LAHDEN AMMATTIKORKEAKOULU
Lahti University of Applied Sciences

CHOOSING A NEW HEATING ENERGY SOURCE

Case study: Housing Cooperative Pakkalankulma

LAHTI UNIVERSITY OF APPLIED SCIENCES
Faculty of Technology
Master’s Degree in Environmental Technology
Master’s Thesis
Spring 2015
Leena Julin

Lahti University of Applied Sciences
Faculty of Technology

Master's Degree in Environmental Technology

JULIN, LEENA: Choosing a New Heating Energy Source
Case study: Housing Cooperative Pakkalankulma

Master's Thesis in Environmental Technology, 55 pages, 4 pages of appendices

Spring 2015

ABSTRACT

Climate change is a fact that cannot be cold-shouldered anymore. It is taking place at this very moment, and the consequences are already occurring: glaciers have shrunk and global sea level has risen an alarming 17 cm, global surface temperature has risen since the end of the 1900th century, and snow cover decreased. Moreover, extreme heat waves, droughts and heavy precipitation have all taken place more often. Animal and plant species have either been forced to move or become extinct.

Harsh predictions for the future of the human race have been made, including famine and lack of drinking water. However, scientists believe it is still not too late to save the planet. This means drastically cutting greenhouse gas emissions, which are at the current rate the main reason for the climate change.

The biggest emitter of greenhouse gases is the burning of fossil fuels, such as coal, oil and natural gas. Emissions need to be cut both at national and regional levels. On a household scale, the biggest producer of greenhouse gases is the heating of the houses. In addition to saving energy, one option could be choosing a new source of energy.

This Master’s thesis is a case study, which explores one Finnish fossil-fuel-burning housing cooperative’s options for a new heating energy source. Heating energy sources using fossil fuels are proved harmful for the climate and quantitative evidence of e.g. greenhouse gas emissions is presented and compared between different energy sources.

After an evaluation of different heating systems, possible solutions for the housing cooperative are presented. The condition of the current heating system should be studied by a professional, and according to this, two first phase options are either implementing an air-to-water heat pump to support natural gas heating, or changing the current heating system to a ground source heat pump with boreholes. The second phase could include the installation of solar thermal collectors, and the third a change from regular electricity to eco-electricity.

Keywords: climate change, global warming, natural gas, ground source heat pump, air-to-water heat pump

Lahden ammattikorkeakoulu
Ympäristöteknologian koulutusohjelma (YAMK)

JULIN, LEENA:

Uuden lämmitysjärjestelmän valinta
Tapaustutkimus As Oy Pakkalankulma

Ympäristöteknologian koulutusohjelman (YAMK) opinnäytetyö, 55 sivua ja 4 liitesivua

Kevät 2015

TIIVISTELMÄ

Ilmastonmuutos on fakta, jota ei voi enää sivuuttaa. Se tapahtuu nyt ja muutokset ovat jo nähtävillä: jäätiköt ovat kutistuneet, merenpinta on noussut hälyttävät 17 cm, maapallon pintalämpötila on noussut tasaisesti 1800-luvun lopulta lähtien ja lumipeitteet ovat harventuneet. Myös äärimmäiset sääilmiöt, kuten lämpöaallot, kuivuudet ja toisaalla rankkasateet, ovat lisääntyneet. Useat eläin- ja kasvilajit ovat joutuneet muuttamaan asuinaluettaan tai kuolleet sukupuuttoon.

Ihmiskunnan kohtalosta on esitetty tylyjä ennusteita, mukaan lukien nälänhätää ja puhtaan juomaveden puutetta tulevaisuudessa. Tiedemiehet kuitenkin uskovat, ettei vielä ole liian myöhäistä pelastaa maapalloa. Tämä vaatisi kuitenkin kasvihuonekaasupäästöjen voimakasta vähentämistä, sillä ne ovat nykyisellä tasollaan pääsyy ilmastonmuutokseen.

Suurin kasvihuonekaasujen tuottaja on fossiilisten polttoaineiden käyttö. Niihin kuuluvat esimerkiksi hiili, öljy ja maakaasu. Päästöjä pitää leikata sekä valtakunnallisella, että paikallisella tasolla. Ruohonjuuritasolla, kotitaloisten suurin kasvihuonekaasujen tuotto tulee talojen lämmityksestä. Energiansäästön lisäksi yksi vaihtoehto on uuden lämmitysenergianlähteen valinta.

Tämä opinnäytetyö on tapaustutkimus, joka tarkastelee yhden suomalaisen fossiilista polttoainetta lämmitykseen käyttävän taloyhtiön muita lämmitysvaihtoehtoja. Fossiilisia polttoaineita käyttävät lämmitysmuodot todetaan ilmastolle vaarallisiksi ja kvantitatiivisia todisteita esim. kasvihuonekaasupäästöistä esitetään ja verrataan energiamuotojen välillä.

Kun erilaiset lämmitysmuodot on arvioitu, taloyhtiölle esitellään mahdolliset ratkaisut. Nykyisen lämmitysjärjestelmän kunto tulisi arvioittaa alan asiantuntijalla, ja tämän perusteella suositellaan ensivaiheessa joko ilma-vesilämpöpumpun hankintaa maakaasun rinnalle tai maalämpöön siirtymistä. Seuraavassa vaiheessa ehdotetaan aurinkoenergian hyödyntämistä ja kolmannessa sähkösopimuksen vaihtamista vihreään sähköön.

Avainsanat: ilmastonmuutos, ilmaston lämpiäminen, maakaasu, maalämpö, ilma-vesilämpöpumpppu

CONTENTS

LIST OF ABBREVIATIONS

Bq	Becquerel
C_2H_6	Ethane
C_2H_6O	Ethanol
C_3H_8	Propane
C_4H_{10}	Butane
$(CH_2)_4$	Tetrahydrothiophene
CH_4	Methane
CO_2	Carbon dioxide
COP	Coefficient of Performance
GSHP	Ground Source Heat Pump
LNG	Liquefied Natural Gas
N_2	Nitrogen
NASA	National Aeronautics and Space Administrations
OSF	Official Statistics of Finland
ppm	Parts per million
SO_2	Sulphur dioxide
STUK	Radiation and Nuclear Safety Authority
W/mK	Thermal conductivity (Watt per metre-Kelvin)

1 INTRODUCTION

Burning fossil fuels has emitted greenhouse gases, such as carbon dioxide (CO_2), into the atmosphere for 200 years, of which the last 50 years more powerfully than ever. Since the Industrial Revolution in the 19th century, the amount of CO_2 in the atmosphere has increased by nearly 40 % so far. (Houghton 2009, p. 29.)

It has been possible to study historical CO_2 concentrations by ancient air bubbles trapped in ice. These studies show, that the levels of CO_2 in the atmosphere are higher than they have been in the past 400 000 years:

> *During ice ages, CO_2 levels were around 200 parts per million (ppm), and during the warmer interglacial periods, they hovered around 280 ppm. In 2013, CO_2 levels surpassed 400 ppm for the first time in recorded history (NASA 2014).*

The Scripps CO_2 −program has measured the amount of carbon dioxide in the atmosphere for more than 50 years. During that time, a clear trend can be seen (Figure 1). Alone during the last 19 years the rise has been 6 %. (Scripps, Institution of Oceanography 2015.)

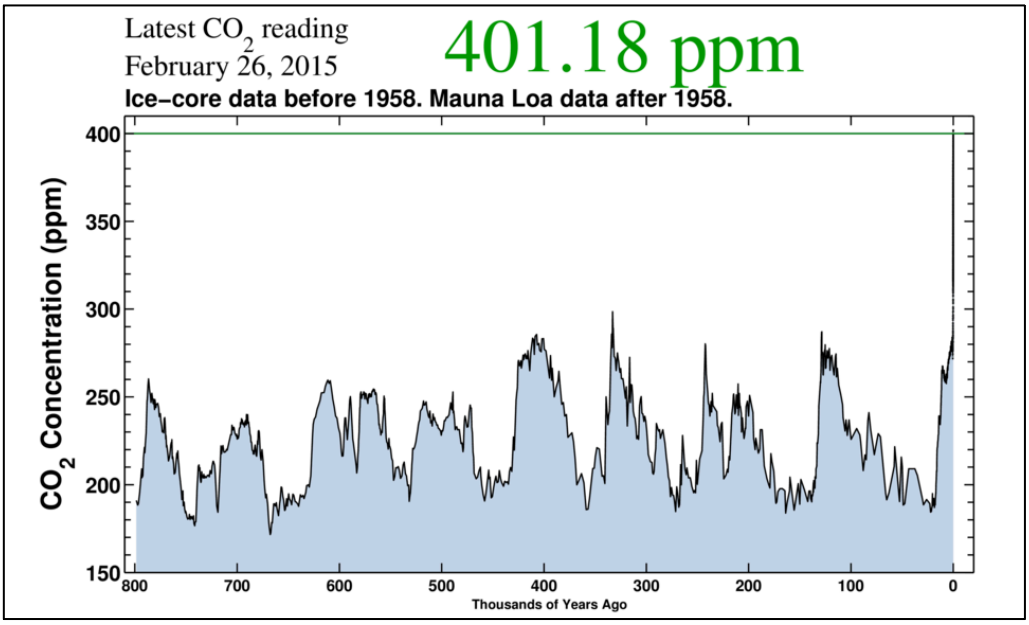


FIGURE 1. Historical CO_2 concentrations in the atmosphere (Scripps, Institution of Oceanography 2015).

In addition, scenarios show that if the world population grows by 37 % through 2050, the atmospheric CO_2 concentration could grow to 450 ppm by volume (Yudelson 2010, p.8). Moreover, a projection with very rapid economic growth and intensive usage of fossil fuel technology in the future can increase the CO_2 concentration to nearly 1000 ppm by 2100 (Houghton 2009, p. 141).

Every year, more than 8000 million tonnes of CO_2 are added to the atmosphere and much of it will remain there for more than 100 years (Houghton 2009, p. 13). Nevertheless, CO_2 is a good absorber of heat from the Earth's surface, and works like a glass roof in a greenhouse. Companied with other greenhouse gases and water vapour, it reflects some solar radiation back to space, lets some into the Earth's surface, and prevents heat from escaping. Without CO_2 and other greenhouse gases, the Earth would be a much colder place, more specifically, the average temperature would be a chilling -18 °C (Telkänranta 2006, p. 13). However, an increasing CO_2 amount due to human activities demonstrably leads to a global climate change (Houghton 2009, p. 13, 20-25).

1.1 Climate change

During the Earth's history there have been many large changes in the condition of the climate. Within the last 650 000 years, seven cycles of glacial advance and retreat have taken place (NASA 2014). However, those historical changes have been slower than these taking place nowadays. Apparently, the present rate of warming, 3 °C per century, is faster than the rate at which the global average temperature has changed during the last 10 000 years (Houghton 2009, p. 13). Studies show that particularly the last decades have been unusually warm. Globally, of the 100 last years the last 30 have been the warmest. (Houghton 2009, p. 2.) Moreover, the ten warmest years of the 100-year recording time have all occurred since 1998 (NASA 2014) (Figure 2).

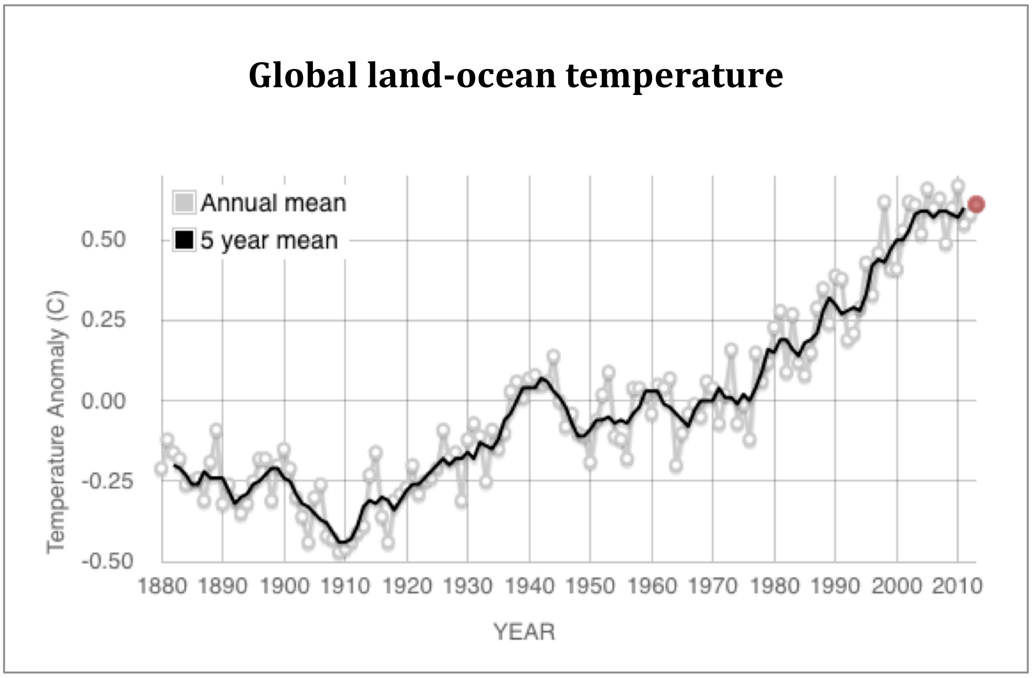


FIGURE 2. Global land-ocean temperature 1884-2013 (NASA 2014)

Already, there are several signs showing that global warming is taking place with serial consequences (Table 1).

TABLE 1. Some twentieth-century changes in the Earth's atmosphere, climate and biophysical system. (Houghton 2009, p.76-77; NASA 2014.)

Indicator	Observed changes in the twentieth century
Global mean surface temperature	Increased by 0,6 ± 0,2 °C
Cold/frost days	Decreased for nearly all land areas
Heavy precipitation events	Increased at mid and high northern latitudes
Global mean sea level	Increased at an average annual rate of 1-2 mm, totally 17 cm in the last century
Duration of ice cover of rivers and lakes	Decreased by approx. two weeks in mid and high latitudes of the northern hemisphere

Arctic sea-ice extent and thickness	Thinned by 40 % in recent decades in late summer to early autumn, decreased in extent by 10-15 % since the 1950s in spring and summer
Permafrost	Thawed, warmed and degraded

Only few changes were mentioned above but the consequences of just those can be dramatic and differ depending on the location on the planet. Scientists believe that the extremes of climate, such as droughts, floods and storms will be more common. Moreover, heat waves and the number of extremely warm days will increase. More intense precipitation will lead to floods, which are a threat to water resources and food security. On the other hand, some parts of the planet will suffer from drought. Ultimately, changing living conditions, and especially the rapidness of those, will cause some species to become extinct which will damage the delicate ecosystem. (Houghton 2009, p. 154.)

Another disaster would be the shutdown of the Atlantic thermohaline circulation, which means that the ocean currents would not bring warm water to the North. The winters in the Nordic countries would cool down and the already short growing season would shorten even more (Ganopolski 2010, p. 302).

1.2 Cutting greenhouse gases

Even though horror pictures and catastrophes have been forecast, scientists believe that by reducing greenhouse gas emissions it is still possible to decrease the harms caused by global warming. Moreover, it would be possible to avoid the extreme and irreversible changes for the humanity. (Berninger 2012; Telkänranta 2006.)

However, saving the planet *needs* actions. Greenhouse gas emissions need to be cut drastically, and currently the biggest emitter is the use of fossil fuels. Fossil fuels are created, when plant and animal remains are subjected to extreme pressure and temperature for millions of years (Midthun & Tomasgard 2010, p. 73). Fossil fuels include coal, natural gas and oil, in addition to all oil refined products such as gasoline and diesel (Telkänranta 2006, p. 15). Burning those for e.g. to produce heating energy releases tonnes of CO_2 into the atmosphere.

