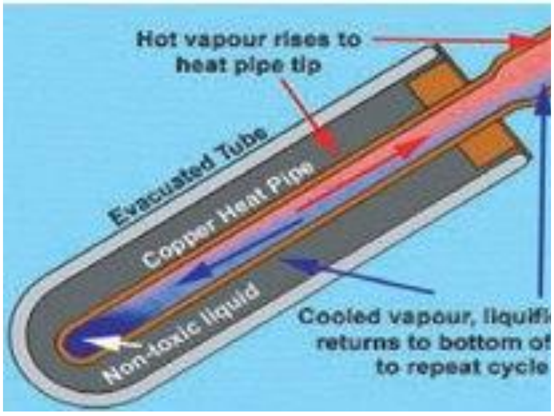

Figure 12. Evacuated tube collectors

Water or antifreeze is inside of it. The whole construction is made on the principle of the thermos device. A kind of vacuum chamber is created around the cavity which is filled with liquid to reduce unproductive heat loss. Using this element the water can be heated even if the ambient temperature is minus.

Internal vacuum tubes are made faceted shape or form letter «U» to improve the efficiency of appliances. The outer shell of the tubes is made from borosilicate glass which is improved durability and a long time does not lose its optical properties.

Inside the evacuated tube is a liquid having a lower boiling point, for example, ammonia. One end of the tube is inserted into the heat exchanger tank. When heating from solar radiation the liquid begins to boil, steam rises up and transfers heat to the heat-transfer agent which circulates in the general collector. Solar collectors with similar tubes are the most effective solar collectors. In addition to increased efficiency they are extremely resistant to mechanical stress.

Exploitation of solar installations gives following benefits:

- significant reduction of costs for heating and hot water;
- reduced operating costs;
- increase the lifetime of the auxiliary heating system.

Currently, a full line of high-quality equipment such as solar collectors, heat accumulators, solar stations, pump groups is produced by Viessmann, Buderus, Vaillant, Wolf, Jaspi, TiSUN et al. companies.

2.2.3 Geothermal energy

Earth interior have huge reserves of energy. The surface of the planet is divided into three geothermal areas. They are hyper thermal, semi thermal and normal. Hyper thermal region with a temperature gradient of over 80 ^{0}C/km is the most preferred for the construction of geothermal power plants. Semi thermal area has a temperature gradient from 40 to 80 ^{0}C/km. Quality of geothermal energy is usually low and it is better to use it directly for heating buildings and other structures. Normal thermal region has a temperature gradient of less than 40 ^{0}C/km. Low-potential heat can be used only in conjunction with thermo transformer or heat pump.

In the past decades, large-scale program for energy savings realized in the world involves extensive use of heat pumps and heat pump systems of heat and cold supply.

Heat pump is a compact heating installation designed for decentralized heating and hot water supply of residential and industrial premises. The principle of heat pump is shown in Figure 13.

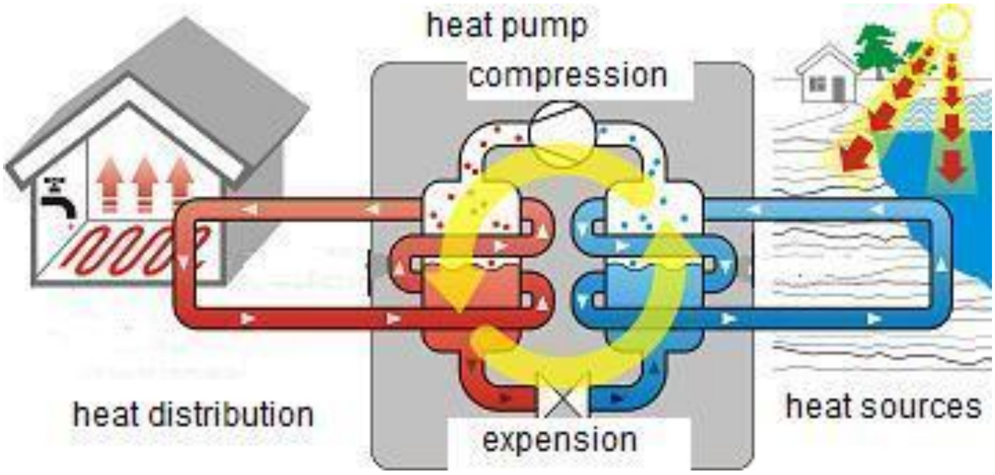

Figure 13. The principle of heat pump work

The heat pump is very economical and can produce up to 4 - 6 kW of heat energy consuming just 1 kW of electricity. The heat pump works on the principle of the refrigerator (or air conditioner). It takes heat from the environment and gives (transfers) its to the house. Heat pumps as refrigerators do not require maintenance to 30 years.

The main benefits of heat pumps are:

- no need for an oil or gas boiler;
- can provide all heating and hot water needs;
- save up to 85% in energy costs against conventional systems;
- no need for gas connections or fuel tanks.

There are several heat collection methods. They are horizontal closed ground loops, vertical closed ground loops, vertical open loops and closed pond loops. The main options for heat collection are represented below.

Horizontal closed ground loops are shown in Figure 14. In a case of available land this is normally the most cost effective method. Polyethylene pipe is laid in trenches approximately 1 m deep and a mixture of water and anti-freeze is circulated to collect energy from the ground.

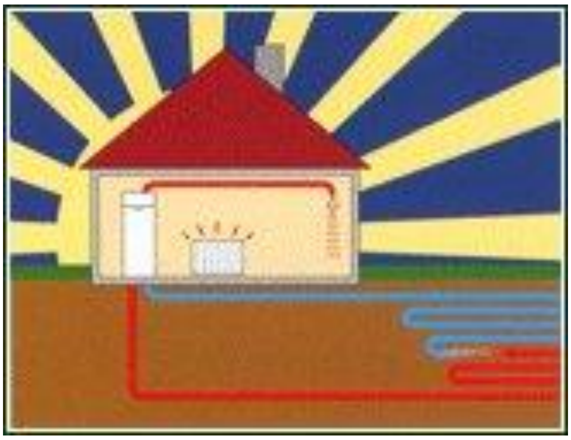

Figure 14. Horizontal closed ground loops

Vertical closed ground loops are represented in Figure 15. In a case of a space lack vertical boreholes may be the answer. They can range from 25 m – 150 m deep but can be expensive depending on the location. A closed U-tube is placed in the borehole and a mixture of water and anti-freeze is circulated to collect energy.

Figure 15. Vertical closed ground loops

Vertical open loops are shown in Figure 16. This type of loop system may be cost-effective if ground water is plentiful. Ground water from an aquifer is pumped to a heat exchanger then transfers its heat to the heat pump. After it leaves the building, the water is pumped back into the same aquifer via a second well, called a discharge well, located at a suitable distance from the first.

Figure 16. Vertical open loops

Closed pond loops are represented in Figure 17. This type of loop design may be the most economical if your building is near a body of water such as a large pond or lake. The brine circulates underwater through polyethylene piping in a closed system. Because it's a closed system, there are no adverse impacts on the aquatic system.

Figure 17. Closed pond loops

Danfoss, OCHSNER, Lämpössä and others represent a full line of geothermal high-quality equipment on world market.

2.2.4 Electrical heating

Direct electric heating is the most promising in Russia and the most popular form of heating in Finland. The premises are heated without the heat-transfer agent. The electrical energy is converted into heat without any intermediaries. Electric heating of houses require good insulation because otherwise the owner will pay the high cost of electricity. Electric heating is the best of modern forms of heating from the standpoint of security for tenants.

Electric heating of houses has many significant advantages including:

- ease and convenience of system maintenance;
- effective control the heat supply;
- small dimensions of heating appliances, which do not require special care;
- high hygiene and environmental advantages of electric heaters;
- quietness of heating system.

The only disadvantage of electric heating is its high cost. Cost per unit of produced heat with electrical heating is several times higher than in the heat generation in boilers. This disadvantage can be reduced by using systems with storage water tank. In such systems, the electrical energy is used for heating the heat-transfer agent (water) at night, when preferential tariff for electricity acts. In the daytime the heating uses heat accumulated during the night. At the same time consumption of electricity during the day is significantly reduced or completely eliminated.

Electric heating can be carried out through:

- electric boilers;
- wall and plinth heaters;
- cable and film systems for heating the floor and ceiling;
- ceiling infrared long-wavelength heaters.

Currently there are two main types of electric boilers: tubular electro heaters, electric boilers and electrode boilers.

In **the electrode boilers**, hot water is heated because of pass through it alternating electrical current. The voltage applied to the electrodes placed in water ionizes it. The phenomenon of electrolysis is not observed, as the cathode and anode are constantly changing places with the frequency of the electrical network. Structurally, the electrode boiler is a container with electrodes placed in it. It acts as a flow-through water heater. The main feature of the electrode boiler is very high efficiency about 96 - 98%. The water in the electrode boilers is both a heat-transfer agent and an element of an electrical circuit. Therefore it must have some conductivity and some resistance to avoid short circuit. For instance, distilled water cannot be used in the boilers because of its low conductivity. Self-adjustment depending on the desired temperature is another one advantage of such boilers. Electrode electric boilers are disconnected automatically at the electrical short circuit, leakage of heat-transfer agent and excess of predetermined temperature.

Work of **wall and plinth heaters** are based on the phenomenon of convection (circulation) of air, resulting in more than 80% of heat is given to the air. Due to high moisture protection and reliability electrical convectors can be installed in bathrooms and children's rooms as the temperature on the surface does not exceed +60 ^{0}C. Principle of operation of the wall heaters is shown in Figure 18.

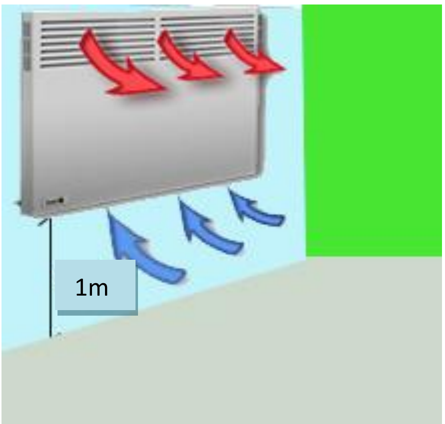

Figure 18. Principle of operation of the wall heaters

Work of heaters is based on heating the incoming cold air of a room into the instrument. Heating is carried out by a heating element made of conductive component. After heating the air is increased in volume and risen up through the blinds of the output lattice. Additionally, the air is heated by heat radiation from the surface of heaters.

The advantage is there is no maintenance costs and prevention together with the overall low cost of equipment.

Disadvantage of heaters is that they warm up the room uneven in height. Warm air is accumulated near the ceiling while the floor temperature is low. Other disadvantage is dependence on electricity when it is turned off, in addition circulating flows entrain a dust. Nowadays some companies offer models of heaters that reduce the collection of dust around devices.

Electric warm floor is a built-in cable heating system. A cable is used as the heating element in the system of electric warm floor. Floor temperature is fixed and regulated by thermostat. Electric warm floor is used for heating of various types of industrial and residential premises and premises of social and cultural sphere. Mounting of the floor with the electric heating is shown in Figure 19.

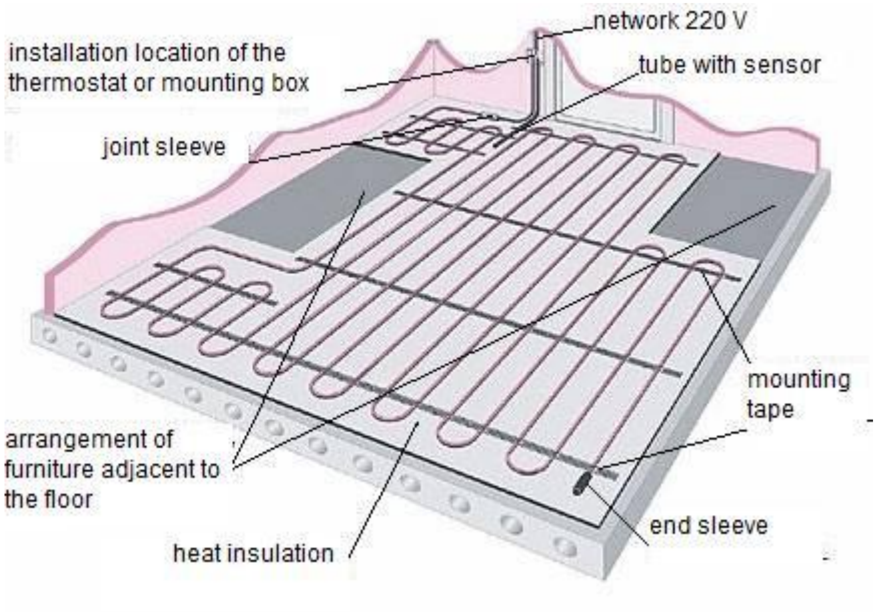

Figure 19. Mounting of the floor with electric heating

All surface of the floor or wall turns into a large working panel, evenly radiating heat during the work. The floor temperature is a few degrees higher than air temperature, which creates a soft, perfectly comfortable heating for a human. Electric floor heating system can be arranged using a heating cable or a heating mat. Heating cable is the main element of the electric floor heating. In fact, it is a conductor with high resistance, which is heated by passing electric current through it. The heating cable laid on the plastic thermo stable mesh and fixed on it by fixing belt is called a heating mat.

