RESEARCH REPORT

VTT-R-03174-11

SGEM WP3.6

Impacts of large penetration of heat pumps on the electricity use

Authors: Ari Laitinen, Maija Ruska, Göran Koreneff

Confidentiality: Public

Report's title	
Impacts of large penetration of heat pumps on the electricity use	
Customer, contact person, address	Order reference
Project name SGEM WP3.6	Project number/Short name 41103 task 1.9
Author(s) Ari Laitinen, Maija Ruska, Göran Koreneff	Pages 65 p.+ app. 13 p.
Keywords Heat pump, load curves, electric heating	Report identification code VTT-R-03174-11

Summary

The study is part of the Smart Grid and Energy Market (SGEM) research programme, which in turn is part of the Finnish Energy and Environments Competence Cluster (Cleen). The report describes part of the results from task 3.6.1 in SGEM 1 funding period work package "Impacts of changes in heating solutions" (SGEM 1FP WP3.6). The first funding period started in 2009 and ended 28.2.2011.

The aim of the task was to analyse passive and dynamic grid impacts of large scale penetration of different heat pumps in the residential sector and changes in heating solution, possibilities and disadvantages in short and long-term run.

Today there are slightly over 390 thousand heat pumps in Finland according to the statistics of Finnish heat pump association SULPU. Ground source heat pumps are 47 thousand, exhaust air heat pumps 17 thousand, air/water 6 thousand and air/air 320 thousand. The growth has been nearly five-fold in 5 years and the vision is that the market continues to increase. By 2020 the number of heat pumps will be about 1 million of which nearly 60 % is air/air heat pumps and 25 % ground source heat pumps. By 2030, it is estimated that the number of heat pumps totals 1.6 million, of which 44 % are air/air heat pumps and 32 % ground source heat pumps. The popularity of heat pumps is contributed to the rising energy prices, tightening energy regulations and subsidies given when changing the heating system.

Confidentiality	Public

Espoo 16.6.2011

Written by	Reviewed by	Accepted by
Ari Laitinen, Research scientist	Jari Shemeikka, Team leader	Seppo Hänninen, Technology manager

VTT's contact address
VTT, P.O.Box 1000, 02044 VTT

Distribution (customer and VTT)
Net publication, VTT, Cleen Oy

Preface

The study is part of the Smart Grid and Energy Market (SGEM) research programme, which in turn is part of the Finnish Energy and Environments Competence Cluster (Cleen). The report describes part of the results from task 3.6.1 in SGEM 1 funding period work package “Impacts of changes in heating solutions” (SGEM 1FP WP3.6). The first funding period started in 2009 and ended 28.2.2011.

The aim of the task is to analyse passive and dynamic grid impacts of large scale penetration of different heat pumps and changes in heating solution, possibilities and disadvantages in short and long-term run. The effects on local distribution networks are analysed and reported by Tampere University of Technology (TUT) in a separate task report. The research resulting in this study was done by VTT Technical Research Centre of Finland.

SGEM 1FP WP3.6 steering group consisted of Santtu Vähäkuopus, Vattenfall, Pekka Verho, TUT, and Göran Koreneff, VTT.

The authors like to thank Juhani Heljo for his valuable contribution to WP 3.6 seminars and workshops and overall to the research topic.

Espoo 31.3.2011

Authors

Contents

Abbreviations and acronyms

AWHP	Air/Water Heat Pump
BAU	Business-As-Usual
COP	Coefficient of Performance
DHW	Domestic Hot Water
EHPA	European Heat Pump Association
EPBD	Directive on Energy Performance of Buildings (2010/31/EU)
GSHP	Ground source heat pump
HP	Heat pump
NREAP	National Renewable Energy Action Plans
RES	Renewable Energy Resources
SG	Smart Grid(s)
SGEM	Smart Grid and Energy Market research programme, part of Cleen Oy
SPF	Seasonal Performance Factor of heat pumps
SULPU	Finnish heat pump association (SUomen LämpöPUmppuyhdistys ry)
TWh	TeraWattHour = 1,000,000 MW -hours

1 Introduction

Energy saving policies of the national government and the EU puts pressure on oil and direct electric heating which is shown as rising energy prices and tightening building regulations. There is also governmental pressure to increase the use of renewable energy sources in heating and to encourage heaters, by the way of subsidies, to change from oil or direct electric heating to heat pumps or bio fuel heating. On the other hand, heat pump technology has developed and new products have come to the market and, moreover, the new heat pump are more reliable, cheaper, and more energy efficient than they were just some years ago.

The expected increase in heat pump installations will affect the use of electricity, both the level and the load curve form. This study is an attempt to assess the effects. After a glance at the European heat pump markets (Chapter 2), a overview of Finnish energy use for space heating and domestic hot water heat is presented in Chapter 3. Chapter 4 gives a short introduction to heat pump types and characteristics. Chapter 5 assess heat pump scenarios for the residential sector, in specific for detached houses, attached houses, block of flats, and free-time residencies. Load curves for air-air and ground source heat pumps are presented in Chapter 6 and a summary in Chapter 7.

2 European heat pump markets

2.1 European heat markets

Heat can be used for various purposes. Industry uses heat for melting, evaporating, and drying processes, while in residential and other buildings, heat is used for space heating and domestic hot water (DHW) supply.

Climatic, national, regional and local conditions vary, and thus space heating demands have been met in many different ways in Europe (Ecoheatcool 2005-2006). In the Mediterranean area, where heating demands are low, space heating sector is rather unorganised. In the northern countries, heating demands are more often met with organised district heating systems. Many European countries use natural gas in local boilers for heating purposes. The EU development of the use of different energy sources for space heating and DHW is presented in Figure 1. The share of gas has increased while coal and oil usage has diminished. Gas has the largest share followed by oil, wood and electricity.

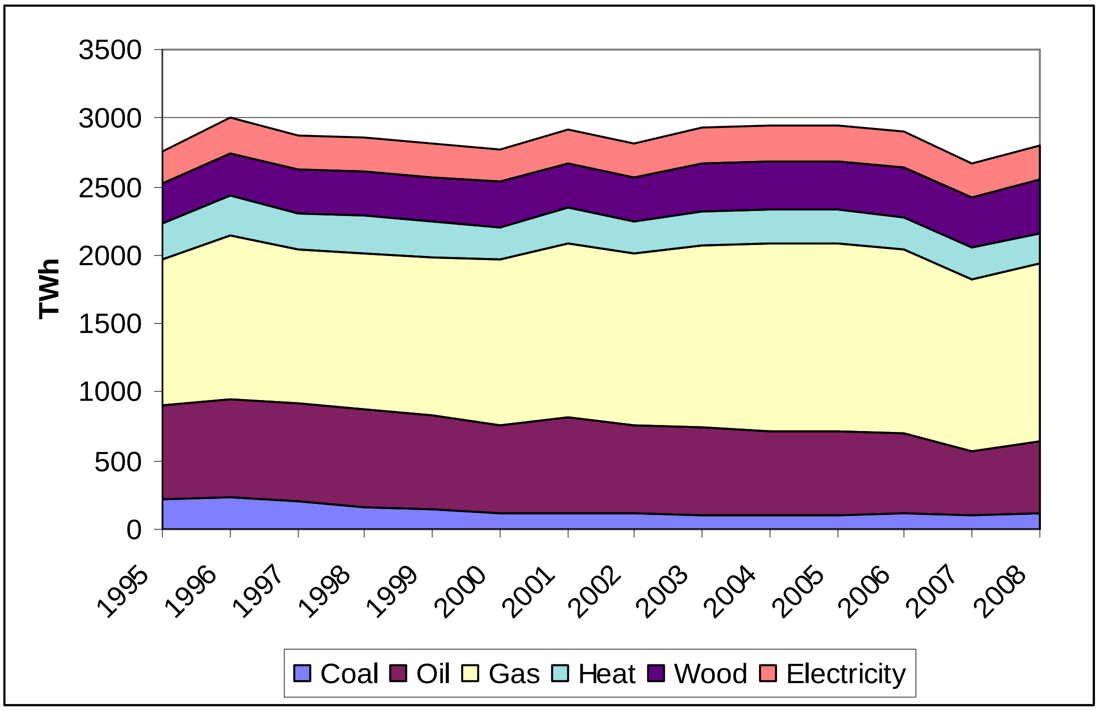


Figure 1. Space heating and DHW according to energy source in the EU 1995-2008. (Data source: Odyssee)

The European heat market has eight dimensions, with respect to primary energy supply, emissions, heat carriers, heat demands, community sectors, locations, time, and cost (Ecoheatcool 2005-2006). Therefore no coherent and harmonised description of the markets exists. Figure 2 shows the energy use for space heating and DHW in selected countries. The assumption would be, that the share of DHW would increase the more south one goes, but although Spain displays a share of 36%, Finland has the second largest share, 30%. Sweden has a DHW share of 14%, comparable to Germany and France. Overall, the EU average is 17%.

The DHW share of total heating energy depends on the energy source. The interpretation of Figure 3 can be, that electricity is quite often used only for DHW and that coal and wood is often used only for space heating.

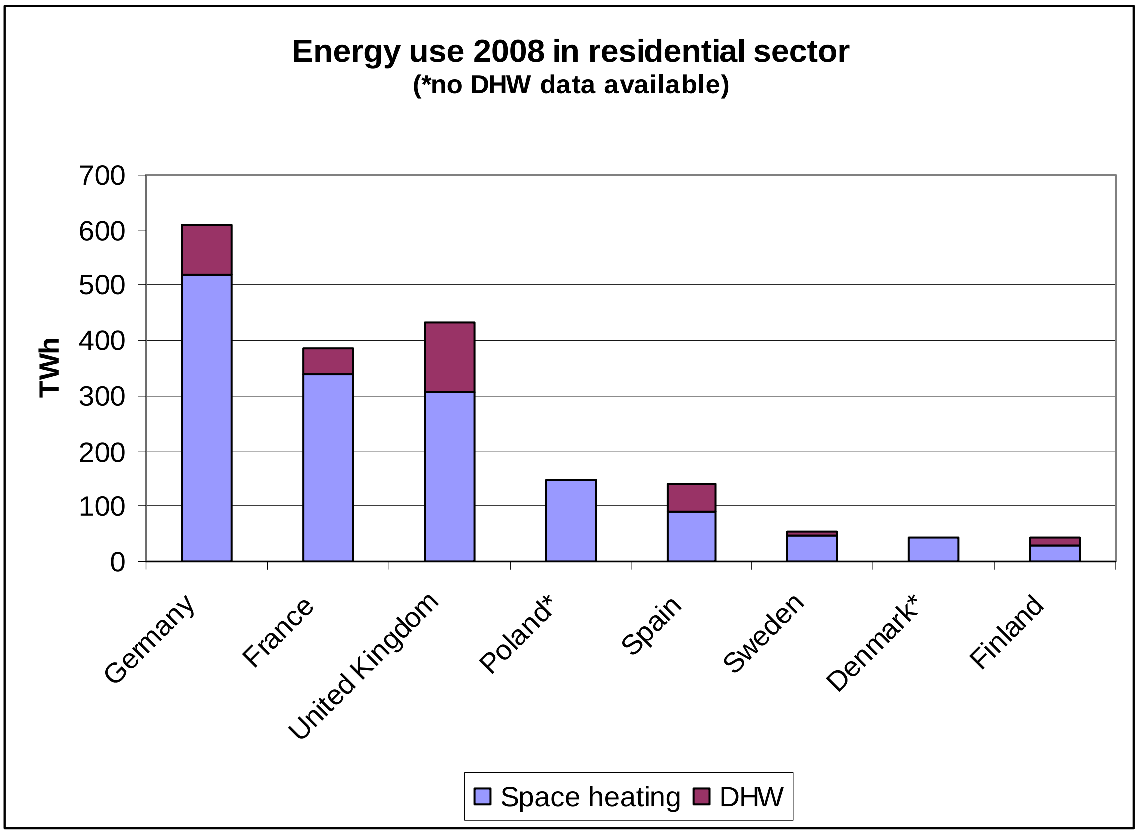


Figure 2. Energy use for space heating and domestic hot water for selected countries in 2008. No DHW data was available for Denmark and Poland. (Data source: Odyssee)

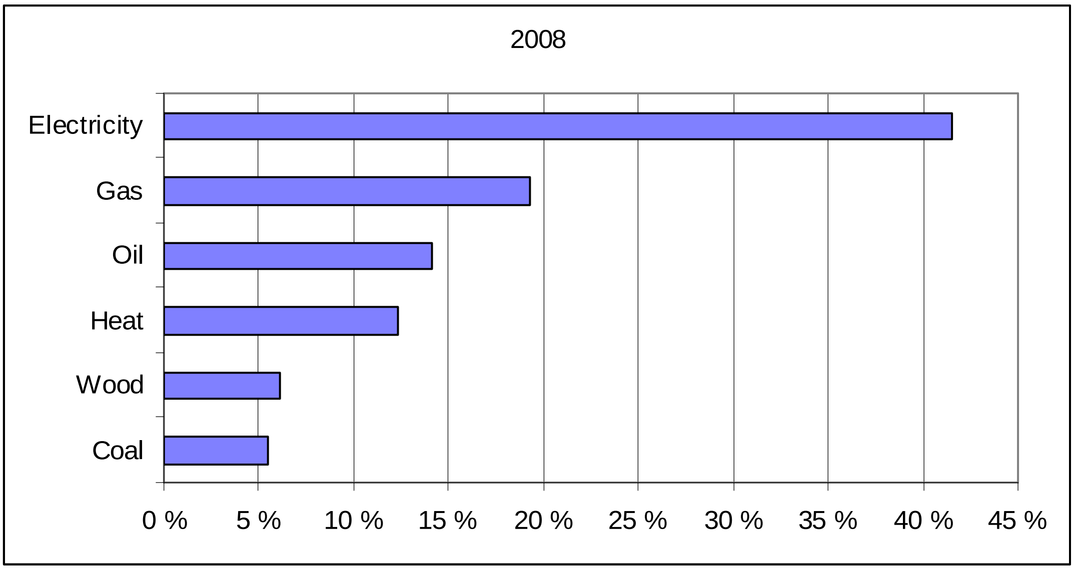


Figure 3. According to energy source, the share of energy used for DWH compared to total heating including space heating and DHW. (Data source: Odyssee)

2.2 The European Union heat pump policies and directives

The European Union has the target to increase the share of renewable energy sources (RES) in its gross final consumption of energy to 20 %, decrease greenhouse gas emissions by 20 % and to enhance energy efficiency by 20 % by 2020. At present, the heating and cooling sector consumes at least 40 % of the final energy in the EU, and most of this energy is produced from fossil fuels. Achieving the 20-20-20 targets requires that renewable energy sources are further promoted in the heating and cooling sector.

Heat pump technologies can provide renewable heating and cooling to cover the needs of a variety of users, from private to public and commercial building owners throughout Europe (EHPA 2008).

With the Directive 2009/28/EC on the promotion of energy from renewable sources (RES-directive), the European Union recognised heat pumps as renewable energy sources. The Directive states that aerothermal, geothermal and hydrothermal heat energy captured by heat pumps shall be taken into account as renewable energy provided that the final energy output significantly exceeds the primary energy input required to drive the heat pumps. When calculating the renewable energy output, the energy used to drive heat pumps is deducted from the total usable heat.

On 19 May 2010 a recast of the Directive on energy performance of buildings (EPBD) was adopted (2010/31/EU). The renewed Directive strengthens the energy performance requirements.

In the longer term, the EU has a target to keep the global warming less than 2 degrees compared to pre-industrial level. This target would require the EU to cut the emissions by 80-95 % by 2050. This requires tremendous changes in the energy sector: for instance in the electricity generation, virtually all electricity generated should come from carbon-neutral sources by 2050. Heat pump technologies' contribution to renewable energy targets is also expected to increase substantially.

2.3 Projected heat pump trajectories by country from 2010 to 2020

Article 4 of the renewable energy Directive (2009/28/EC) required the Member States to submit National Renewable Energy Action Plans (NREAP) to the European Union by 30 June 2010. These plans provide detailed roadmaps of how each Member State expects to reach its legally binding 2020 target for the share of renewable energy in their final energy consumption. By the end of the year 2010, all 27 Member States had published their National Renewable Energy Action Plans.

NREAPs include estimates for the contribution expected from each renewable technology in each Member State to meet the binding 2020 targets in heating and cooling sector. Figure 4 provides an illustration of the projected total heat pump thermal energies for the years 2010, 2015 and 2020. The figures only include the renewable energy obtained from heat pumps, and thus the figures are not comparable to total heat energy. In 2010, the countries expecting largest energies from heat pump technologies are Italy (15 TWh), France (10 TWh), Germany (5

TWh), Sweden (4 TWh), and Finland (3 TWh). In 2020, the countries expecting largest renewable energies from heat pumps are Italy (34 TWh), the UK (26 TWh), France (22 TWh), Germany (13 TWh), Sweden (12 TWh), and Finland (8 TWh).

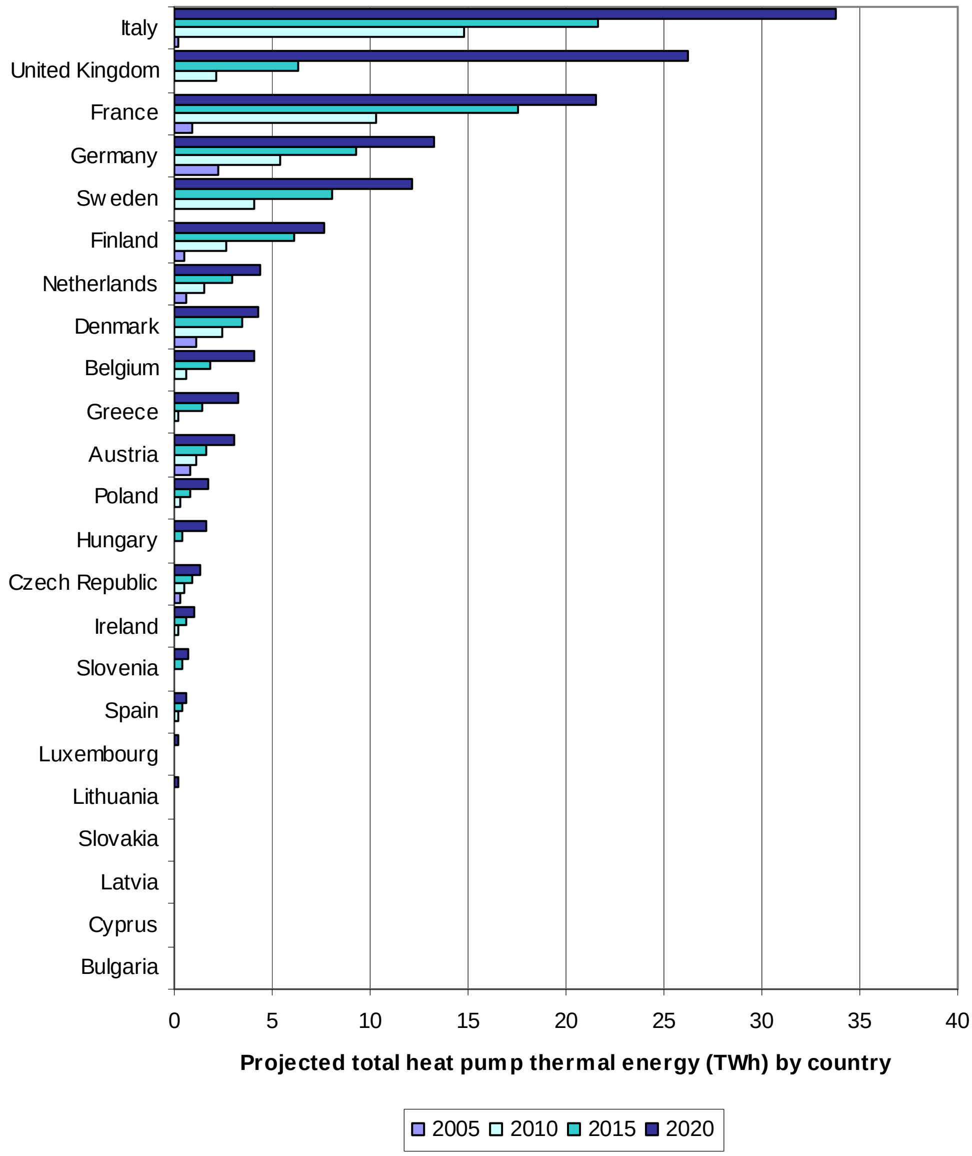


Figure 4. Projected total heat pump thermal energy (TWh) from NREAPs. The figures only include the renewable energy obtained from heat pumps.