Finally, greenhouse gas emissions should be cut down fast, while it is still possible to stop the global warming. To a certain point, it might not be achievable anymore. Scientists suggest that the two best ways to decrease the emissions are saving energy, and replacing fossil fuels with renewable energy. (Telkänranta 2006, p. 30)

1.3 Reducing energy consumption

The amount of energy used per person varies worldwide. The billion richest people in the world use nearly 25 times more energy annually than the 2 billion poorest. On the other hand, one third of the world's population lack an access to electricity, oil or other modern energy sources, instead they rely wholly on traditional fuels such as wood, dung and rice husks. (Houghton 2009, p. 326.)

Finland's total energy consumption in 2012 was approximately 1371 petajoules and has not decreased to this day. Only a third of this is produced by renewable sources. (Motiva 2014.) The European Union has set a goal for its member countries to increase the use of renewable energy sources. Since all the members have different starting points, country-specific targets have been set up. Therefore, Finland needs to increase the use of renewable energy sources up to 38 % of the total energy consumption. (Berninger 2012, p. 49, 53.)

The EU has also defined that all the member countries should reduce their greenhouse gas emissions by 20 % before 2020 (Berninger 2012, p. 36). These two goals go hand in hand: by reducing the use of fossil fuels, man-made greenhouse gas emissions will decrease. Some progress has already been made as can be seen in Appendix 1.

Of the total energy produced in the world, 44 % is used in buildings, two-thirds of that in residential buildings (Houghton 2009, p. 326). Housing is also the biggest share of the Finnish households' environmental impacts, 33 %. Approximately half of the energy consumed is used for keeping the houses warm. (Berninger 2012, p. 48). Indoor heating also reveals to be the households' biggest source of

CO_2 emissions (Kimpanpää 2009, p. 51), and therefore it should be the first thing to be considered on a residental-scale, in order to fight global warming.

1.4 Towards energy efficient housing

Energy efficient buildings are no more science fiction, buildings heated by solar power, ground source heat pumps or even by waste already exist on this globe. Much water has been flown under the bridge since the only way to warm the house in Finland was a fireplace. However, world widely, not much has changed during the past 50 years; the same energy sources (oil, gas and coal) are still used today (Yudelson 2010, p. 228). The only difference is that they are used with a higher volume.

A vital fact is that the cost of the house is not the only expense for the homeowners, and the ever-increasing price of electricity is already encouraging people to think about all the different ways to save energy in their homes. In other words, while heating energy needed is minimized, also money is saved. According to several test buildings (Isosaari 2012, p. 10), the need of the heating energy can be halved by an only 3 to 5 percent increase in the building costs, the payback time being less than five years.

While brand new houses are properly insulated and equipped with new energy efficient inventions, such as heat recovery ventilation, there are thousands of old houses still using only high-cost electricity, or particulate matter emitting fireplaces for warming. Not to forget the 280 900 households in 2013 warmed by fossil fuels, such as oil or gas (OSF 2014).

1.5 Aim of the thesis

This Master’s thesis explores one housing cooperative in the Pakkalankulma area of Pirkkala, depending at the moment only on fossil fuels. The board of directors of the housing cooperative has suggested to the long-term plan of the housing company that the current heating system should be investigated, and possibilities for a different, more environmentally friendly system, studied. This is estimated to be done between 2014 and 2017. This Master’s thesis aims to help the board of directors to evaluate the different possibilities suitable for replacing the housing company's current heating system.

The research method of this thesis is a case study. It enables the in-depth analysis of a housing cooperative known by the author. Most of the data is quantitative and also quantitative analysis has been used. The data collected consists of the existing materials, sometimes combined from several sources, such as books, documents, laws (qualitative), and statistics.

Heating energy sources using fossil fuels are proved harmful for the climate, and quantitative evidence of e.g. greenhouse gas emissions will be presented and compared between the energy sources. Finally, recommendations are given.

The objective is to find out if an energy option which emits less greenhouse gas exists and would be suitable for this climate, infrastructure, and plot to fight the global warming. Even a better solution would be, if the existing heating system and the facilities could somehow be utilized, i.e. hot water radiators. In addition, the new system has to be easy to use, need no constant supervising or maintenance, be accepted by the local council, and have a reasonable payback time. Thus, objectives are mainly qualitative. Next, some background information of the municipality and the housing company itself will be presented.

2 HOUSING COOPERATIVE PAKKALANKULMA

Since the housing cooperative's location, climate and other basic information may have some important aspects for this case study, background information of the municipal will be represented.

2.1 Pirkkala – basic information

Finland being one of the most sparsely populated countries in Europe, with an average of 17 inhabitants per square kilometre (OSF 2015), the municipality of Pirkkala is a pleasant exception. The vivid municipality of 18 300 people has a population density of 227 people per km^2 (OSF 2014).

Pirkkala is situated 180 kilometres north from the capital Helsinki, neighbouring the most populated inland city of the Nordic countries, i.e. Tampere. Moreover, Pirkkala is a part of the Pirkanmaa region and, at the moment, the fastest growing municipality of the region (The Municipality of Pirkkala 2014).

More than half of all the people in Pirkkala live in row or small residential houses, approximately 2,4 persons in one housing unit. Rental apartments sum up 17 % of the houses (OSF 2014).

The municipality of Pirkkala has an environmental program for years 2012-2016 which has 5 main goals: to work toward sustainable development, to advance eco-efficient urban planning and construction, to encourage recreational use and the diversity of the forests, to enhance the state of the drainage system, and to reduce noise pollution caused by traffic (Municipality of Pirkkala 2014).

Finally, some heating energy sources require drilling the ground hundreds of meters. Therefore, some things to be considered are soil types, possible groundwater reservoirs and radon. That is why some background information of those will be presented. First, the climate is presented.

2.1.1 Climate of Pirkkala

According to Köppen's climate classification, Pirkkala and whole Finland belong to the temperate coniferous-mixed forest zone with cold, wet winters (Ilmatieteenlaitos 2014). The temperatures of Pirkkala are usually a little bit warmer than average Finnish temperatures due to the large water systems: the municipality has a long shoreline with the lake Pyhäjärvi (Ilmasto-opas 2013).

The annual average temperature in Pirkkala varies between 4 and 6 °C (Figure 3).

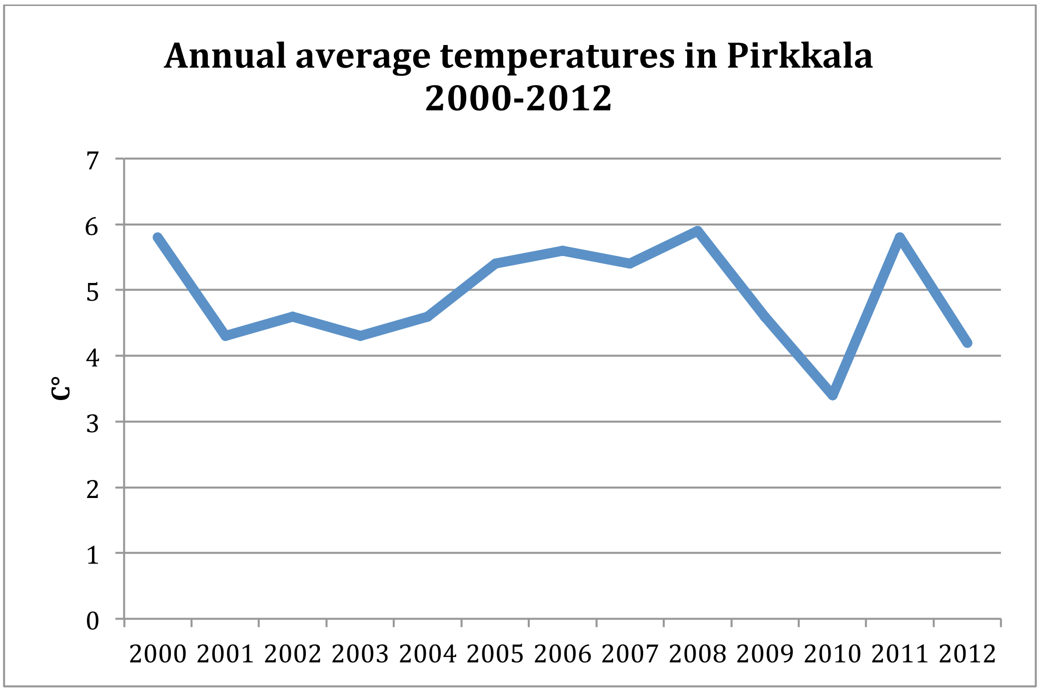


FIGURE 3. Average temperatures in Pirkkala 2000-2012 (Climateguide 2012).

Climate change has already reached Finland and Pirkkala. According to Yle News (2014), climate is warming twice faster in Finland than in the rest of the world. Lakes freeze later than before and spring comes earlier, both the annual mean temperature and the annual precipitation have increased. (Rummukainen 2014; Kimpanpää 2009.)

Also different temperature forecasts have been made depending on the amounts of future greenhouse gas emissions. Figure 4 shows the measured average annual temperatures in Pirkkala (blue curve) and three different forecasts for the future.

The red curve corresponds to a scenario where emissions are high, the yellow to fairly high emissions and the green low emissions. The temperature difference between the red and the green curve in 2085 is 1,7 °C. (Climateguide 2012).

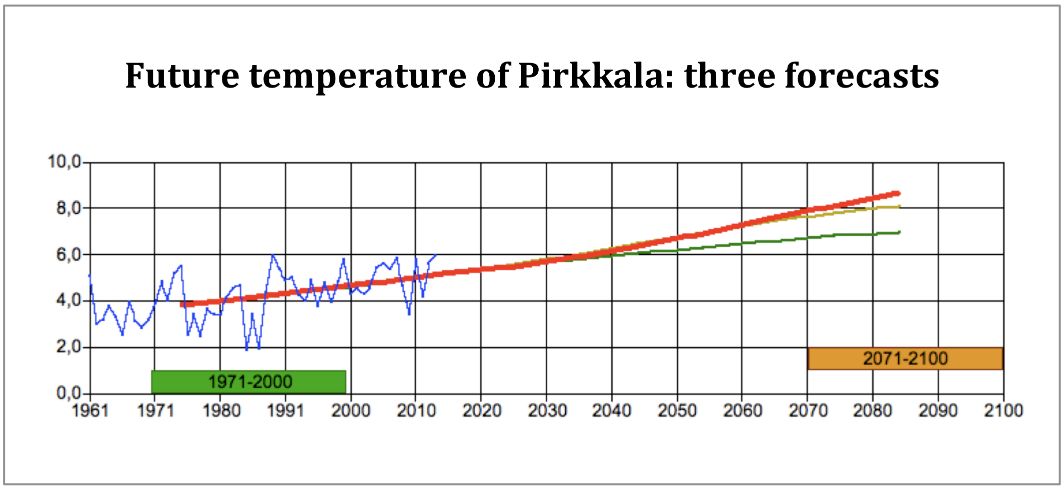


FIGURE 4. Average temperature in Pirkkala 1961-2012 and different forecasts (Climateguide.fi).

2.1.2 Ecology of Pirkkala

Pirkkala lays on a steady, ancient mountain chain formed 1900-2000 million years ago, called Paleoproterozoic Svecofennian domain, which used to run from Southern Finland through Pirkkala all the way to Sweden. Today, the topography is quite even (Figure 5).

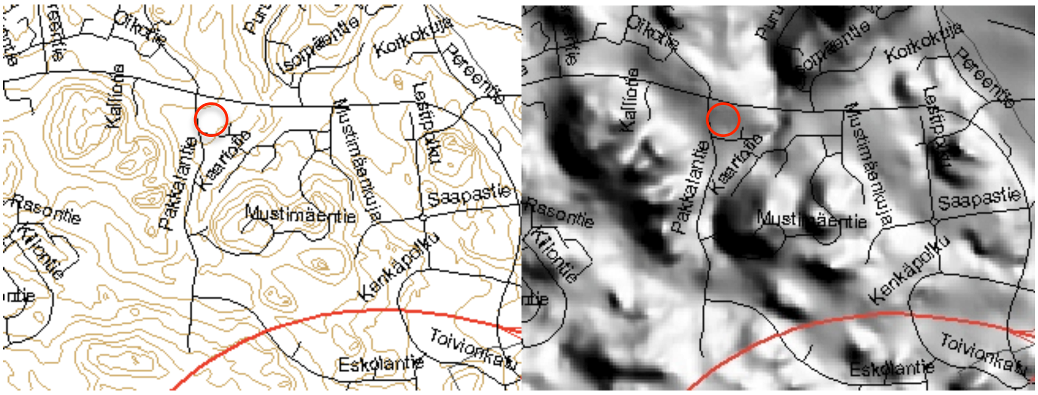


FIGURE 5. Contour line map and topography of Pakkalankulma (Tampereen seudun GeoTieto 2009).

Moreover, Pirkkala is situated in over 100 km long metamorphic rock area, which continues from Tampere to Hämeenlinna, thus the rock foundation in the area is mainly mica gneiss/migmatite. However, Pakkalankulma is located in the area of gabbro-diorite-peridotite. The dominant rock foundation type is gabbro (Figure 6).

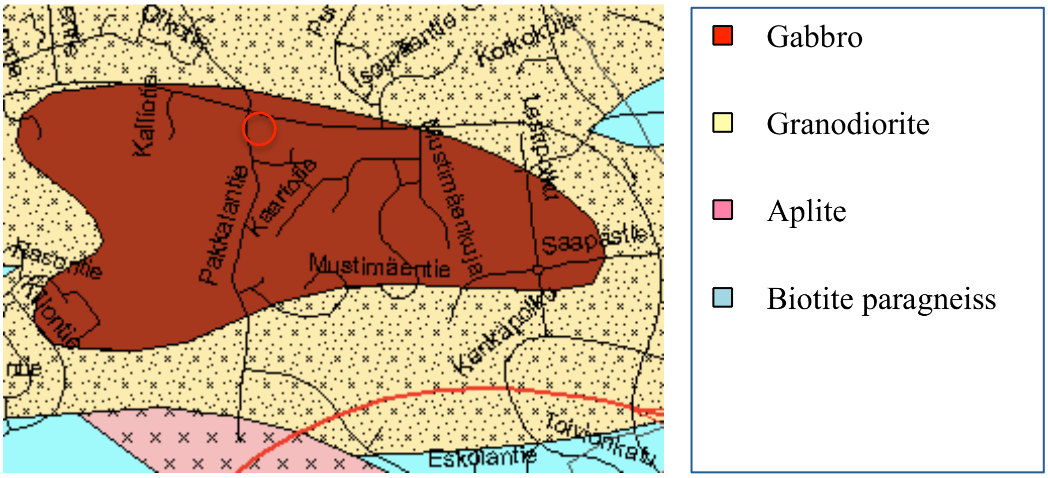


FIGURE 6. Rock foundation type of Pakkalankulma (Tampereen seudun GeoTieto 2009).

The thickness of overburden above of the bedrock in the Pirkanmaa region is approximately 3-4 metres (Figure 7) (Tarvainen, Backman & Luoma 2010).

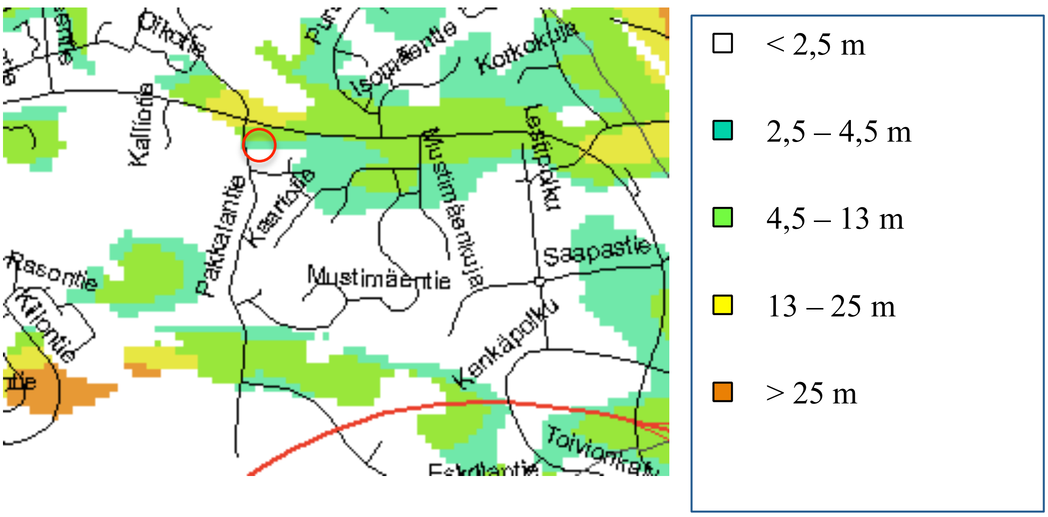


FIGURE 7. Thickness of overburden of Pakkalankulma (Tampereen seudun GeoTieto 2009).