The advantages of warm floors are:

- their use doesn't engage in effective area of the premises;
- decreasing temperature heating of surfaces compared with conventional radiator and convector systems, as well as equalizing temperature in height of heated premises.

Infrared heaters are the latest achievement in the development of systems of direct electric heating and are designed for space heating of any type. They are fixed on the ceiling and emit the flow of energy in the infrared range of frequencies, which like the sun don't heat the air and transfer heat to the surrounding objects. By the nature of the emitter luminosity the infrared heaters can be divided into luminous and long-wave heaters.

Infrared heaters can work on different energy sources. Electric infrared heaters are often used for rooms heating. The most popular brands are infrared heaters of Frico and General which are shown in Figure 20.

Figure 20. Infrared heaters of the Swedish Frico company

Luminous infrared heater is a special chandelier or radiating panel with a surface temperature over 600 ^{0}C. These heaters are used where a lot of heat is needed. A surface temperature of long-wave infrared heater is less than 600 ^{0}C. They are used in premises and indoor greenhouses. Permissible temperature of the radiating surface is 100 - 120^{0}C for residential buildings with a ceiling height 2.5 – 3.5 m.

3 ELECTRICITY SUPPLY FROM GRID IN RUSSIA AND FINLAND

Electricity is basic sector of economy of any country, providing the needs of the economy and population in the electrical and thermal energy; largely it determines the sustainable development of all sectors of the economy. Effective use of electric power industry potential, setting priorities and parameters for its development create the necessary preconditions for economic growth and improve the life quality of the population.

Finland is one of the top countries in Europe in electricity consumption calculated per head which is about 10 MWh/a (Ymparisto.fi, 2007). This is because of Finnish industrial structure and its location. Industry accounts for about half of total electricity consumption. Housing and agriculture account for approximately a quarter of total electricity consumption. Total electricity consumption in Finland is shown in Figure 21. In Finland, amount of electricity produced per 24 hours averages 8600 MW. The share of plants in electricity production is represented in Figure 22. It is interestingly to notice that electricity imports from Russia covers approximately 14% of Finnish electricity demand (Kinnunen 2006, 2828).

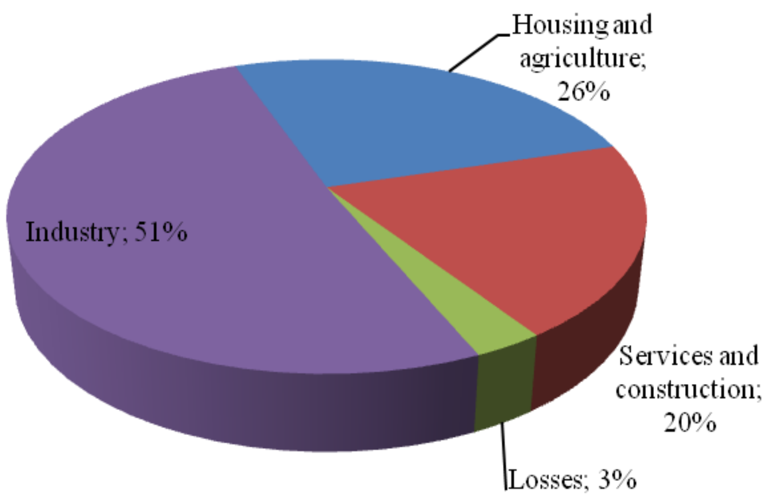

Figure 21. Total electricity consumption in Finland. **[**Kauniskangas 2010, 8]

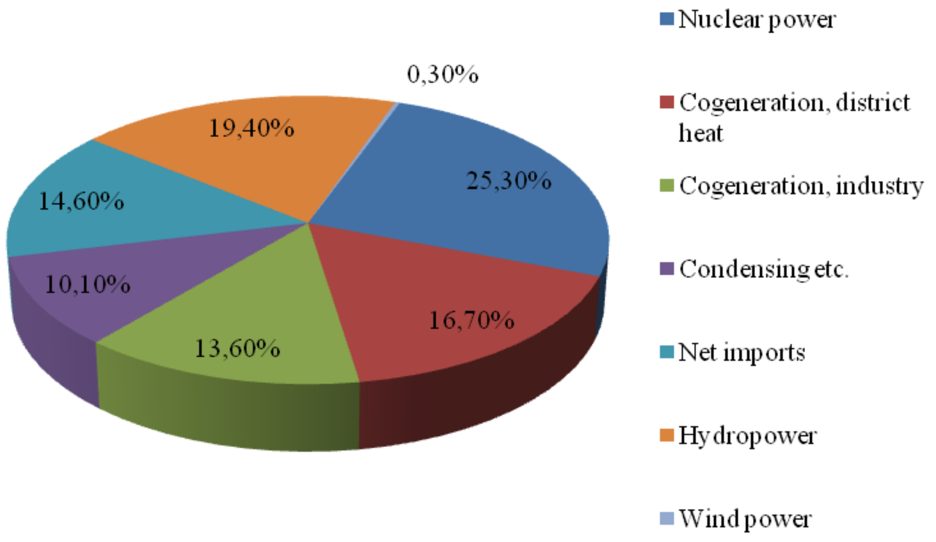

Figure 22. Net supply of electricity in Finland. [Kauniskangas 2010, 8]

Modern Electric Power Complex of Russia includes nearly 600 power plants with unit capacity of more than 5 MW. The total installed capacity of power plants in Russia is 220 000 MW. The main burden of electricity generation in Russia performs cogeneration power plants. Installed capacity of existing power plants by generation type of is shown in Figure 23 (Ministry of Energy of the Russian Federation. 2010). The share of renewable sources such as geothermal and wind power in total electricity production is less than 1% and they can be neglected.

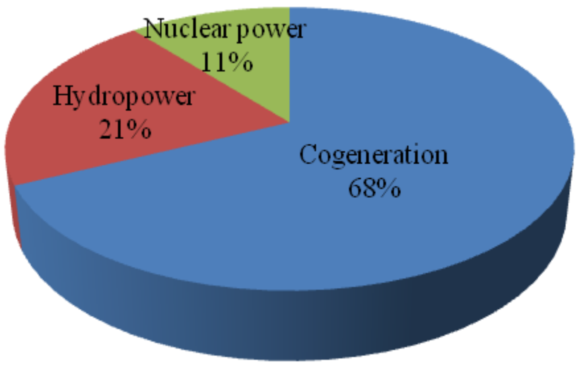

Figure 23. Net supply of electricity in Russia. 2008.

Industry is a major consumer of electricity in Russia; its share is 52%. Final consumption of electricity in Russia by sector is presented in Figure 24.

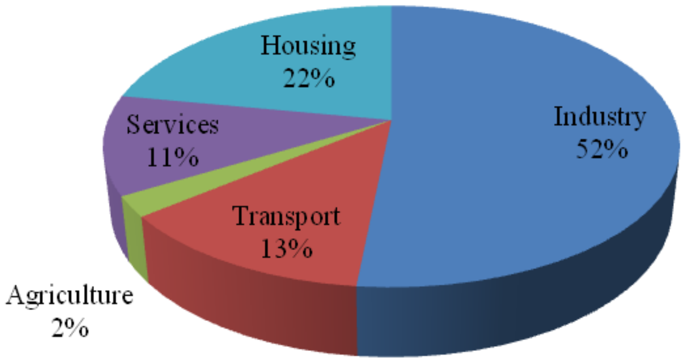

Figure 24. Total electricity consumption in Russia

3.1Electricity market

Liberalization in Nordic countries started in 1993, when Nordic power exchange Nord Pool was established. The first international electricity trade in Nord Pool began in 1996 by Norway and Sweden (Similä. 2006, 7). In Finland, the electricity market began to open up in stages in 1995. The principle of a monopoly provider was canceled by the first electricity and gas Directives (96/92/EC; 98/30/EC) which allowed large users to choose their electricity and gas supplier. If one utility is responsible for local electricity supply, it is a monopoly supplier. Investments in networks, generation capacity and their use are planned by publicly owned utility or company. Prices for services are determined by authorities, or regulated. Prices that are set by authorities are referred as tariffs. Tariffs are set on a level to cover the costs of electricity sector functions. In liberalized or free markets, prices are determined according to supply and demand. Product or service exchange is voluntarily between seller and buyer. Companies make their investment and pricing decisions individually. Production volume is determined in the markets according to buyers and sellers actions.

Electricity market operates on a large scale and sells electricity to large electricity users, the local electric companies, electricity retailers who sell electricity to households, the agricultural sector and small and medium-sized enterprises. Opening of electricity markets, electricity wholesalers and retailers, has resulted to that the same company may be both the electricity wholesaler and retail markets.

Electricity sales activity does not require a license. Any company, organization or individual may be the electricity distributor. The seller must provide the client electricity requests at a reasonable price, if it doesn't have other competitive contracting opportunities. Delivery obligations to customers within the retailers will be a public electricity prices, terms and conditions. The Energy Market Authority supervises the obligation to sales and pricing.

Electricity retailers are mainly local distribution companies, which sell its own production or electricity which was bought from the wholesale market. List of Finnish retailers is listed in Appendix I (Energiamarkkinavirasto. 2010). Recently, the major production companies along with many other players have been interested in retail sales of electricity. Electricity sector has also become a traditional for electric power companies, independent distributors and brokers.

New rules for Russian wholesale market for electricity (capacity) were introduced on September 1, 2006 according to decision of the Russian Federation Government. New rules for the wholesale market are changing the whole system of relationships between buyers and suppliers of electric energy and power.

On the wholesale market, electricity suppliers are the generation companies and importers of electricity. Buyers are:

- consumers who buy electricity to meet their own production needs;
- marketing companies including guaranteeing suppliers which purchase power in order to further resale to end users and acting on their behalf;
- exporters (export operators) of electricity i.e. an organization engaged in activities to purchase electricity from the domestic wholesale market in order to export to foreign energy.

Basic operation structures of the new wholesale market for electricity (capacity) in Russia are shown in Figure 25 where System Operator is Central Dispatch Administration of the Unified Energy System (SO-CDU UES). It is a specialized organization providing sole control of technological modes of electric power facilities. The system operator is authorized to issue operational dispatching commands and orders which are binding on all subjects of operative-dispatch administration and consumers of electricity with a controlled load. Administrator of Trading System (ATS) is a non-profit partnership, the principal purpose of which is providing services on the wholesale market of electricity (capacity), and the maintenance of financial accounts for the electricity supplied and services provided to the wholesale market.

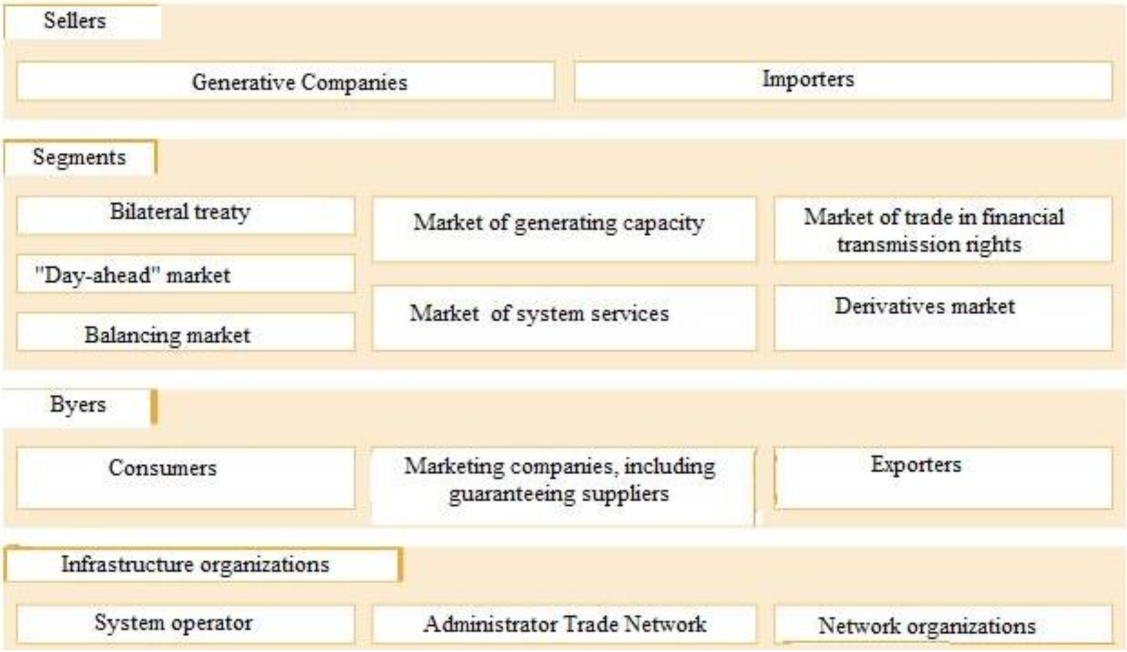

Figure 25. Basic operation structures of the new wholesale market for electricity (capacity) in Russia.