Figure 5 illustrates the projected heat pump thermal energies for the year 2020 broken down into source type. Only 13 Member States provided this information. From these 13 Member States, largest heat pump markets are expected to be Italy, the United Kingdom, France, Germany, and Sweden. In Italy, the UK, France and Greece, over 60 % of the renewable energy is obtained from aerothermal heat pumps, while in Sweden, the Netherlands, and Denmark most of the energy is obtained from geothermal heat pumps. In Austria, the total energy obtained from heat pumps is small, but unlike other Member States half of the energy is obtained from hydrothermal heat pumps.

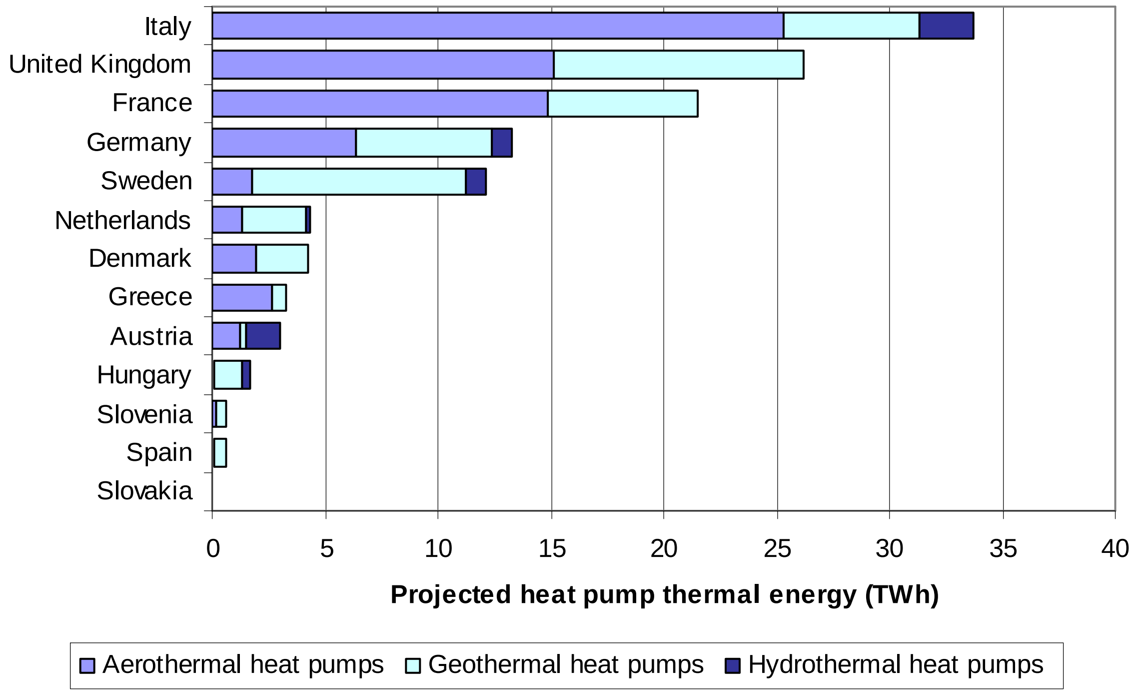


Figure 5. Projected heat pump thermal energy (TWh) broken down into source type in 2020. Data for the Member States which have included breakdown into source types in their NREAPs. The figures only include the renewable energy obtained from heat pumps.

2.4 Heat pump markets

The market for heat pumps started developing in the 1980's. In the beginning, heat pump systems suffered from quality issues, which slowed the market growth. Precise statistics on heat pump sales are not available, but the European Heat Pump Association (EHPA) collects data provided by its member companies.

The EHPA statistics provides statistical data for 9 countries since 2005. Figure 6 illustrates the total heat pump sales development from 2005 to 2010 for these countries. Provided figures are a conservative estimate of the total EU sales numbers, since some significant national markets are not included. In the period from 2005 to 2008, heat pump sales increased. As a consequence of the global economical downturn and lower fossil fuel prices, heat pump sales have shown negative growth rates for the years 2009 and 2010.

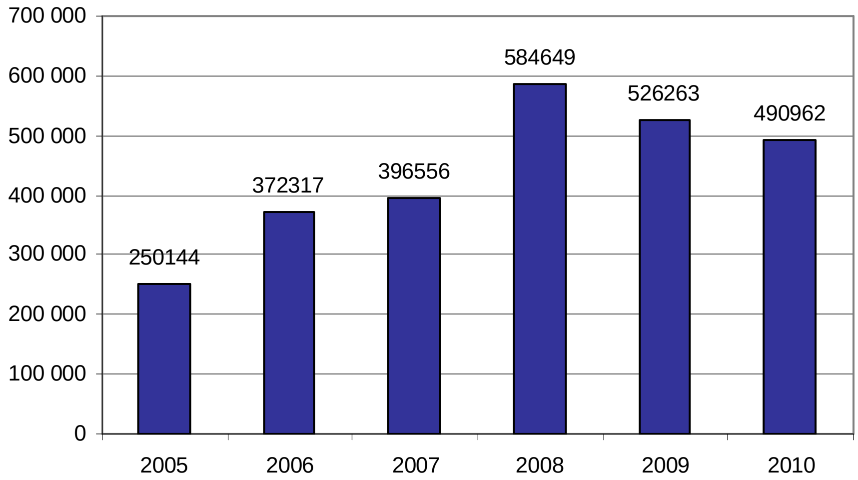


Figure 6. European heat pump sales 2005-2009 covering Austria, Finland, France, Germany, Italy, Norway, Sweden, Switzerland and the UK (data provided by EHPA 2011).

Country-specific heat pump sales numbers are illustrated in Figure 7. In 2009, largest heat pump sales numbers were in France (126 700), Sweden (116 900), Norway (84 000), Germany (67 000), Finland (48 300), and Italy (30 000).

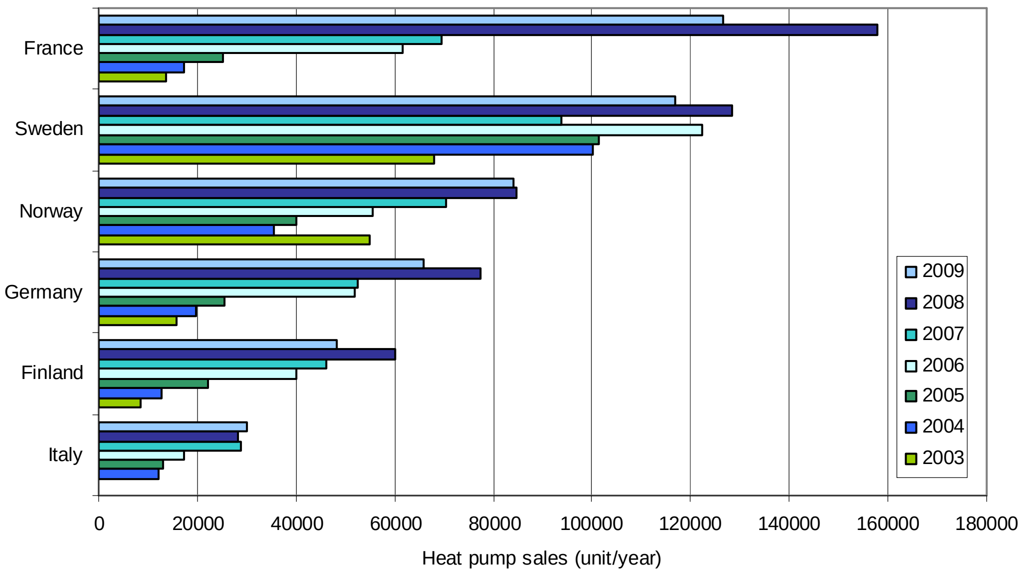


Figure 7. Heat pump units sold 2003-2009 in selected European countries (original data from European Heat Pump Association).

Based on EHPA statistics, a total of more than 2 million heat pumps were sold in the period from 2005 to 2009 in the 9 largest heat pump national markets. These heat pumps are annually providing a total of almost 26 TWh of renewable energy (EHPA 2011).

3 Energy use for space heating and DHW in Finland

Finland uses a lot of energy to keep the buildings warm wintertime. Energy use according to source and building type in 2009 in Finland is shown in Figure 8. The heat pump number includes only the produced net energy (heat −electricity). Burning of wood is significant for the residential sector, but also for agricultural buildings.

Residential building usage dominates the sector. Although the service sector uses substantial amounts of heating, it mostly stems from district heating and as such is not so susceptible to heating system changes. To better grasp the possibilities of the future, especially the residential sector must be given a more detailed attention (see Chapter 5).

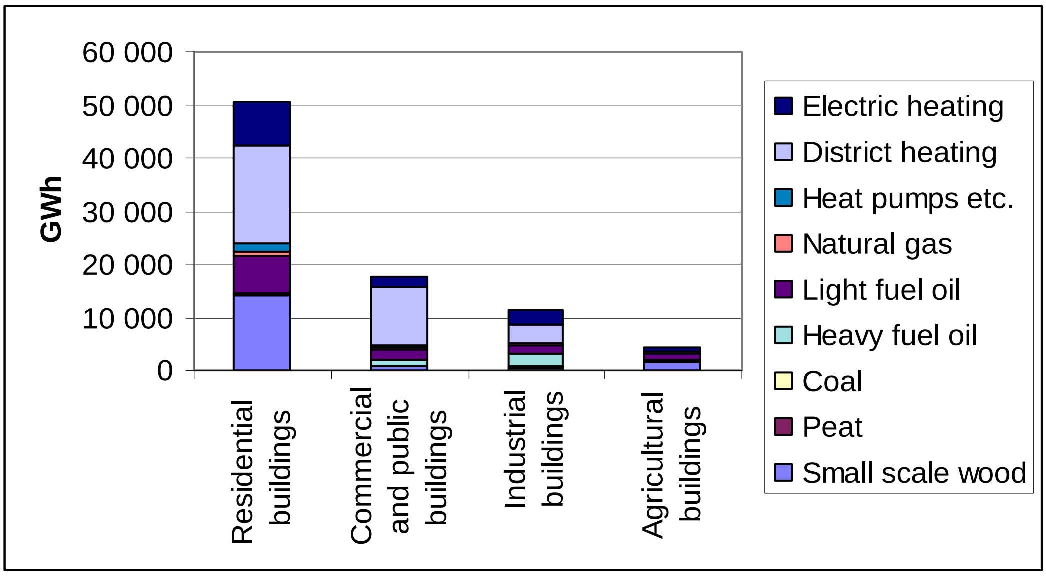


Figure 8. Heating energy in Finland 2009 according to energy source and building type. (Data source: Statistics Finland 20110)

Electricity has a 15% market share in the residential space heating sector in Finland. The share is above the EU average, but higher shares exist, see Figure 9. For example Spain and Sweden have larger market shares of electricity in space heating and France has a similar market share.

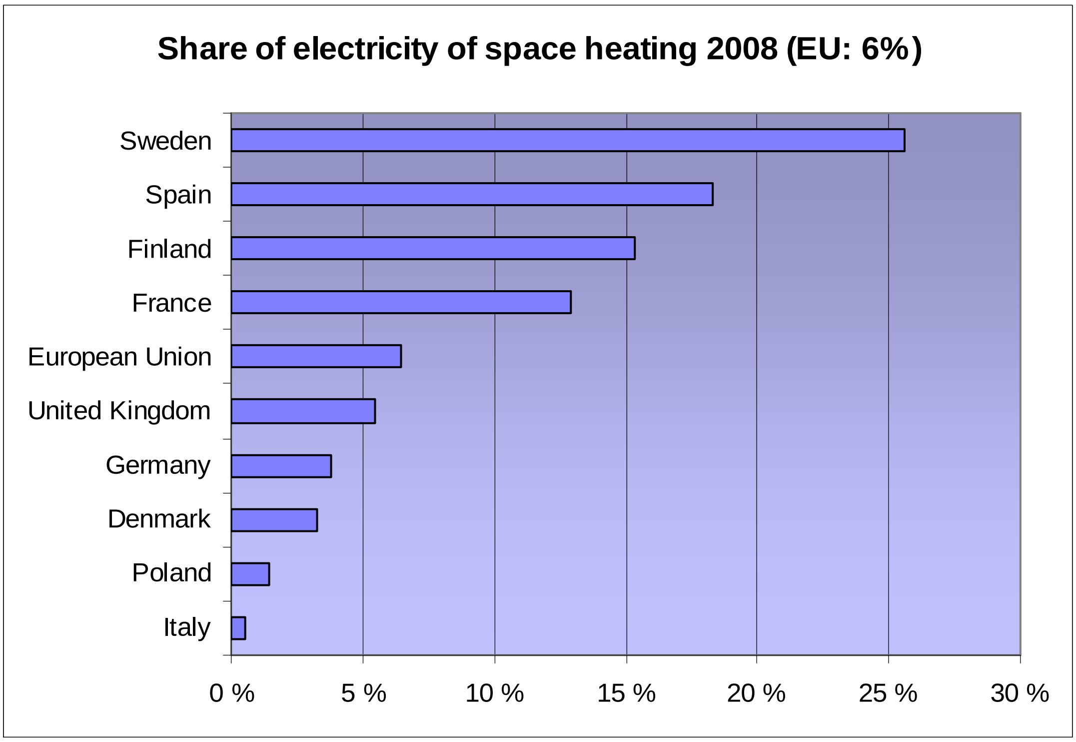


Figure 9. The share of electricity for space heating in Finland compared selected countries and the EU average.

When comparing the energy use for residential space heating between different countries, it can be done in several ways. Just looking at average consumption per dwelling, we get results as shown in Figure 10. Even though Finland is a Northern and cold country, Denmark and Germany show higher consumptions. There are several explanations, for example

- The average size of a dwelling.
- The fuels used: for example. district heat and electricity have high final efficiencies, but wood hasn't.
- The question of what is included in the statistics. For example, Denmark has no separate data for DHW in the database, so DHW might very well be included in these figures or then not. It is good to bear in mind that the heating numbers are more or less the results of models and estimations.
- The local climate.
- The customary indoor temperature.

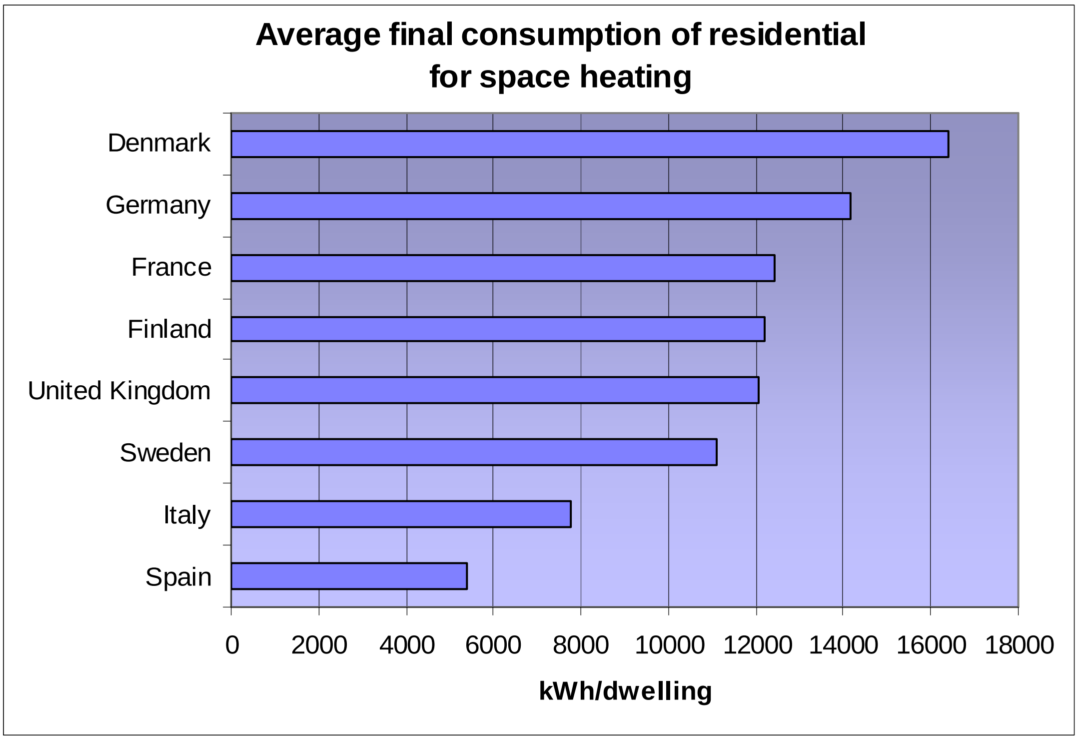


Figure 10. Average final consumption of dwellings for space heating in 2008. (Data source: Odyssee)

For example, the results are different if we take into account the average size of dwellings, see Figure 11. Here Finland surpasses both Denmark and France in consumption for space heating, and italy and Spain have changed places.

If the consumptions are adjusted for the climate, for example by scaling to EU average climate (see Figure 12), the results change once again. Although the scaling done by Odyssee can be critised to a certain degree, the overall results are quite clear. Finland has a very low unit consumption, mainly thanks to well insulated houses. Except for Spain, Finland and Sweden have the lowest unit consumptions, clearly lower than the rest. The question concerning Spain is, to what degree are the residents heated during the winter season?