One of the most typical overburden types in Pirkkala is clay. This is due to the time spent underneath the Yoldia Sea 10 000 years ago. Also rock and moraine/till are typical soil types in Pirkkala (Figure 8) (Ranta 2008, p. 14, 16-17).

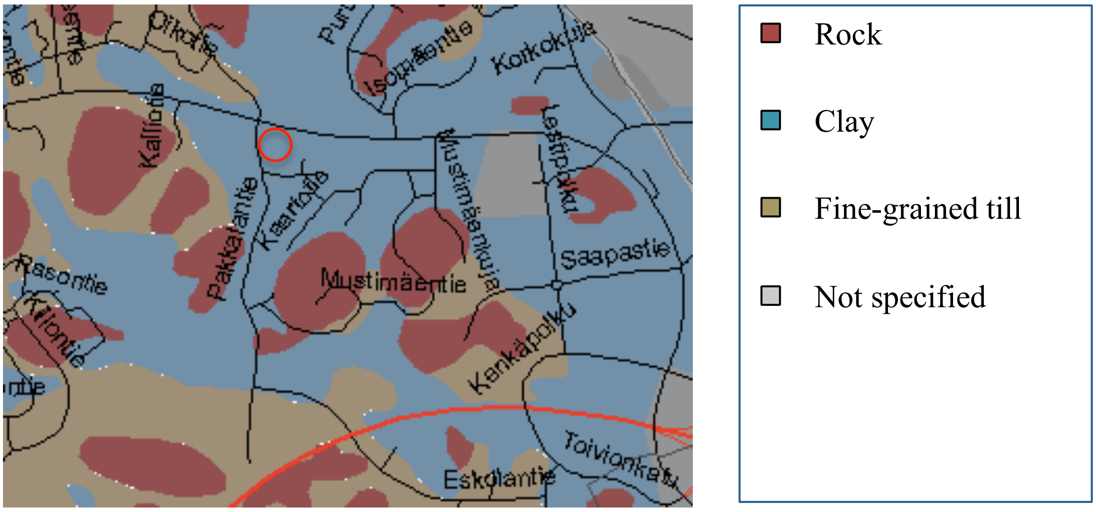


FIGURE 8. Soil types of Pakkalankulma (Tampereen seudun GeoTieto 2009).

Pirkkala has a long coastline with Lake Pyhäjärvi and multiple small lakes, 20 to be specific, but groundwater is not found in the area, excluding a few springs, which are not located near Pakkalankulma. The lack of groundwater is caused by the fact that there are no eskers in the municipality area. (The Municipality of Pirkkala 2014.)

Pirkanmaa region is known for its eskers, and although those are not found in Pirkkala, the consequence is, in this case, radon. The region is famous for its high radon concentrations. While the average concentration in Finnish homes is 96 Bq/m3, the average in Pirkkala is twice the amount. STUK, Radiation and Nuclear Safety Authority, has measured the consistency of radon in 972 apartments in Pirkkala. The average value of radon was 185 Bq/m^3 and 36 % of the houses studied were above the allowed limit in new houses (200 Bq/m^3) and 9 % over the maximum limit allowed in old apartments (400 Bq/m^3). Moreover, statistics are also available per postal code. If the postal code area of the housing cooperative Pakkalankulma is studied, 82 apartments have been measured, with the average concentration of radon 180 Bq/m3. Otherwise, excesses of the maximum measured values of new and old houses were similar to the average of Pirkkala. The maximum values are assigned by the Ministry of Social Affairs and Health. (STUK, 2015.) Apparently, radon is found in the area, and this needs to be taken into account, if drilling at the site is required.

2.2 The housing cooperative Pakkalankulma and the administration

As Oy Pakkalankulma (hereinafter housing cooperative Pakkalankulma), situated in North-East Pirkkala, is an owner-occupied housing cooperative, a typical housing system in Finland. Two-thirds of the Finnish homes are owner-occupied and half of these are housing cooperatives. Every resident is a shareholder of the housing company, and all the most important decisions are made at the shareholders’ meetings. (Saikkonen, Strandell & Karkinen, 1999, p. 35.)

In addition to shareholders’ meetings, housing cooperative Pakkalankulma also has a board of directors, selected from the shareholders. The current board of directors consists of a chairman, two actual members, and two supplementary members. The board of directors prepares important issues for meetings, suggests solutions, and enjoys the confidence of the shareholders. The board also proposes, if any changes are needed for the monthly maintenance charge collected from all the households to cover expenses.

2.2.1 Maintenance charges

The management and upkeeping of joint facilities are responsibilities of the housing cooperative; in return a maintenance charge is collected (Saikkonen, Strandell & Karkinen, 1999, p. 35). The amount of the monthly maintenance charge consists of, for example, company loan paybacks, real estate management costs, water and waste water, waste management, and, to save the best for last – heating. In 2013, heating for the housing cooperative Pakkalankulma made up approximately 47 % of all the management expenses (Figure 9).

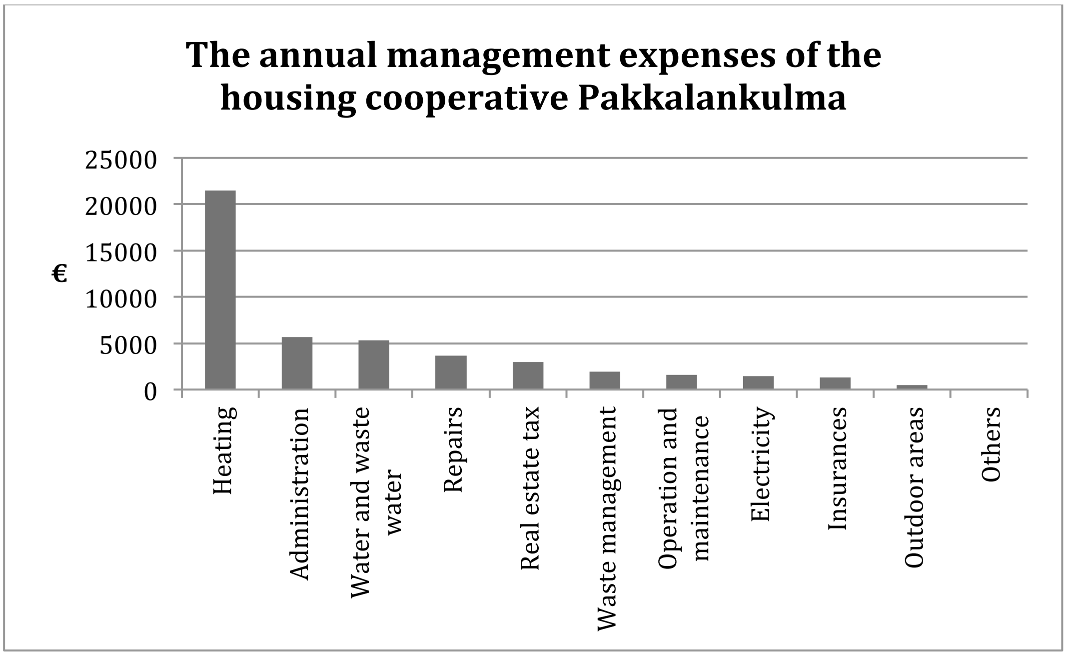


FIGURE 9. The deviation of management expenses in 2013.

Running a housing cooperative differs a little from leading other companies. In order to break even, expenses need to be smaller than incomes. On the other hand, in housing cooperatives, making lots of profit is not the main point; excess profit will be taxed. Instead covering all the expenses and saving money for future reparations are more important issues. Nevertheless, the incoming money is paid by the shareholders monthly maintenance fee, and everybody wants to pay as little as possible. This means that if there are ways to decrease the fee, no stones are left unturned.

On the other hand, saving money for future renovation from the maintenance fee can take years. This is what the housing cooperative Pakkalankulma has done, and it currently has no loans. However, it is possible for Finnish housing cooperatives to take out a loan using the real estate as collateral. If a major renovation of the heating system will be implemented, a company loan will be needed.

2.3 Building information and city plan

Housing cooperative Pakkalankulma consists of 5 concrete/brick row houses, totally 15 apartments, built in 1995. The total floor area of the houses is 1091 m^2 and the total volume 3743 m^3. All this is situated in a 5913 m^2 –size plot, owned by the housing cooperative (Figures 10-13, APPENDIX 2).

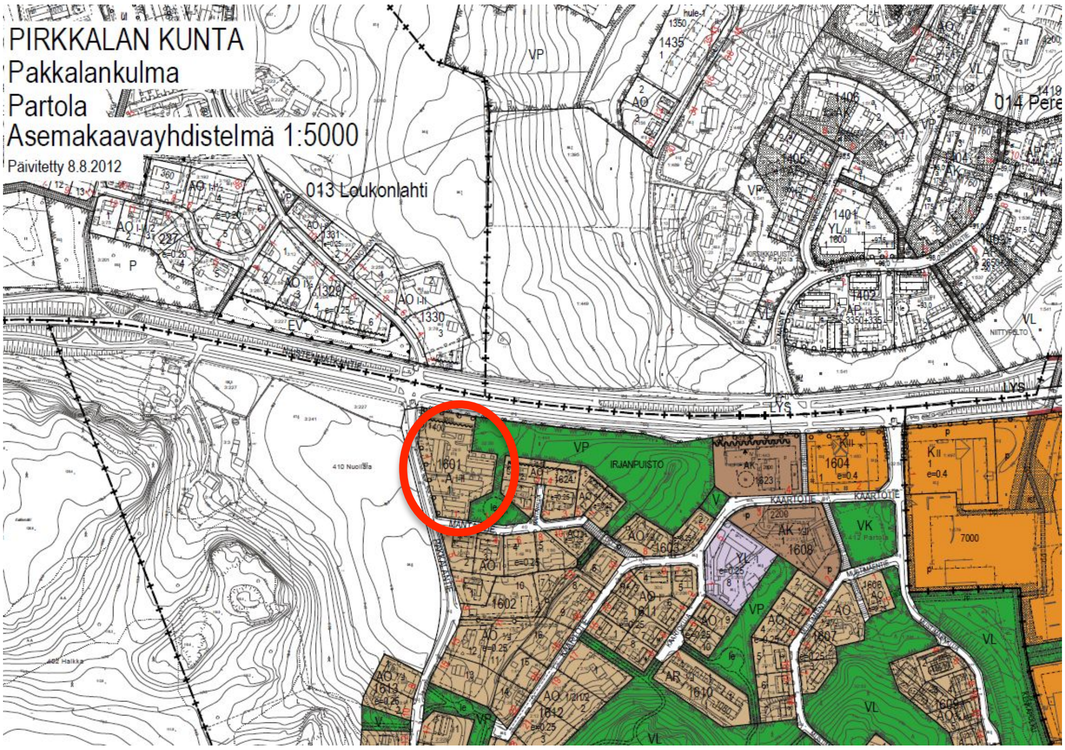


FIGURE 10. City plan of the Pakkalankulma area. Plot of the housing cooperative circled (Municipality of Pirkkala 2014).

From three sides, a road borders the plot (Figure 11): in the north by the main road of the municipality, Naistenmatkantie and its combined cycle and walk path, in the west Pakkalantie with less traffic, and in the south small Mantantie. A common playground, owned by the municipality can be found on the southeast border. In the east, the plot joins to a park.

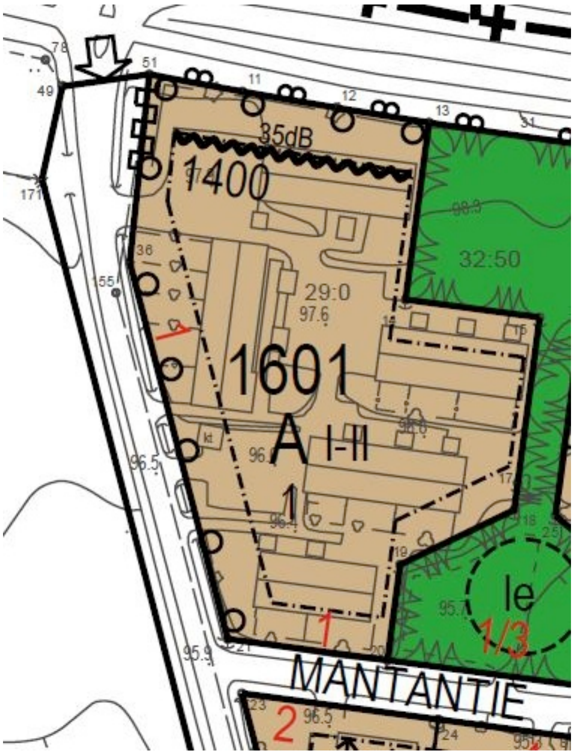


FIGURE 11. Close-up of the city plan of the Pakkalankulma area (Municipality of Pirkkala 2014).

The five houses of the housing cooperative are named from A to E (Figure 12). One parking lot is situated west from house A, and another west from house D.

A common storage area for bicycles and the heat distribution centre are located in the south part of house B. The houses contain multiple, different-size apartments (Table 2).

TABLE 2. Deviation of apartments in housing cooperative Pakkalankulma (Board of Directors 2014).

HOUSE	APARTMENTS
A	A1 49 m^2 A2 93 m^2 A3 93 m^2

B	B4 47 m^2
	B5 47 m^2
	B6 47 m^2
	B7 64 m^2
C	C8 47 m^2
	C9 93 m^2
	C10 97 m^2
D	D11 64 m^2
	D12 93 m^2
	D13 97 m^2
E	E14 93 m^2
	E15 97 m^2

FIGURE 12. Aerial photo of the housing cooperative Pakkalankulma (Google maps 2014).

More small residential buildings have been planned to the other side of Pakkalantie (Figure 13).