According to the Decision of Russian Government, the system of regulated contracts between buyers and sellers of electricity is introduced in the wholesale market instead of the regulated sector and the sector of free trade. Contracts are called regulated because the price of electricity under these contracts is regulated by the Federal Tariff Service.

Sellers and buyers of the wholesale market are entitled to enter into long-term regulated contracts (from 1 year). The Ministry of Industry and Trade of the Russian Federation in coordination with the concerned ministries and departments will establish the duration of such contracts.

The transition of participants to long-term bilateral relations in the context of market liberalization provides a predictable cost of electricity (capacity) in the medium and long terms. That is the key to investment attractiveness of electricity.

Since 2007, the volume of electric energy (capacity), sold in the wholesale market at regulated prices has been steadily decreasing. The pace of this decline is set annually by the Russian Federation Government in accordance with the forecasts of socio-economic development. In 2007, the share of electricity sold at regulated prices was fixed in the rules of the wholesale market of electric energy (capacity) transition and amounted 95 per cent of the forecast production and consumption balance.

A separate sector of the new wholesale market is power trade, which is implemented in order to ensure reliable and uninterrupted supply of electrical energy. Power and electricity are paid separately. When selling the power, suppliers receive some commitments in maintaining its generating equipment in constant readiness for the development of electric power. These obligations are supplier's compliance of the specified System Operator mode of generating equipment, including compliance with selected equipment combination and its parameters in the regulation of frequency in the network, etc. The powers cost depends on the implementation of commitments generating companies which have a direct financial incentive to comply with all requirements were met. Such mechanisms are introduced to reduce security risks in the current reliability of power systems with the growing demand for electricity.

The volume of electricity not covered by regulated contracts is sold at free prices. There are two methods of electricity trading in the new wholesale market model. This is free bilateral contracts and market "day ahead". Participants determine the counterparty, prices and supply volumes under free bilateral contracts market by themselves. A competitive selection of suppliers and buyers bids a day before the actual delivery of electricity to the definition of price and volume of delivery for every hour of the day is a basis of "day ahead" market. If there are deviations from the planned day-ahead supply volumes, participants buy or sell them on the balancing market. The purpose of the "day ahead" market is to define the prices and volumes of purchase/sale of electricity as to achieve maximum mutual benefit of suppliers and buyers from trade. Calculation of the “day-ahead” price is represented in Figure 26 (Houmøller. 2010, 4).

In fact, the new wholesale market model of transition is the basis for the formation of the target (fully competitive) model. Mechanisms of formation of equilibrium prices and volumes in the market "day-ahead and balancing market, accounting mechanisms of bilateral treaties, the principles of payment variances won't be changed in the future. Further liberalization of the wholesale market for electricity (capacity) will go towards creating a "subsidiary" markets serving the work of the power system. Later the market of system services, market of trade in financial transmission rights and the derivatives market will be formed. The purpose of the market of system services is to maintain the specified technical parameters of the power system.

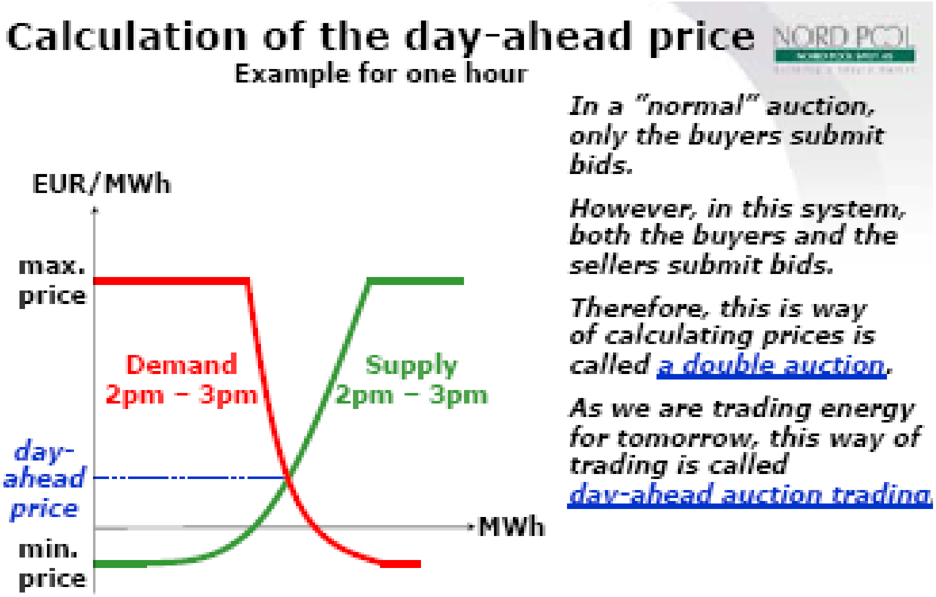

Figure 26. Calculation of the "day-ahead" price.

The market of system services is one of the tools (mechanisms) to maintain the required level of reliability and quality of functioning of the power system. For example, consumers may conclude an agreement to regulate the load ("consumers with a controlled load") in this market. In the case of a sharp surge in electricity consumption system operator can limit the electricity supply to such consumers. All limiting the supply of electricity will be paid in accordance with the terms of the contract. Producers may conclude contracts for the maintenance frequency and voltage, providing power reserves, etc. Market of rights trade to use the capacity of the power grid (the financial rights on the transfer) will create a transparent market mechanism of allocation of scarce resources (the capacity of electricity grids), as well as a mechanism to support private investment in construction and development of networks in order to minimize these constraints.

It is assumed that the market of trade in financial transmission rights will be realized in competitive auctions. The derivatives market will create a system of price risk management in the electricity market. The main tool is the forward contract (bilateral contract). Search of counterparties to such contracts will be through direct interaction of buyers and sellers. Involving of participants that are not related to energy (investment companies, banks, etc.) in the derivatives market reallocates some price risks for the benefit of buyers and sellers of wholesale electricity market.

Incentive system of participants to the filing of competitive bids is introduced in the wholesale market system to reduce the risk of price manipulation. In line with trade rules, the demands of the power supply with the lowest price are primarily met. Order to identify cases of non-competitive behavior (excessive prices for electricity, generating companies attempt to "steal" a part of their capacity from the wholesale market) is controlled by the Federal Antimonopoly Service of Russia (EnergyFuture.RU. 2009).

3.2Electricity network

The path of electricity in homes starts from transformer substations, where the high-phase voltage from 6 to 35 kV is reduced to a low-phase (380/220 in Russia and 400/230 in Finland). High voltage in the municipal transformer substations as well as a low voltage is delivered by underground cable channels. The device of small-town and rural transformer substations is more simple, usually there is no a separate building for them. They represent a fenced area with the installed outdoors transformer substation, consisting of only one transformer. High voltage to such substations is delivered by air lines, and then low voltage is distributed among consumers.

Network companies are transmission system, operator and distribution, network companies. During the transmission electricity is transported long distances in national network; during the distribution electricity is transported more locally to end users through distribution networks.

When the electricity market was opened to competition, electricity transmission was left outside competition. The consumer cannot choose his electricity network company as electricity transmission is the responsibility of the network operator in whose area of responsibility the customer lives. Electricity is first transmitted from a major power plant to Fingrid’s main grid (50.8%-owned by Finnish state). Fingrid owns Finland’s main grid and all significant connections to neighboring countries. Fingrid quotes the day-ahead market price for each hour of the day on the basis of purchase and sales bids. About 72 % of electricity is traded through spot market in the Nordic area while the rest is based on bilateral transactions. In Finland, there is a total of 380,000.00 km of electricity network. As the transmission system operator, Fingrid has a role as a developer of market-focused rules for the physical electricity market. As a part of this role, Fingrid has an ownership of 20 per cent in Nord Pool Spot AS, the Nordic electricity exchange for physical electricity trade.

In recent years the radical transformation took place in Russian power industry. The system of state regulation of the industry was changed. New companies were created. Also industry structure was changed. Separation of natural monopoly functions such as transmission and dispatching and potentially competitive ones such as generation and supply, repair and services was carried out. Instead of the former vertically-integrated companies performing these functions, structures specializing on individual activities were created.

Joint-stock company RAO UES of Russia includes the whole electricity sector excluding nuclear electricity generation. RAO UES of Russia has almost 75 % of Russia's electricity generation capacity and almost all of transmission and distribution infrastructure (Similä. 2006, 7). Controlling share of RAO UES belongs to Russian Federation.

Trunk network is under the control of the Federal Grid Company, distribution networks are integrated in Interregional Distribution Grid Companies (IDC), the functions and assets of regional dispatch administrations have been transferred to the System Operator (SO UES).
Generation assets are merged into interregional companies of two kinds in the process of reform. They are Power Generation Company (PGC) and Territorial Generating Companies (TGC). PGC combined power plants, specializing in electric power generation. Heat and power plants (CHP) were mainly included in the TGC. Six of the seven PGC are formed on the basis of thermal power plants, and one (RusHydro) is on the basis of hydro assets.

In Russia, system operation and transmission are separated. The length of the electric grid with 110 - 1150 kW voltage of all power-pooling arrangements as at 31 December 2006 amounted to over 442,200.00 km.

3.3Electricity price

Consumption of electricity varies within a year. Seasonal variation can be seen in yearly, weekly and daily cycles. Daily and weekly cycles are due to behavior rhythm of society. In the night time, consumption is lower compared to day time. In the morning, consumption rises when people wake up and start their activities. Weekly variation can be seen between weekdays and weekends. Temperature is key random factor that affects the consumption of electricity. This is due to electricity use for heating in the winter or air cooling in the summer.

In Finland electricity is composed of two different commodities such as electricity transmission service and electric energy. Both of asset price comprise taxes including VAT at the rate of 22%. VAT is levied on electric energy, electricity transmission, electricity tax and the supply fee.

The local electricity company which owns the distribution network is responsible for transmission of electricity. Electricity transmission prices are supervised by the Energy Market Authority. Charges for electricity transmission can be fixed (for example, EUR/month) or can depend on consumed energy (c/kWh). Electricity transmission price takes into account the transmission of electricity and the distance. Electrical energy prices are affected by many factors such as cost of production and exchange rates. For example, Fortum’s energy price for housholds this year amounts to 6.48 c/kWh in general tariff (Fortum. 2010).

There are three type of electricity tariffs in Finland. They are general, time and power.

Power tariff is suited for large companies. The customer can choose a local company available to the tariffs they want.

The common tariff is suitable for general electrical customers who use a bit of electricity per year (in practice less than 10 000 kWh). General Electricity charges consist of a fixed basic fee (per month) and the consumption charge (c/kWh).

Time tariff consists of a fixed basic fee (EUR/month) and two consumption charge (c/kWh). Consumption charges are used in pricing, either day/night breakdown (time electrical/off-peak electricity) or a winter's day/rest of the time-breakdown (seasonal electricity). The consumer can choose their electricity supplier, which can be found in the local distribution system choice. Time division of time tariff may varies depending on the distribution system (Vaihovirta.FI. 2010).

Households, agriculture and service activities pay tax on electricity. Electricity tax in Finland amounted 0.90646 c/kWh in 2004. Tax is paid according to consumption (Vaihovirta.FI. 2010).

Consumers pay for electricity transmission in their electricity bill. Network service fees include some costs of the building and maintenance of the national main grid.

Breakdown of the Finnish electricity price for a household customer (Kauniskangas 2010, 15) consists of:

1. Sale price of electric energy
– Electricity procurement – 37%;
– Electricity sales – 7 %
– Main grid transmission – 2 %;
– Regional network transmission – 1%
2. Network service price
– Value added tax – 18 %;
– Electricity taxes – 7 %;
– Distribution – 28%.

The electricity price in Russia includes (Order of FTS RF No. 348-e/12. 2006.)