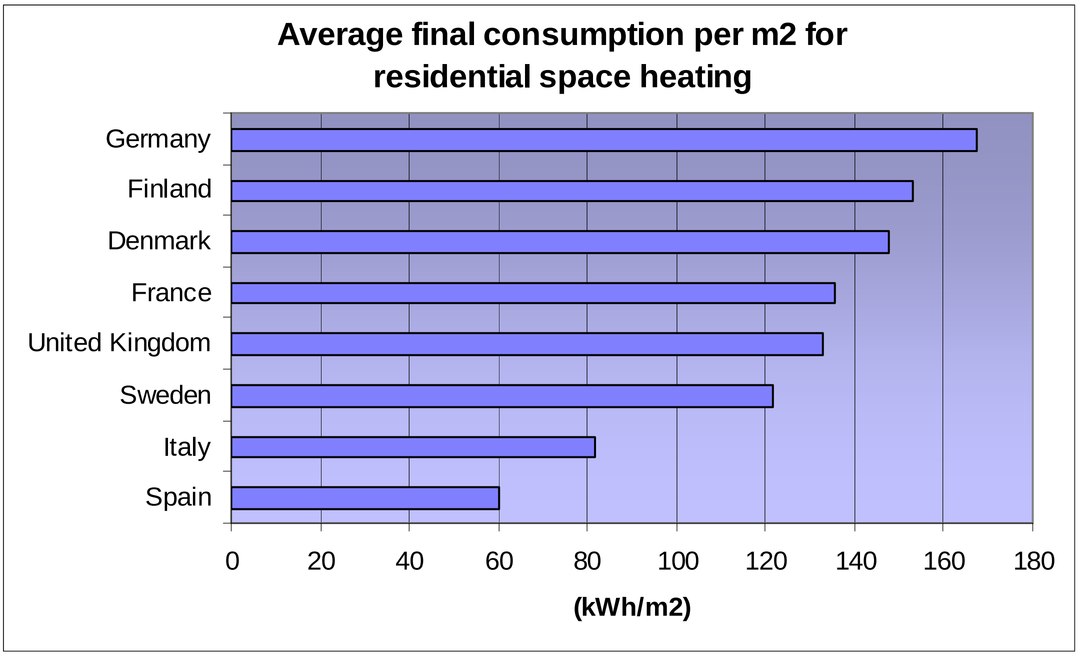


Figure 11. Average consumption (kWh/m^2) of residential space heating in 2008. (Data source: Odyssee)

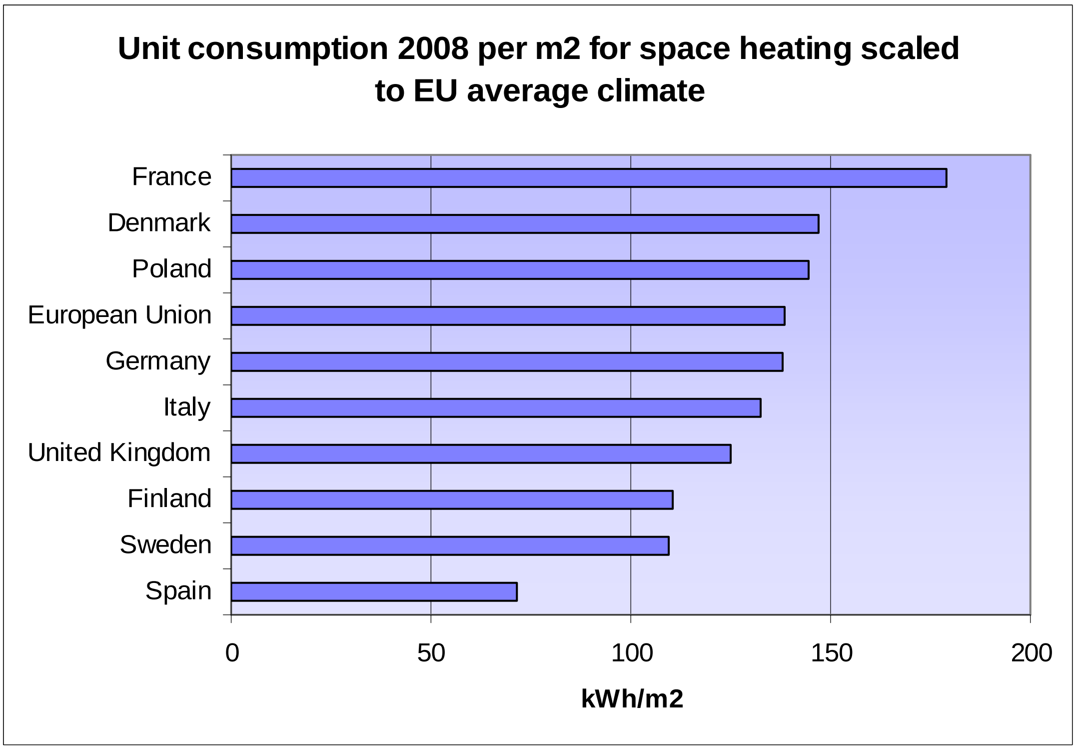


Figure 12. Unit consumption (kWh/m^2) in 2008 of space heating scaled to EU average climate. (Data source: Odyssee)

4 Heat pump types and characteristics

4.1 Air/air heat pumps

4.1.1 Heat source

Air/air heat pumps use outside air as heat source which means that the temperature of the heat source vary dramatically during the heating season. The energy efficiency of heat pumps is measured by the coefficient of performance (COP), which is defined as the ration of heat delivered by the heat pump and the electricity used for this. TheCOP of the air/air heat pumps depends on the outside air temperature; the colder it is the poorer is the efficiency. This is why the performance of the very same heat pump is different in the northern climate than in the south. The operating performance of an electric heat pump is called the seasonal performance factor (SPF) and it takes into account the variation in the heating demand (including defrosting of the heat pump) as well as the weather conditions over a year

In this study the climate data for Jyväskylä (year 1979) has been used. Jyväskylä presents average climate in Finland. The duration curve of the outside air temperature is presented in Figure 13.

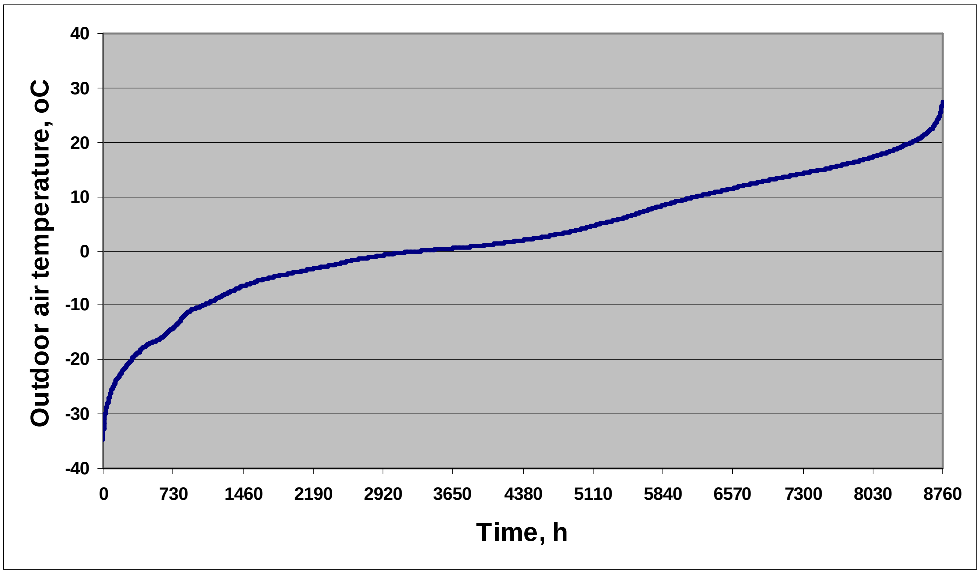


Figure 13. Duration curve for outside air temperature in Jyväskylä year 1979.

Ambient air is a possible heat source for a heat pump, see Figure 14. However, according to the Finnish heat pump association (SULPU, Suomen lämpöpumppuyhdistys), when the temperature of the outdoor air goes down to -20…-30 °C the COP and capacity (see Figure 15) of the heat pump goes so low that there is no use in running it. This means that an extra heating system is needed to cover the total heating demand during the coldest period.

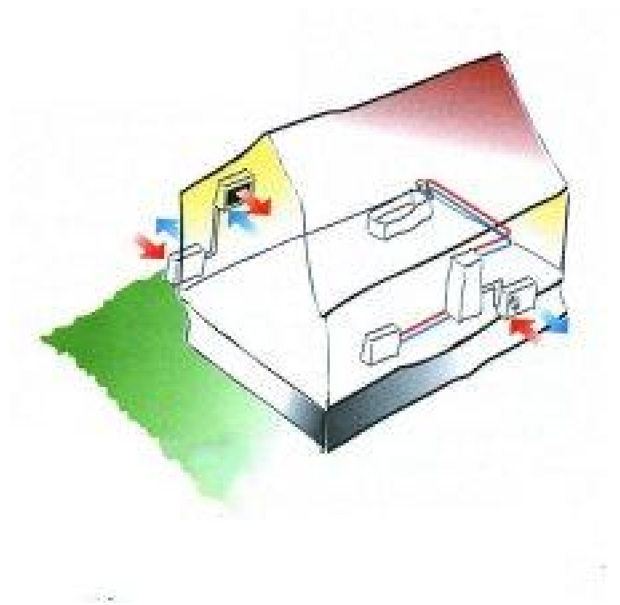


Figure 14. Outside air heat pump types (SULPU).

Typically the heat from the heat pump is delivered directly to the room air in which case the indoor unit should be located centrally in open space so that the heat is delivered evenly to the whole flat. SPF of about 2.0 and even higher is possible. There are also systems where the heat from the heat pump is delivered to the water based heating system.

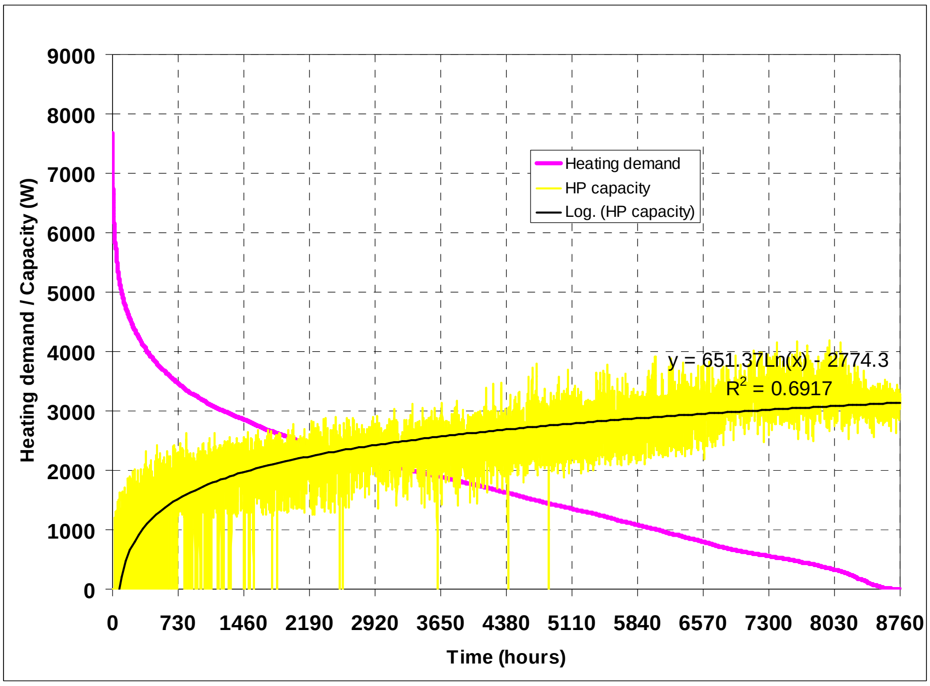


Figure 15. Capacity of an outside air heat pump versus heating demand of a detached house.

4.1.2 Product data of air/air heat pump

Public product data available for air-air heat pumps is limited. Usually manufacturers publish operating values based only on standard measurements (EN 14511:2007), see Table 1. In most cases manufacturers report only characteristics on standard rating condition which is not enough for year round hour by hour analysis. A Finnish importer (www.scanoffice.fi) announces also test reports (by VTT) that are far more comprehensive than the standard test. These reports include, for instance, the impact of defrosting on the characteristics. The characteristics used in this study are based on VTT's tests and the product modelled is chosen so that it presents "average" air-to-air heat pump on the market. Air/air heat pumps are also tested by Swedish Energy Agency (Energimyndigheten). The characteristics of the modelled heat pump and test results by VTT and Energimyndigheten are presented in Figure 16.

Table 1. Air-to-air heat pump rating conditions according to the EN 14511:2007 standard.

Condition	**Outdoor temperature °C**	**Indoor temperature °C**
Standard rating condition	+7	+20
Application rating conditions	+2	+20
	-7	+20
	-15	+20

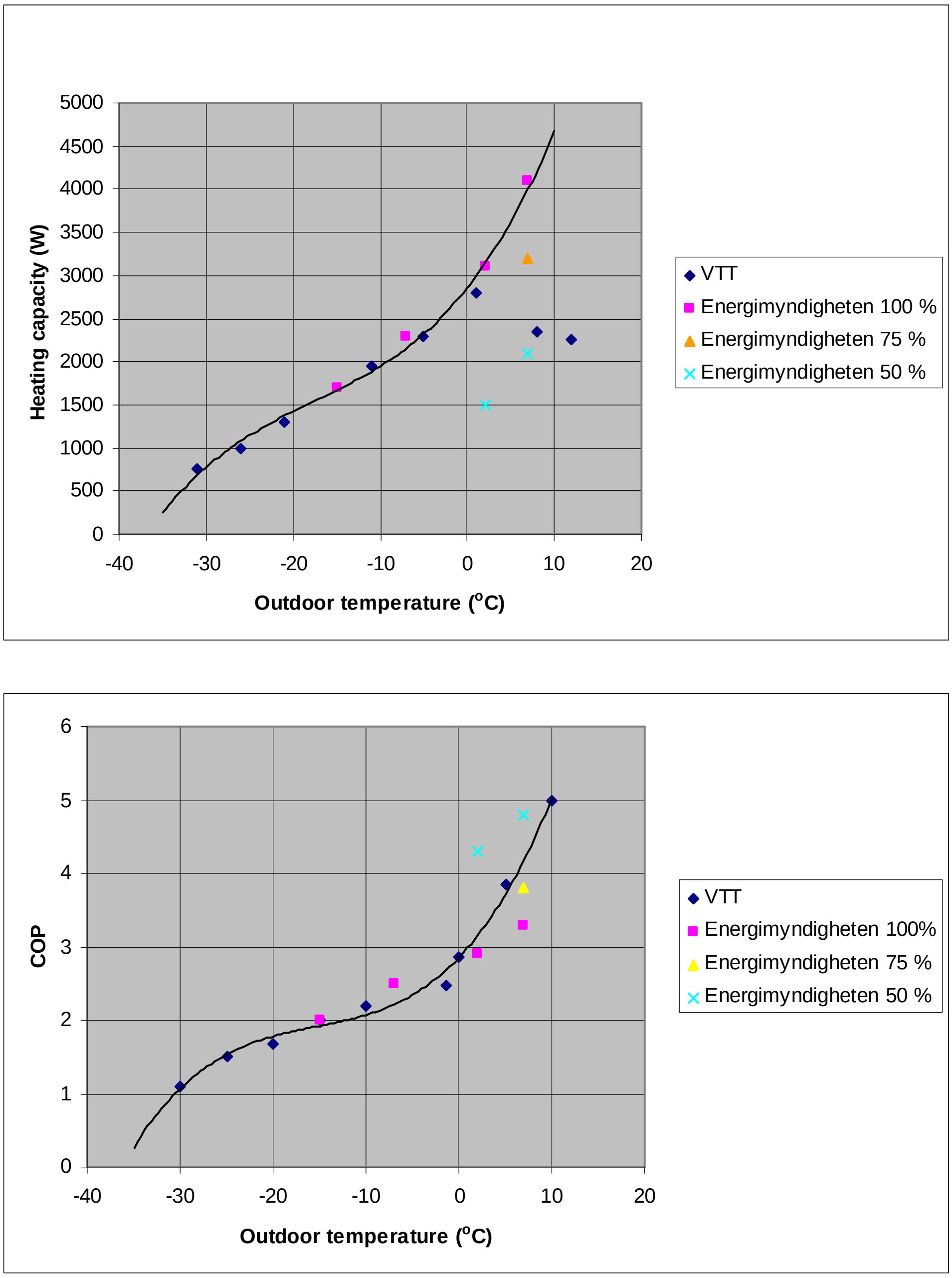


Figure 16. Product data (heat output and COP)and test results by VTT and Energimyndigheten of the modelled air/air heat pump.

4.2 Ground source heat pumps

4.2.1 Heat sources

The heat pump unit is linked to a brine loop, which serves as the evaporator in heating mode, in the ground. In many cases the unit covers the domestic hot water and heating demand of the building. Underfloor heating is the most popular combination in such systems.

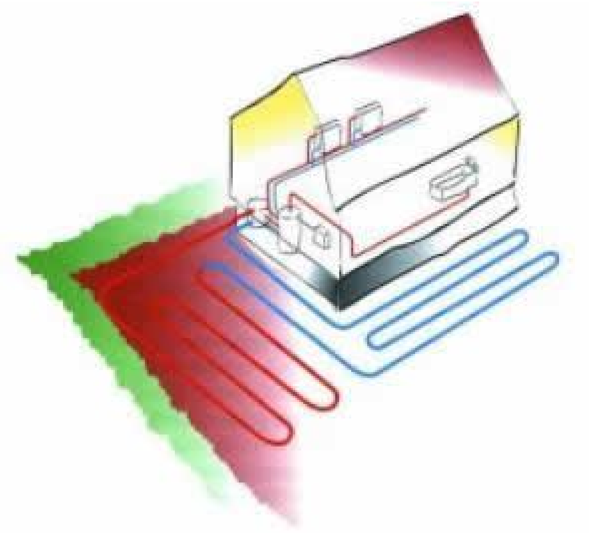


Figure 17. Ground coupled heat pump with horizontal pipe installation (SULPU)

Typical dimensioning values for horizontal ground piping loops are:

- installation depth of ground pipes 0.7 - 1.2 m
- piping distance 1.5 m (minimum 1.2 m)
- pipes are laid in trenches side by side
- pipe material is plastic PELM DN 32, DN40 or DN50
- SPF values are 2.5 … 3.5

Table 2. Receivable heat from ground for horizontal pipe installations.

Geographic area	Receivable heat from ground (kWh/m/year)	
	Clay	Sand
Southern Finland	50 – 60	30 – 40
Middle Finland	40 – 45	15 – 20
Northern Finland	30 – 35	0 – 10

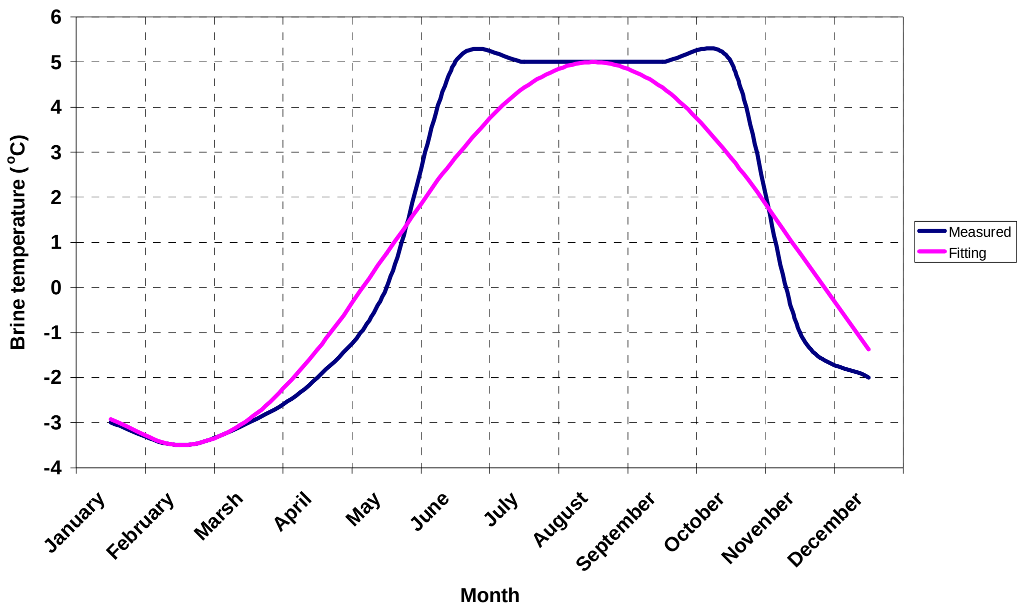


Figure 18. Measured inlet temperature on source side of the horizontal pipe installation (Aittomäki) and a curve fitting to that.

A vertical closed-loop arrangement is an appropriate choice where land area is limited, for example in residential suburban homes where land space is often restricted. The most common type of vertical borehole heat exchanger is single U-tube (i.e. one loop per bored hole) but also 3 and 4 pipe systems are used.

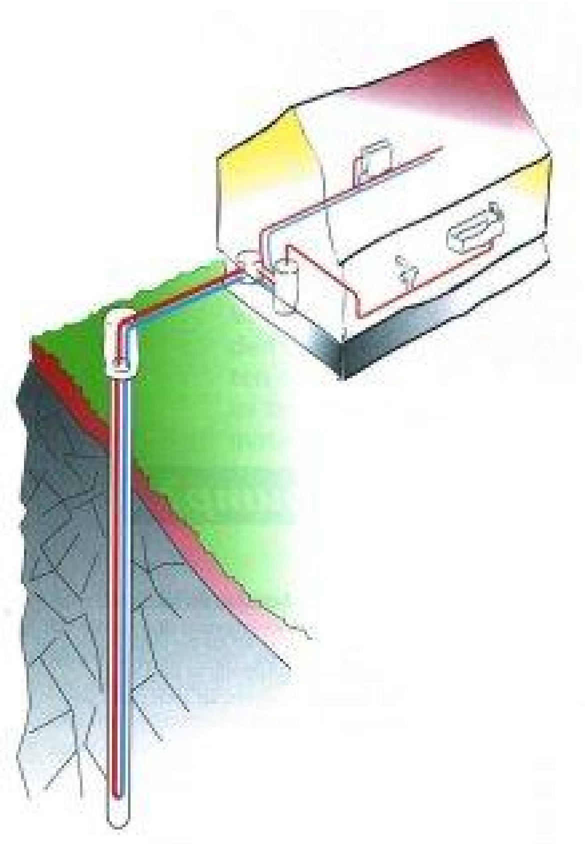


Figure 19. Ground coupled heat pump with bore hole installation (SULPU).