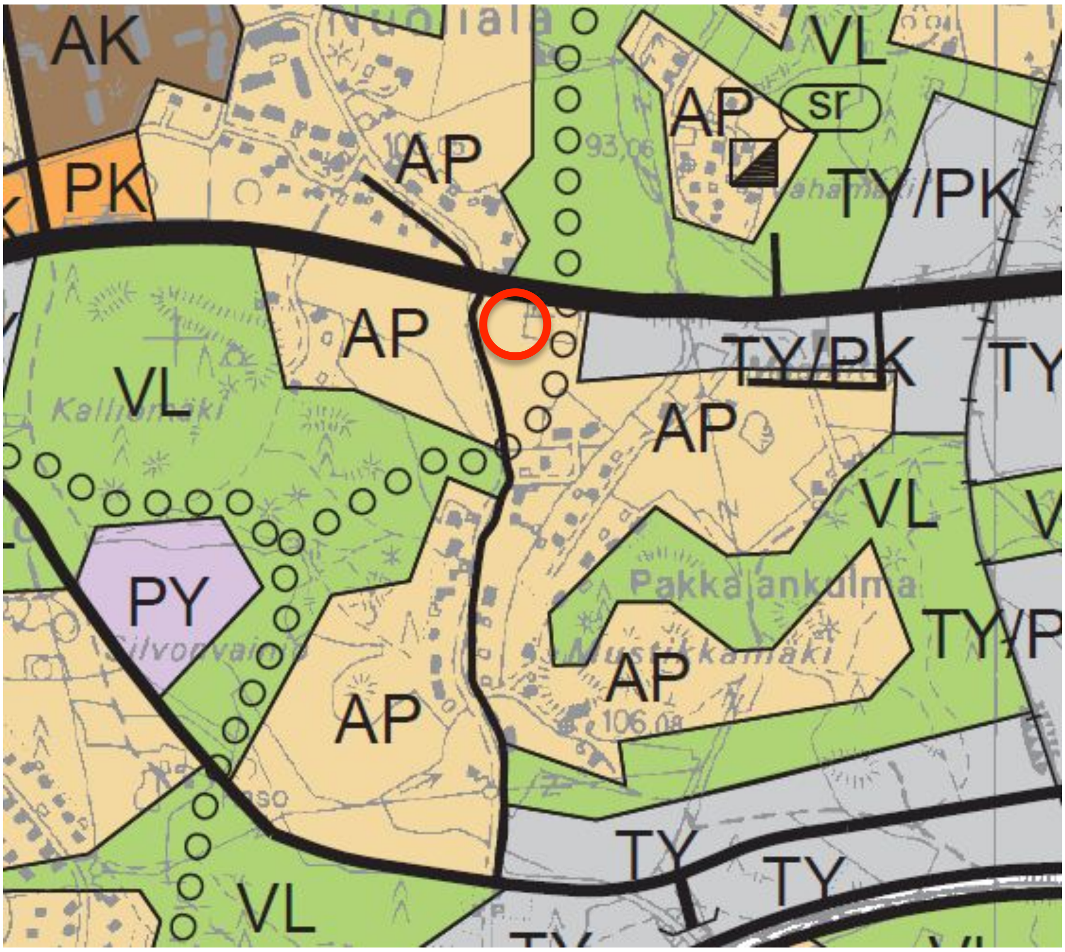


FIGURE 13. Master plan of the Pakkalankulma area, housing cooperative circled (Municipality of Pirkkala 2014).

2.4 Implemented reparations and energy efficiency

The Act on Energy Certification of Buildings (50/2013) states that when an apartment is sold, an energy certification needs to be provided for the buyer. At the moment, this covers only buildings, which are bigger than 50 m^2, built after 1980, and used more than four months in a year.

A special eco-efficiency number is displayed as kWh/m^2: a calculatory annual energy consumption divided by the size of the building. This will determine the energy class of the building. Buildings are given a rating from A to G: A being a low-energy-consuming house and G high consuming. (Motiva 2013.) The rating scale and the ranking of the housing cooperative's buildings can be seen in Table 3.

TABLE 3. The rating scale of the energy class in energy certification and housing cooperative Pakkalankulma's buildings (Lännen isännöintipalvelu 2015).

ENERGY CLASS OF THE BUILDING	CALCULATORY ANNUAL ENERGY CONSUMPTION / m^2 (ECO-EFFICIENCY NUMBER)	HOUSING COOPERATIVE PAKKALANKULMA'S BUILDINGS
A	…80	
B	81-110	
C	111-150	
D	151-210	
E	211-340	Building D: 335
F	341-410	Building A: 342 Building C: 345 Building E: 347 Building B: 370
G	411…	

Before the new energy efficiency legislation in 2013, energy efficiency numbers were calculated with real energy consumption. In the new calculating method, real consumption is also shown, but when the energy efficiency number is calculated, energy consumption is weighed by coefficients. This situates all the fossil fuel burning houses very low in the scale. However, comparing different buildings should be easier, since the properties of the buildings are compared, not the energy consumption habits of different people. (Motiva 2013.)

There are some ways to affect the energy efficiency number, and for both environmental and financial reasons this is profitable. It has been studied that in many EU countries the rise of the energy class by just one letter has risen the value of the house by 1,5−8 % depending on the country and the city. This study was conducted on a voluntary energy classification, but it can represent the public opinion on energy efficient buildings. (Mudgal et al. 2013.)

Possible ways to raise the energy efficiency number include improving thermal insulation, using renewable energy, and implementing heat recovery ventilation (Motiva 2013).

Inadequate insulation is one of the leading causes of energy waste in buildings. In addition to keeping the house warmer in winter, the adequate insulation will also keep it cooler in summertime. Moreover, sealing air leaks around windows and doors is one of the easiest ways to reduce heating energy consumption. (Gevorkian, 2010, p. 175.)

In 2014, more blow-in loose fill insulation was added to the ceilings of the housing cooperative Pakkalankulma. Also in 2014, front and back doors were sealed with special sealing lists, installed on door frames.

Moreover, temperatures of the apartments were measured, and windows and doors studied with a thermal camera in spring 2015, also radiator vents and pre-settings were checked. Recently, ventilation was also measured and adjusted.

All in all, there are not many more simple steps left for improving the energy efficiency of the housing cooperative. Possible ones could be e.g. heat recovery, changing the windows (or at least increasing the sealing of the windows), or changing the doors. A more dramatical improvement would be adding more insulation to the walls. However, considering the age of the current heating system itself, updating it might be more important at the moment. Next, the current heating energy source is presented.

3 NATURAL GAS – THE CURRENT HEATING SYSTEM

As mentioned before, in 2013 there were 280 900 houses in Finland using natural gas or oil for heating. Only 6 % of this number were row houses since most row houses in Finland use district heating as the main heating energy source (Figure 14, APPENDIX 3).

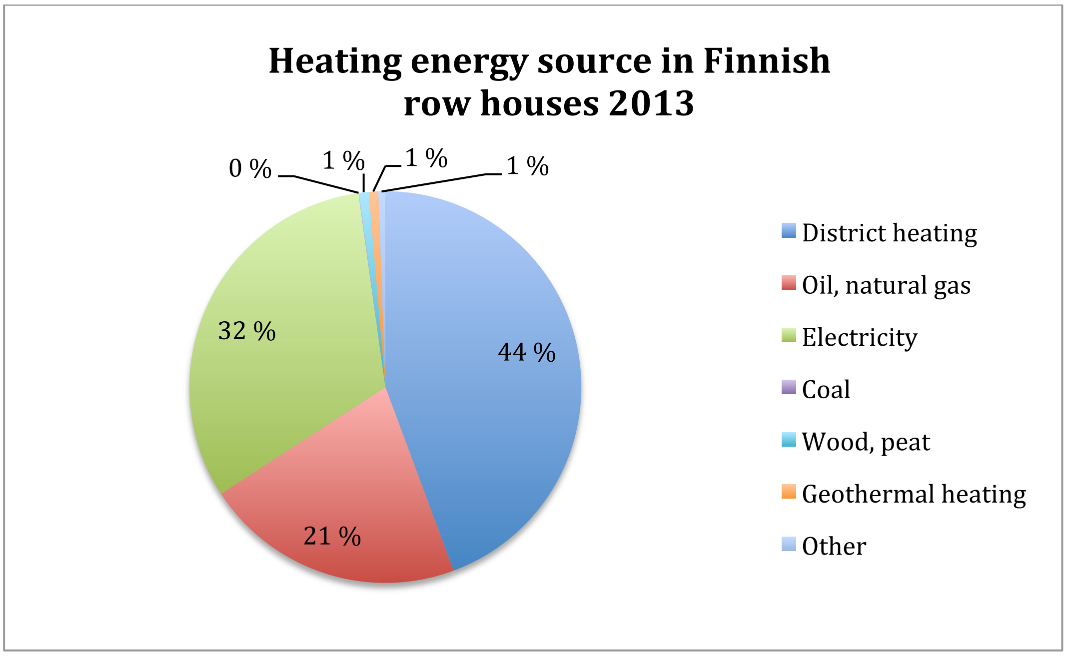


FIGURE 14. Heating energy sources in row houses (OFC 2014.)

The composition on energy sources used in Finland for heating has changed since 1990. Both the use of heavy and light fuel oil has decreased significantly while energy from natural gas has doubled. (Kimpanpää 2009, p. 51.)

Natural gas has been imported to Finland since 1974 by Gasum Oy (Finnish Energy Industries 2015) and the amount used in space heating has changed during the years (Figure 15). One reason for the changes is the outside temperature: if the winters are warm, less heating is needed. This might also continue during the climate change.

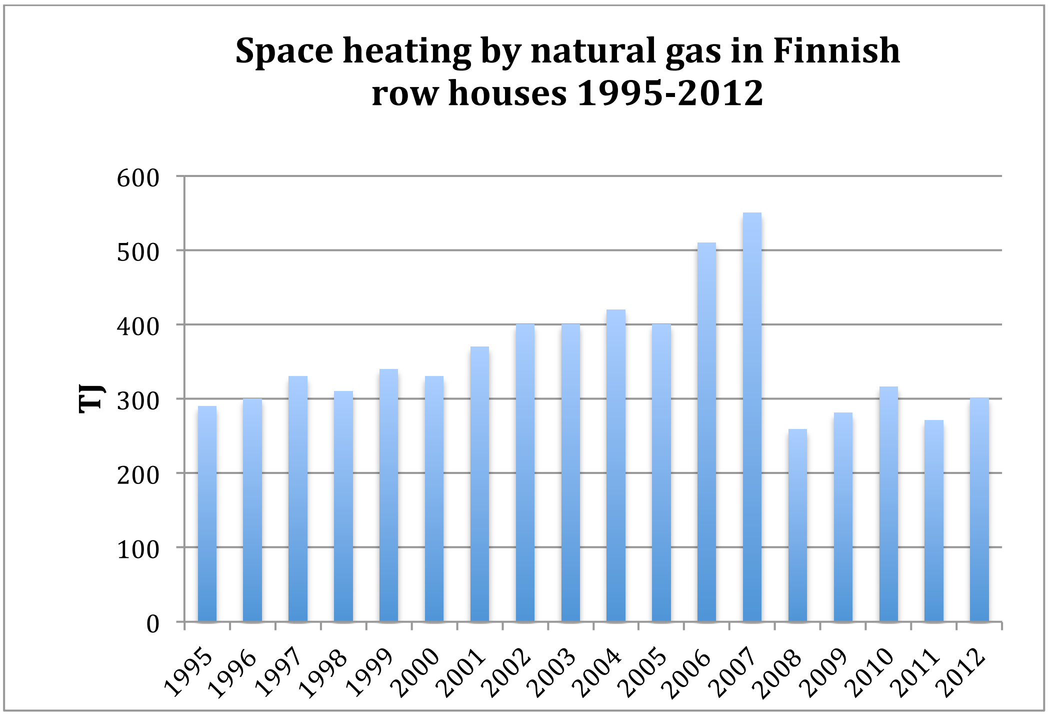


FIGURE 15. Space heating by natural gas in Finnish row houses 1995-2012, includes also liquid gas (OSF 2014).

As the amount of natural gas burned changes, so do its CO_2 emissions (Figure 16).

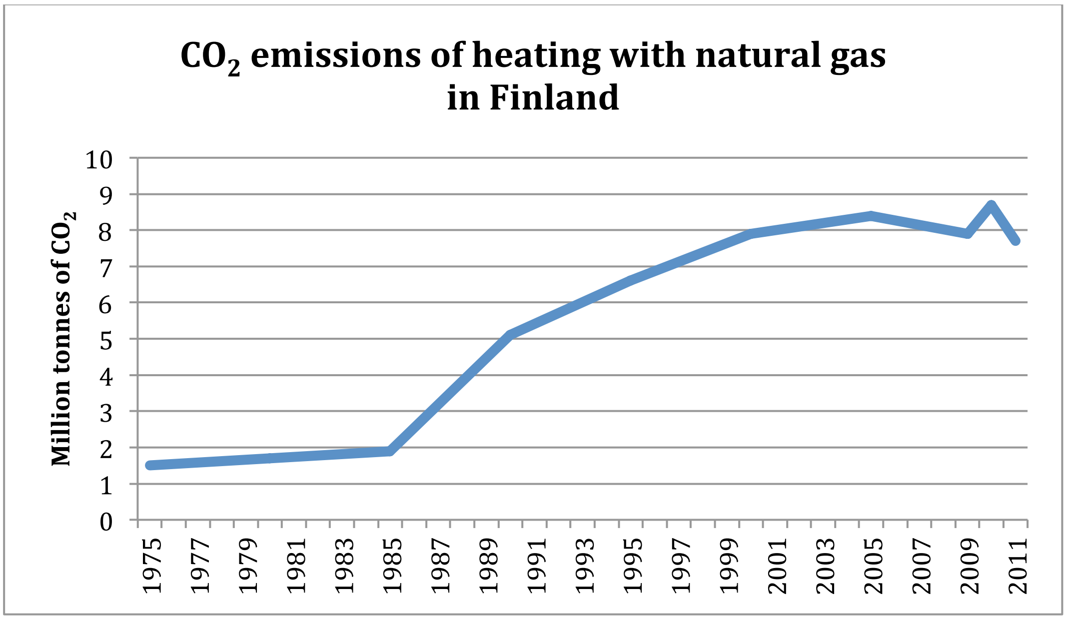


FIGURE 16. CO_2 emissions of heating with natural gas in Finland (IEA 2013).

3.1 Features of natural gas

Natural gas was formed when the organic material of plant and animal remains was subjected to high pressure and temperature for millions of years. Natural gas can be found in underground porous reservoirs in a gaseous phase or in solution with crude oil. (Midthun, Tomasgard 2010, p. 73.) Mainly, natural gas consists of methane (CH_4) but the composition depends on the place it is found. Methane is one of the greenhouse gases, and at the moment contributes 15 % to the present level of global warming (Houghton 2009, p. 305).

Two-thirds of all the known natural gas resources are located in Middle East and Russia. (Finnish Energy Industries 2015.) It is estimated that those resources will last less than 100 years (Gustafsson 2005 p. 329).

Natural gas is imported to Finland from Siberia by long pipelines, and is not available in the whole country. Instead, pipeline network only covers southeast and southern Finland, including the Pirkanmaa region (APPENDIX 4). (Finnish Energy Industries 2015.) Gasum Oy imports the gas to Finland and Tampereen Kaukolämpö Oy (subsidiary of Tampereen Sähkölaitos Oy) sells it to the households (Tampereen Sähkölaitos 2015). A natural gas pipeline in the housing cooperative Pakkalankulma is shown in yellow in Figure 17.

FIGURE 17. Natural gas pipeline (yellow) in Naistenmatkantie and Pakkalantie (Tampereen Kaukolämmön Karttapalvelu 2015).

In some parts of the world, natural gas is also transported across the seas in a liquid state (LNG) in gas tankers (Anderson, Christiansen & Fagerholt 2010, p. 427). Both transportation methods have major environmental risks, since methane (CH_4) is one of the most powerful greenhouse gases, 21 times stronger than carbon dioxide, and it can leak into the atmosphere in several stages of the transportation (Gustafsson 2005 p. 148, 272). For safety reasons, natural gas is perfumed in Finland with tetrahydrothiophene ($(CH_2)_4$) (Pietikäinen 2007, p. 90).

The Siberian natural gas consists of 98 % methane (CH_4), with traces of ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), nitrogen (N_2) and carbon dioxide (CO_2) (Finnish Gas Association 2014).

The combustion of natural gas is a complex function but e.g. the following equations take place (Finnish Gas Association 2014):

1. Combustion of methane:
   $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

2. Combustion of propane:
   $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

3. Combustion of butane:
   $C_4H_{10} + 6{,}5O2 \rightarrow 4CO_2 + 5H_2O$

As seen above, the combustions produce carbon dioxide and water vapour, which are both greenhouse gases, although the CO_2 emissions of burning natural gas are half of coal's or oil's. Moreover, no sulphur dioxide (SO_2), particle matter, heavy metal emissions or ash is created. (Finnish Energy Industries 2015.) Still, the contribution to climate change is inevitable.

3.2 The current heating system

Housing cooperative Pakkalankulma has used natural gas for heating since the houses were completed in 1995. Housing cooperative Pakkalankulma has a dual fuel burner, Oilon, which uses natural gas as primary and oil as secondary (back-up system) fuel. More info of the current system can be seen in Table 4.