- calculated growth index of unit costs that are attributable to the financing of capital investments at the expense of profits;
- income tax rate;
- inflation;
- prices growth index for natural gas sold at regulated prices;
- rise indexes in prices for non-regulated fuels (including gas sold at unregulated prices);
- calculated growth index rates of payment for the use of water bodies (water tax);
- calculated growth index of indicative price for the electricity consumed by pumping installations in the pump mode.

Average retail selling price of electricity for customers in Russia amounted to 3.86 c/kWh in 2009. Energy Forecasting Agency of Russia predicts the average annual increase in electricity prices by 16% in 2010 and 24,5% in 2011 (Savelieva, 2010).

Comparison of values of the equilibrium prices index in Russia and Finland for 2010 is represented in Table 6.

Table 6. Value of the equilibrium prices index in Russia and Finland for 2010 (BigPower. 2010; Fingrid. 2010)

	P_e, EUR/MWh	P_{max}, EUR/MWh	P_{min}, EUR/MWh
Siberia	11.06	22.74	6.00
Centre and Ural	20.05	33.85	11.67
The Nord Pool Spot area (Denmark, Norway, Sweden and Finland)	50.58	-	-

3.4 The impact of power plants on the environment

Main sources of emissions into the atmosphere in the energy sector are the combustion power plants. Major pollutants are nitrogen dioxide NO_2, nitric oxide NO, carbon monoxide CO, carbon dioxide CO_2, sulfur oxides SO_x, PM10 (Particulate matter less than

10 µm), benzopyrene. Comparison of total emission values for CHP in Finland and Russia are listed in Table 7.

Table 7. Total emission values for CHP

<table>
<tr><th rowspan="2">Pollutant</th><th colspan="3">Emission value, t</th></tr>
<tr><th>Finland, 2004 (EPER, 2004)</th><th colspan="2">Russia, 2006 (Kozhukhovsky, 2008)</th></tr>
<tr><td>Carbon dioxide, CO_2</td><td>28,015,000.00 t (67% of total)</td><td colspan="2">456,000,000.00 (23 % of total)</td></tr>
<tr><td>Carbon monoxide, CO</td><td>2,168.00 t (18% of total)</td><td colspan="2">-</td></tr>
<tr><td>Nitrogen oxides, NO_x</td><td>45,251.00 t (58 % of total)</td><td rowspan="2">754,000.00 t</td><td rowspan="3">16% of total</td></tr>
<tr><td>Nitrous oxide (N_2O)</td><td>708.30 t (13% of total)</td></tr>
<tr><td>PM10 (Particulate matter less than 10 µm)</td><td>2,066.50 t (18% of total)</td><td>919,000.00 t</td></tr>
<tr><td>Sulphur oxides (SO_x)</td><td>36,172.00 t (61% of total)</td><td colspan="2">1,065,000.00 t</td></tr>
</table>

In case of Russia, nitrous oxide (N_2O) is included in nitrogen oxides NO_x.

The sources of payments for air pollution in Russian Federation are payments within allowable emissions standards of pollutants are carried by the prime cost of production (works, services); payments for exceeding of allowable emissions standards of pollutants and limits are implemented by the profit remaining at the disposal of company.

The amount of payment is defined as the amount of pollution charges within the amount not exceeding the established maximum allowable emission standards; within the established emissions limits; for the excessive pollution of the environment (including those resulting from the accident caused by natural resource users).

The fee of emission in an amount not excesses the established maximum allowable concentrations (MAC) is determined by the following equation:

$$P_n = k\sum_{i=1}^{n} C_{ni} \times m_i \quad \text{eq. 1}$$

where $m_i \leq m_{ni}$

i- type of the pollutant, i = 1,2.3,4, ... n

P_n – fees for pollutants emissions into the atmosphere at a rate not exceeding the maximum allowable emission limits, RUB;

C_{ni} - fee rate for the emission of 1 ton of i-th pollutant within the allowable emission rates, RUB/t

m_i - actual mass of discharge of i-th pollutant, t/a;

m_{ni} - maximum allowable emission mass of i-th pollutant, t/a;

k - inflation factor

$$C_{ni} = N_{ni} \times \delta_{atm} \quad \text{eq. 2}$$

N_{ni} - fee norm for 1 ton emissions of i-th pollutant in an amount not exceeding the maximum allowable emission limits, RUB/t;

δ_{atm} - coefficient of the environmental situation and environmental significance of the atmosphere in the region.

The fee for pollutants emissions within prescribed limits (P_{lim}) is defined by equation:

$$P_{lim} = k \sum_{i=1}^{n} C_{lim.i} \times (m_{lim.i} - m_{n.i}) \quad \text{eq. 3}$$

where $m_{n.i} < m_i \leq m_{lim.i}$

$C_{lim.i}$ - fee rate for the emission of 1 ton of i-th pollutant within the prescribed limit, RUB/t;

$m_{lim.i}$ - mass of discharge of i-th pollutant within the prescribed limit, t/a.

$$C_{lim.i} = N_{lim.i} \text{ x } \delta_{atm} \quad \text{eq. 4}$$

$N_{lim.i}$ - fee norm for 1 ton emissions of i-th pollutant within the prescribed limit, RUB/t.

Fee for the excessive emission of pollutants is calculated by equation:

$$P_{ex} = 5k \times \sum_{i=1}^{n} C_{lim.i} \times (m_i - m_{lim.i}) \quad \text{eq. 5}$$

Total charges for air pollution are determined by equation:

$P = P_n + P_{lim} + P_{ex}$ eq. 6

The fee norms for the emissions of some pollutants in Russia are shown in Table 8 (Committee on Natural Resources, Environmental Protection and Ecological Safety, 2003).

Table 8. The fee norms for the emissions of some pollutants

No.	**Pollutant**	**Fee norm for 1 ton emissions of pollutants into the air, RUB**	
		within the prescribed allowable emission rates	**within the prescribed limit**
1	Carbon monoxide, CO	0,6	3
2	Nitrogen dioxides, NO_2	52	260
3	Nitrogen oxide NO	35	175
4	PM10 (Particulate matter less than 10 µm)	13,7	68,5
5	Sulphur dioxides SO_2	40	200

Using data from Table 7 and 8 and knowing the limits it is easy to determine different kind of fees for emissions. MAC and limit values of typical pollutants of CHP for Russia and Finland are listed in Appendices II and III (GN 2.1.6. 1338-03, 2003; EurLex, 2008).

Budget Code of Russia establishes payments distribution for negative impact on the environment in the budgets of Russian Federation in the amount of:

- 20% in the federal budget,
- 40% in the budgets of Russian Federation
- 40% in the budgets of municipal districts and urban districts.
- 80% in the budgets of Moscow and St. Petersburg cities.

Under the Kyoto protocol, the EU has agreed to reduce greenhouse gas (GHG) emissions by 8% between 2008 and 2012 relative to 1990 levels. Russia should not exceed the base year emissions.

Main documents of Russian Federation connected with payments for air pollution are listed in Table 9. Main documents of Russian Federation connected with payments for air pollution.

Table 9. Main documents of Russian Federation connected with payments for air pollution

No.	**Document title**	**Field of application**
1	Order of Federal Service for Ecological, Technological and Nuclear Supervision of Russian Federation of 08.06.2006 No. 557	Terms of payment Payments are made quarterly till the 20th of the month following the quarter (not later than April 20, July 20, 20 October and 20 January
2	Order of Federal Service for Ecological, Technological and Nuclear Supervision of Russian Federation of 05.04.2007 No. 204	The form of payment calculation and procedure for its completion
3	Resolution of the Government of the Russian Federation of 12.06.2003 No. 344	Fee norms, RUB/unit
4	Federal Law of 02.12.2009 No.308-FZ "On the Federal Budget for 2010 and for the planning period 2011 and 2012"	Ccoefficients taking into account environmental factors (1.79, 1.46)

The introduction of CO_2 trade has a significant influence on the growth of electricity prices. According to the International Agency the price per ton of CO_2 emissions will be 25$ by 2050. Forecast price per ton of CO_2 on the European program is about 100$ in 2030. Prices of CO_2 will affect the relative effectiveness of different types of electricity generation. The strongest effect CO_2 has on the market for power plant running on coal technology. Forecasts of fee growth for CO_2 emissions are shown in Figure 27 (Kozhukhovsky. 2008, 5)

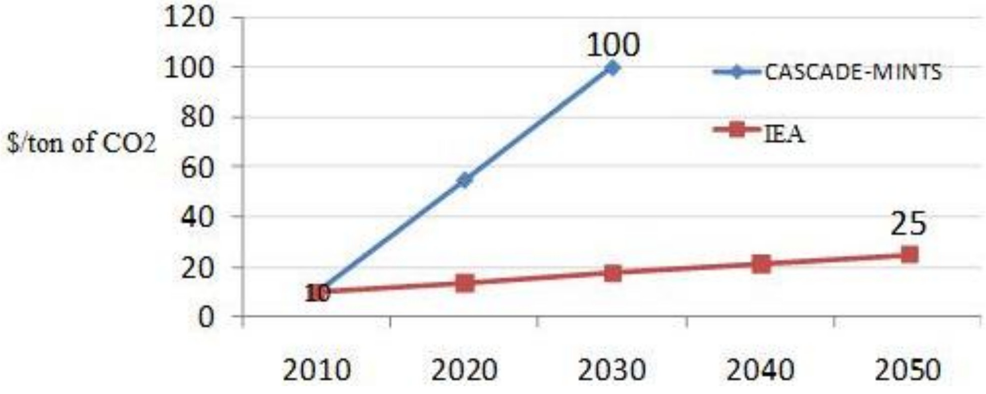

Figure 27. Forecasts of fee growth for CO_2 emissions

The connection between CO_2 emissions and the cost to produce 1 kWh of electricity are shown in Figure 28 (Kozhukhovsky. 2008, 5).

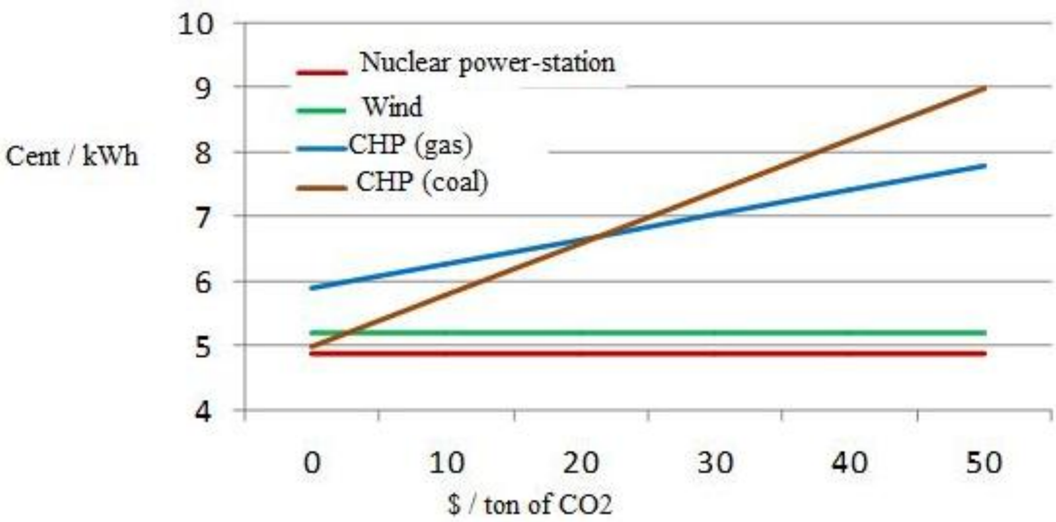

Figure 28. The connection between CO_2 emissions and the cost to produce 1 kWh of electricity.

4 DESCRIPTION OF THE ENVIRONMENT

4.1 The environment of Russia

Russian territory is 17,075,400.00 square kilometers. Russia is the largest country in the world, covering more than a ninth part of the Earth's land area.

Russia is situated in the northern hemisphere, in the north of the Eurasia continent. It is washed by the Pacific and Arctic oceans, as well as the Baltic, Black, Azov seas of the Atlantic Ocean and the Caspian Sea, while possessing the longest coastline (37653 km). Ural Mountains, the river Emba and Kuma-Manych Depression divide Russia into the European and Asian parts; the latter includes the North Caucasus, Siberia and Far East of Russia.

The plains and lowlands occupy over 70% of Russia. Southern and eastern parts of the country are predominantly mountainous.

Russia has more than 120 thousand rivers and about 2 million lakes. The major rivers are the Amur, Lena, Yenisei, Irtysh, Ob, Volga, Kama; the largest lakes are the Caspian Sea, Baikal, Ladoga and Onega.