- diameter of the bore holes are generally 130 mm to 150 mm
- depth of the bore hole is 70 - 200 m (typically 150 m) depending on the soil conditions and size of the system.
- in big plants the distance between the holes is 10 – 20 meters
- pipe material is plastic PEM DN30 or DN40
- SPF values are 2.5 … 3.5

For an indirect system, the circulating fluid in ground loops is a water/antifreeze solution. Very common antifreeze solutions are alcohols and glycols and recently also potassium acetate.

4.2.2 Product data of ground source heat pumps

Ground source heat pump (GSHP) manufacturers report only characteristics based on standard operating conditions EN 14511:2007, Table 3. In practise, the manufacturer catalogues include two operating points: brine temperature 0ºC and water temperatures 35 ºC and 55 ºC. In this study the heat pump characteristics are interpolated to the respective source/sink temperatures based on the data given by manufacturers and they are presented in Table 4 and Figure 20.

Table 3. Brine-to-water heat pump rating conditions according to the EN 14511:2007 standard.

Condition	**Brine temperature ºC**	**Inlet/Outlet water temperature ºC**
Standard rating condition	0	40/45 (30/35 floor heating application)
Application rating conditions	5	-/45
	-5	-/45
	0	-/55

Table 4. Characteristics of the simulated ground source heat pumps.

Building	*Dimensioning*	*Heat distribution supply ºC*	*Heating capacity kW*	*Electricity power kW*	*Volume of the heat storage dm³*
1970	*100 %*	*35/50*	*16.7/15.3*	*3.57/4.64*	*520*
	50 %	*35/50*	*7.90/7.20*	*1.74/2.27*	*420*
2000	*100 %*	*35/50*	*9.90/9.00*	*2.12/2.76*	*420*
	50 %	*35/55*	*5.40/5.00*	*1.35/1.65*	*200*
Passive	*100 %*	*35/55*	*7.30/6.70*	*1.80/2.20*	*260*
	50 %	*35/55*	*3.25/3.00*	*0.81/1.00*	*150*

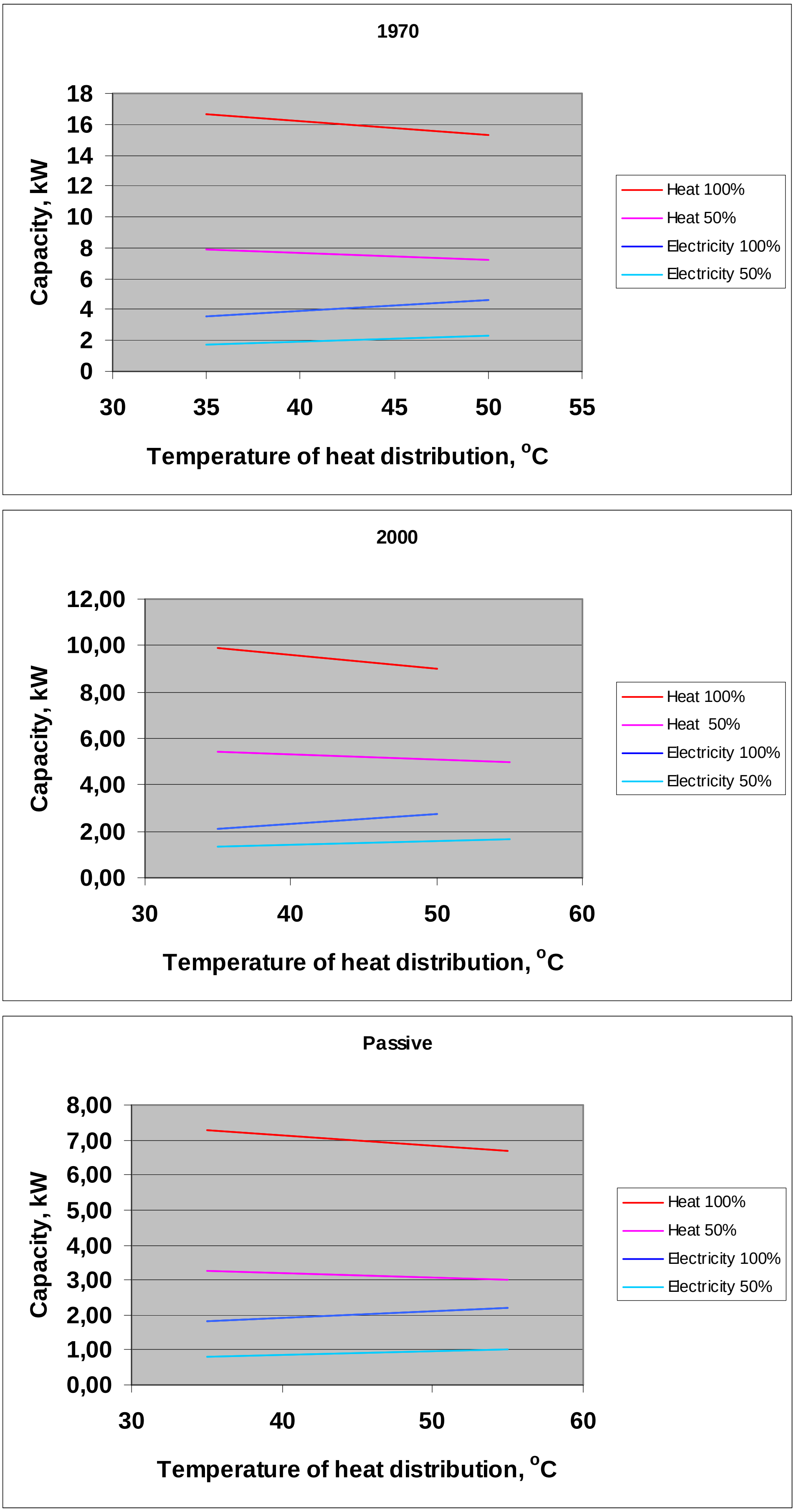


Figure 20. Product data (heat output and electricity power) of ground source heat pumps in three different house types.

5 Impacts of heat pump penetration in the residential sector

5.1 Research methodology

The impacts of large scale penetration of heat pumps on the electricity consumption and power demand are analysed separately for different building types: detached houses, semi-detached houses, apartment buildings, public buildings and recreational residences. The analysis includes scenarios until 2030 and they are based on the current building stock, current heating choices and foreseen changes both in building (volume, heating demand) and heating systems. There are several reasons to changes heating system when renovating the system. One very obvious reason is the demand for energy saving due to rising energy prices. Other reasons are, for example, energy politics that strive for environmentally sound systems, which is realized in tightening building regulations and incentives to systems that save energy and utilize renewable energy sources. Heat pump technology is one answer to all these demands and this has boost heat pump sales during the past few years into new dimensions. Finnish heat pump association (SULPU) has predicted that in the year 2020 there will be about 1 million heat pumps in Finland (Hirvonen) as the current figure is nearly 400 thousand of which over 80 % is air-air type heat pumps.

A big potential is seen in oil heated houses changing over to other energy sources, mainly to heat pumps, but also direct electric heaters are searching for ways to save energy and thus to lower the energy bill and in this the various heat pump solutions are quite attractive.

The total number of apartment building stock of Finland will increase due to the foreseen increase of population. Statistics Finland has estimated that the population will be 5.6 million in 2020 and 6.1 million year 2050. Population projection means that the need for new apartments is about 15 000 on a yearly basis.

Heating demand

Heating demand of the building stock will decrease because of the tightening building regulations. At the moment the regulations are related to new buildings but will in the future most likely cover also the renovations of old buildings. It is not only the regulations but also the raising energy bills and incentives to energy retrofits that motivate to invest in energy saving technology.

The scenario presented in this study assumes that the heating energy need of the new building will gradually decrease so that after the year 2020 the energy demand of a new building is at the most on the passive house level. Moreover, it has been expected that there will not be remarkable decrease in the heating energy demand of the existing building stock but the investments will focus on the heating system renovations which will decrease heating energy use (but not demand).

Scenarios

The effects of heat pump penetration on the heating electricity consumption and electric power demand are reviewed in 20 years perspective.

In BAU scenarios, the division of heating systems of the total building stocks will stay more or less at the present state in the period under review. Minor changes are expected because the heating choices of new building differ from that of the total stock.

In HP (heat pump) scenarios it has been assumed that heat pump penetration will increase substantially. Mainly ground source heat pumps will gradually replace oil and electric heating. The biggest change is expected in the oil heating sector. Air/air heat pumps as auxiliary heating will increase especially in electric heating sector and as the main heat source in basic heating of free-time residences

Methodology
In this study, we have analysed the most potential building types for heat pumps, mainly detached houses, attached houses, blocks of flats and free-time residences. Each building type has been treated separately.

Energy demand and heating power demand analysis consists of the following steps:

1) Number of buildings by energy source (oil, electricity, ground source heat pump, wood and district heat) is adjusted to match the data of Statistics Finland
2) Heating energy and heating power demand is adjusted to match the energy statistics
3) Penetration of heat pumps is adjusted to match the vision of SULPU of the growth of the heat pump markets
4) Expert predictions are made of the renovation choices for each heater type (oil, electricity, ground source heat pump, wood and district heat)
5) Construction of new building is adjusted to match common knowledge
6) Reduction of buildings is adjusted to match common knowledge
7) Number of renovations per year is based on expert estimation

5.2 Detached houses

5.2.1 Building stock

According to the Statistics Finland (2010) there were altogether 1 101 707 detached houses in Finland at the end of year 2010. The distribution of detached houses according to building year is shown in Figure 21. A third of the houses were built between 1940 and 1969. It has been predicted in many scenarios that the number of the houses will rise slowly. In this study it has been assumed that the number of houses will be about 1 285 000 in year 2030 which means over 180 000 more houses during the 20 years time perspective.

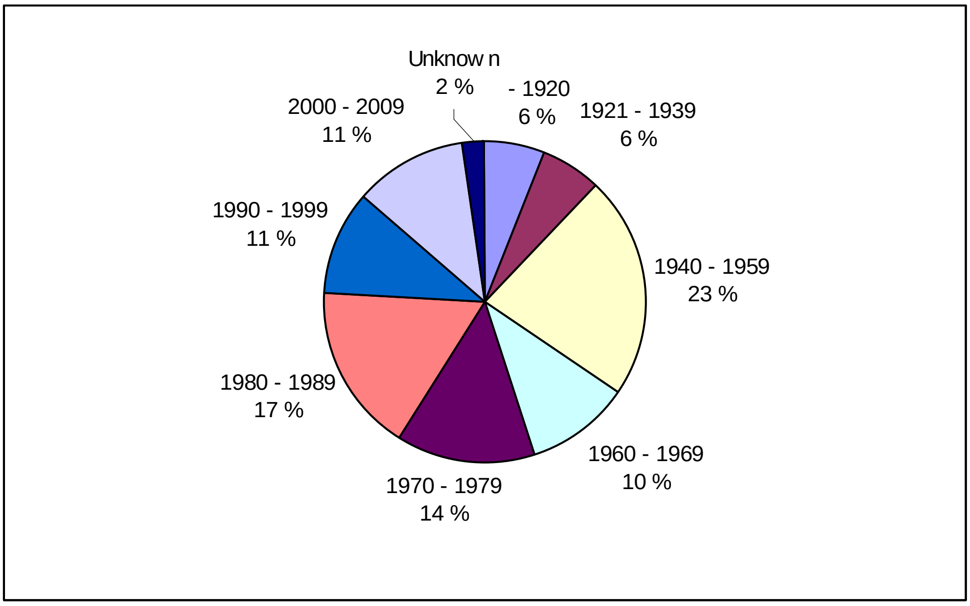


Figure 21. The distribution of detached houses according to construction year.

Reduction of old buildings is assumed to be 0.4-0.6 % per year and the rate of new building 14 000 per year.

5.2.2 Heating demand

The estimated heating demand 2010 to 2030 is presented in Figure 22.

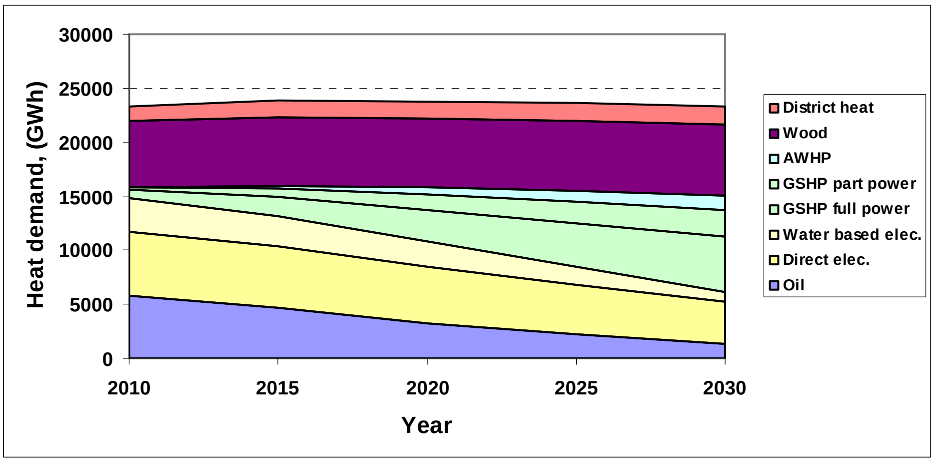


Figure 22. Heating demand scenario of the detached house building stock. AWHP = Air/water heat pump, GSHP = Ground source heat pump.

5.2.3 Heating systems

The most common main heating systems used in detached houses are electric, wood, oil, district heat and ground source heat pumps, Figure 23. Moreover there are numerous auxiliary heating systems in use like fire places (about 550 thousand) and air-air heat pumps (over 300 thousand).

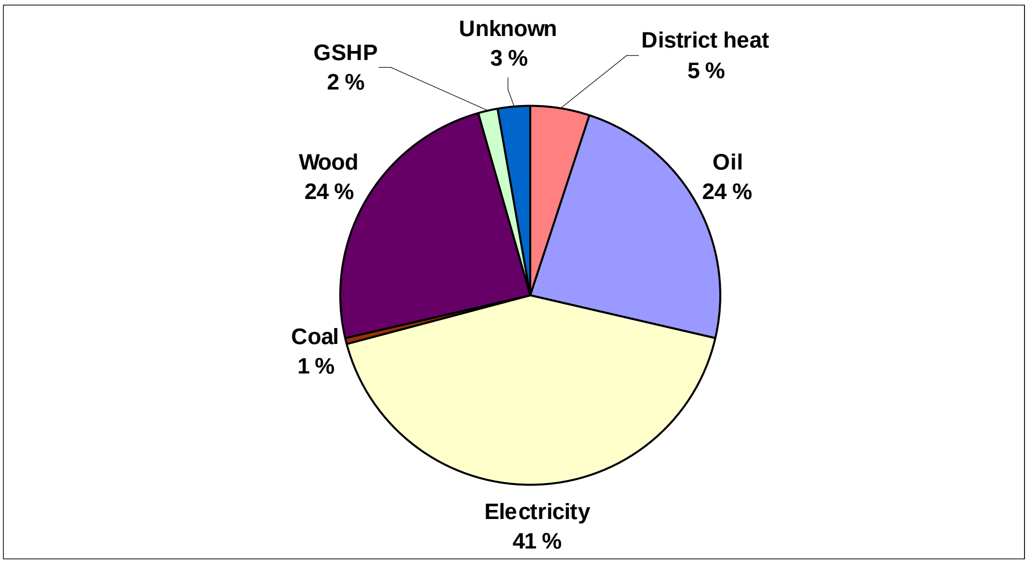


Figure 23. Main heating systems of detached houses at the end of year 2009 according to the Finnish Statistics. GSHP = Ground source heat pump.

In the future the proportions of different heating systems will change and it has been envisioned that oil heating will decrease drastically and that direct electrical heaters will change to heat pumps. The heating system choices of new buildings are open to any system and at the moment heat pump solutions, especially ground source heat pumps, are dominating the new building markets. In the renovation cases there can be seen some limitations to the heating system choices i.e. in those buildings which have no water based heat distribution system it is much harder (= much more expensive) to change the whole heating “infrastructure” thus for example electric radiator heaters will rather choose air-air heat pump than ground source heat pump.

The heat pump markets is dominated under the reference period by the renovation cases and it has been estimated that there will be about 15 – 25 thousand heating system retrofits yearly.

The scenario presented in Figure 24 is based on expert estimates of the heating system choices taking into account the different limitations of the suitability of a specific heating solution to a certain case. Figure 25 shows the predicted heating system distribution in the year 2030.

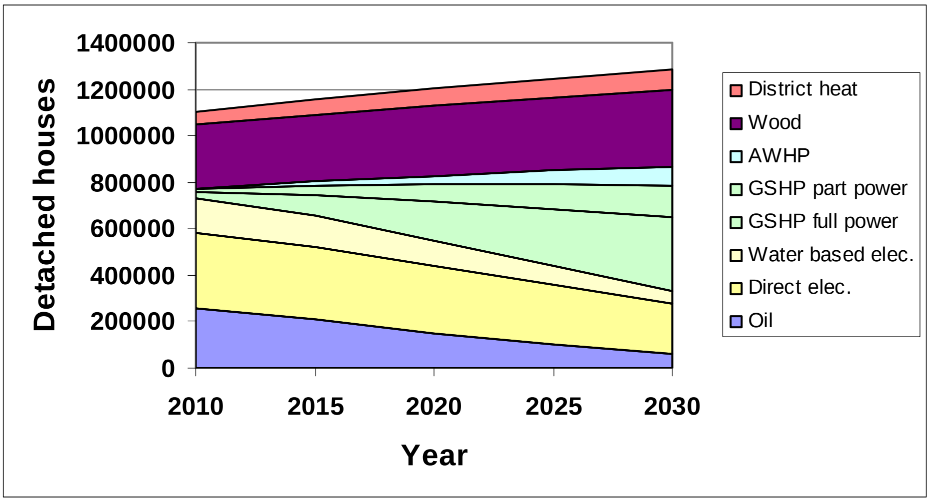


Figure 24. Building stock and heating system scenario.

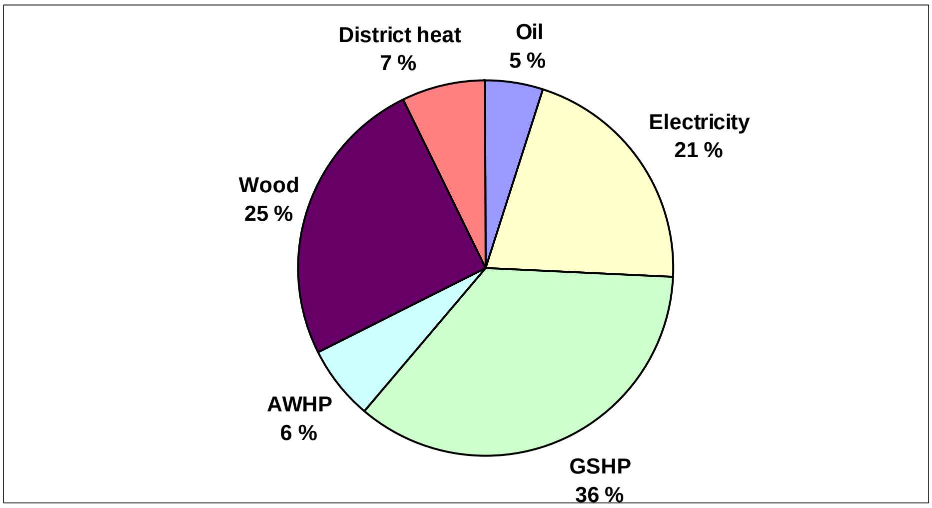


Figure 25. Predicted main heating system pie with heat pump scenario in year 2030. GSHP = Ground source heat pump, AWHP = Air-water heat pump.