TABLE 4 Details of the current heating system

Burner	Oilon GKB 6.21 H dual fuel burner for oil and natural gas Power 60-120 kW/h Installed in 1995
Boiler	Laatukattila (LAKA) ZV60/120 Power 120 kW
Expansion tank	Reflex 100 litres Max. pressure 6 bar, 1,5 in use
Circulator pump	Grundfos UPE 32-120 Model A
Oil tank	Plastic, 1500 litres Located inside the heat distribution room

Natural gas is lead from the plant to the housing cooperative's heating distribution centre through pipes. As the gas burns, the water in the boiler is warmed. The heat development equipment warms the water which is then transferred to central heating. Hot water runs through the radiators of the apartments, and releases its heat. Room temperatures can be adjusted by radiator vents. The cooled down water returns to the heat distribution centre by its own pipes.

The current system (Figures 18-19) is original, thus at the moment 20 years old, but maintained annually. The technical lifetime of a boiler is generally 20-30 years, but during its last years it might not work very energy efficiently (Isosaari 2012, p. 13). This means that there might not be many years left for the current technical heating system of the housing cooperative Pakkalankulma.

FIGURE 18. Details of the current heating system. Burner, boiler and circulation pump pictured.

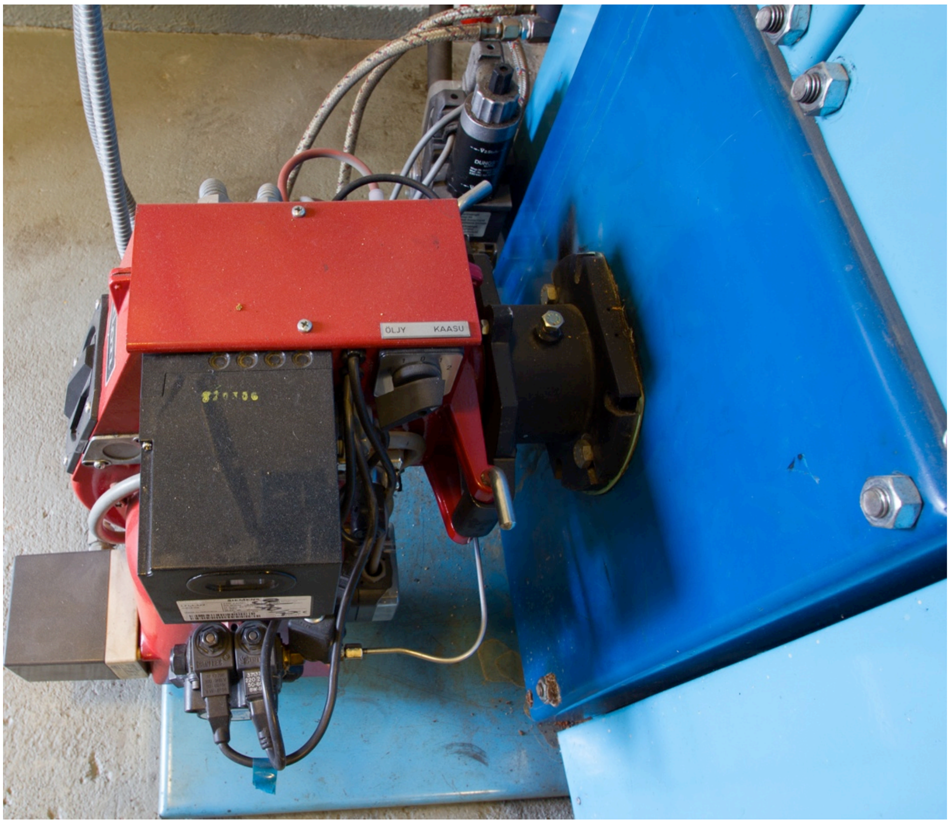


FIGURE 19. Details of the current heating system: Burner.

3.2.1 Consumption of energy

One kWh of heat produced by natural gas produces 198 grams of CO_2 (Motiva 2015). The total heat consumption of Pakkalankulma in 2014 was 238 017 kWh (238 MWh). This means that in 2014, Pakkalankulma was responsible for 47 tonnes of CO_2. Divided for the 15 apartments this means an annual 3,1 tonnes CO_2 per household, if the size of the apartments is not taken into account.

Divided for the 24 residents it equals to 1,96 tonnes of CO_2/person. The same amount of CO_2 is released after driving 7500 km with an average car (Suomen Ympäristökeskus 2013).

The heat consumption of the housing cooperative has slightly decreased during the last years (Figure 20).

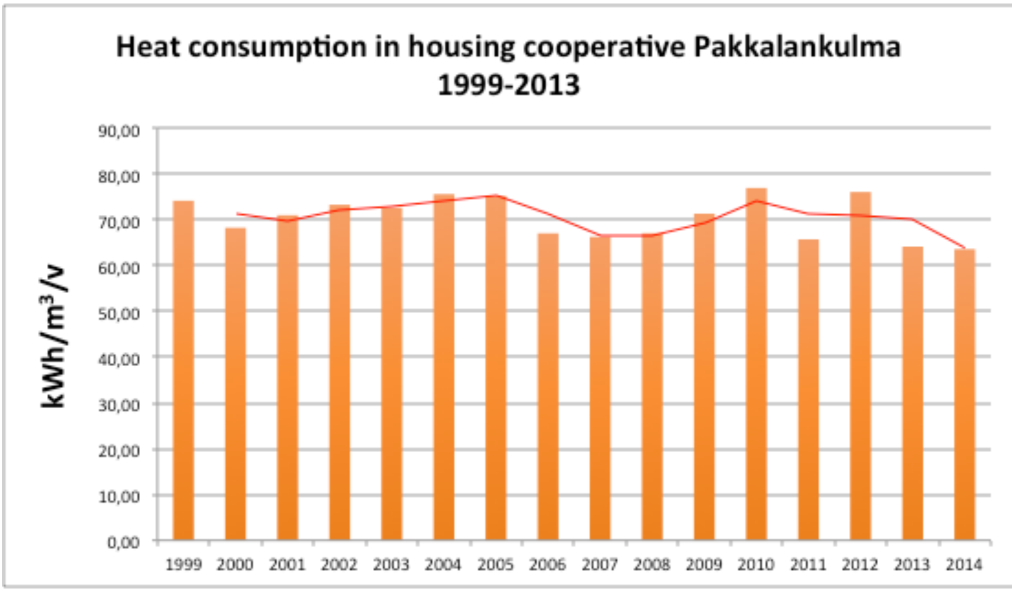


FIGURE 20. Heat consumption and the moving average line of housing cooperative Pakkalankulma.

3.3 Taxation of natural gas

Government can support the energy efficiency and the usage of renewable energy sources by making those financially more tempting options than the traditional methods (Berninger 2012, p. 38). Thus, this means setting high taxes for the more polluting alternatives.

> *In the definition of environment-related taxes and charges, a tax or charge is to be directed to some measurable physical quantity that has a harmful environmental effect (Statistics Finland 2012, p. 153).*

Environmental taxes are divided into two categories: pollution taxes and resource taxes. Natural gas is taxed on the basis of consumption (Statistics Finland 2012, p. 153).

Taxation partly explains why the price of the natural gas consists of several pieces, and is often hard to compare with other sources of heating energy. Currently, the total taxation of natural gas (Finnish Customs 2014) consists of (without VAT 24 %):

- Energy content tax (6,65 €/MWh)
- Carbon dioxide tax (8,71 €/MWh)
- Strategic stockpile fee (0,084 €/MWh)
- Total taxation 15,44 €/MWh)

The taxation has constantly risen, especially after the revision of the energy taxation, being less than 9 euros/MWh in 2011-2012 to almost 16 euros/MWh in 2015. (Berninger 2012, p. 38; Statistics Finland 2012, p. 156).

Environmentally related taxes, fees and charges have increased in number and in total revenue since 2000. Currently, energy taxation generates about 7 percent of the total tax revenue of Finland. In the future, it might be a bigger proportion, as implemented in many other EU countries. (Statistics Finland 2012, p. 154-156.)

3.4 The future of natural gas and oil

There are some problems in the future waiting for housing cooperative Pakkalankulma and also other users of natural gas and oil. One of the biggest is sufficiency. Scientists believe that at the current rates of use, the known reserves of fossil fuels could meet the demand already in 2050. Before that, more reservoirs will be searched and found but the difficulty of extraction can mean higher prices for households. (Houghton 2009 p. 328.)

Also politics play a role. For example, new oil resources have been discovered in the recent years, but unfortunately those are often located in politically unsteady areas, such as Iraq and Libya (Berninger 2012, p.21). Politics and relationships between the countries also play a major role, since Finland is dependent on imported fuels, mostly coming from Russia.

Climate change mitigation will have a significant effect on the economy. Structural change to a low-carbon economy will be needed because of both national and international mitigation policies, which will increase the energy costs. (Kimpanpää 2009, p. 162.) The rising costs of energy will have an influence on the living costs; this is also a problem if the apartments in the housing cooperative are about to be sold.

Some of the driving forces to change the current heating energy source might be more social than environmental, or economical, such as tenant demand and moreover, future competitiveness.

All things considered, heating in the future with natural gas does not seem secure and environmentally healthy. Perhaps a better option will be presented in the next chapter.

4 POSSIBLE SOLUTIONS

Due to nowadays climate, houses need warming in Finland. Since the heating energy needed is such a huge part of Finnish homes' energy consumption, it might not come as a surprise that the second biggest consumer of energy per capita in the EU countries in 2009 was Finland (Statistics Finland 2012, p. 131). However, the quantity of heating energy needed may decrease in the future because of global warming. On the other hand, it can also increase in the worst-case scenario if the Gulf Stream, or more specifically the North Atlantic drift, slows down due to the shutdown of thermohaline circulation (Ganopolski 2010, p. 302). This would drastically decrease the annual mean temperature in Finland.

All in all, it is possible to warm the house by either producing the heating energy in the house with specific equipment (natural gas, oil etc.), or bring the heat into the house from elsewhere (district heat, electricity). Things to be considered are not only the equipment, such as boilers, burners and accessories, but also the storage of the fuel chosen. Finally, the availability sufficiency of energy and different backup systems should be thought of. (Pietikäinen 2007, p. 11-12).

There are different technical ways to warm the apartments: underfloor heating by pipes or electricity, single or double-pipe hot-water radiators, electric radiators, warm air systems through floor, roof or walls, or radiant ceiling panels. Not all the heating systems might be available for all the heating energy sources. (Pietikäinen 2007, p. 11-12).

Housing cooperative Pakkalankulma has working double-pipe hot-water radiators, maintained in spring 2015. This should be the starting point for choosing the new heating energy source. At the moment, the water flowing through the pipeline is warmed by burning natural gas. However, scientists believe that in the long run, the only way to cover the humankind's need of energy is to use renewable energy sources (Telkänranta 2006, p. 85).

Sometimes nuclear energy is offered as a solution for replacing the use of fossil fuels. This, however, cannot be recommended for various reasons. First, the mining of uranium causes massive environmental problems. Secondly, nuclear waste repository is not a solution in such. Thirdly, uranium is not a renewable source of energy. The real renewable energy sources include e.g. water, sunlight, wind and geothermal heat, or heat stored in the bedrock. (Telkänranta 2006, p. 85.)

Hydropower from flowing water is impossible to harness as such for a housing company to use, the only option would be buying electricity produced elsewhere by hydropower. This would require the radiators to be converted to electric ones, or the current water heater to a completely electric one. With the current prices of electricity, this seems absurd. However, some other renewable energy sources and plans to utilize those are presented in the following.

4.1 Ground source heat pump

A ground source heat pump (GSHP) is a heating system which is often mixed with geothermal heating. GSHP is mainly solar energy stored in the Earth's crust, as geothermal heat comes from inside the Earth itself.

The first heat pumps were used in Finland in 1970s, but only after 1990, the share of heating energy produced from GSHPs has grown, and already replaced light fuel oil in many Finnish detached houses. In 2012, there were over 80 000 GSHPs in Finland. A future scenario made by the Ministry of the Environment also predicts that the proportion of ground heat or other types of heat pumps will increase coming towards 2020s. (Kimpanpää 2009, p. 52, 141; Juvonen & Lapinlampi 2013, p. 11.)

4.1.1 Operating principle

The average temperature of the ground in Southern Finland is approximately 5-6 °C in depth of 14-15 m. Going deeper, the temperature rises 0,5-1 °C per 100 metres. Thus, in 300 metres the temperature is somewhere between 6,5-9 °C. (Juvonen & Lapinlampi 2013, p. 7.)

Even though, 6,5-9 °C sounds like a relatively cold temperature to heat the house, it is well enough. Depending on how much heating energy is needed, the adequate amount of holes are bored in the ground with the depth varying between 120 and

300 metres. It is possible to bore deeper but often it is more feasible to make another hole. The diameter of the boreholes in Finland is 105-165 mm. It is also possible to set a horizontal loop of pipes, but it is a less effective method and needs a huge free plot area. Other variations are available as well. (Juvonen & Lapinlampi 2013, p. 33.)

The operating principle of GSHP is quite simple (Fig. 21). A closed loop of pipe is inserted into the borehole and a mixture of water and antifreeze (e.g. ethanol C_2H_6O) is pumped inside the closed loop by a heat pump. The fluid will absorb heat from the ground and the warm liquid will be fed into an evaporator. There, heat will be extracted from the liquid with a refrigerant that boils in a low temperature. This will turn the refrigerant into a gas form and move to a compressor. The cooled down water-antifreeze fluid will continue to the closed loop to gain again heat. In the compressor, the gas-vapour is compressed in volume. This will increase the temperature significantly. Hot gas is fed through a condenser, which changes the refrigerant back into a liquid form. It condenses, and heat passes into a heat exchanger, thus into hot-water radiators. Finally, the pressure of the condensed liquid is reduced in the expansion valve. (Juvonen & Lapinlampi 2013, p. 12.)

In addition to space and domestic water heating, GSHP can also be used for cooling the house.

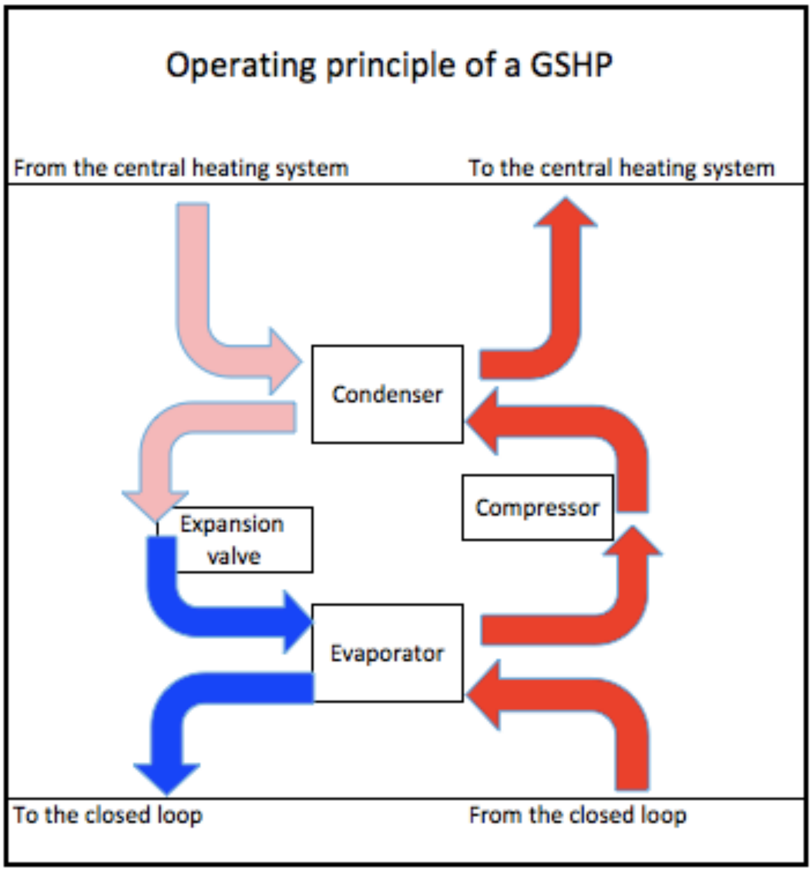


FIGURE 21. Illustration how GSHP works. (Juvonen & Lapinlampi 2013, p. 12.)