The country's territory lies mostly beyond a latitude of fifty degrees north. Russian position in the northern part of Eurasia resulted in its placement in the arctic, subarctic, temperature and partly in subtropical climates. The majority of the territory is located in the temperate zone. The diversity of climate also depends on the topography and the proximity or remoteness of the ocean.

Latitudinal zonation is most become apparent on the plains. The most complete range of natural areas distinguishes the European part of the country where successive zones of arctic desert, tundra, forest tundra, boreal forests, mixed forests, forest-steppe, and steppe, semi-desert are changed from the north to south. The climate becomes more continental; the number of natural areas in the same latitudinal range is greatly reduced with the advance in the east.

Average temperatures in January are ranged from 6 to -50 ° C, in July from 1 to 25 ° C according to different regions; precipitation from 150 to 2000 mm per year. Permafrost (areas of Siberia and the Far East) occupies 65% of the Russian territory (Wikipedia. 2010 a).

Russia is among the richest countries on the availability of natural resources around the world. Shares of major mineral resources of Russia in the overall share of world reserves are shown in Figure 29 (IAC Mineral. 2010).

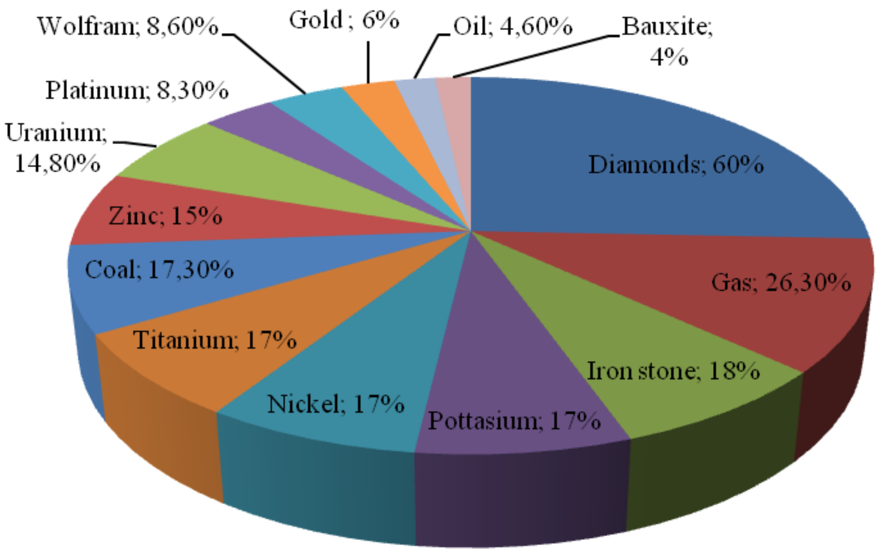

Figure 29. Russian mineral resources in the overall share of world reserves.

As mentioned above, forest covers 45 % of Russian land area. 300 - 550 mm of precipitation per year falls in most parts of Russia (Geography. 2010).

Solar radiation reaching the surface of the Earth is the main base of climate formation. The farther it is from the equator, the less the angle of incidence of sunlight, the less the intensity of solar radiation. The lowest annual total radiation is on the polar islands of the Arctic region and the Varanger Fjord on the Kola Peninsula (2500 MJ/m^2). Total radiation increases to the south, reaching a maximum at the Taman Peninsula and in the Hanka Lake in the Far East (over 5000 MJ/m^2). Thus, the annual global radiation increases from the northern border to the southern in half (Ecological centre "Ecosystem. 2010).

It is believed that the construction of wind plants with a capacity up to 5.6 kW is economically feasible at a wind speed in excess of 3.5-4.0 m/sec. Larger installations require wind speed 5.5 – 6.0 m/sec. World experience shows that areas with annual average wind speed of 8 m/sec at a height of placement wind wheel are preferred for the construction of wind power installation capacity of several megawatts. Here are the data on wind speed for individual regions of Russia (Magomedov. 1996, 143). Wind velocities of 8 m/sec or more are observed in the following regions of Russia (the values of average wind speed at 10 m in m/sec are indicated in parentheses): Amderma (8.0), Marhotsky pass in the Krasnodar Region (9.3), Zhelanie promontory in the Arkhangelsk Region (8.0), Pestraya Dresva in Magadan (9.0), Simutir on the Kurile Islands (10.4), Syurkul in Khabarovsk Region (10.4), Mount Elbrus (8.7). Wind velocities from 7 to 7.9 m/sec are typical for the following items; Anadyr (7.6), Vaida Bay in the Murmansk Region (7.5), Vankarem (7.9), Gizhiga in the Magadan Region (7.9) Kolyugino on Chukotka, (7.4), Kresty of the Taimyr (7.3), Petropavlovsk-Kamchatsky (7.0), Shumshu on Sakhalin (7.9). At the same time low-intensity winds from 1.5 to 3.5 m/sec dominate in the areas east of the Yenisei River to the shores of the Okhotsk Sea, only at the coast, they rise.

Russia has huge reserves of hydrogeothermal resources i.e. accumulated in groundwater, and petrothermal resources accumulated in the rocks. Geothermal regions of Russia are shown in Figure 30 (Svalova. 2009).

Figure 30. Geothermal regions of Russia

a - areas suitable for heating buildings by using heat pumps; b - areas perspective for "direct" use; c - areas of recent volcanic, most promising "direct" use (generation of heat and electricity in binary units, as well as the creation of large GeoPP).

1 - North Caucasus (platform Province), 2 - North Caucasus (alpine region), 3 - Western Siberia, 4 - Baikal, 5 - Kuril-Kamchatka Region, 6 - Primorye, 7-8 - Okhotsk-Chukotka Volcanic Belt.

The current situation of air pollution in the Russian Federation is not optimistic. Almost half population of country live on the 15% of the territory of Russian Federation, and the main part of industry is concentrated in this territory. Due to the high concentration of industry and population the air conditions are unsatisfactory and ecological safety is not guaranteed. At that the specific indexes of the negative effects on the environment on the expectation of one person and units of GDP in Russia are one of the highest in the world. The excess of the MACs of the air pollutants is observed in the atmospheric air of 185 cities and industrial centers with the population of more than 61 million people (40% of the whole population of the country). The main sources of air pollution are heavy industry, chemistry and petrochemical industry, emissions of coal-fired electric plants, construction industry, power engineering, pulp and paper industry and transportation in major cities. The main air pollutants are carbon monoxide, nitrogen oxides, sulfur dioxide, hydrocarbons, aldehydes, heavy metals (Pb, Cu, Zn, Cd, Cr), ammonia, atmospheric dust. (Artyuhov. 2000).

Consideration of the environment in the Leningrad Region is of interest because of its proximity to the border of Finland.

The Region's climate is Atlantic-continental. Maritime air masses determine a comparatively mild winter with frequent thaws and moderately warm, sometimes cool summer. Average temperature in January is -8 ... -11 °C, July +16 ... +18 °C. The absolute maximum temperature is +36 °C, absolute minimum is -52 °C. The coldest regions are eastern ones; the warmest regions are the south-western ones.

Precipitation for the year is equal 600-700 mm. The minimum amount of precipitation falls on the coastal lowlands. Most precipitation falls in summer and autumn. In winter, precipitation falls mainly as snow. Permanent snow cover appears in the second half of November - the first half of December. The snow melts in the second half of April.

The total length of all rivers in the Leningrad Region is about 50 thousand km. Also 1800 lakes are located in the area, including Ladoga Lake, the largest in Europe. Much of the area is swamped. The territory of the region is located in the taiga zone, namely, in its middle and southern subzones. There is a transition from coniferous forests to mixed ones in the south area. Forests cover 55.5% of the territory. Forest resources are severely depleted (Wikipedia. 2010 b).

The duration of sunshine is only 35-40% of possible duration of the year. The number of days without the sun is about 20 days per month during the period from November to January and more than 25 in December. Days without the sun are rare in the warm season (May-August). They are only 1-2 per month. The annual number of sunshine hours varies according to the territory from 1600 to 1900. The longest duration of sunshine (over 1800) is observed on the coast and islands of Ladoga Lake, and on the islands of the Gulf of Finland due to the reduction of cloudiness in the warm season and increase of transparency of the atmosphere in these regions (Pigoltsina. 2005, 182). Duration of sunshine in Leningrad Region is shown in Figure. 31.

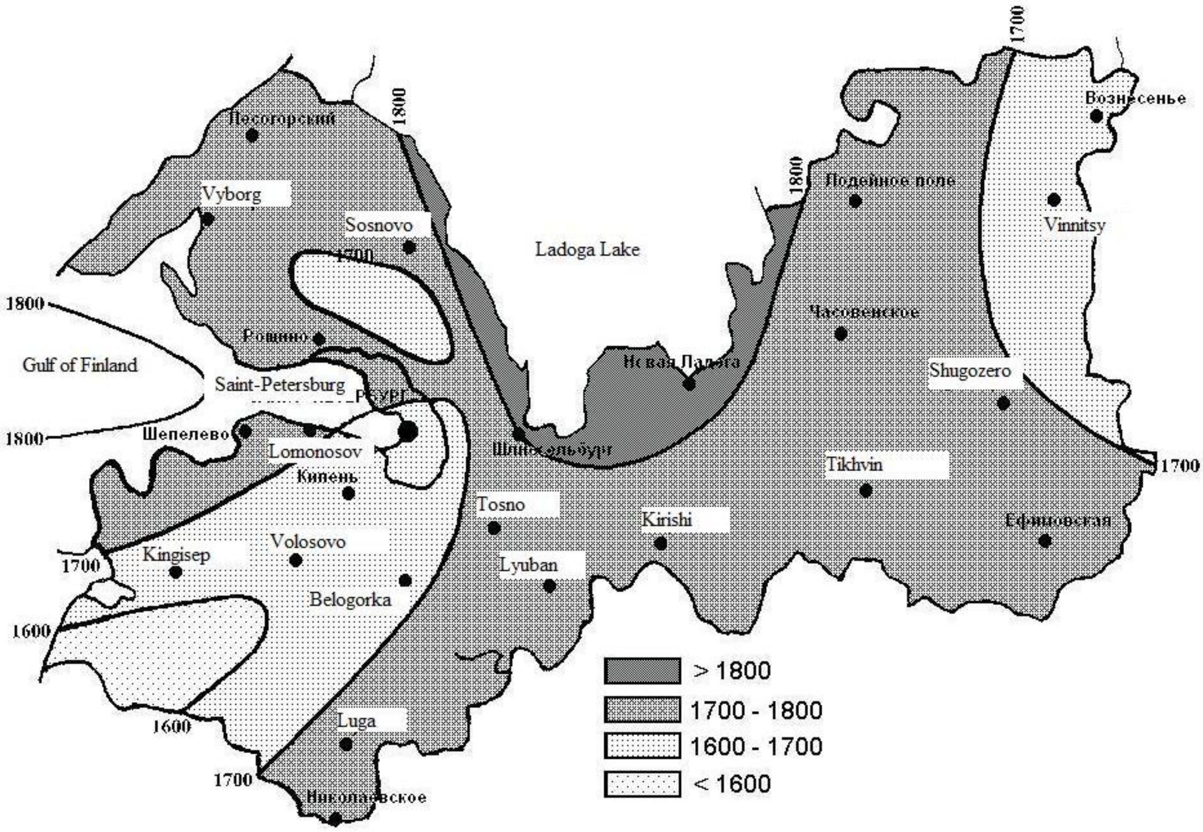

Figure 31. Duration of sunshine in Leningrad Region (hours/year)

The annual arrival of the direct solar radiation on a horizontal surface under clear skies varies across the region from 3950 to 4350 MJ/m^2. Annual amount of diffuse radiation under clear skies is ranged from 1100 to 1300 MJ/m^2. Zoning of the Leningrad Region on the annual amount of total radiation is presented in Figure. 32 (Pigoltsina. 2005, 185).