5.2.4 Number of heat pumps

Penetration of heat pumps in the scenarios presented in this study is partly based on the real potential of heat pumps in the building stock and partly on the vision of the Finnish heat pump association.

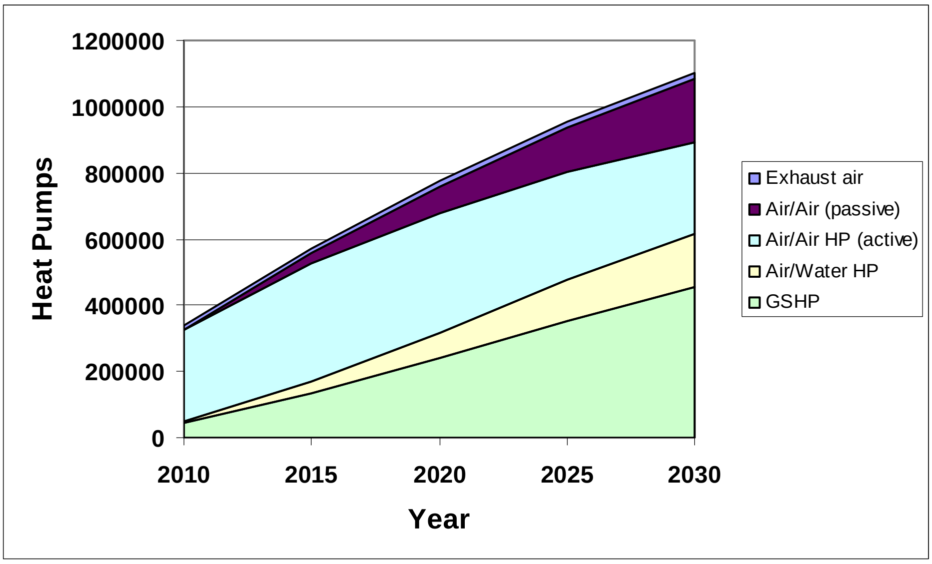


Figure 26. Predicted scenario of the evolution of the the number of heat heat pumps.

The active and passive air-air heat pumps presented in Figure 26 are based on the assumption that air-air heat pumps that have been purchased, for example, to an oil heated house will not be used for heating after the heating system is changed to, for example, a ground source heat pump.

5.2.5 Heating energy consumption

The heating energy consumption presented in Figure 27 is based on the predicted building stock and both space and domestic hot water demands of detached houses as well as assumed heating system choices and the efficiency of each system. The consumption figures include also assumed penetration forecasts of different auxiliary heating systems, i.e. fire places, solar system, air-air heat pumps and exhaust air heat pumps.

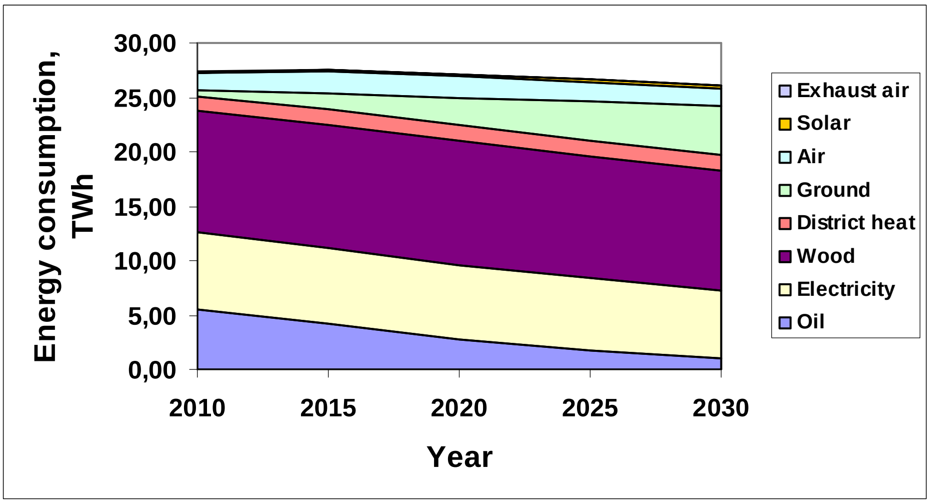


Figure 27. Heating energy consumption (space heating + DHW) scenario of detached houses; division of consumption is made by energy source.

Electricity consumption scenario is visualized separately in Figure 28 to get a better understanding of the predicted electricity consumption over the years. Heating electricity consumption is assumed to decrease despite the fact that the number of electrically heated houses (direct electricity + heat pumps) will increase from 2010 to 2030, which is clear when comparing heating system distributions presented in Figures 23 and 25. This is the case when oil heated houses are changed to ground source heat pumps and utilize increasingly auxiliary air-air heat pumps which will increase electricity use. At the same time, direct electric heaters will change to ground source and air-water heat pumps as well as utilize increasingly air-air heat pumps in space heating and air-water heat pumps in domestic hot water production.

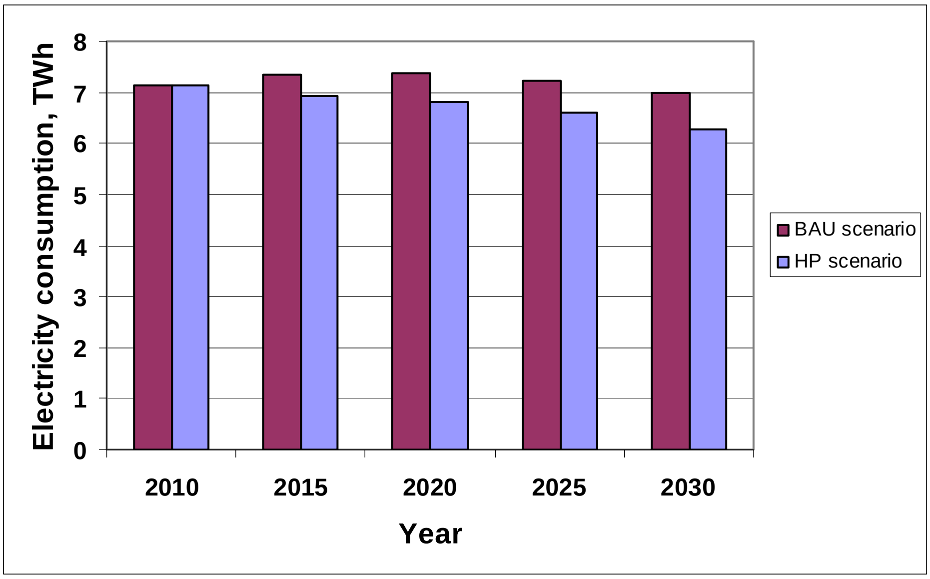


Figure 28. Heating electricity (space heating + DHW) scenarios for detached houses.

5.2.6 Heating power demand

Heating power demand of space heating is about 10 kW in average old buildings and less than 5 kW in the new building. Heating power demand of domestic hot water is about 50 kW in average building if there is no storage capacity like with district heating. The lowest possible heating power demand of hot water is about 3 kW in the case of off-peak storage.

Electricity heating power demand of detached houses is estimated to increase slightly compared to the BAU scenario, Figure 29.

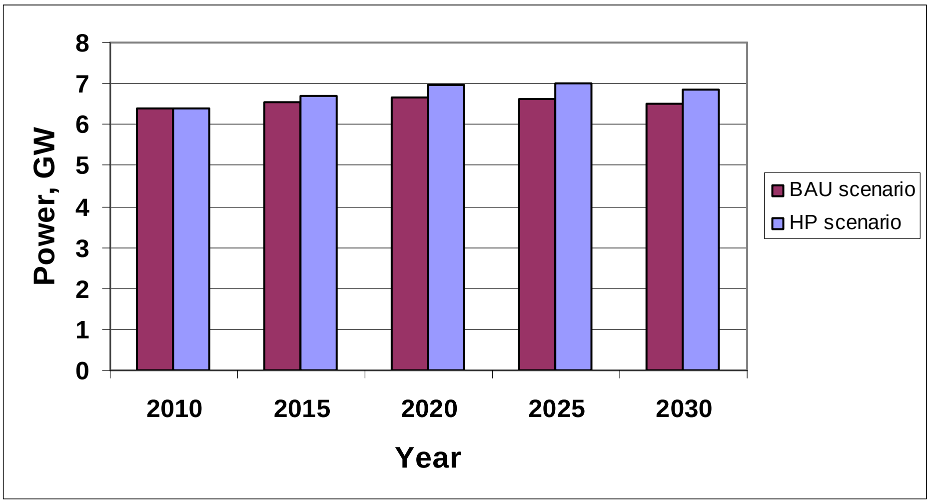


Figure 29. Predicted vision of heating electricity power demand of detached houses.

5.3 Attached houses

5.3.1 Building stock

The total number of buildings was 76 241 at the end of year 2010 with 383 thousand apartments. The number of buildings is expected to increase so that there will be nearly 80 thousand buildings in 2030.

Reduction of old buildings is assumed to be 0.3-0.5 % per year and the rate of new building is expected to equal 500 per year. Heating system renovations is predicted to be at the level of over 1 600 buildings per year. Average building size of attached houses according the Statistics Finland in 2009 was 425 m^2:

5.3.2 Heating systems

Most common heating systems of attached houses are district heating (43 %), electricity (32 %), oil (23 %) and wood (1 %).The number of installed ground source heat pumps was 115 at the end of year 2009 according to the Statistics Finland.

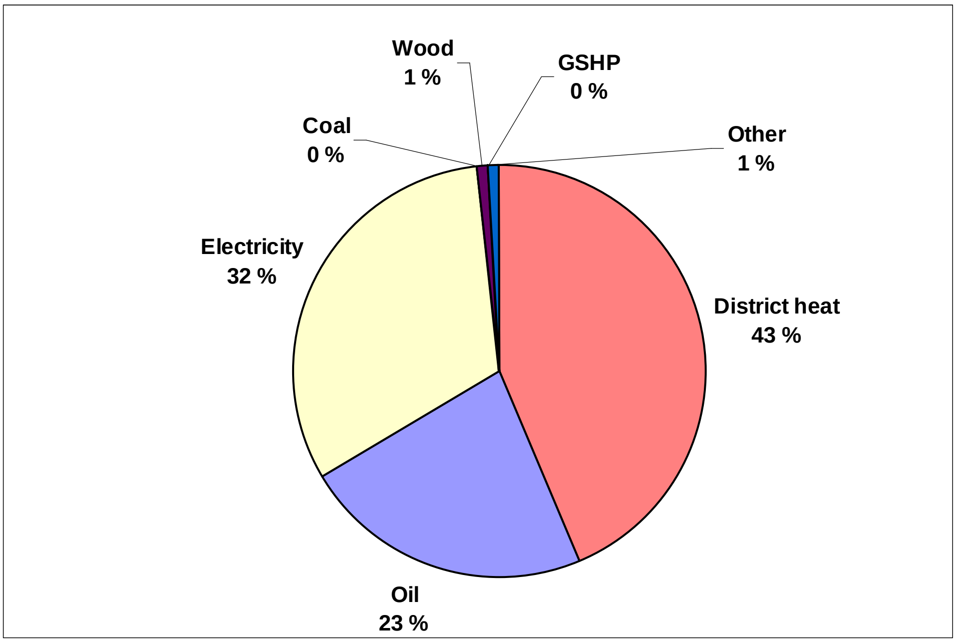


Figure 30. Main heating systems of attached houses at the end of year 2009 according to the Statistics Finland. GSHP = Ground source heat pump.

The penetration of heat pumps will change the heating system percentages. The following scenario presented in Figure 31 is based on expert estimates of the heating system choices taking into account the different limitations of the suitability of a specific heating solution to a certain case. It has been assumed that especially oil heated buildings will gradually change to ground source heat pumps whereas district heated buildings will stay in the same system. In the new buildings sector, the market is expected to be dominated by GSHP as the market leader with a 53 % and district heat with a 45 % market share.

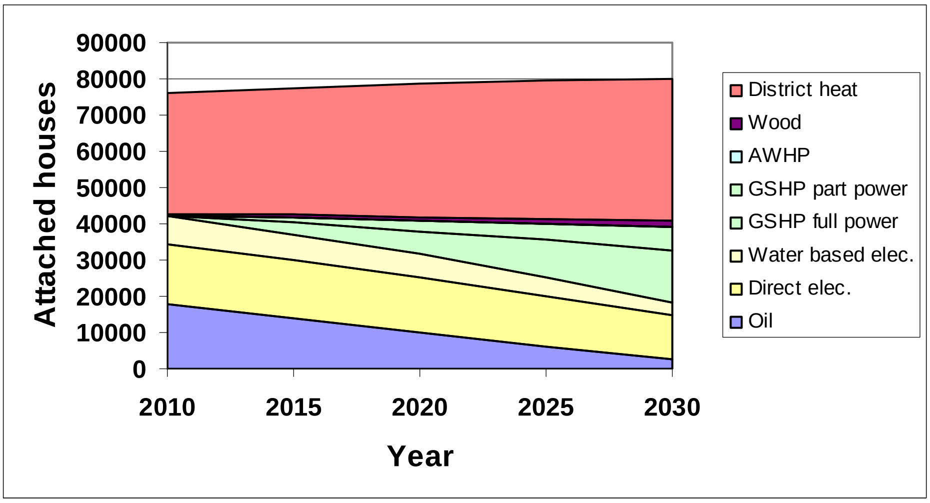


Figure 31. Building stock and heating system with heat pump scenario, attached houses.

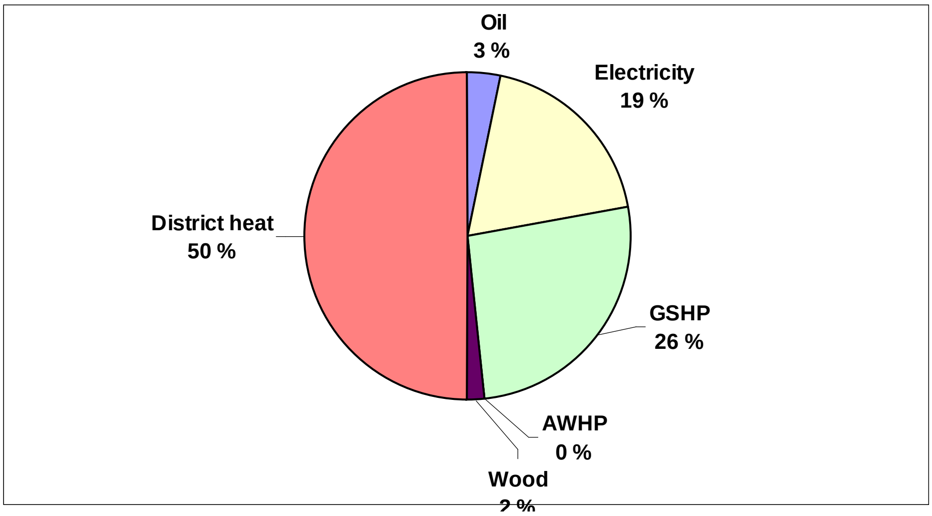


Figure 32. Predicted main heating system distribution with heat pump scenario in the year 2030, attached houses. GSHP = Ground source heat pump, AWHP = Air-water heat pump.

5.3.3 Number of heat pumps

Penetration of heat pumps in the scenarios presented in this study is partly based on the real potential of heat pumps in the building stock and partly on the vision of the finish heat pump association.

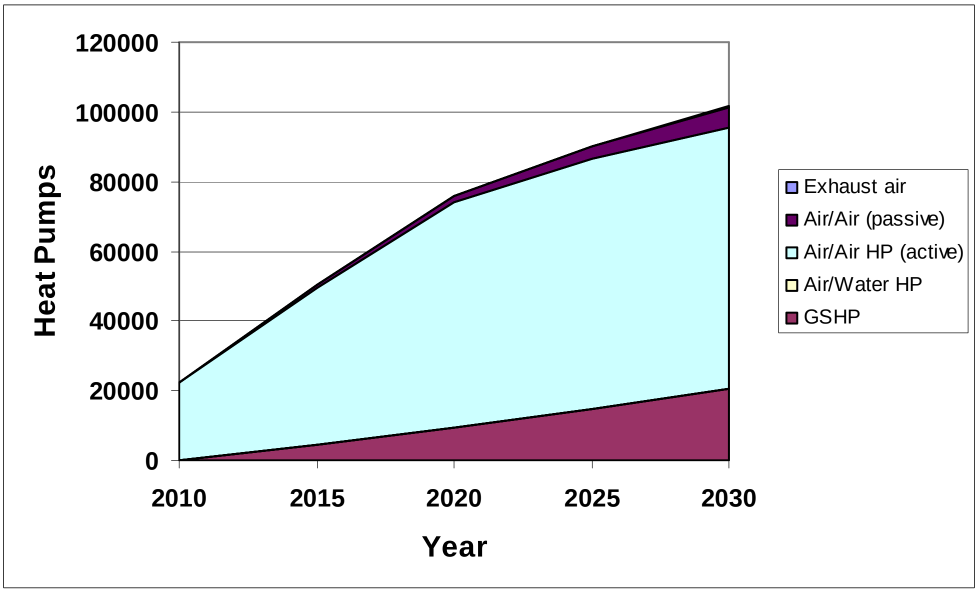


Figure 33. Predicted scenario of the evolution of the number of heat pumps, attached houses.

The active and passive air-air heat pumps presented in Figure 33 are based on assumption that air-air heat pumps that has been purchased for example to an oil heated house will not be used for heating after the heating system change to for example ground source heat pump.

5.3.4 Heating energy consumption

The heating energy consumption presented in Figure 34 is based on the predicted building stock and both space and domestic hot water demands of attached houses as well as assumed heating system choices and the efficiency of each system. The consumption Figures include also assumed penetration forecasts of different auxiliary heating systems, i.e. fire places, solar system, air-air heat pumps and exhaust air heat pumps.

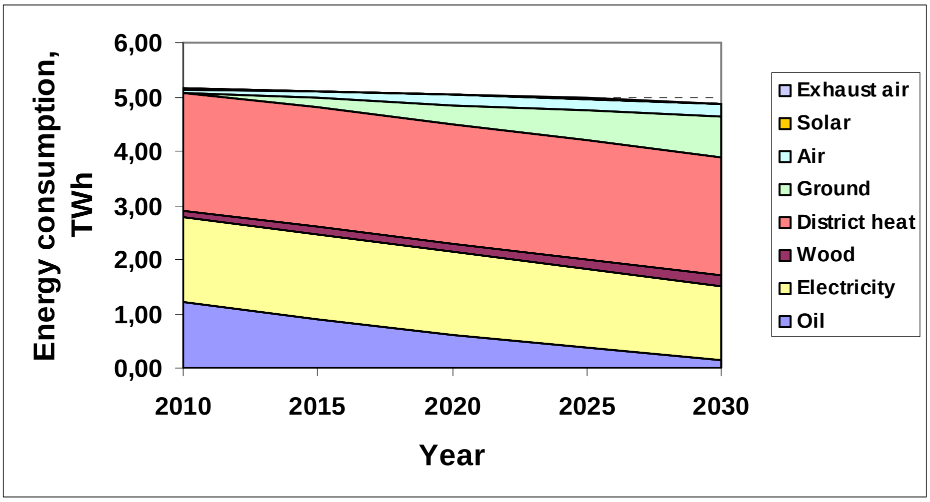


Figure 34. Heating energy consumption (space heating + DHW) scenario of attached houses; division of consumption is made by energy source.

Electricity consumption scenario is visualized separately in Figure 35 to get a better understanding of the predicted electricity consumption over the years.