The housing cooperative Kangasalan Pirkkarivi is approximately the same size of the housing cooperative Pakkalankulma, situated in Kangasala, 20 km from Pirkkala. There, natural gas was changed to GSHP already in 2011 with 5 boreholes, each 210 metres deep. The annual natural gas usage was 200 000 kWh, a little smaller than in the housing cooperative Pakkalankulma. The electricity bill after changing to GSHP has been 9300 € annually. Compared to the price of natural gas, the housing cooperative has saved every year from 11 600 – to 13 700 euros. (Senera 2015.)

4.1.2 Prerequisites

There are many things that need to be considered when evaluating GSHP as a possible heating energy source. One of those is the heating system and the quantity of heat needed. GSHP is good for low-temperature heating systems as underfloor heating with pipes; sometimes in old houses the amount or size of the hot-water radiators is not enough since the water is not warmed as hot as in other heating systems. (Juvonen & Lapinlampi 2013, p. 10.) This should not be a problem in the housing cooperative Pakkalankulma.

Secondly, boreholes are not allowed in groundwater area. To be sure, the area planned for those is adequate, the Building supervision department of the municipality of Pirkkala requires a specific application for GSHP and approximately 10 different attachments. A separate article is also dedicated for GSHP in the environmental protection regulation of the municipality. This section will e.g. remind the resident that the anti-freeze fluid should not enter the surrounding nature, and that the drilling waste should be handled properly. (The Municipality of Pirkkala 2014.) As mentioned before, there is no groundwater in the Pakkalankulma area.

The housing cooperative should get familiar to the legislation concerning the GSHP. The acts and decrees, which are related to building a GSHP system in Finland, are the following (Juvonen & Lapinlampi 2013, p. 15-18):

- Land Use and Building Act (132/1999)
- Water Act (587/2011)
- Environmental Protection Act (86/2000)
- Real Estate Formation Act (554/1995)
- Chemicals Act (744/1989)
- Health Protection Act (763/1994), mainly Chapters 5 and 7
- Decree of the Ministry of Social Affairs and Health Relating to the Quality and Monitoring of Water Intended for Human Consumption (461/2000) and (401/2001)

Thirdly, the bedrock and soil cover will have an affect on the sizing of the piping system. Some rock types conduct heat better than others, e.g. granite 3,4 W/mK and mica schist 2,0 W/mK. (Juvonen & Lapinlampi 2013, p. 31.) Most likely, the contractor will drill an exploratory well (Thermal response test) and determine the heat conductivity among other things. The amount of overburden on top of the bedrock will slow the boring and/or create extra work (Rototec 2015).

Fortunately, the Pakkalankulma area seems to be in a well heat conducting area with only moderate amount of overburden.

Fourthly, free plot area in the housing cooperative Pakkalankulma is limited. Similar size housing cooperatives have needed at least 5 boreholes, so situating all those within a 3-meter distance from the buildings, 7,5 m from the plot border, and 15 m distance from each other can be a tough puzzle. Yet, the distance can be smaller, if there is an angle of camber between the holes. (Juvonen & Lapinlampi 2013, p. 25.) Boring the holes should not exclude similar actions from the new planned housing area on the other side of the road.

Lastly, since the construction site is located in an area with high radon concentrations, the inlet of the transferring pipeline from the borehole to the heat distribution centre must be carefully insulated and sealed with a specifically elastic sealing substance. Boring a hole can open new routes for radon to escape from the cracks of the bedrock. (Juvonen & Lapinlampi 2013, p. 38, 43-44.)

GSHP is a long-lasting heating system, yet not eternal. The average operating life is 50 years but the system needs some maintenance. The boreholes last forever. (Juvonen & Lapinlampi 2013, p. 48.)

4.1.3 Other heat pumps

Air source heat pumps are the most common heat pumps in Finland, though not powerful enough to be the only source of heating energy in most houses. Usually, air source heat pumps are used as an auxiliary heat source for direct electric heating. The device consists of outdoor and indoor units. The outdoor unit takes heat from the outdoor air similarly to a ground source heat pump from the ground. Through compressor and automation, warm air is transferred to the inside unit, which has a fan that circulates the air to be heated. Pumps have so good coefficient of performance that they heat more than consume electricity. In the summer time, the heat pump can be used for cooling. (Finnish Energy Industries 2015.)

A better option for a housing cooperative which has a water-circulated heat distribution system is an air-to-water heat pump. The device can be used side by side with the original heating system, and is only not usable in the coldest days of the year. (Finnish Energy Industries 2015.) If the old system is replaced, the coldest days can be overcome with electricity as a back-up system (electric boiler).

Air-to-water heat pumps need no building permissions and can be installed within a day or two. Air-to-water heat pumps are considerably cheaper than a GSHP, and also a hybrid system with solar energy is possible. However, the placement of the outdoor unit has to be thought of carefully, since it makes noise. In addition it should not be installed onto the wall because of noise travelling through the frame of the building. (Virta & Pylsy 2011, p. 120.) A possible place for an air-to-water heat pump in the housing cooperative Pakkalankulma would be the south-east corner of building B.

One example of the efficiency of an air-to-water heat pump is a row house in Hanko. The housing cooperative one-third bigger by area than the housing cooperative Pakkalankulma consumed 30 500 litres of oil per year. After installing an air-to-water heat pump, the consumption has been only 3 000 litres. Even the electricity included, the annual save has been over 16 000 euros. (Hankintaturvaliike 2014-2015.)

4.2 Solar energy

Solar power originates from the Sun. Two most popular ways to harness its power are solar panels for electricity production, and solar thermal collectors for heating water. In Finland, solar panels have mainly been an option for remote summer cottages with no electricity. At the moment, the price of solar panels has decreased but is still relatively high. Another problem with the panels is storing electricity. Fortunately, some new inventions are made frequently. (Telkänranta 2006, p.89.)

One basic misunderstanding with solar power is that it can only be used in countries with hours of sunlight each day. Technically, sun energy passes through clouds and charges the batteries also when there is no direct sunlight, yet, slowlier than on a sunny day. (Telkänranta 2006, p.89.)

However, the majority of the solar panels are crystalline panels which cannot tolerate any kind of shadowing. According to sources (Isosaari 2012, p. 104), if 10 percent of the surface area is left in shadow, 90 percent of the revenue is missed.

On the other hand, when talking about *solar thermal collectors*, the interest of the public has risen. It is estimated (Isosaari 2012, p. 107), that there were 4000 to 5000 solar thermal systems in Finland in 2012. Between 400 to 600 new ones are installed per year. Solely, solar thermal collectors are not usually used. Instead, it has been installed in addition to oil heating, as much as 80 % of solar thermal systems are used with oil heating. Recently, a block of flats near the housing cooperative Pakkalankulma added 52 m^2 solar thermal collectors onto the roof. These are used in addition to district heating. (Suomen Aurinkoenergia 2015.)

One of the reasons for the rising popularity is the easiness of the system. (Isosaari 2012, p.108.) Solar power systems have a very low maintenance requirement. One of the reasons for this is the absence of mechanical or moving parts. (Gevorkian 2010, p. 146.) The lifespan of high quality collectors can be 30 years, half of that for pumps, expansion tank and automation (Suomen Aurinkoenergia 2015). However, the smallest systems cost 4000 euros, and bigger ones almost 10 000 euros plus the installation work. (Isosaari 2012, p.108.)

There are a few different types of collectors for energy. However, in all of those, projection must be correct for maximum sunlight. Thus, the obvious direction would be south. Since the heat is transferred to a liquid, and through pipes, the length of the pipeline cannot be long. It is estimated (Isosaari 2012, p. 110) that a 20-metre pipeline would already be the maximum for a detached house. Relying to these facts, the only roof feasible for solar energy is building B since the boiler is located there. However, it is located east-west, so additional tilting is needed in order to get the collectors to face south. If the solar thermal collectors would be installed to the east side of the roof without facing to south, approximately 25-30 % less energy would be gathered. Still, the loss could be taken back with extra collectors. All in all, this would increase the costs. (Suomen Aurinkoenergia 2015.)

Finally, on average, solar thermal collectors could gather one-third of the heating energy. The majority would need to be collected using some other heating energy source. (Suomen Aurinkoenergia 2015.)

4.3 Wind energy

Wind turbines have appeared to Finnish field and archipelago landscapes. So far, only a small portion, less than 0,5 %, of the whole energy production in Finland is generated via wind power. Nevertheless, wind turbines have caused huge disputes – they are too noisy, too high, too expensive (even though not paid by the complainers) and often in a wrong place. Wind power complements solar power well, because statistically, winds blow more in the time of year when solar power is less usable. (Telkänranta 2006, p.90.)

Wind energy turbines for households need a 15-20 high mast (industrial ones even 130 metres) that would require a permission from the municipality of Pirkkala. Also the neighbours and the residents of the housing company Pakkalankulma would have opinions for the new landmark. Smaller wind generators with a 6-metres-long mast are sold to households e.g. on the Internet. In all cases, a proper lightning protection is needed (Motiva 2012).

In theory, it is possible to replace some of the fossil fuel usage in heating with a wind turbine. In addition to a mast and a wind turbine, this would need an underground cable from the mast to the heat distribution room. (Motiva 2012.)

Since bigger masts need open space, they are more usable in the rural countryside than in the city infrastructure. When smaller wind turbines, e.g. for roofs, become cheaper and more efficient, they might be one way to replace the use of fossil fuels in heating, or decrease the electricity bill. At the moment, they might not be the best solution for the housing cooperative.

4.4 Energy from wood

Wood used for heating in the traditional form would only suit the housing company Pakkalankulma if all the apartments would have their own fireplaces. For central heating, the only reasonable way to use wood is burning pellets.

Finland is one the biggest producers of pellets in Europe with annually producing half a million tonnes of pellets. Unfortunately, the majority of it is exported to e.g. central Europe. Only approximately 20 % of the annual production stays in Finland to warm the industrial buildings and 13 000 homes. That is dreary, since it only costs half the amount compared to oil. (Isosaari 2012, p. 66.)

Pellets are compressed sawdust pieces, about the size of a short pencil. One kilogram of pellets produces approximately 4,7 kWh heat energy (Virta & Pylsy 2011, p.115). In central Europe, pellets are transported to a pellet tank of a house by trucks, and automatically dosed to a pellet burner. In Scandinavia, the pellet system is usually less automated, and requires the user to clean the boiler from the ash 1-2 times a month. Moreover, the equipment needs to be monitored and maintained every once in a while. (Telkänranta 2006, p. 197; Isosaari 2012, p. 66.)

The newest models in Finland also have an automatic pellet feeder and ash removal, but these are more expensive than the traditional ones (Virta & Pylsy 2011, p. 115). Pellet burning on a housing cooperative's scale requires a huge storage tank, and still it needs to be fulfilled by pellet trucks every once in a while. Thus, indirectly, pellet burning has an effect to greenhouse gas emissions. Also, only a highly automated model would be suitable for the housing cooperative.

Before pellet burning is upgraded to a more automated heating system, it cannot be recommended to the housing company Pakkalankulma.

4.5 District heating

District heating is a common heating system in Finland; almost half of all the heating energy needed in the country is produced this way. The majority of public buildings, offices and blocks of flats are heated by district heating. (Pietikäinen 2007, p. 8.) Over a quarter of the amount is renewable. (Saikkonen, Strandell & Karkinen, 1999, p. 47.)

District heating is practically a carefree heating energy source. District heat is often produced in collaboration with electricity. Pipes from a district heating plant bring hot water (65-115 °C) into the heat exchanger of the houses, and water releases its energy to the circulating water of the hot-water radiators. (Note, the two water systems never physically meet, only energy is changed.) Cooled down (25-50 °C) water heads back to the plant. (Pietikäinen 2007, p. 34-35.)

District heating is an efficient way to heat the house, however, it is not much more environmentally friendly option of heating. According to Tampereen sähkölaitos, a utility providing electricity, natural gas and district heating in the area, the district heat they offer is produced from fossil fuels by 74 %. Nevertheless, 56 % is provided using natural gas. (Tampereen sähkölaitos 2015.)

CO_2 emissions were smaller than heating with pure natural gas, in 2014, 195 g/kWh. It should also be noted that the share of renewable energy has increased a bit every year since 2010, and the CO_2 emissions have decreased. (Tampereen sähkölaitos 2015.) The nearest pipeline can be found in the border of the housing cooperative's plot in Naistenmatkantie side (Figure 22).

FIGURE 22. District heating pipeline in Naistenmatkantie and Pakkalantie (Tampereen Kaukolämmön Karttapalvelu 2015).

The working life of district heat installations varies between 20 to 25 years. Some parts' average life span is only 8 years. (Pietikäinen 2007, p. 30.) Possible breakdowns of the pipeline can have environmental effects.

Without the equipment and installation, only the joining fee to district heat in 2011 was approximately 8000 euros for a row house (Virta & Pylsy 2011, p.110).

Yet district heating has advantages, and if the ratio of fossil fuels and renewable energy sources would raise it could be one possible option for the housing cooperative Pakkalankulma in the future.

4.6 Final comparison

Since solar and wind energy can only produce relatively small amounts of the whole annual heating energy consumption, those are left from the final comparison as the main energy source. However, especially solar energy could be utilized in the housing cooperative Pakkalankulma as an addition to the main heating energy source.

Moreover, the origin of electricity needed for the heating system equipment should be considered. Finnish homes are not bound to buy electricity from the closest energy plant. Instead, electricity contracts can be tendered out e.g. by price or production method. In order to decrease the environmental impact of heating, one option could be choosing electricity produced by renewable sources, such as wind or hydropower.

There are a few websites that compare the costs of different heating energy sources. One of those is Bioenergiapörssi, which promotes wood fuels. Nevertheless, other heating energy sources are also compared. In the following table (Table 5.) the calculations are based on the annual energy consumption (238 017 kWh), area (1091 m^2), room height (2,5 m), climate region (Tampere) and the number of people (24).

TABLE 5. Comparison of costs of different heating energy systems (Bioenergiapörssi 2015).

HEATING ENERGY SOURCE	PRICE OF FUEL €/KWH	COST OF HEATING ENERGY €/A	COST OF INVESTMENT €
Ground source heat pump, bore hole, hot-water radiators	0,1266	11 369	113 368
Pellet heating	0,0526	16 129	43 625
District heating	0,0632	16 727	41 921
Air-to-water heat pump	0,1266	15 158	84 328

The annual cost of energy is the lowest in GSHP, but, at the same time, the total cost of the investment is the biggest. Vice versa, the total cost of investment in joining district heating is the lowest, but the annual cost is the biggest. In addition, the termination fee of natural gas should be added to all the investment costs. This equals to 1860 euros (Tampereen sähkölaitos 2015).

Nevertheless, all the four options have their advantages and disadvantages. The increasing price of electricity will have an effect for all energy systems, but more severely to both heat pumps. Recently, the price of electricity has decreased, but most likely will not stay at that level (Figure 23). The prices of district heat and pellets have also risen. Technology for pellet burning might still have some teething issues and might need more maintenance than other methods.