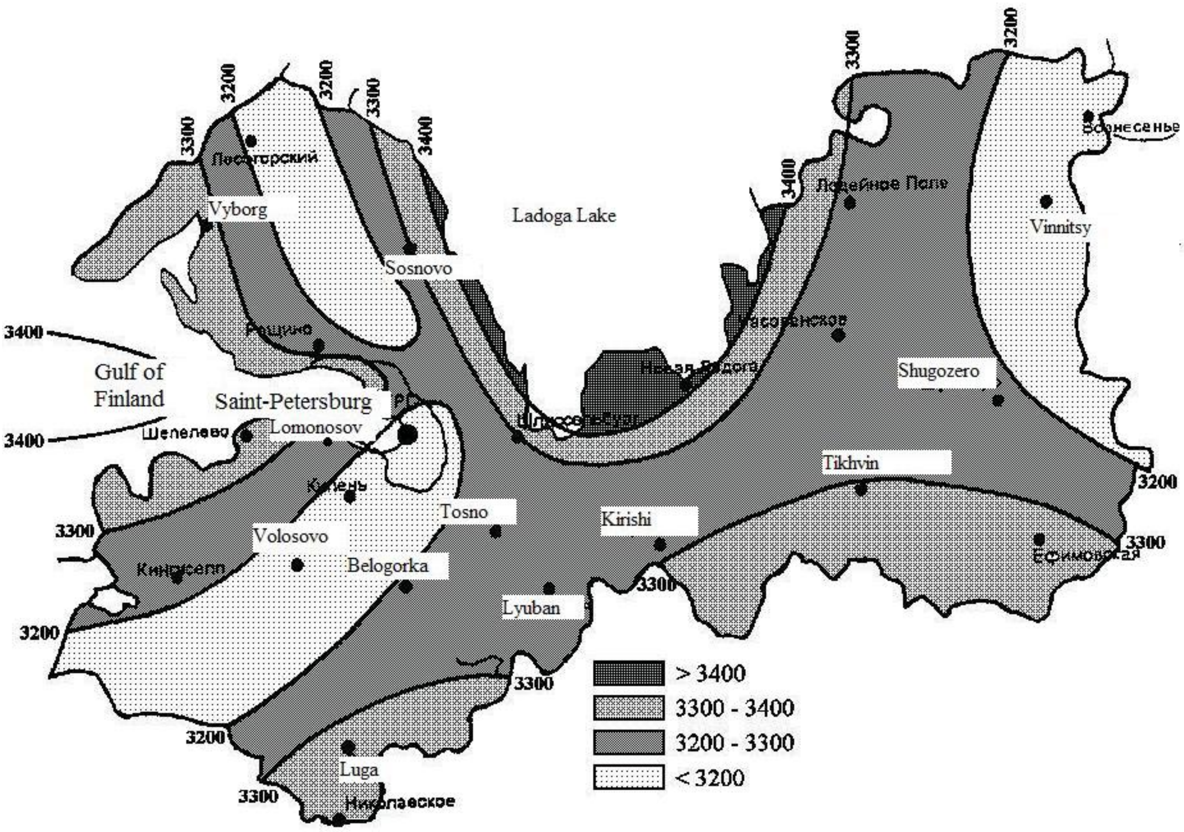

Figure 32. Zoning of the Leningrad Region on the annual amount of total radiation

Ambient air is polluted by carbon monoxide, nitrogen oxides, sulfur dioxide, hydrocarbons, aldehydes, heavy metals (Pb, Cu, Zn, Cd, Cr), ammonia, atmospheric dust. Organic petroleum products, suspended substances, detergents, salts of heavy metals, chlorides, sulfates, nitrogen compounds are the main pollutants of water bodies.

4.2. The environment of Finland

Finland is located in northern Europe; 25% of the territory is located above the Arctic Circle. The length of the outer coastline without tortuosity is equal to 1,100 km. The climate is temperate, the transition from maritime to continental. Average temperature in February is - 6 ° C in the south of the country, -14 ° C in Lapland. In July, it is equal 17 in the south and up to 14 in the north.

Finland has many lakes and rivers and other water bodies. All inland waters have a total area of approximately 3.4 million hectares, equivalent to 8% of Finland's total area, and 10% of a land and water sector, which does not include the share of Finland in the Baltic Sea (Luonnontila.FI. 2010).

The climate of Finland is determined by the radiation energy of the sun, and its distribution and fluctuations. The level of radiation changes with the seasons in the north and south. The highest annual radiation levels are in early June. The highest annual amount of sunshine is 1900 hours in the south western maritime and the lowest (1300 hours) is in coastal regions and in eastern Lapland. Average solar radiation in June in Helsinki area is about 160-170 kWh/m^2 a month. Solar radiation is equal about 30 kWh/m^2 in January-February and October-December. Monthly amount of solar radiation in Helsinki, Jyväskylä and Sodankylä is represented in Figure 33 (Ground Energy. 2010).

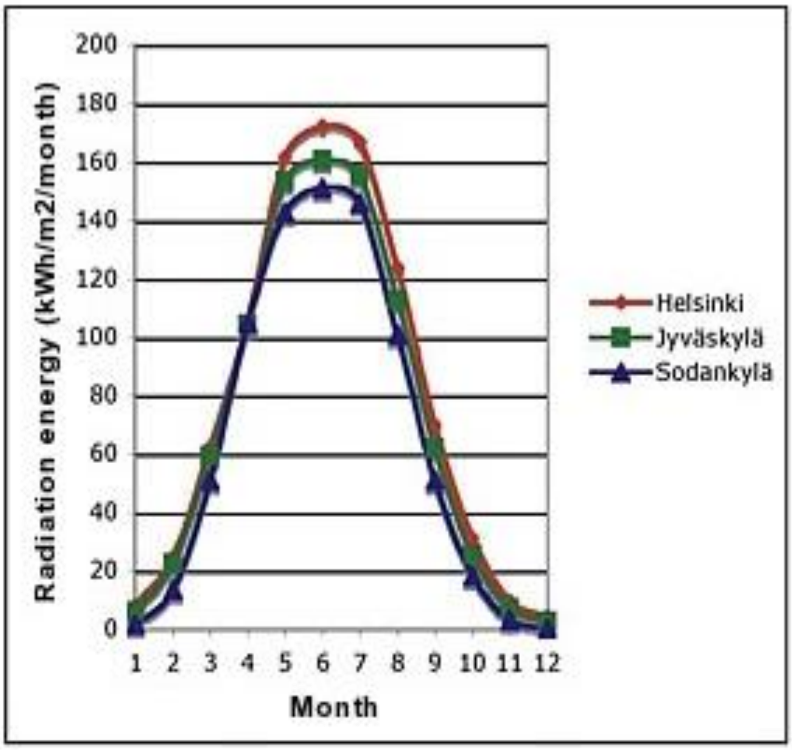

Figure 33. Monthly amount of solar radiation in Finland

There are great variations in air pressure and winds, especially in winter. In the whole country, the wind blows most commonly from the southwest and least commonly from the northeast. The average wind speed is 3 to 4 m/sec inland, slightly higher on the coast and 5 to 7 m/sec in maritime regions. The highest wind speeds are typically in winter and the lowest in summer.

Relative humidity is about 90% in November and December and 65% to 70% is in May and June. Precipitation for year is usually between 600 and 700 mm except on the coast.

The lowest annual rainfall is 200 to 300 mm and the highest annual rainfall is 700 mm in northern Finland and 900 to 1100 mm elsewhere (Finnish Meteorological Institute. 2010).

Finland lacks petroleum, gas, and coal reserves but has some metals deposits. The map of metal deposits of Scandinavian countries is represented in Figure 34 (Nurmi. 2010, 5).

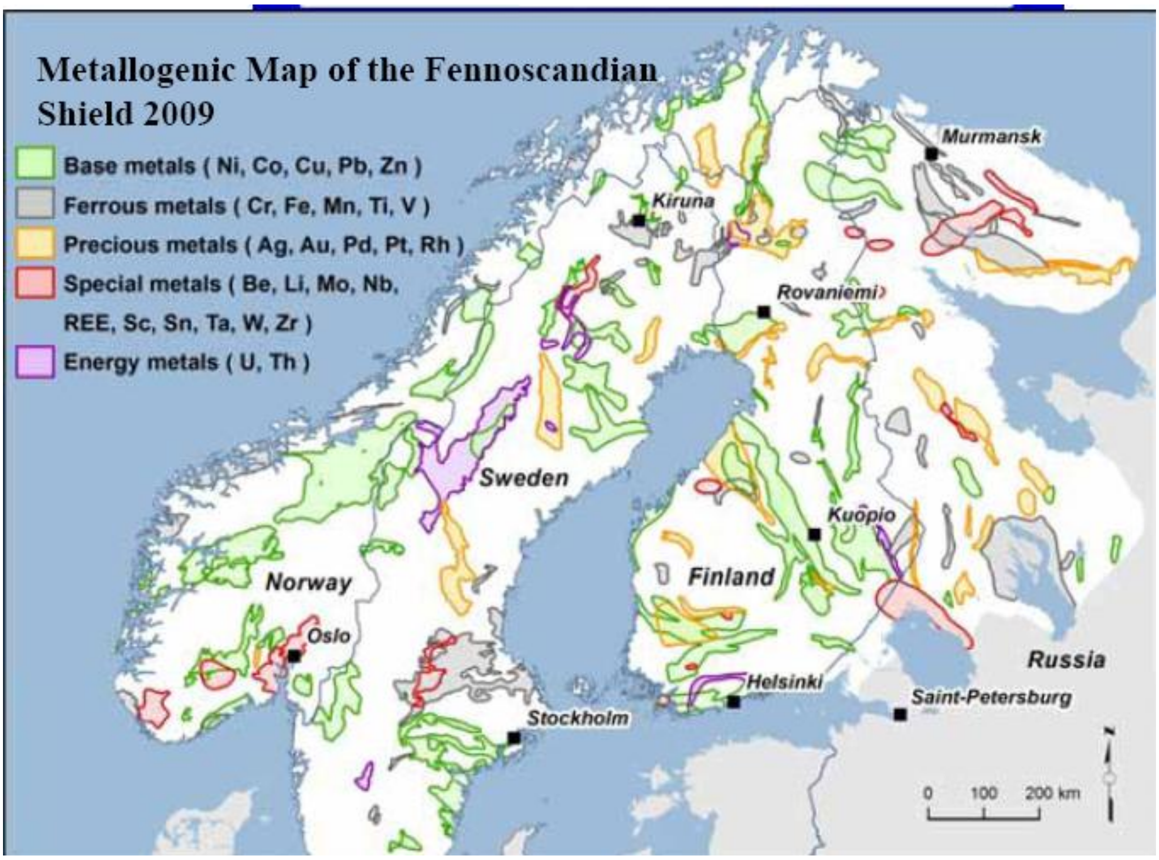

Figure 34. Metallogenic map of the Fennoscandian shield.

Finnish air contains sulphur dioxide, carbon monoxide, carbon dioxide, nitrogen dioxide, malodorous sulphur compounds, heavy metals, polycyclic aromatic hydrocarbons, volatile hydrocarbons (Ilmanlaatuportaali. 2010).

5 COMPARISON OF HEATING METHODS

For the reliability of the results, all comparisons of heating methods will be done between Finland and Leningrad Region due to their proximity to each other.

The following heating methods were considered in this work:

- district heating which is suitable for detached houses as well as small villages;
- individual boilers with different fuel types (private house);
- solar collectors;
- heat pump;
- electric boilers;
- wall and plinth heaters;
- cable and film systems for heating the floor and ceiling;
- ceiling infrared long-wavelength heaters.

Technical and environmental advantages of each method were described in Chapter 2. Therefore the accent will be made on economical benefits.

The annual consumption of heat for heating of residential and public buildings can be determined by the equation 6 (Guidelines. 2003, 15).

$$Q_{0\,a} = 24 \times Q_{0\,av} \times n_0; kcal \qquad \text{eq. 7}$$

$Q_{0\,av}$ - hourly average consumption of heat for the heating period, kcal / h;

$Q_{0\,av} = 14\ \frac{kcal}{h \times m^2} = 16.27\ W/m^2$ for big cities (MGSN 1.01-99);

n_0 - duration of the heating period in days by the number of days with a stable average daily temperature is 8 ° C and below; n_0 = 219 for Saint-Petersburg (Reference manual for SNIP 2.01.01-82. 1989), n_0 = 270 for Finland (Customers. 2010, 3);

24 are hours in a day.

$$Q_{0\,a\,Rus} = 24\ x\ 14 \times 219 = 73584 \frac{kcal}{m^2} = \ 85578.2 \frac{Wh}{m^2} = 85.6\ kWh/m^2$$

$$Q_{0\,a\,Fin} = 24\ \times 14 \times 270 = 90720\ \frac{kcal}{m^2} = 105507.4 \frac{Wh}{m^2} = 105.5\ kWh/m^2$$

Let's assume that detached houses in Russia and Finland are identical and have living space of 150 m^2. Hence, the annual consumption of heat for heating of residential and public buildings in Finland will be equal $Q_{0a\ Fin}$ = 105.5 x 150 = 15825 kWh; in Russia it will amount $Q_{0\ a\ Rus}$ = 85.6 x 150 = 12840 kWh.

If duration of the heating period in days by the number of days with a stable average daily temperature is 8 ° C and below is similar in both countries we can assume that the annual consumption of heat for heating of residential house on average is equal 14000 kWh/a.