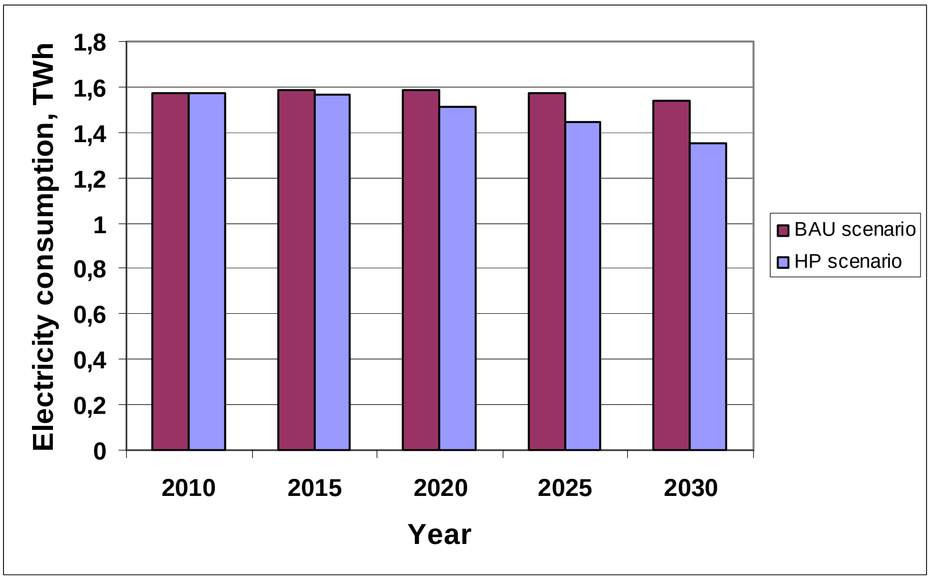


Figure 35. Heating electricity (space heating + DHW) scenarios of attached houses.

5.3.5 Heating power demand

Heating power demand of space heating is about 25 kW in average old buildings and 11 kW in the new building. Heating power demand of domestic hot water is about 64 kW in average building if there is no storage capacity like with district heating. The lowest possible heating power demand of hot water is about 12 kW in the case of continuous heating capacity and suitable storage capacity.

Electricity heating power demand of attached houses is assumed to increase over the 20 years time span, Figure 36.

The effect of heat pump penetration on the electricity power demand of heating (space + domestic hot water) is calculated as the sum of all electricity heated attached houses assuming that the power demand of one building is 37 kW and in heat pump heated houses (full load) the power demand is 12.3 kW.

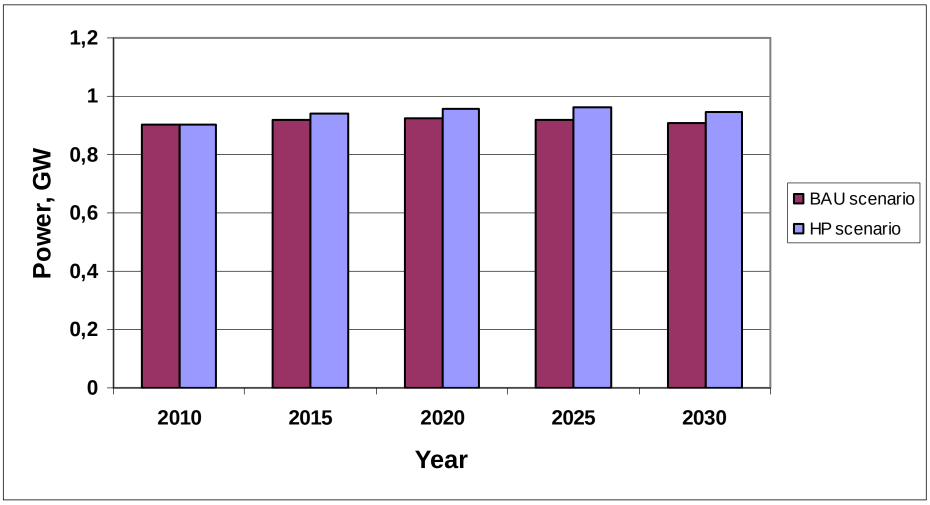


Figure 36. Predicted heating electricity power demand of attached houses with BAU and heat pump scenarios.

5.4 Blocks of flats

5.4.1 Building stock

At the end of year 2009 the number of buildings totalled 56 228 and 1.22 million apartments. The number of buildings is expected to increase so that there will be over 67 thousand buildings in 2030.

Reduction of old buildings is assumed to be 0.3-0.5 % per year and the rate of new buildings is expected to equal 800 per year. Heating system renovations is predicted to be at the level of over 1 100 buildings per year.

Building sizes of block of flats according the Statistics Finland are by heating system:

- District heating 1 800 m^2

- Oil heating 1 000 m^2
- Electric heating 600 m^2
- Wood 350 m^2

5.4.2 Heating systems

The statistics show (see Figure 37) that most popular heating system for block of flats is district heating (76 %), the other systems are oil heating (17 %), electric heating (4 %) and wood heating (2 %). Ground source heat pumps were only in 22 buildings.

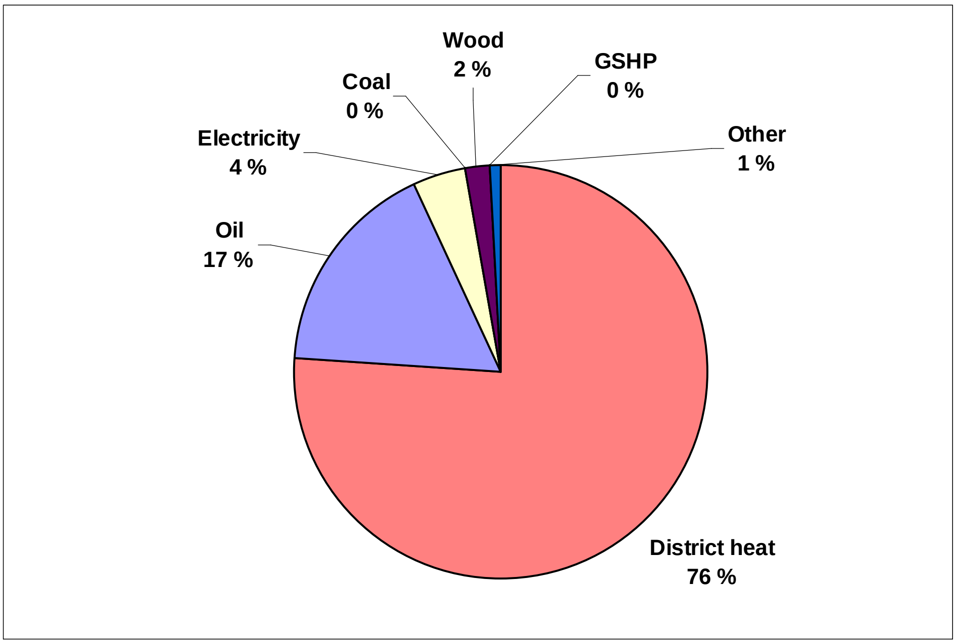


Figure 37. Main energy sources of blocks of flats at the end of year 2009 according to the Statistics Finland. Presented percentages are based on heated floor area . GSHP = Ground source heat pump.

The penetration of heat pumps will change the heating system percentages. The following scenario presented in Figure 38 is based on expert estimates of the heating system choices taking into account the different limitations of the suitability of a specific heating solution to a certain case. It has been assumed that especially oil heated buildings will gradually change to ground source heat pumps whereas district heated buildings will stay in the same system. In the new buildings sector, district heat will dominate, but the percentage of GSHP will increase up to 12 % of the markets, Figure 39.

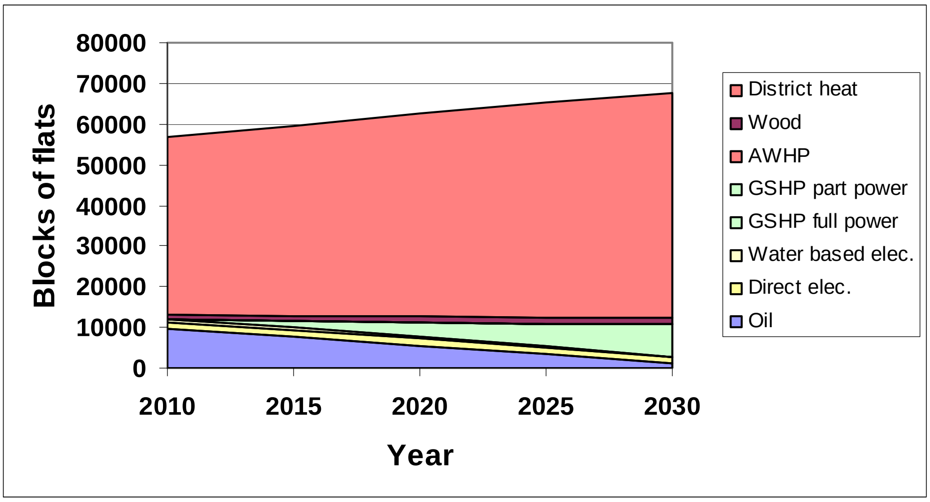


Figure 38. Building stock and heating system with heat pump scenario.

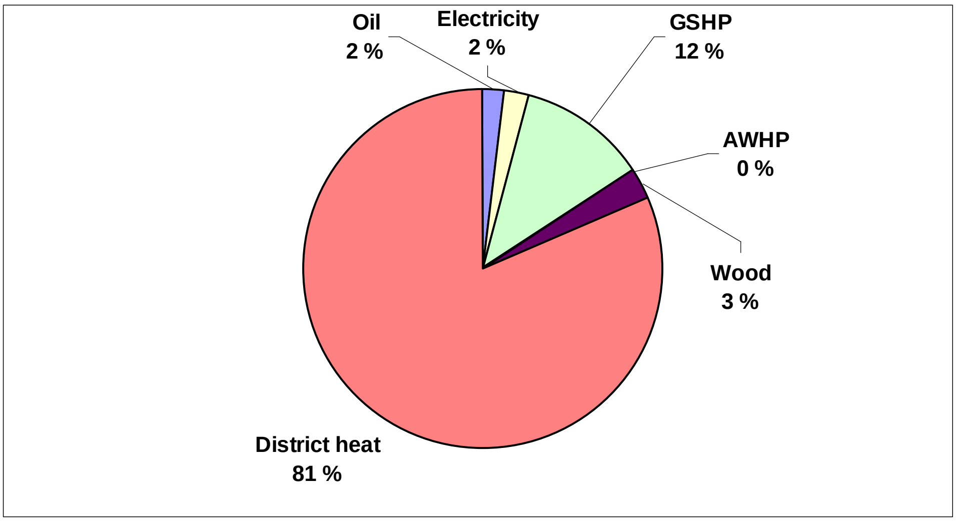


Figure 39. Predicted main heating system distribution with heat pump scenario in year 2030. GSHP = Ground source heat pump, AWHP = Air-water heat pump.

5.4.3 Number of heat pumps

According to the statistics of the Building Information Foundation RTS there were 15 thousand air/air heat pumps in block of flats at the end of 2010. The number of installed ground source heat pump was 22 units according to the Statistics of Finland.

The growth potential of ground source heat pumps is seen to be in the oil (9500 buildings) and electric heated buildings (2 300 buildings). These buildings form about 12 % of the building stock of the block of flats. The number of air/air heat pumps will increase in the future because of the increasing standards of comfort: people want their apartments to be cooled during the summer. The question is how much air/air heat pumps are used for heating because people don’t save any money by using them. Air/water heat pumps are not expected to be installed noteworthy to block of flats. Exhaust air heat pumps may play some role in the energy saving of ventilation in the future when the building regulations will cover also old building stock.

Penetration of heat pumps in the scenario presented in Figure 40 is partly based on the real potential of heat pumps in the building stock and partly on the vision of the Finnish heat pump association and on expert estimates.

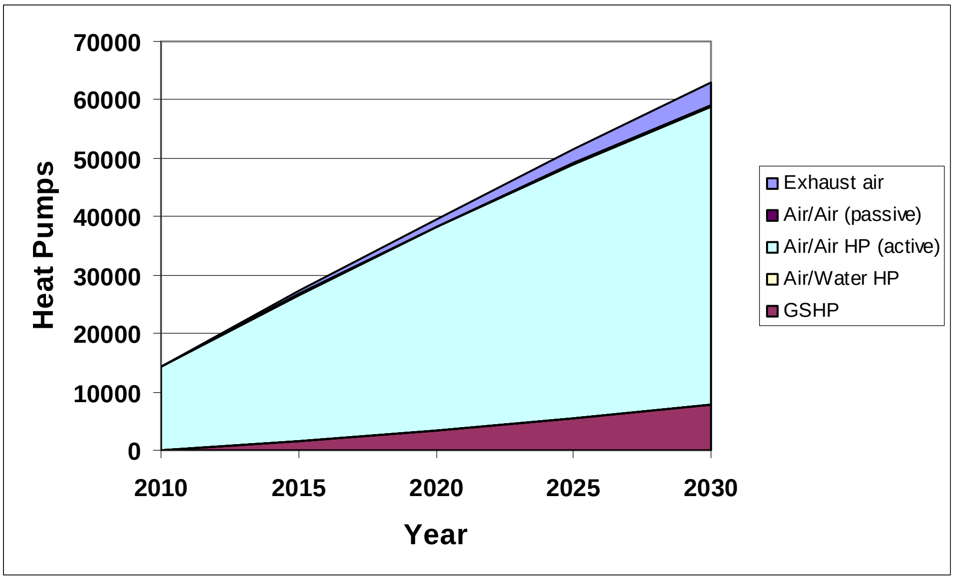


Figure 40. Predicted scenario of the evolution of the number of heat pumps in block of flats.

The active and passive air-air heat pumps presented in Figure 40 are based on assumption that air-air heat pumps that has been purchased for example to an oil heated house will not be used for heating after the heating system change to for example ground source heat pump. In the case of block of flats the role of passive air/air heat pumps is not notable.

5.4.4 Heating energy consumption

The heating energy consumption presented in Figure 41 is based on the predicted building stock and both space heating and domestic hot water demands of block of flats as well as assumed heating system choices and the efficiency of each system. The consumption figures include also assumed penetration forecasts of different auxiliary heating systems, i.e. fire places, solar system, air-air heat pumps and exhaust air heat pumps.

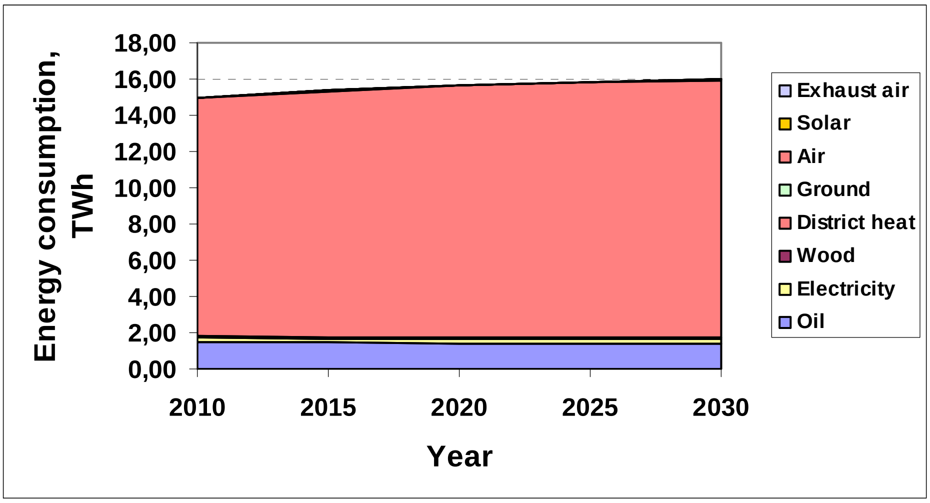


Figure 41. Heating energy consumption (space heating + DHW) scenario by energy source of blocks of flats.

Electricity consumption scenario is visualized separately in Figure 42 to get a better understanding of the predicted electricity consumption over the years.

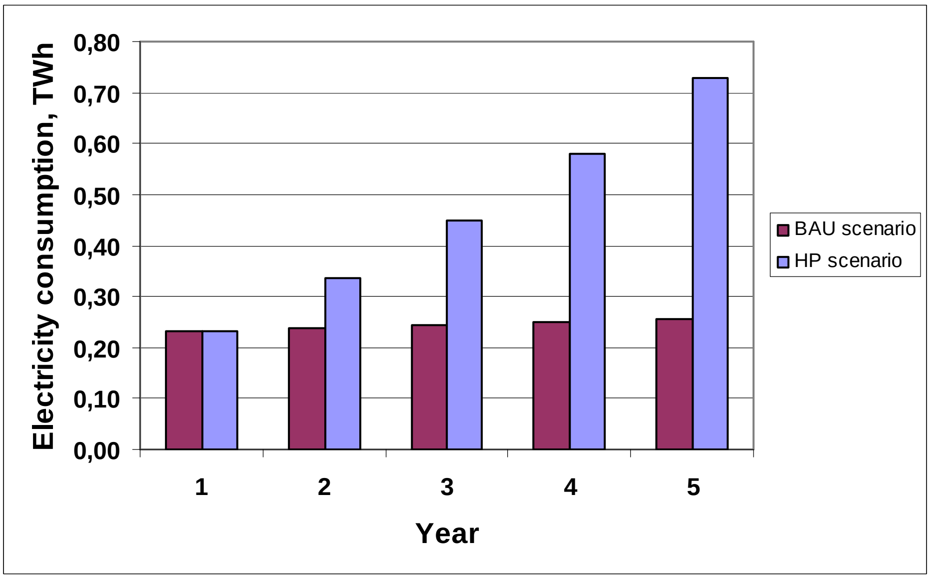


Figure 42. Heating electricity (space heating + DHW) scenarios for block of flats.

5.4.5 Heating power demand

Heating power demand of space heating is about 100 kW in average old buildings and less than 50 kW in new buildings. Heating power demand of domestic hot water is about 200 kW in an average building, if there is no storage capacity like with district heating. The lowest possible heating power demand of hot water is about 25 – 30 kW in the case of continuous heating capacity and suitable storage capacity.

It is predicted that the increased use of heat pumps will increase the heating electricity power demand of block of flats remarkably, see Figure 43.

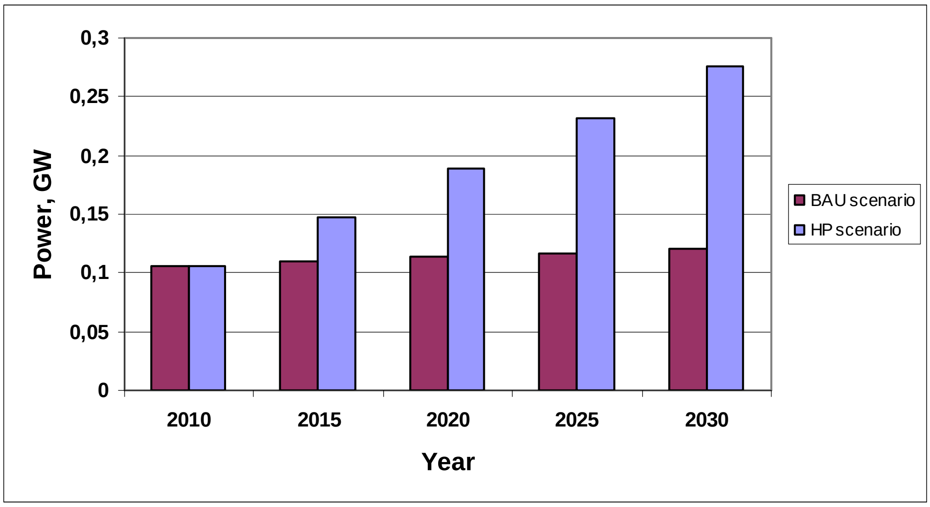


Figure 43. Predicted vision of heating electricity power demand of block of flats.

5.5 Free-time Residences

5.5.1 Building stock

According to the Statistics Finland, there were altogether 489 200 free-time residencies in Finland at the end of 2010. It has been predicted that the number of the residences will rise slowly (Perrels). In this study it has been assumed that the number of houses will follow the present growth trend of about 4300 new buildings per year. This means that there will be about 580 000 free-time residences in year 2030 which means roughly 90 000 more houses during the next 20 years, Figure 44.