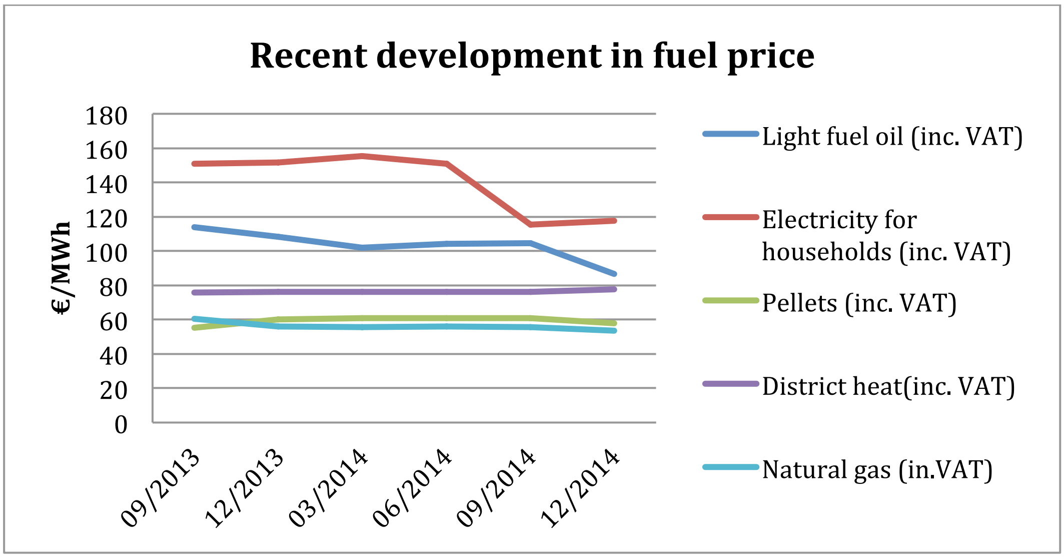


FIGURE 23. Recent development in fuel price (OSF 2015).

The table and figure above compare the financial sides of the different heating energy sources. Environmental issues should also be taken into account. Different heating energy sources produce different amounts of greenhouse gases (Figure 24).

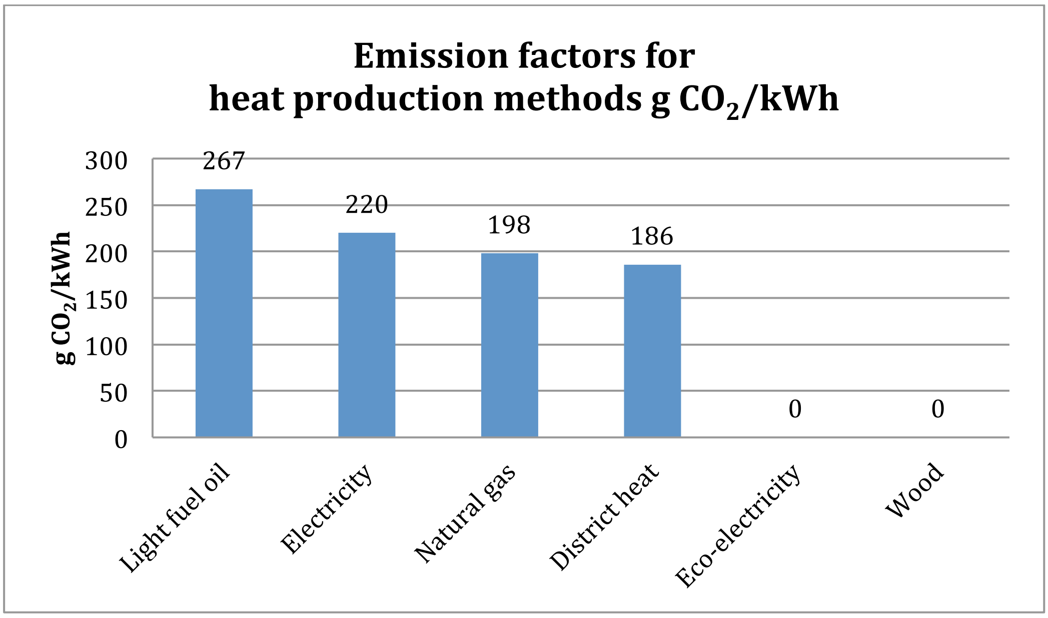


FIGURE 24. Emission factors by heating energy source (Motiva 2015).

The figure above needs some clarification. Changing natural gas to e.g. air-to-water heat pump would not mean that the CO_2 emissions of the housing cooperative would increase. This is due to the differency in coefficient of performance, e.g. heat pump with a COP 3,0 provides 3 units of heat for each kWh of electricity consumed. (Isosaari 2012, p. 85.)

Eco-electricity is produced from renewable energy sources, such as wind and water, and CO_2 emissions are presented as zero, even though some emissions might be produced indirectly in the transportation of electricity, or when the production plant is built. If those would be considered in the emission factors, it would roughly grow from zero to 20 g. Still, less than 10 % of the value of "normal" electricity. (Nissinen & al. 2013.)

The emission factor of wood burning, including pellets, is zero. This is due to the fact that trees absorb the same amount of CO_2 during their lifetime that is released when burning. Thus, the CO_2 in wood burning belongs to the current carbon cycle, opposite to fossil fuels. However, the quality and burning method will have an influence on the particulate matter released. (Climateguide 2012.) If wood harvesting and transport operations had been taken into account, the emission factor would have been approximately 14 g CO_2/kWh (Nissinen & al. 2013.).

Finally, considering all the financial and environmental aspects, regarding the present machinery and equipment, the following suggestions for choosing the new heating energy source for housing cooperative Pakkalankulma are made:

1. **The first phase: Inspection of the current heating system should be conducted.** According to this, two options:
    a. Current system needs no repairs in the near future. Natural gas heating is not removed. Air-to-water heat pump is installed. Boiler and burner still have working life and the heat pump decreases the heating costs significantly. At the same time, money for GSHP could be saved.
    b. Current system needs significant repairs in the near future. Natural gas heating is changed for GSHP. Approximately 6 boreholes are needed. A detailed plan, and a qualified designer and contractor are needed. The result of changing the windows in the future should be observed.
2. **The second phase:** Adding solar thermal collectors. Using a renewable energy source will increase the self-sufficiency of the housing cooperative and cut the electricity bill. By the time of implementing, more sophisticated models might be for sale.
3. **The third phase:** Eco-electricity. This will cut the remaining CO_2 emissions of the housing cooperative.

5 CONCLUSION

Firstly, one may think, does one housing cooperative have an effect to climate change? And does changing the current heating energy source to a more environmentally one make any sense? On a large scale, there are about 1500 million people living in cold climates where heating in buildings is needed (Houghton 2009, p. 341). Earlier it was calculated that the residents of the housing cooperative Pakkalankulma produced 1,96 tonnes of CO_2 per person annually. If all those 1500 million people living in cold climates had the same figures, and everyone reduced their share for even just 10 %, staggering 294 million tonnes less CO_2 would be emitted into the atmosphere. Since the heating of homes is a key factor in the household's CO_2 load, it should definitely be something everyone should consider improving, developing and/or changing.

Converting an old house into a more energy effective one is not rocket science. There are products and practices available, and not even the price is a road block anymore. With the current prices of oil and electricity, the payback time of a new heating source installation can be less than five years. (Isosaari 2012, p. 10.)

No doubt, not all the possible energy sources were included for this case study since Finland's climate plays a huge role. The size of the housing cooperative's plot also sets limits, as well as the location in an urban area. Most likely, not all the future ways to heat houses are even invented yet. One of the new interesting heating energy sources is the use of the excess heat from the huge data centres. This is explored in Mäntsälä. (Virtanen 2015.)

Changing the source of the heating energy may not solve all the problems, especially if there is no heat recovery ventilation, and windows or doors leak warm air outside. Minor actions, such as extra sealing and insulation, are also important factors to consider before changing the heating energy source. Lots of energy can be saved by simply educating people. Rooms do not need to – and should not - be warmed to 30 °C. In addition to that, dusting up the house should be done quickly and effectively, not keeping windows open for several hours.

An interesting fact is also the increase for both the average residential floor space, and floor space per person. When in 1990 the average home in Finland was 74 m^2, in 2007 it had grown to 79 m^2. What comes to the average residential floor space per person, in 1970 it was 19 m^2, in 1990 31 m^2, and in 2007 39 m^2. (Kimpanpää 2009, p. 50-51.) Apparently, Finns want bigger homes, but could downsizing Finnish apartments decrease our heating energy consumption and also our greenhouse gas emissions?

As mentioned before, the government can support energy efficiency and the usage of renewable energy sources by offering financially more tempting options. In addition to the taxation of the polluting options, different financial supports can be given for projects increasing energy efficiency. (Berninger 2012, p. 38.) Also the municipality of Pirkkala supports these kinds of activities. Financial supports have strickt limits of income and possessions. These might need to be checked in order to increase the implementation of renewable energy.

Finally, something has already been done right, since the proportion of fossil fuels from the total consumption of energy has dropped from the 1970s 80 % to the present less than 45 % (Statistics Finland 2012, p. 129). Still, there is lots of work to do for our – and the next generation.

SOURCES

Printed sources:

Andersson, H., Christiansen, M. & Fagerholt, K. 2010. Transportation planning and inventory management in the LNG supply chain. In Bjørndal, E., Bjørndal, M., Pardalos, P.M. & Rönnqvist, M. (ed.) 2010. Energy, natural resources and environmental economics. Berlin: Springer-Verlag.

Berninger, K. 2012. Hiilineutraali Suomi. Miten luodaan ympäristöystävällinen yhteiskunta? Helsinki: Gaudeamus Oy.

Ganopolski, A. 2010. Ocean currents and their role in biosphere. In Jørgensen, S. (ed.) 2010. Global ecology. A derivative of encyclopedia of ecology. Oxford: Elsevier B.V.

Gustafsson, J. (ed.) 2005. Maailmanlaajuiset ympäristöongelmat. Uhkakuvista yhteistyöhön. Turku: Turun yliopiston täydennyskoulutuskeskus.

Hankintaturvaliike. Autumn 2014- winter 2015. Kiinteistölämmitysjärjestelmät. Lämpöpumppuammattilainen. Vantaa: Scanoffice Oy.

Houghton, J. 2009. Global warming. The complete briefing. 4th edition. Cambridge: Cambridge University Press.

Isosaari, K. (ed.) 2012. Mistä energia taloon? Omakotiasujan energia- ja ympäristöopas. Keuruu: Otavamedia Oy.

Juvonen, J. & Lapinlampi, T. 2013. Energiakaivo. Maalämmön hyödyntäminen pientaloissa. Helsinki: Ympäristöministeriö

Kimpanpää, M. (ed.) 2009. Finland’s fifth national communication under the United Nations framework convention on climate change. Helsinki: Ministry of the Environment and Statistics Finland.

Midthun, K. & Tomasgard, A. 2010. Analysis of natural gas value chains. In Bjørndal, E., Bjørndal, M., Pardalos, P.M. & Rönnqvist, M. (ed.) 2010. Energy, natural resources and environmental economics. Berlin: Springer-Verlag.

Pietikäinen, A. (ed.) 2007. Rakennusten lämmitysjärjestelmät. Helsinki: Rakennustieto Oy.

Ranta, P. 2008. Tampereen kaupunkiluonto. Opas kaupunkiekologiaan. Tampere: Tampere-Seura ry.

Saikkonen, J., Strandell, C. & Karkinen, K. 1999. The built environment in Finland. Land use, housing and building. Helsinki: Ministry of the Environment.

Statistics Finland. 2012. Environment statistics. Yearbook 2012. Helsinki: Edita Publishing Oy

Telkänranta, H. 2006. Elävä planeetta. Ratkaisuja maailman ympäristöongelmiin. Helsinki: Edita Prima Oy.

Virta, J. & Pylsy, P. 2011. Taloyhtiön energiakirja. Helsinki: Kiinteistöalan Kustannus Oy.

Yudelson, J. 2010. Greening existing buildings. Washington: McGraw-Hill

Digital sources:

Bioenergiapörssi. 2015. Uusiutuvan energian markkinapaikka. [Retrieved 3 May 2015] Available at: http://www.bioenergiaporssi.fi

Google maps. 2014. [Retrieved 9 February 2015] Available at: https://www.google.fi/maps/place/Pakkalantie+1,+33950+Pirkkala/@61.4694146,23.7035572,316m/data=!3m2!1e3!4b1!4m2!3m1!1s0x468ed8dedec776ab:0x57574fc31bedaa21?hl=fi

Climateguide. 2013. Finland’s changing climate. [Retrieved 7 March 2015] Available at: https://ilmasto-opas.fi/fi/ilmastonmuutos/suomen-muuttuva-ilmasto/-/artikkeli/c42c4ec4-5eac-482b-b288-d54dd60bac71/pirkanmaa-lampimampia-jarvilaaksoja-ja-viileampia-ylamaita.html

Climateguide. 2012. Finland's changing climate. [Retrieved 7 March 2015] Available at: https://ilmasto-opas.fi/en/datat/mennyt-ja-tuleva-ilmasto#DoubleMapTimelinePlace:vertailu

Finnish Customs. 2014. Customer bulletin No. 21, January 2014. [Retrieved 26 February 2015] Available at: http://www.tulli.fi/en/finnish_customs/publications/excise_tax/excise_taxation/021.pdf

Finnish Energy Industries. 2015. Maakaasu. [Retrieved 1 March 2015] Available at: http://energia.fi/energia-ja-ymparisto/energialahteet/maakaasu

Finnish Energy Industries. 2015. Electric heating. [Retrieved 2 May 2015] Available at: http://energia.fi/en/home-and-heating/electric-heating/heat-pumps

Finnish Gas Association. 2014. Maakaasukäsikirja. Helmikuu 2014 [Retrieved 15 February 2015] Available at: http://kaasuyhdistys.fi/sites/default/files/kuvat/kirja/MaakaasuKasikirja_helmi2014.pdf

Finnish Meteorolocial Institute. 2014. [Retrieved 7 March 2015] Available at: http://ilmatieteenlaitos.fi/suomen-ilmastovyohykkeet

International Energy Agency (IEA). 2013. CO_2 emissions from fuel combustion. Highlights. [Retrieved 27 April 2015] Available at: http://www.iea.org/publications/freepublications/publication/co2emissionsfromfuelcombustionhighlights2013.pdf

Motiva Ltd. 2015. Yksittäisen kohteen CO_2-päästöjen laskentaohjeistus sekä käytettävät CO_2-päästökertoimet. [Retrieved 9 May 2015] Available at: http://www.motiva.fi/taustatietoa/energiankaytto_suomessa/co2-laskentaohje_energiankulutuksen_hiilidioksidipaastojen_laskentaan/co2-laskentaohje_yksittainen_kohde

Motiva Ltd. 2014. Energiankäyttö Suomessa. Energian kokonaiskulutus. [Retrieved 26 February 2015] Available at:

http://www.motiva.fi/taustatietoa/energiankaytto_suomessa/energian_kokonaiskulutus

Motiva Ltd. 2013. Energiatodistus. [Retrieved 2 May 2015] Available at: http://energiatodistus.motiva.fi/mika-on-energiatodistus/

Motiva Ltd. 2012. Opas pientuulivoimalan hankkijalle. [Retrieved 3 May 2015] Available at: http://www.motiva.fi/files/6107/Omaa_tuulienergiaa.pdf

Mudgal, S., Lyons, L., Cohen F., Lyons, R. & Fedrigo-Fazio, D. 2013. Energy performance certificates in buildings and their impact on transaction prices and rents in selected EU countries. Final report. [Retrieved 2 May 2015] Available at: http://ec.europa.eu/energy/sites/ener/files/documents/20130619-energy_performance_certificates_in_buildings.pdf

The Municipality of Pirkkala. 2014 [Retrieved 9 February 2015] Available at: http://www.pirkkala.fi/in-english/

NASA. 2014. Global Climate Change. Vital Signs of the Planet. [Retrieved 26 October 2014] National Aeronautics and Space Administrations. Available at: http://climate.nasa.gov

Nissinen, A., Salo, M., Mattinen, M., Manninen, K. & Grönroos, J. 2013. Ilmastodieetti – mihin sen antamat ilmastopainot perustuvat? [Retrieved 9 May 2015] Available at: http://www.ilmastodieetti.fi/pdf/Ilmastodieetti_dokumentaatio_2013-12-20.pdf

Official Statistics of Finland (OSF). 2015. Asumisen energiankulutus. [Retrieved 9 May 2015] Available at: http://tilastokeskus.fi/til/asen/index.html

Official Statistics of Finland (OSF). 2014. Statistics of Finland. [Retrieved 26 October 2014] Available at: http://stat.fi

Official Statistics of Finland (OSF). 2014. Carbon dioxide emissions from fossil fuels and peat use. [Retrieved 28 February 2015] Available at: http://www.stat.fi/til/ehk/2014/03/ehk_2014_03_2014-12-19_kuv_002_en.html