Let's accept the height of our detached houses is 3 m. This way the house capacity will be 150 m^2 x 3m = 450 m^3

District heating. According to Energiateollisuus RY data the price for DH in Finland including all taxes for houses with living space till 500 m^3 and annual energy consumption till 20 MW varies from 50.43 EUR/MWh to 97.89 EUR/MWh. The average price for DH is 71.62 EUR/MWh (Energiateollisuus Ry. 2010, 4).

Average Russian district heating's tariff is equal 1143.2 RUB/Gcal = 0.98 RUB/kWh. Taking into account the current rate of exchange (1 EUR = 38.95 RUB) the average Russian district heating's tariff will be equal 2.5 c/kWh = 25.2 EUR/MWh.

If the house has a counter that controls incoming heat, the annual costs for DH in Finland will be amount 14 MWh x 71.62 = 1002.68 EUR. In Russia these costs will be lower and will be equal 14 MWh x 25.2 = 352.8 EUR.

Fuel balance of Finland and Russia in the production of heat is given in Table 10 (5ka.su. 2010; CHP/DHC Country Scorecard: Finland. 2008, 3).

Table 10. Fuel balance of Finland and Russia in the production of heat

Fuel	Share of fuel in the fuel balance of Finland and Russia, %	
	Finland	Russia
Oil	5.3	20
Coal	26.7	40
Gas	33.3	40
Peat	20	-
Wood	10.7	-

Using data on carbon dioxide emissions from different fuels (see Table 1) and fuel balance of Russia and Finland (see Table 10), we can calculate the amount of carbon dioxide emissions from thermal power plants in Russia and Finland by equation 8. Carbon dioxide emissions of wood fuels are not calculated into emissions of thermal power plants, because their net emission effect is 0.

$$E_{CO_2} = \frac{c_i \times \partial_i}{\sum \partial_i} \qquad \text{eq.8}$$

E_{CO_2} - carbon dioxide emissions from thermal power plants, $kgCO_2/MWh$;

c_i - carbon dioxide emission factor of i-th fuel, $kgCO_2/MWh$;

∂_i - share of fuel in the fuel balance.

Amount of carbon dioxide emissions from thermal power plants in Russia is equal

$$E_{CO_2} = \frac{340.6 \times 0.4 + 283.76 \times 0.2 + 198 \times 0.4}{0.4 + 0.2 + 0.4} = 272.2\ \frac{kgCO_2}{MWh}$$

Amount of carbon dioxide emissions from thermal power plants in Finland is equal

$$E_{CO_2} = \frac{283.76 \times 0.053 + 340.6 \times 0.267 + 198 \times 0.333 + 381.6 \times 0.2}{0.053 + 0.267 + 0.333 + 0.2 + 0.107} = 258.6\ \frac{kgCO_2}{MWh}$$

Taking into account heat losses during transportation (10% for Finland and 20% for Russia), annual CO_2 emissions from one house when DH is used will be equal (14 MWh + 14 MWh x 0.1) x 258.6 $\frac{kgCO_2}{MWh}$ = 3982.4 kg CO_2 in Finland and

(14 MWh + 14 MWh x 0.2) x 272.2 $\frac{kg\,CO_2}{MWh}$ = 4573 kg CO_2 in Russia.

Electric boiler. Approximately 1.03 kWh of electricity is consumed for thermal energy production in 1 kWh. The cost of 1 kWh of electricity in Finland is about 0.065 EUR/kWh; 0.039 EUR/kWh in Russia. Multiplying the energy consumption for a season (14000 kWh x 1.03) by the cost of 1 kWh for use of electric we are getting the cost of heating over the entire heating season 937.3 EUR in Finland and 562.4 EUR in Russia (Sanuzel-service. 2010).

CO_2 emissions from electricity generation are equal 484 $\frac{kg\,CO_2}{MWh}$ in Russia and 295 $\frac{kg\,CO_2}{MWh}$ in Finland (Lighbucket. 2008). Taking into account boiler efficiency and annual energy consumption, annual CO_2 emissions from electric boiler operation is 14 MWh x 1.03 x 484 $\frac{kg\,CO_2}{MWh}$ = 6979.3 kg CO_2 in Russia and 14 MWh x 1.03 x 295 $\frac{kg\,CO_2}{MWh}$ = 4253.9 kg CO_2 in Finland.

Gas boilers. About 36 MJ or 10.1 kWh of heat energy is received from one cubic meter of natural gas (Gasum. 2010). When efficiency of gas boiler is 90%, we get 10.1 x 0.9 = 9.09 kWh of thermal energy from one cubic meter. Total for the year will be spent 14000 / 9.09 = 1540.2 m^3 of natural gas (Planete Plastic. 2010). Retail gas prices in Russia for the population in the presence of metering devices accounted for 51 EUR /1000 m^3 (Premier Newspaper. 2009). The total annual price for the gas heating in Russia will be 1540.2 x 0.051 = 78.5 EUR. Average European gas price is 220 EUR/1000 m^3 (ComMetrics. 2009). The total annual price for the gas heating in Finland will be 1540.2 x 0.22 = 338.8 EUR.

Annual CO_2 emission from gas boiler taking into consideration boiler efficiency will be equal (14 MWh + 14 MWh x 0.1) x 198 $\frac{kg\,CO_2}{MWh}$ = 3049.2 kg CO_2

Pellet boilers. Calorific value of pellets (depending on quality, etc.) is a 19 MJ / kg (4500 kcal/kg = 5.2 kWh/kg). Average cost of 1 ton of pellets is 80 EUR/t both in Russia and Finland. When efficiency of peat boiler is 90%, we get 5.2 x 0.9 = 4.7 kWh of thermal energy from one kg of pellets. Total amount of pellets required per year is 14000 / 4.7 =

2.98 t. The total annual price for the pellet heating in Finland and Russia will be 2.98 x 80 = 238.4 EUR

Carbon dioxide emissions of pellet fuels are not calculated into emissions, because their net emission effect is 0.

Oil boilers. About 40.5 MJ or 11.25 kWh of heat energy is received from one kilogram of light oil (Coolforengineers. 2010). When efficiency of oil boiler is 90%, we get 11.25 x 0.9 = 10.12 kWh of thermal energy from one kilogram of oil. 14000 / 10.12 = 1383.4 kg of light oil will be spent for the year. 1 ton of light oil costs about 560 EUR in Russia and 750 EUR in Finland. The total annual price for the oil heating in Russia will be 1383.4 x 0.56 = 774.7 EUR. The total annual price for the oil heating in Finland will be 1383.4 x 0.75 = 1037.6 EUR.

Annual CO_2 emission from oil boiler taking into consideration boiler efficiency will be equal (14 MWh + 14 MWh x 0.1) x 266.8 $\frac{kg\,CO_2}{MWh}$ = 4108.7 kg CO_2

Wood boiler. About 15 MJ or 4.2 kWh of heat energy is received from one kilogram of dry wood. When efficiency of wood boiler is 90%, we get 4.2 x 0.9 = 3.8 kWh of thermal energy from 1 kg of wood fuel. 14000 / 3.8 = 3684.2 kg of wood will be spent for the year. 1 ton of wood fuel costs about 20.5 EUR (Recyclers.Ru. 2010) in Russia and 130 EUR (Klapinatti. 2010) in Finland. The total annual price for the oil heating in Russia will be 3684.2 x 0.0205 = 75.5 EUR. The total annual price for the oil heating in Finland will be 3684.2 x 0.13 = 479 EUR.

Carbon dioxide emissions of wood fuels are not calculated into emissions, because their net emission effect is 0.

*Heat pumps***.** To receive 14000 kWh of heat through the medium effective universal heat pump we should spend 14000 / 3.1 = 4516 kWh of electricity per year (3.1 is coefficient of energy transformation). Total annual costs on heating in Finland will amount 4516 x 0.065 = 293.5 EUR; for Russia it is 4516 x 0.039 = 176 EUR.

Annual CO_2 emission from heat pump use is 4.516 MWh x 484 $\frac{kg\,CO_2}{MWh}$ = 2185.7 kg CO_2 in Russia and 4.516 MWh x 295 $\frac{kg\,CO_2}{MWh}$ = 1332.2 kg CO_2 in Finland.

Solar collectors. As mentioned in Chapter 2 economically viable area of solar panels application is the regions located below the 50 degrees north latitude [Polonskiy et al. 2006, 50]. So we won't consider this method in our work.

Modern systems of *wall and plinth heaters; cable and film systems for heating the floor and ceiling; ceiling infrared long-wavelength heaters* have about 90 % of efficiency (Heating sector. 2010). That is to receive 1 kWh of thermal energy we need to spend 1.1 kWh of electric energy or to get 14000 kWh of thermal energy we need 14000 / 0.9 = 15556 kWh of electricity. Total annual heating costs in Finland will be equal 15556 x 0.065 = 1011.1 EUR; for Russia this amount will be equal 15556 x 0.039 = 606.7 EUR.

Annual CO_2 emission from electric methods use is 15.556 MWh x 484 $\frac{kg\,CO_2}{MWh}$ = 7529.1 kg CO_2 in Russia and 15.556 MWh x 295 $\frac{kg\,CO_2}{MWh}$ = 4589 kg CO_2 in Finland.

Total annual operating costs and CO_2 emissions for different methods in Finland and Russia are listed in Table 11.

Table 11. Total annual operating costs and CO_2 emissions.

Heating method	Total annual costs, EUR/a		Total annual CO_2 emissions, t/a	
	Finland	Russia	Finland	Russia
District heating	1002.7	352.8	3.98	4.57
Electric boiler	937.3	562.4	4.25	6.98
Gas boiler	338.8	78.5	3.05	3.05
Oil boiler	933.3	697	4.11	4.11
Wood boiler*	479	75.5	0*	0*
Pellet boiler*	238.4	238.4	0*	0*
Heat pumps	293.5	176	1.33	2.19
Other electrical	1011.1	606.7	4.59	7.53

* Carbon dioxide emissions of wood and pellet fuels are not calculated into emissions, because their net emission effect is 0.

Costs of new equipment for above described methods vary widely and some examples are listed in Table 12.

Table 12. Costs of new equipment of heating methods

Equipment	Cost, EUR	Source
District heating	0	
- Vitorond 100 KC2 boiler (40 kW, fuel: diesel, gas) - Keston C40 Gas Boiler - Grandee HE 23/28kW External Wall Combi Condensing Oil Boiler With Flue - Grandeg GD – AIR 40 boiler (40 kW; fuel – pellets) - Trianco Gravity Fed TRG80 Solid Fuel Boiler	2562.00 2447 2625 9020.00 2512	(Aotex. 2010) (UK Plumbing. 2010) (UK Plumbing. 2010) (Ehlite-heat. 2010) (UK Plumbing. 2010)
– FIGHTER 200 P heat pump – SI 17TE heat pump	4970.00 8760.00	(Teplovye nasosy. 2010) (Komtex. 2010)
– MND -1,2 (180 W) heating floor-mat for 150 m^2 of living space – Heat floor energy cable (1000 W) for 150 m^2	10180.00 1925.00	(ChTK. 2010) (Energy. 2010)
– ACV ETech S 240 Floor Standing Electric Combi Boiler – IK-2 ceiling infrared long-wavelength heater(8 items for 150 m^2) – Amstrong Termic C-1,2 ceiling and wall infrared long-wavelength heater (8 items for 150 m^2)	3570 1075.00 500.00	(UK Plumbing. 2010) (System of infrared heating. 2010) (System of infrared heating. 2010)

6. RESULTS AND DISCUSSIONS

According to the work made it was found that there are a plenty of options for detached houses heating.

All heating methods can be roughly separated in two types. They are district heating and decentralized heating. Shortly it can be concluded that the main advantage of district heating for consumer is absence of investment. At the same time main disadvantages of the method are high level of CO_2 emissions in the production of thermal energy and consumer dependence on heat supplier. The decentralized heating system has opposite pros and cons if compare with DH. The advantage is independence on heat supplier; and disadvantage is high investment in equipment. In spite of these characteristics it was noticed that share of DH in all heating methods is increasing in Finland and decreasing in Russia.

The following methods of decentralized heating were considered in this work:

- combustion in boilers;
- solar collectors;
- geothermal methods;
- electrical heating.

Combustion in boilers is the most commonly used method in Finland and Russia due to its simplicity and ability to work with different fuel. But the main disadvantage of the method is emissions and waste from fuel incineration. Although burning wood and pellets do not produce harmful emissions of carbon dioxide into the atmosphere, a large quantity of ash is produced during fuel combustion and it requires disposal or utilization.

Solar collectors are not widespread in both countries because of their geographical locations.

Geothermal method with heat pump use is a relatively new method which started to be widely used. It produces low indirect CO_2 emissions into the atmosphere due to the electricity use and has no waste for disposal.