Reduction of old buildings is assumed to be 0.45 % per year, i.e. about 2 500 houses per year, and the rate of new buildings 7 000 per year. The estimated number of heating system renovations per year is 9 000.

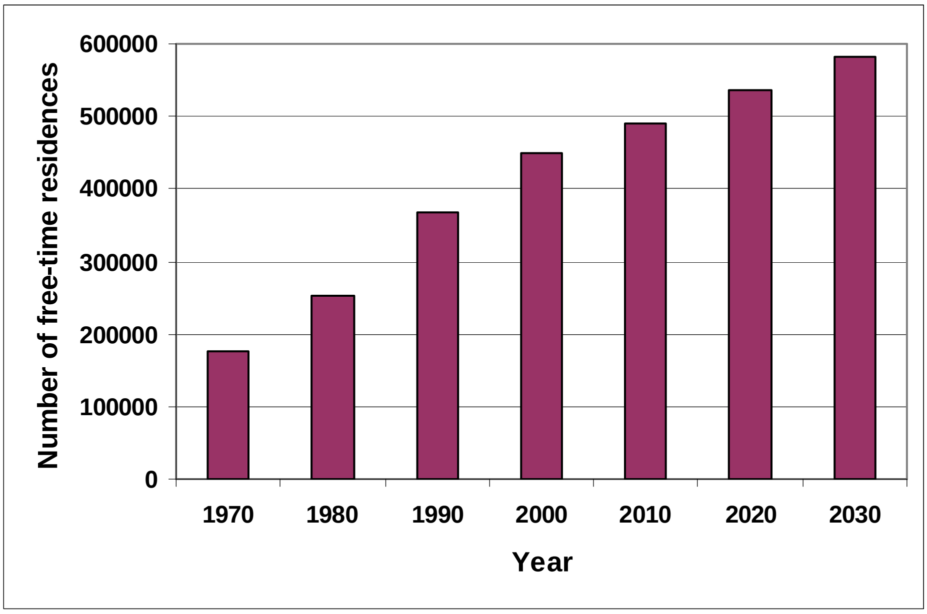


Figure 44. Number of free-time residences (Statistics Finland until 2010, estimation by author (Laitinen))

5.5.2 Heating demand

In this study, it has been estimated that the specific heating demand of the free-time residences will decreas,e but very slowly. The decrease is because of the tightening building regulations, but still a significant number of residences is not built for winter time use (Perrels), which means that the heat insulation is very poor. Heating demand of free-time residences is not only dependent on the heat insulation level but largely also on the indoor temperature that is maintained during the winter time. In many cases the indoor air temperature is kept at +5…+10 ºC with so called basic heating. The house is heated to avoid moisture and freezing problems but basic heating will also help in saving energy and it will also speed up heating the house to normal indoor temperature level +21 ºC during the short visits to the cottage during weekends and holidays. A new concept has been presented to avoid moisture problems and to save energy: constant heat power (Rytkönen). With low (about 500 W) and constant heat power the indoor temperature is kept somewhat higher than the outdoor temperature. Indoor air temperature will go under 0 ºC, which means that in those cottages there is water in the piping systems this must be taken into account.

But more important for the building stock energy need of free-time residences is the rising number of heated ones. Approximately 76 percent of all cottages were connected to the power grid in 2006 and only about 35 % were heated (basic heating) (Rytkönen). According to the present trend, the share of heated buildings will rise to 44 % in the year 2025 (Perrels).

A very rough estimation of the electricity use of electrified summer cottage without winter time heating is 1 500 kWh per year of which heating covers about 80 %. If the cottage is heated during the winter time the estimated electricity use is 8 000 kWh per year of which over 95 % is heating (Perrels). These figures have also been used as basis of this study.

In this study, it has been estimated that about 20 % of the building stock uses basic heating at the moment and that this figure will rise up to over 40 % by 2030.

5.5.3 Heating systems

Heating is not very well known but the most common main heating systems used are electric and wood (fire place). According to a survey among the free-time residence customers of Suur-Savon Energia the most common heating systems were wood (fire place) and electricity, Figure 45. These results are based on the answers of 1 800 customers.

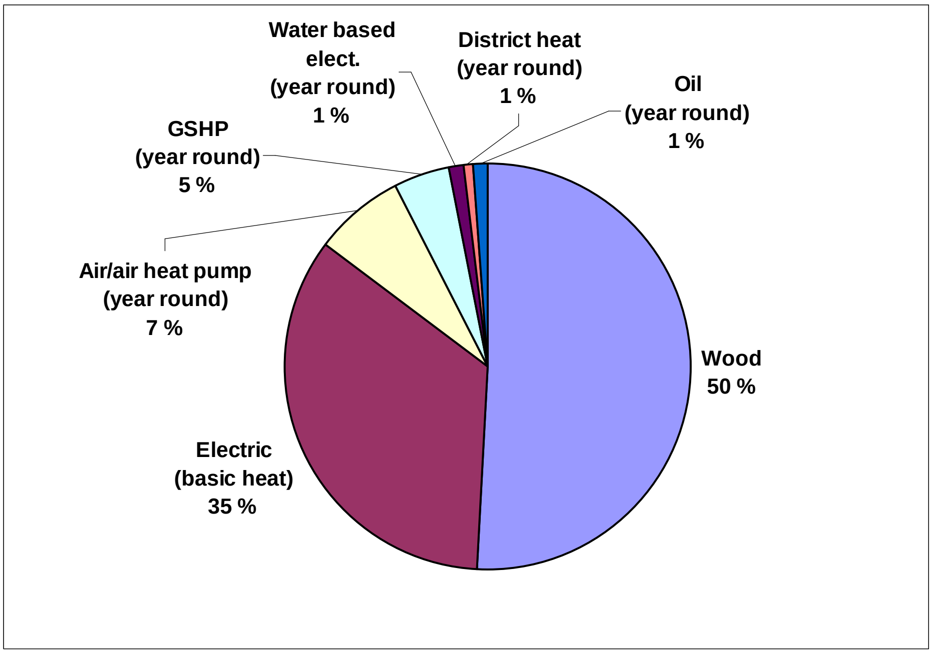


Figure 45. Heating system survey by Suur-Savon Energia (Rytkönen). GSHP = Ground source heat pump.

The scenario presented in Figure 46 is based on expert estimates of the heating system choices taking into account the different limitations of the suitability of a specific heating solution to a certain case.

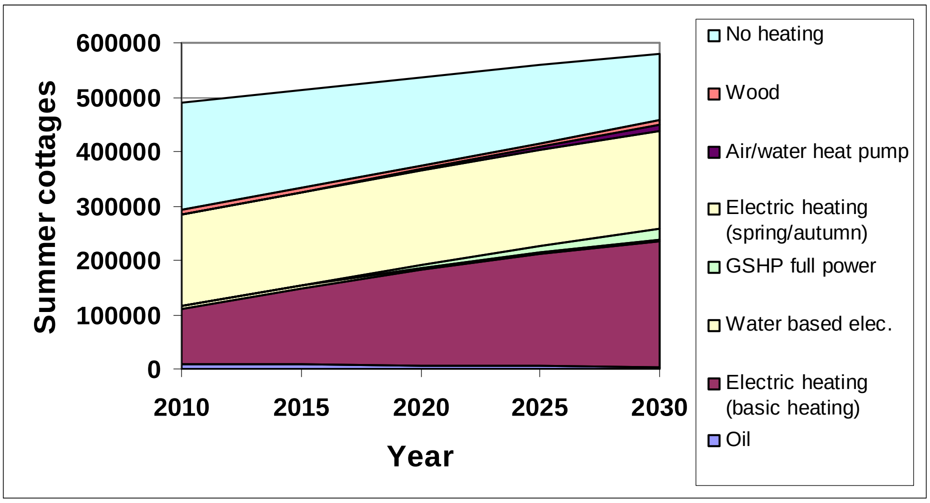


Figure 46. Building stock of free-time residences and heating system scenario.

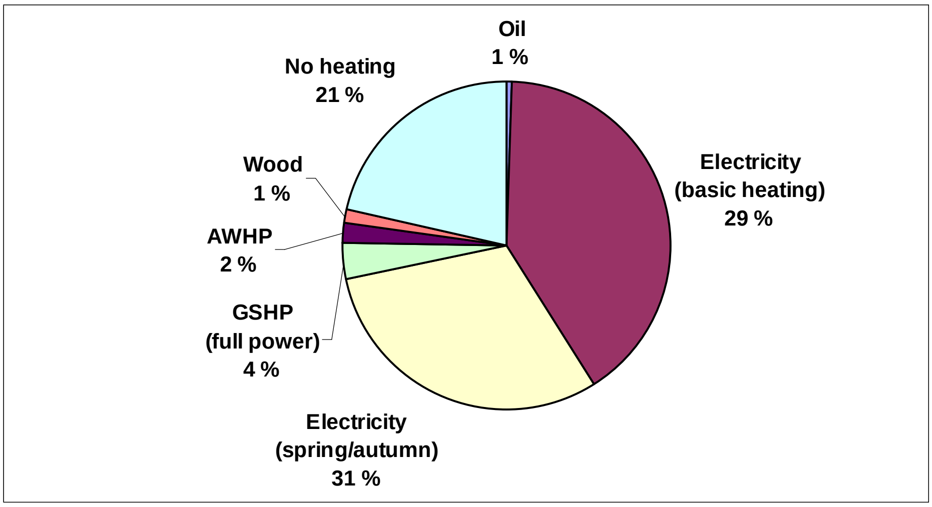


Figure 47. Predicted main heating system distribution scenario of free-time residences in the year 2030. GSHP = Ground source heat pump, AWHP = Air-water heat pump.

5.5.4 Number of heat pumps

Penetration of heat pumps in the scenarios presented in this study is partly based on the real potential of heat pumps in the building stock and partly on the vision of the finish heat pump association.

The biggest growth potential of heat pumps in the summer cottage sector is for air/air heat pumps. Ground source and air/water heat pumps are more suitable for year round use (investment/energy saving) so it is expected that the growth is moderate.

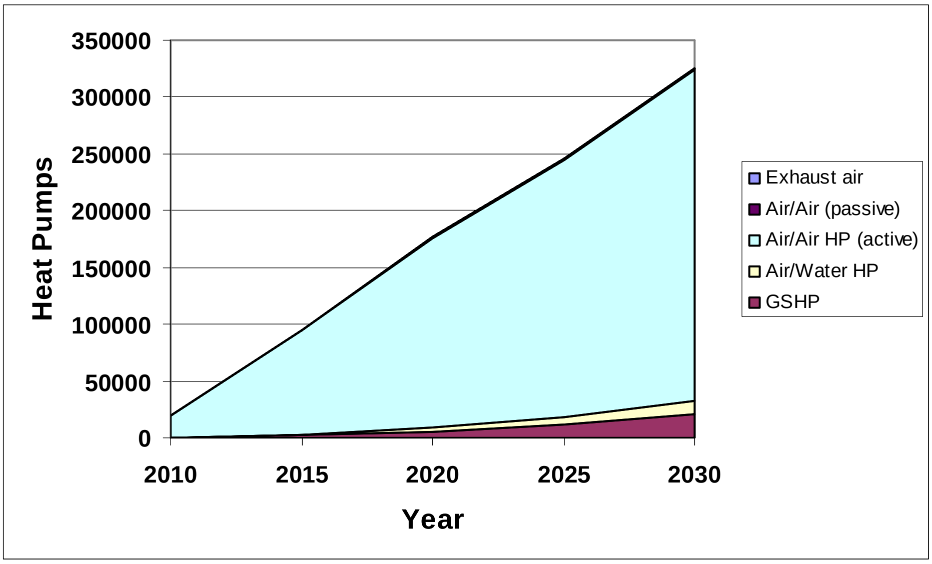


Figure 48. Predicted scenario of the evolution of the number of heat pumps in free-time residences.

The active and passive air-air heat pumps presented in Figure 48 are based on assumption that air-air heat pumps that has been purchased for example to an oil heated house will not be used for heating after the heating system change to for example ground source heat pump.

5.5.5 Heating energy consumption

The heating energy consumption presented in Figure 49 is based on the predicted building stock and both space and domestic hot water demands of free-time residences as well as assumed heating system choices and the efficiency of each system. The consumption figures include also assumed penetration forecasts of different auxiliary heating systems, i.e. fire places, solar system, air-air heat pumps and exhaust air heat pumps.

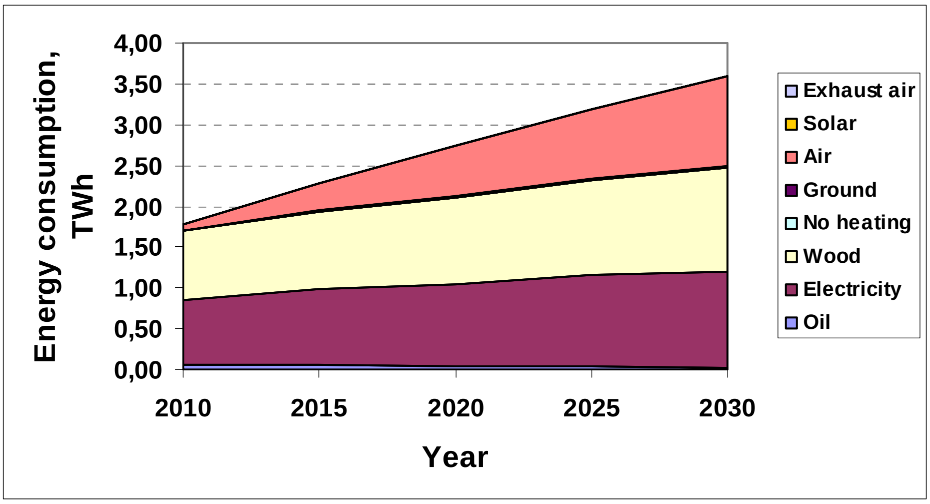


Figure 49. Heating energy consumption (space heating + DHW) scenario of free-time residences, division of consumption is made by energy source.

Electricity consumption scenario is visualized separately in Figure 50 to get a better understanding of the predicted electricity consumption over the years. Heating electricity consumption is assumed to decrease despite the fact that the number of electrically heated houses (direct electricity + heat pumps) will increase from 2010 to 2030, which is clear when comparing heating system distributions presented in Figures 45 and 47. This is the case when oil heated houses are changed to ground source heat pumps and utilize increasingly auxiliary air-air heat pumps, which will increase electricity use. At the same time, direct electricity heaters will change to ground source and air-water heat pumps as well as utilize increasingly air-air heat pumps in space heating and air-water heat pumps in domestic hot water production.

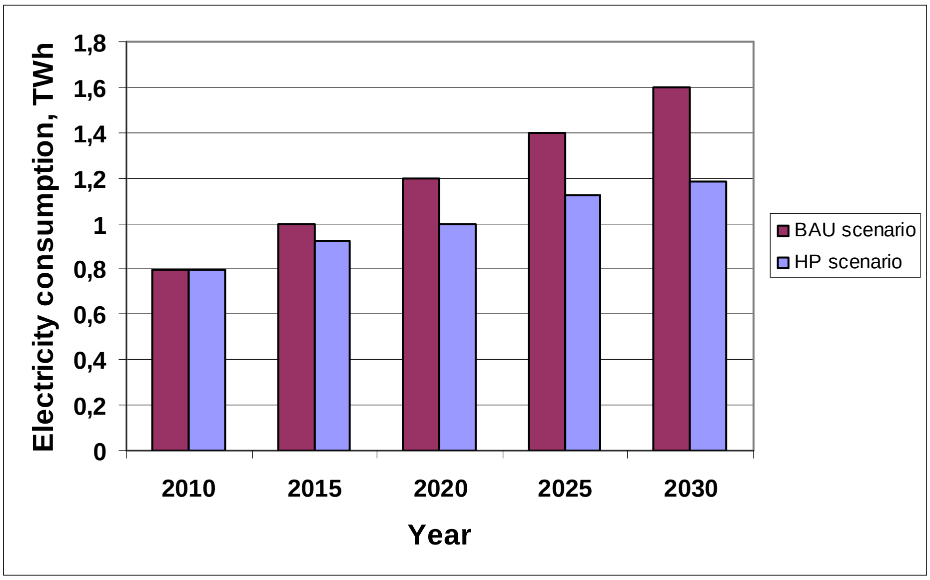


Figure 50. Heating electricity (space heating + DHW) scenario for free-time residences.

5.5.6 Heating power demand

Heating power demand is estimated for that part of the cottages that use heating during the wintertime. The heating power demand is expected to be 5 kW per cottage. Moreover it has been assumed that air/air heat pumps do not lower the power need because the peak is during the coldest period and air source heat pumps are not working then.

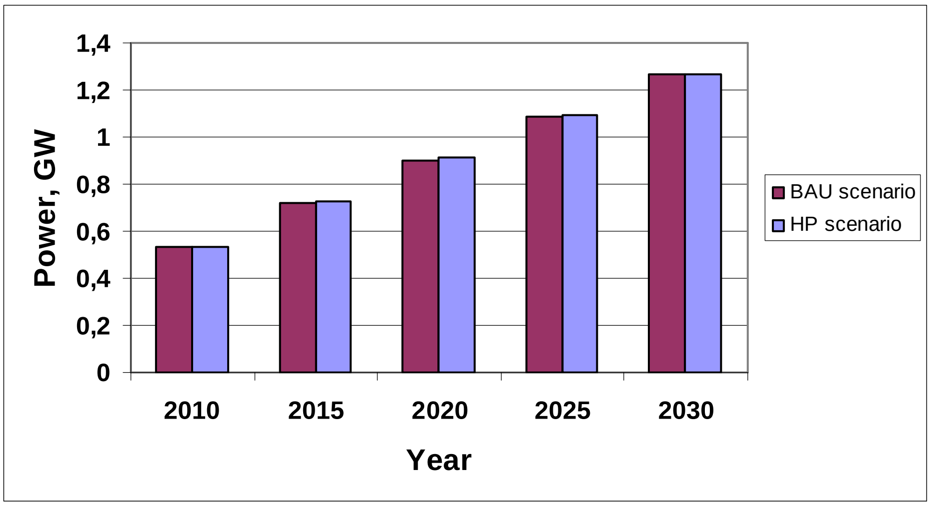


Figure 51. Heating power estimation for free-time residences.

5.6 Combined residential impacts

5.6.1 Heating electricity consumption

The increasing number of heat pumps will decrease electricity consumption of residential buildings, Figure 52. The reason for this is the decreasing electricity consumption of detached houses which more than compensates the increasing consumption of blocks of flats and free-time residences, Figure 53. The main reason for decreasing consumption of detached houses is that direct electric heating is replaced by heat pumps.

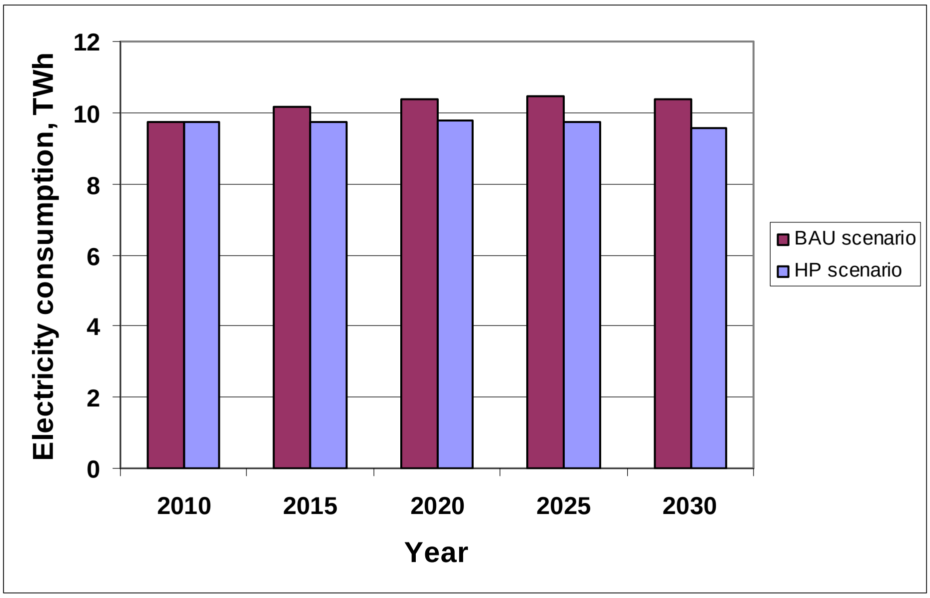


Figure 52. Estimated heating electricity consumption.