Official Statistics of Finland (OSF). 2014. Energy Statistics 2013. [Retrieved 1 March 2015] Available at: http://pxweb2.stat.fi/sahkoiset_julkaisut/energia2013/html/engl0006.htm

Official Statistics of Finland (OSF). 2014. Pirkkala. [Retrieved 7 March 2015] Available at: http://www.stat.fi/tup/kunnat/kuntatiedot/604.html

Rototec 2015. Energiaporaus. [Retrieved 5 May 2015] Available at: http://rototec.fi/tuotteet-ja-palvelut/energiaporaus.html

Rummukainen, A. 2014. Tutkimus: Suomen keskilämpötila nousee muuta maailmaa nopeammin. Yle News, 22.12.2014. [Retrieved 14 March 2015] Available at: http://yle.fi/uutiset/tutkimus_suomen_keskilampotila_nousee_muuta_maailmaa_nopeammin/7703063

Scripps, Institution of Oceanography. 2015. The Keeling Curve. [Retrieved 28 February 2015] Available at: https://scripps.ucsd.edu/programs/keelingcurve/wp-content/plugins/sio-bluemoon/graphs/co2_800k.png

Senera 2015. [Retrieved 5 May 2015] Available at: http://www.senera.fi/Maalampo_Referenssit_Rivitalot

STUK, Radiation and Nuclear Safety Authority. 2015. Radon in Finland. [Retrieved 28 February 2015] Available at: http://www.stuk.fi/sateily-ymparistossa/radon/fi_FI/pientaloasuntojen_radonmittaukset/

Suomen Aurinkoenergia. 2015. [Retrieved 3 May 2015] Available at: http://www.suomenaurinkoenergia.fi/aurinkoenergia

Suomen Ympäristökeskus. 2013. Ilmastodieetti. [Retrieved 10 May 2015] Available at: http://www.ilmastodieetti.fi/Ilmastolaskuri.html

Tampereen Kaukolämmön Karttapalvelu. 2015. [Retrieved 2 March 2015] Available at: http://193.210.131.111/IMS

Tampereen seudun GeoTieto. 2009. [Retrieved 1 April 2015] Available at: http://geomaps2.gtk.fi/taata/

Tampereen sähkölaitos. 2015. Kaukolämpö, -jäähdytys ja maakaasu. [Retrieved 2 March 2015] Available at: https://www.tampereensahkolaitos.fi/kaukolampojaahdytysjamaakaasu/kaukolampo/kaukolämmön%20alkuperä/

Tarvainen, T., Backman, B. & Luoma, S. 2010. Pirkkalan maaperän geokemiallisen arseeniongelman laajuuden esiselvitys. Geological Survey of Finland. [Retrieved 12 April 2015] Available at: http://pirkkala-fi-bin.aldone.fi/@Bin/a7d36311a0323ce14922d3ed0b985396/1428860344/application/pdf/1717414/Pirkkala_esiselvitys_20122010.pdf

Virtanen, S. 2015. Näin Mäntsälässä: hakukonefirman palvelimet lämmittävät 5000 omakotitaloa - tekninen toteutus ensimmäinen laatuaan maailmassa. Tekniikka & Talous, 3.2.2015. [Retrieved 10 May 2015] Available at: http://www.tekniikkatalous.fi/energia/nain+mantsalassa+hakukonefirman+palvelimet+lammittavat+5000+omakotitaloa++tekninen+toteutus+ensimmainen+laatuaan+maailmassa/a1046763

The Acts:

Act on Energy Certification of Buildings (50/2013)

Land Use and Building Act (132/1999)

Water Act (587/2011)

Environmental Protection Act (86/2000)

Real Estate Formation Act (554/1995)

Chemicals Act (744/1989)

Health Protection Act (763/1994), mainly Chapter 5 and 7

Decree of the Ministry of Social Affairs and Health Relating to the Quality and Monitoring of Water Intended for Human Consumption (461/2000) and (401/2001)

Other sources:

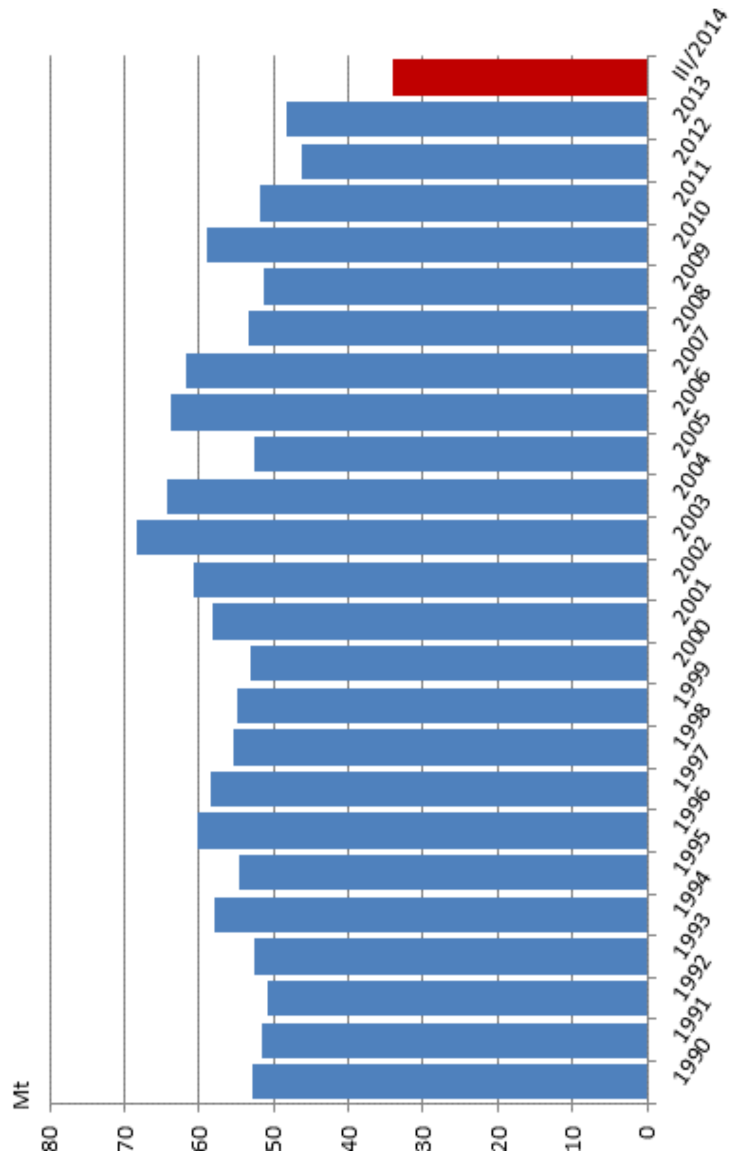
Lännen isännöintipalvelu. 2015. Re: Kokous ja talkoot [email message] Recipient Julin, L. Sent 27 April 2015.

Board of Directors. 2014. Re: Lämmityslukuja [email message] Recipient Julin, L. Sent 29 September 2014.

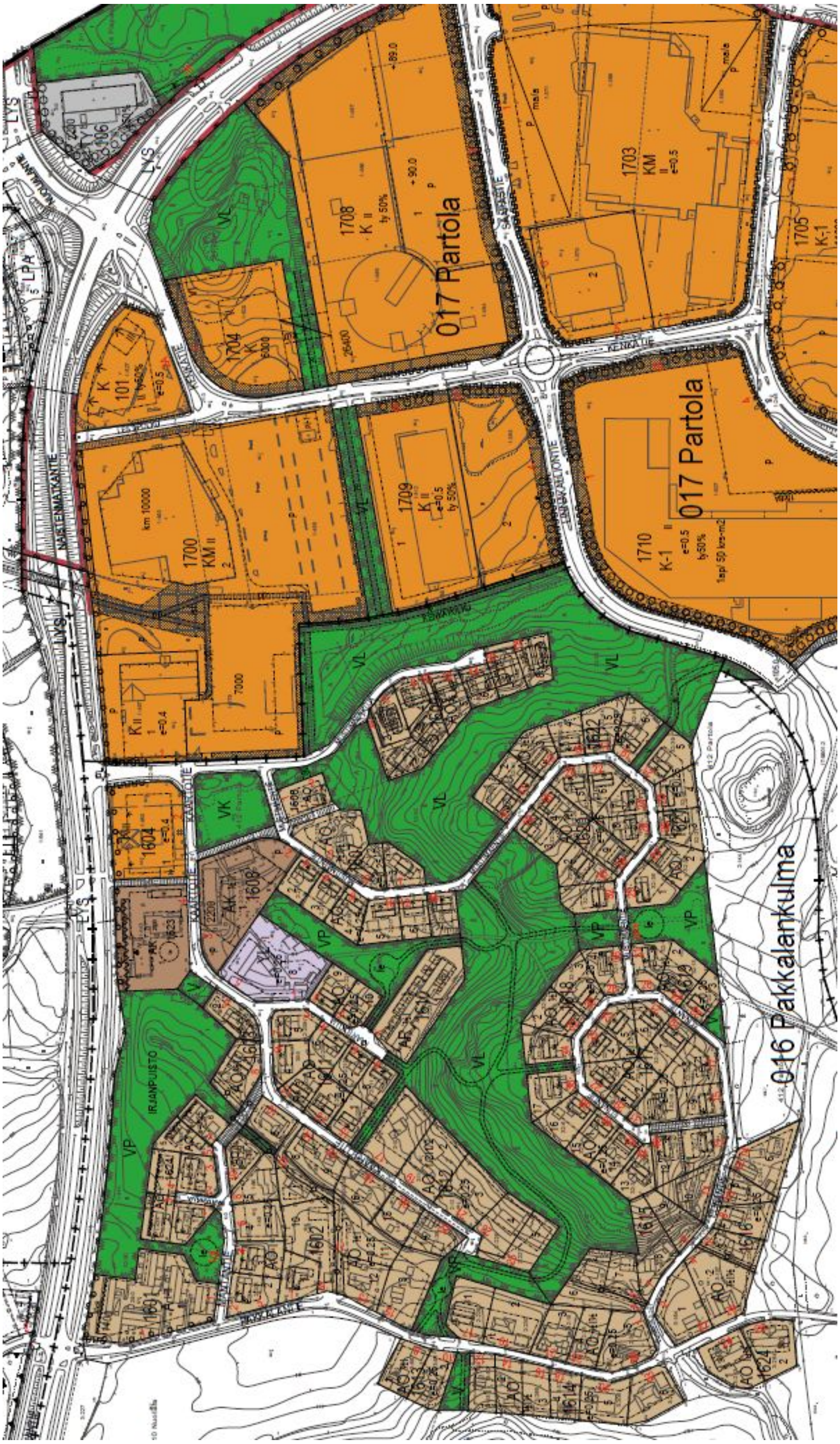
APPENDICES

APPENDIX 1. FINLAND'S CO_2 EMISSIONS FROM FOSSIL FUELS AND PEAT USE (OSF 2014).

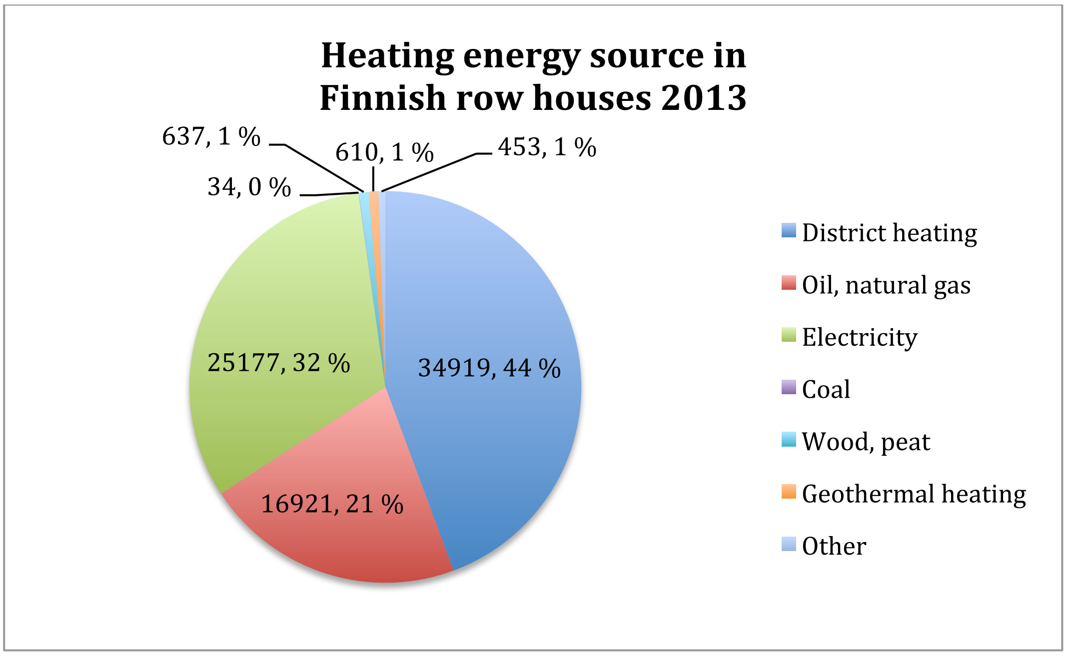
FINLAND'S CO_2 EMISSIONS FROM FOSSIL FUELS AND PEAT USE (OSF 2014).

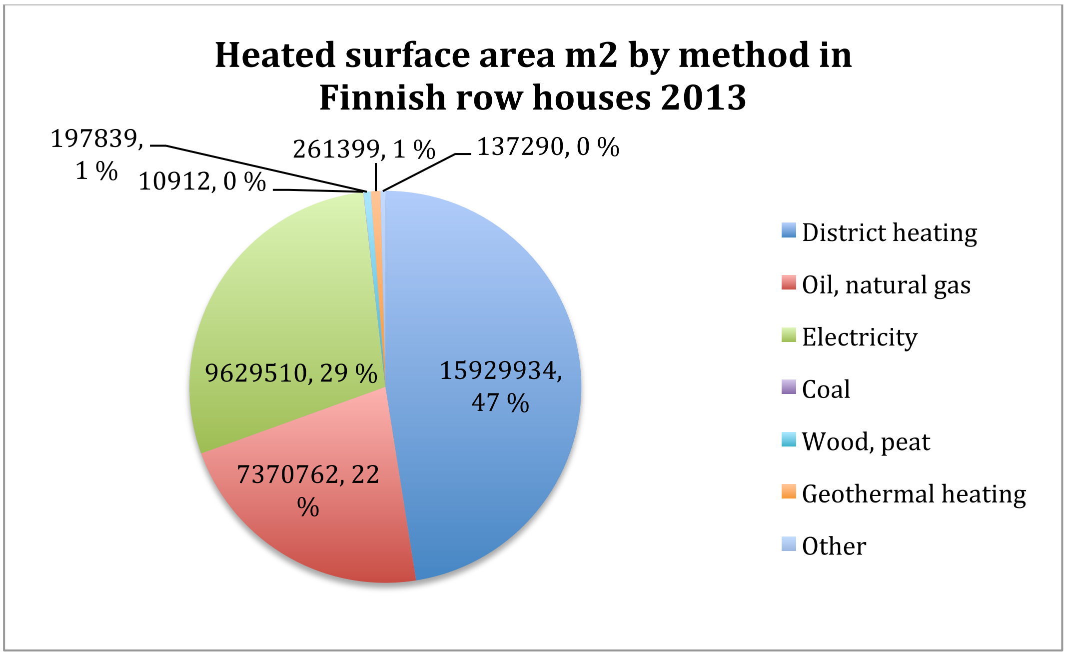


APPENDIX 2. CITY PLAN OF THE PAKKALANKULMA AREA (The Municipality of Pirkkala 2014)



APPENDIX 3. HEATING ENERGY SOURCE AND HEATED SURFACE AREA IN FINNISH ROW HOUSES IN 2013 BY METHOD (OSF 2014).





APPENDIX 4. NATURAL GAS TRANSMISSION NETWORK (Finnish Energy Industries 2015)