Electrical heating methods are easy to handle and have many options in technical applications such as electric boilers; wall and plinth heaters; cable and film systems for heating the floor and ceiling; ceiling infrared long-wavelength heaters. Some of them are relatively cheap. They don't need free areas for fuel storage and don't take up much space for installation. Disadvantages of electrical heating methods are high load on electrical grid and hence high level of CO_2 emissions and high electricity prices.

Fuel and energy balances, state of electricity net supply and total electricity consumption in Finland and Russia were considered in the thesis. The main component of Russian fuel and energy balance is gas. It can be explained a high level of gas reserves in Russia (26.3% of whole world reserves). Oil is in Finland. Industry consumes the greatest part of electricity generated both in Finland and Russia. Nuclear power plants produce the biggest part of electricity in Finland (25.3%); CHP produces the biggest electricity part in Russia (53%). It is explained availability of mineral resources.

As Russian and Finnish electricity markets are based on free trade. Electricity price is determined according to supply and demand bids. Transmission lines are controlled by monopolistic organizations (the main share holding belongs to the states).

It was noticed that combustion power plants make large contribution to GHG emissions. Due to the fact Finland has commitments under the Kyoto Protocol, the offset for CO_2 emission is a great part of all air pollution payments. Russia has no commitments in CO_2 reduction but has a high level of other pollutants emissions. Therefore, main payments for air pollution are formed on the base of those emissions.

Both Russia and Finland have good facilities for wind power generation. Solar radiation level is not high here therefore solar panel collectors use is not widespread. Main pollutants in Russia and Finland are formed from fuel combustion plants, pulp and paper mills, chemical and metallurgical industries.

7. CONCLUSION

Production and consumption of energy is always accompanied by environmental damage. Energy production is leading in the degree of adverse effects on the environment. Environmental damage from power engineering has usually complex nature. Air, water and soil are polluted. Such global problems as acid rains, global warming and ozone holes are connected with energy production. Reducing of energy consumption in the residential sectors, renewable energy use, good house insulation, the correct choice of the heating system are the ways to reduce environmental problems of energy sector.

Existing methods for heating of detached houses in Finland and Russia were considered during the work. The differences between them were identified. The best existing technologies for detached houses heating have been proposed.

It was determined that the operating costs of heating methods in Russia are significantly lower than in Finland. This is explained by the fact that Russia has large reserves of natural resources, so the price of fuel is lower than in Finland. At the same time, equipment and technology are overage at the majority of Russian thermal power plants and do not meet modern environmental and technical requirements. A large amount of heat energy is lost during transmission to consumers. Therefore, CO_2 emissions from the use of DH and electrical heating methods are higher in Russia than in Finland.

According to the made analysis, heating with wood and gas boilers use is the best technology in Russia in terms of operating costs. Operating costs amount to 75.5 and 78.5 EUR/year, respectively. However, the atmosphere is polluted by greenhouse gases when using gas for heating. Therefore, the use of wood boilers is the best available heating technology in Russia in terms of operating costs and environmental responsibility of the population.

Pellet boilers and heat pumps are the most profitable methods of heating systems in Finland from the viewpoint of operating costs. They amount to 238.4 and 293.5 EUR/a, respectively. Emissions of CO_2 at the heat pumps operation are the lowest among all heating methods. But because pellets are made from renewable materials such as wood chips, grass, agricultural wastes, incineration does not produce harmful emissions of CO_2 into the atmosphere. Therefore, the use of pellet boilers for heating of detached houses is the best available technology in Finland in terms of reducing greenhouse gases emissions.

According the obtained results, wood and pellets boilers are the best heating technologies both in Finland and Russia. However, it is not worth forgetting that ash is formed when combusting wood and pellets and it requires disposal. Therefore, further analysis for correct choosing of the best available technology for heating of detached houses should be performed to assess the amount of ash formed, the possibility of its utilization and costs for its disposal in a landfill.

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APPENDICES

Appendix I. Electricity retailers' addresses

Company	Address			Tel.
	Street	Postal code	Place	
Alajärven Sähkö Oy	PL 52	62901	ALAJÄRVI	+358 6 5577470
Asikkalan Voima Oy	Markkinatie 1	17200	VÄÄKSY	+358 3 882650
Ekenäs Energi	PB 31	10601	EKENÄS	+358 20 6192810
Ekosähkö Oy	PL 5	87101	KAJAANI	+358 800 92480
Energiapolar Oy	Veitikantie 4	96100	ROVANIEMI	+358 16 3290600
E.ON Suomi Oy	Itämerenkatu 1	00180	HELSINKI	+358 10 2265500
Esse Elektro-Kraft Ab	Steinpottvägen 3	68820	ESSE	+358 6 7662068
Etelä-Savon Energia Oy	PL 166	50101	MIKKELI	+358 15 1951
Etelä-Suomen Energia Oy	PL 37	04201	KERAVA	+358 9 5849551
Fortum Markets Oy	PL 40	00048	FORTUM	+358 800 1 9900
Halpa-Halli Oy	PL 94	67101	KOKKOLA	+358 6 8268111
Haminan Energia Oy	Reutsinkatu 12	49400	HAMINA	+358 201 758661
Helsingin Energia		00090	HELEN	+358 9 6171
Herrfors Oy Ab	Storgatan 8	68600	JAKOBSTAD	+358 6 7815300
Hiirikosken Energia Oy	Köpingintie 6	66440	TERVAJOKI	+358 6 4785047
Iin Energia Oy	Asemantie 13	91100	II	+358 8 8180220
Helsinki-Vantaan lentoasema	PL 29	01531	VANTAA	+358 9 82771
Imatran Seudun Sähkö Oy	Karhumäenkatu 2	55120	IMATRA	+358 5 68355
Jakobstads Energiverk	Victor Schaumansespl. 1	68600	JAKOBSTAD	+358 6 7851111
Jeppo Kraft Andelslag	Kiitolavägen 1	66850	JEPPO	+358 6 7642116
Joroisten Energialaitos	PL 39	79601	JOROINEN	+358 17 5784310

Jylhän Sähköosuuskunta	PL 49	62201	KAUHAVA	+358 6 434 6300
Jyväskylän Energia Oy	PL 4	40101	JYVÄSKYLÄ	+358 14 624144
Kainuun Energia Oy	PL 5	87101	KAJAANI	+358 10 226000
Keravan Energia Oy	PL 37	04201	KERAVA	+358 9 584955
Keuruun Sähkö Oy	PL 50	42701	KEURUU	+358 14 754754
Koillis-Satakunnan Sähkö Oy	PL 25	34801	VIRRAT	+358 3 485511
Kokemäen Sähkö Oy	Skaffarinkatu 14	32800	KOKEMÄKI	+358 2 8386250
Kokkolan Energia	PL 43	67101	KOKKOLA	+358 6 8289111
Korpelan Voima Kuntayhtymä	PL 13	69101	KANNUS	+358 6 8747311
Kraft&Kultur Sverige AB	Rauhankatu 16	65100	VAASA	+358 6 3577090
Kronoby Elverk	PB 3	68501	KRONOBY	+358 6 8345142
KSS Energia Oy	Hovioikeudenkatu 3	45100	KOUVOLA	+358 5 885111
Kuopion Energia Oy	PL 105	70101	KUOPIO	+358 20 52070
Kuoreveden Sähkö Oy	Korpitie 5	35600	HALLI	+358 3 5320121
Kymenlaakson Sähkö Oy	PL 9	47201	ELIMÄKI	+358 5 77801
Kymppivoima Oy	Lönnrotinkatu 15 C	00120	HELSINKI	+358 10 210210
Köyliön-Säkylän Sähkö Oy	Kuninkaanlähteentie 76	27800	SÄKYLÄ	+358 2 8386200
Lahti Energia Oy	PL 93	15141	LAHTI	+358 3 82300
Lammaisten Energia Oy	Myllykatu 2	29200	HARJAVALTA	+358 2 5352011
Lankosken Sähkö Oy	Hirvijärventie 8	29810	SIIKAINEN	+358 2 5288800
Lappeenrannan Energia Oy	PL 191	53101	LAPPEENRANTA	+358 20 177 6111
Lehtimäen Sähkö Oy	Peräläntie 3	63500	LEHTIMÄKI	+358 6 5271142
Leppäkosken	PL 1	39501	IKAALINEN	+358 3 45031

Energia Oy				
Lännen Omavoima Oy	Vihtorinkatu 2	23800	LAITILA	+358 2 85061
Mäntsälän Sähkö Oy	Sepäntie 3	04600	MÄNTSÄLÄ	+358 19 68991
Naantalin Energia Oy	PL 33	21101	NAANTALI	+358 2 4362900
Nurmijärven Sähkönmyynti Oy	PL 4	01901	NURMIJÄRVI	+358 9 878071
Nykarleby Affärsverk	Kvarnvägen 20	66900	NYKARLEBY	+358 6 7856111
Oulun Sähkönmyynti Oy	PL 116	90101	OULU	+358 8 55843300
Outokummun Energia Oy	PL 53	83501	OUTOKUMPU	+358 13 563011
Paneliankosken Voima Oy	Mäkiläntie 7	27430	PANELIA	+358 2 8386100
Parikkalan Valo Oy	PL 14	59101	PARIKKALA	+358 5 43901
Pohjois-Karjalan Sähkö Oy	PL 141	80101	JOENSUU	+358 13 2663311
Pori Energia Oy	PL 9	28101	PORI	+358 2 6212233
Porvoon Seudun Sähkö Oy	PL 95	06101	PORVOO	+358 19 661411
Sallila Energia Oy	Loimijoentie 65	32440	ALASTARO	+358 2 76431
Savon Voima Oy	PL 1024	70781	KUOPIO	+358 290 223111
Seinäjoen Energia Oy	Varastotie 5	60100	SEINÄJOKI	+358 6 4210400
St1 Oy	Purotie 1	00380	HELSINKI	+358 800 131031
Suomen Energiayhtiö Oy	Hermannin rantatie 24	00580	HELSINKI	+358 20 7789150
Suur-Savon Sähkö Oy	PL 3	50101	MIKKELI	+358 10 21041
Tampereen Sähkönmyynti Oy	PL 175	33101	TAMPERE	+358 20 713 5111
Turku Energia Oy - Åbo Energi Ab	PL 105	20101	TURKU	+358 2 2628111
Vaasan Sähkö Oy	PL 26	65101	VAASA	+358 6 3245111
Valkeakosken Energia Oy	PL 89	37601	VALKEAKOSKI	+358 3 5865111

Vantaan Energia Oy	PL 95	01301	01301	+358 9 82901
Vapo Oy, Lämpö ja Sähkö	PL 111	30101	FORSSA	+358 3 41261
Vatajankosken Sähkö Oy	PL 12	38701	KANKAANPÄÄ	+358 2 578 257
Vattenfall Sähkönmyynti Oy	Maistraatinportti 4	00240	HELSINKI	+358 20 58611
Vetelin Sähkölaitos Oy	Äijäpatintie 4	69700	VETELI	+358 6 8663600
Vimpelin Voima Oy	Uusituvantie 6	62800	VIMPELI	+358 6 5617200
Yli-Iin Sähkö Oy	Ruunatie 12	91200	YLI-II	+358 8 8192100
Ääneseudun Energia Oy	Kotakennääntie 31	44100	ÄÄNEKOSKI	+358 14 5495000

Appendix II. Maximum allowable concentrations of typical CHP pollutants in Russia

(GN 2.1.6. 1338-03, 2003)

Pollutant	**Maximum allowable concentration, mg/m3**
Carbon monoxide, CO	3
Nitrogen dioxides, NO_2	0,04
Nitrogen oxide NO	0,06
PM10 (Particulate matter less than 10 µm)	0,15
Sulphur dioxides SO_2	0,05

Appendix III. Limit values of typical CHP pollutants in Finland

Averaging Period	**Limit value**	**Margin of tolerance**
Sulphur dioxide		
One hour	350 µg/m3, not to be exceeded more than 24 times a calendar year	150 µg/m3 (43 %)
One day	125 µg/m3, not to be exceeded more than 3 times a calendar year	None
Nitrogen dioxide		
One hour	200 µg/m3, not to be exceeded more than 18 times a calendar year	50 % on 19 July 1999, decreasing on 1 January 2001 and every 12 months thereafter by equal annual percentages to reach 0 % by 1 January 2010
Calendar year	40 µg/m3	50 % on 19 July 1999, decreasing on 1 January 2001 and every 12 months thereafter by equal annual percentages to reach 0 % by 1 January 2010
Carbon monoxide		
maximum daily eight hour mean	10 mg/m3	60 %
PM10		
One day	50 µg/m3, not to be exceeded more than 35 times a calendar year	50 %
Calendar year	40 µg/m3	20 %