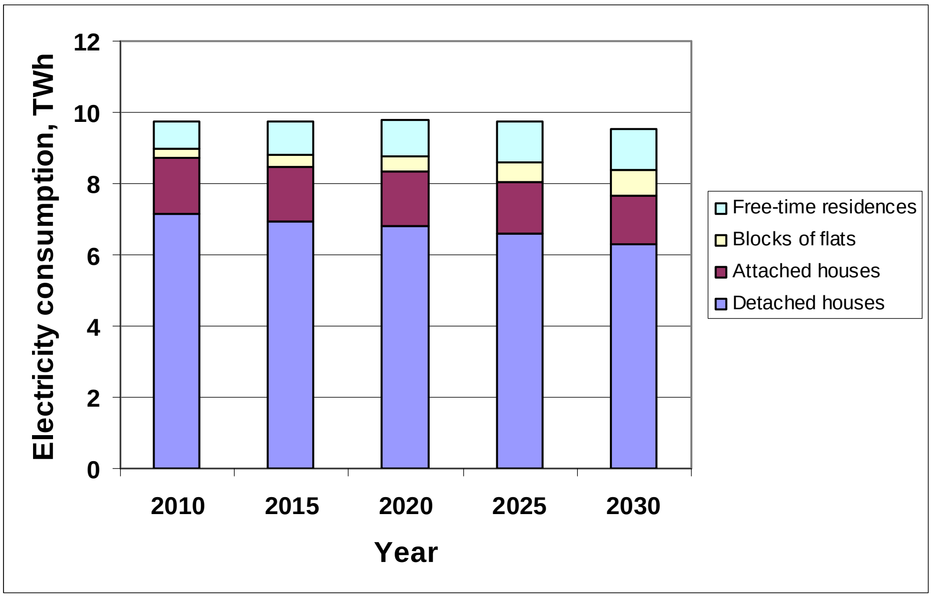


Figure 53. Estimated heating electricity consumption by building type with HP scenario.

5.6.2 Heating electric power demand

The increasing number of heat pumps will increase the electric power demand of residential houses, Figures 54 and 55. These calculations overestimates the power demand because the overlapping of the domestic hot water production between buildings is not taken into account.

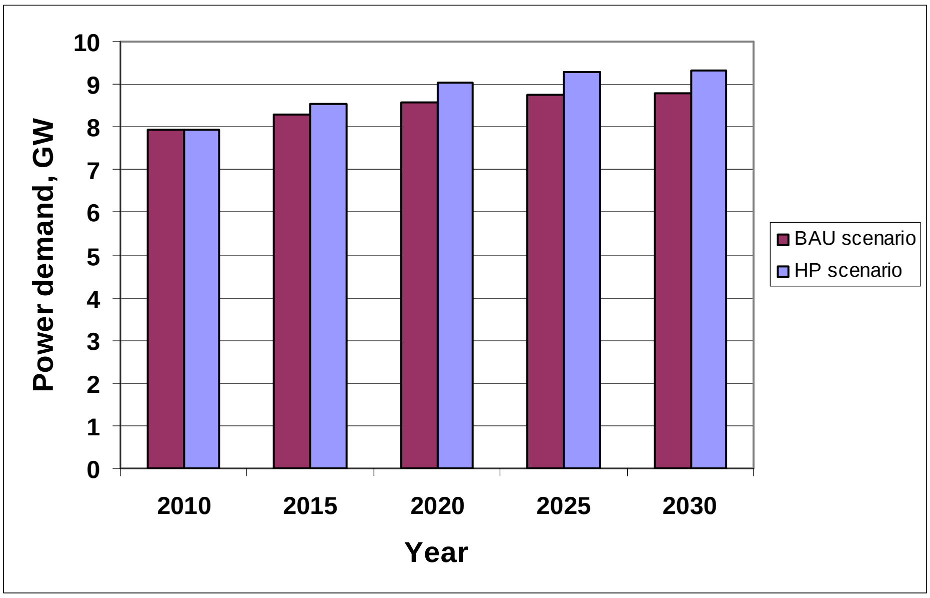


Figure 54. Estimated heating electricity power demand.

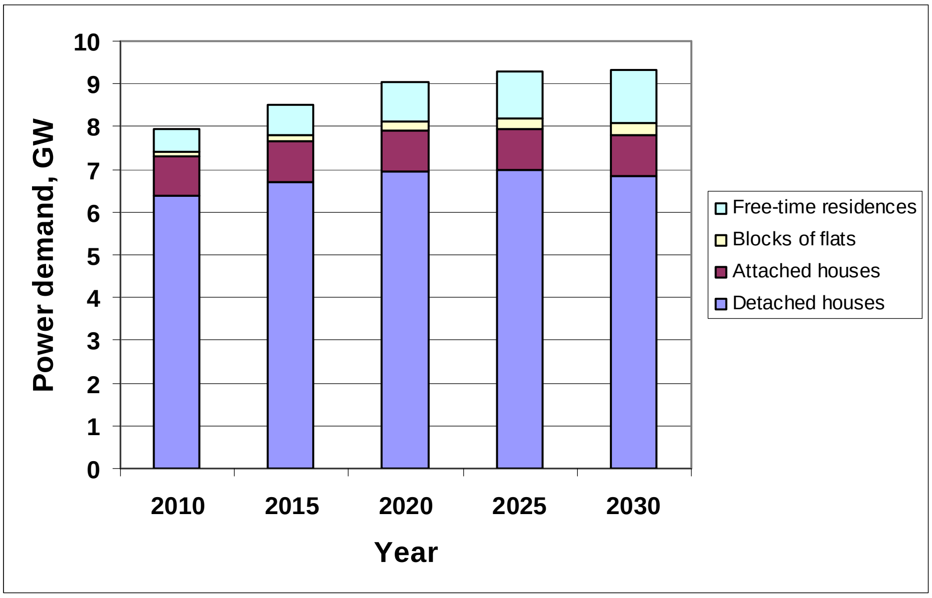


Figure 55. Estimated heating electricity power demand by building type with HP scenario.

5.6.3 Total number of heat pumps

The estimated number of heat pumps will exceed 1 million installations by 2020 which is slightly more than the vision of SULPU with 0.95 million heat pumps. 2030 the number of heat pumps will total 1.6 million. The dominating heat pump types are air/air and ground source whereas air/water and exhaust air heat pumps are rated much lower by numbers, Figure 56. Most of the heat pumps will be installed in detached houses, Figure 57.

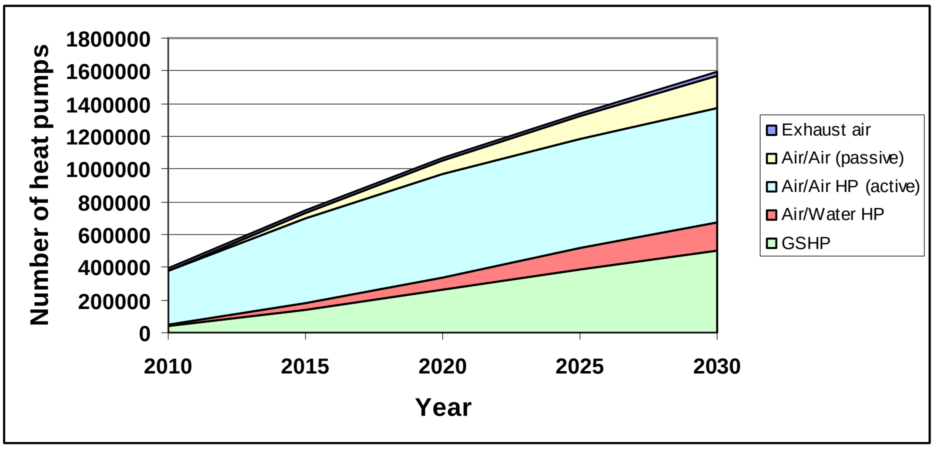


Figure 56. Estimated number of heat pumps by heat pump type in the residential sector.

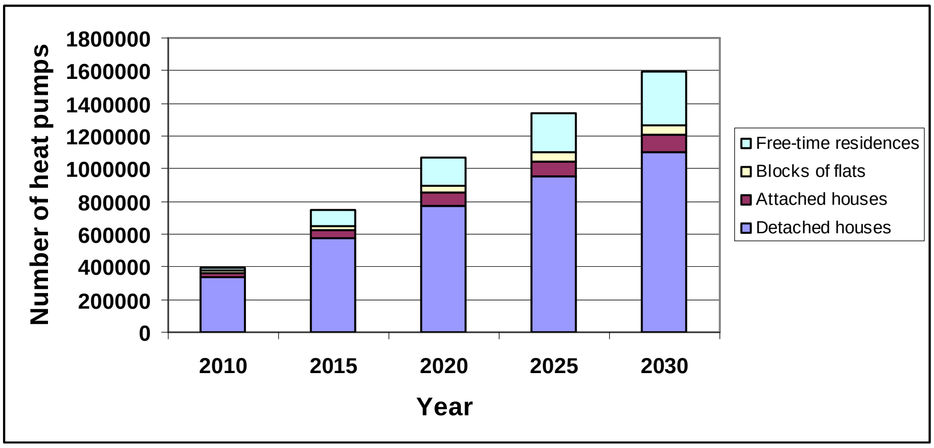


Figure 57. Estimated number of heat pumps by building type in the residential sector.

6 Load curves of heat pumps

The study covered two types of heat pumps i.e. air/air heat pump and ground source heat pump. In both cases the load curves where generated by simulation for the same building layout for three different space heating demands. The heating demand levels where chosen so that the houses represent typical buildings built in the 1970’s and 2000’s, and a future passive house.

The resulting load curves were also converted into index based load profiles, see appendix 1.

6.1 House types

In all simulations, the same single-floor detached house was used, the ground plan is presented in Figure 58. The orientation of the house is such that the living room (OH, room number 15 in plan figure) is facing north and the kitchen (Keittiö, room number 8 in plan) is facing south. The house is occupied by two adults and two children.

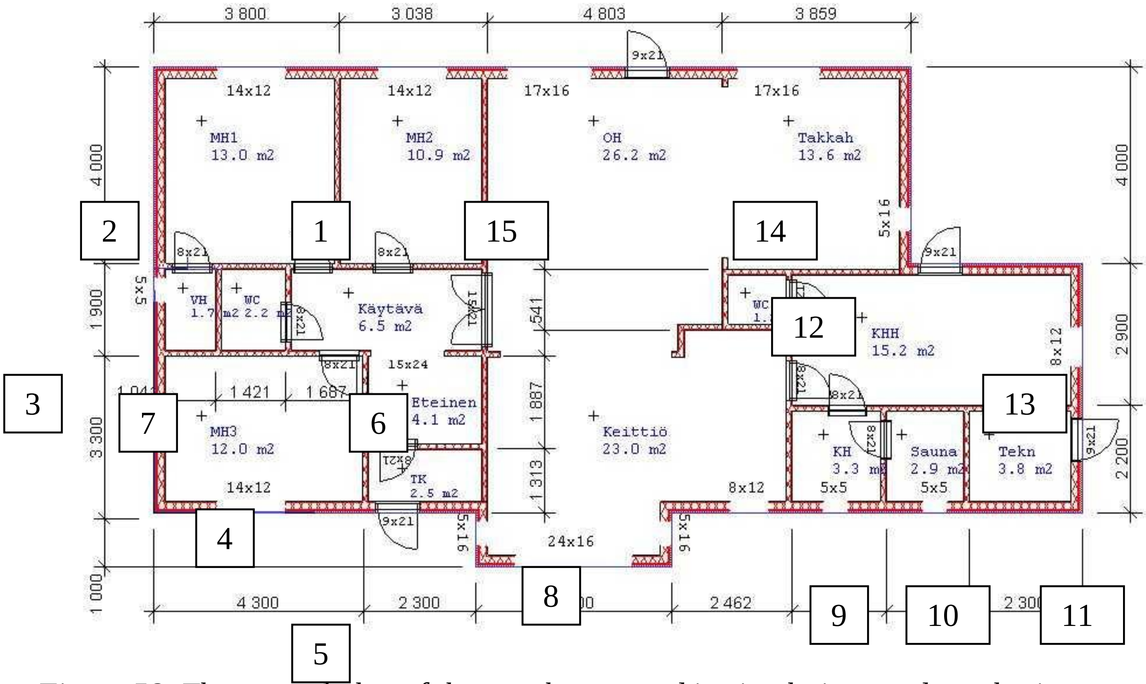


Figure 58. The ground plan of the type house used in simulations and numbering of the rooms.

Construction

The main characteristics of the building are shown in Table 5 and Table 6.

Table 5. Size characteristics of the type house.

Cubic content	466 m^3
Air space	355 m^3
Gross floor area	163 m^2
Useful floor area	147 m^2
Outline	56 m
Room height	25 m

Table 6. Areas of the building elements by orientation. The areas have been calculated using the internal dimensions.

Orientation	Wall m^2	Windows m^2	Doors m^2
North	36.6	8.52	3.8
West	22.4	0.95	-
South	35.7	7.04	2.2
East	19.5	2.36	2.2
Total	114.2	18.9	8.2

Ceiling and floor areas are the same as the useful floor area which is 147 m^2.

The thermal transmittances (U-value) used in the three different house types are given in Table 7. The given U-values comply the required insulation level set at the building regulations at different times.

Table 7. Thermal transmittances (U-values) of the building elements of the different type houses.

Element	U-value (W/m²,K) 1970 ("old building")	U-value (W/m²,K) 2000 ("new building")	U-value (W/m²,K) Passive house ("future building")
Wall	0.475	0.25	0.17
Window	2.2	1.4	1.0
Ceiling	0.335	0.16	0.09
Floor (on ground)	0.48	0.25	0.16

Ventilation

a) 1970 - mechanical exhaust ventilation is used without heat recovery

b) 2000 - mechanical supply and exhaust ventilation is used with heat recovery. The temperature efficiency of the heat recovery unit is 50 %. The air supply unit is equipped with electrical back up heater and the supply air temperature is kept at +15 ºC during the heating season.

c) Passive house - mechanical supply and exhaust ventilation is used with heat recovery. The temperature efficiency of the heat recovery unit is 80 %. The air supply unit is equipped with electrical back up heater and the supply air temperature is kept at +15 ºC during the heating season.

Ventilation rate in each case is 0.5 1/h i.e. the air volume of the building changes every two hours.

Infiltration

The design value of the air tightness of the building envelope is n_{50} = 3 1/h for the 1970's and 2000's type house. This equals to air change rate of 0.15 1/h.

The passive house is built much more tighter, n_{50} = 0.6 1/h, which equals to air change rate of 0.03 1/h.

Room temperature

The set temperature of the living spaces during the heating season is +21 ºC. Exception to this is the living room temperature with air/air heat pump in which case the set temperature of the living room is +23 ºC (+21 ºC in all other rooms).

Weather data

In the simulations the weather data of Jyväskylä (middle Finland) for year 1979 is used.

Internal heat sources

The heat loads of different rooms consists of electrical equipment (lighting, stove, refrigerator etc.) which has been described by hourly use profiles room by room in the simulations.

Space heating demand

The simulated space heating demand for each type house is presented in Figure 59 as duration curves.

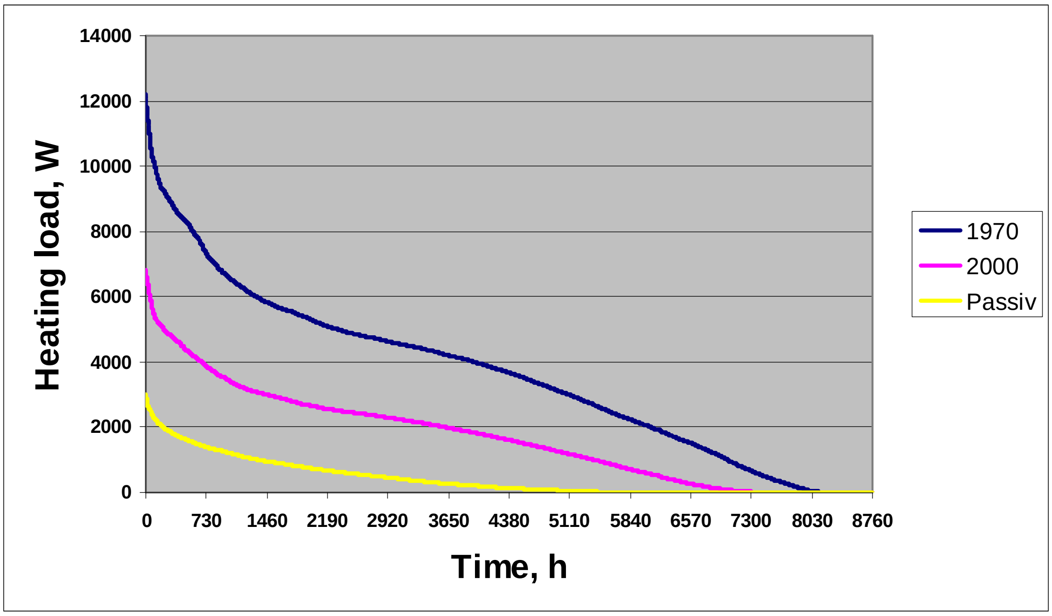


Figure 59. Space heating duration curves for the simulated type houses.

Domestic hot water
The heat demand of domestic hot water (DHW) is modelled as hourly profile which is presented in Figure 60. The same profile is used for each day and for each type house.

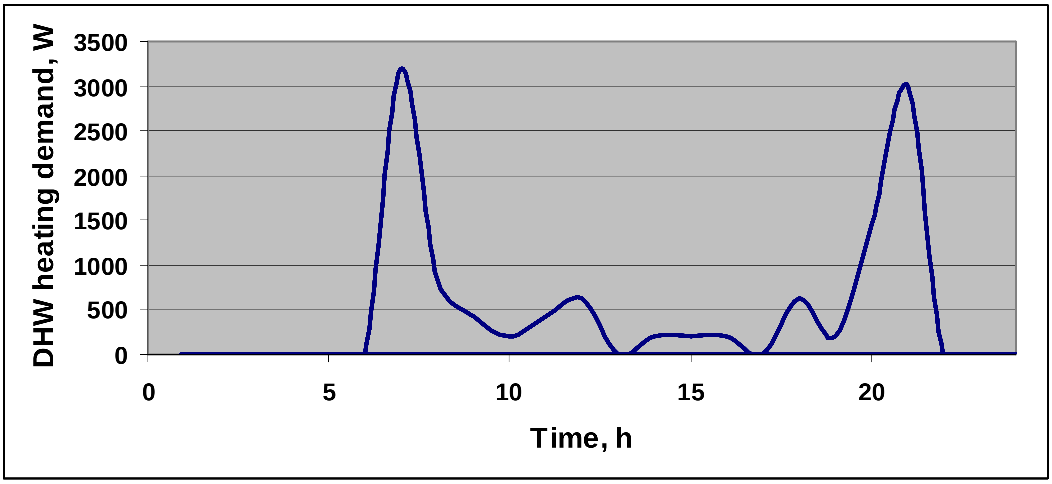


Figure 60. Domestic hot water heating demand load profile. Daily heating energy need is 11.62 kWh.

6.2 Air/air heat pump

Air/air heat pump is located in the living room (room number 15 in Figure 58). In the simulations, the set temperature for the air-air heat pump is +23 ºC while in the other rooms it is +21 ºC. The heat from the living room is filtered to the other rooms via open doors by buoyancy-driven air flows.

The characteristics of the simulated heat pumps are presented in chapter 4.2.1.

Month by month hourly examples of the power demand of the air/air heat pump for each simulated house type are shown in Figures 61 and 62.

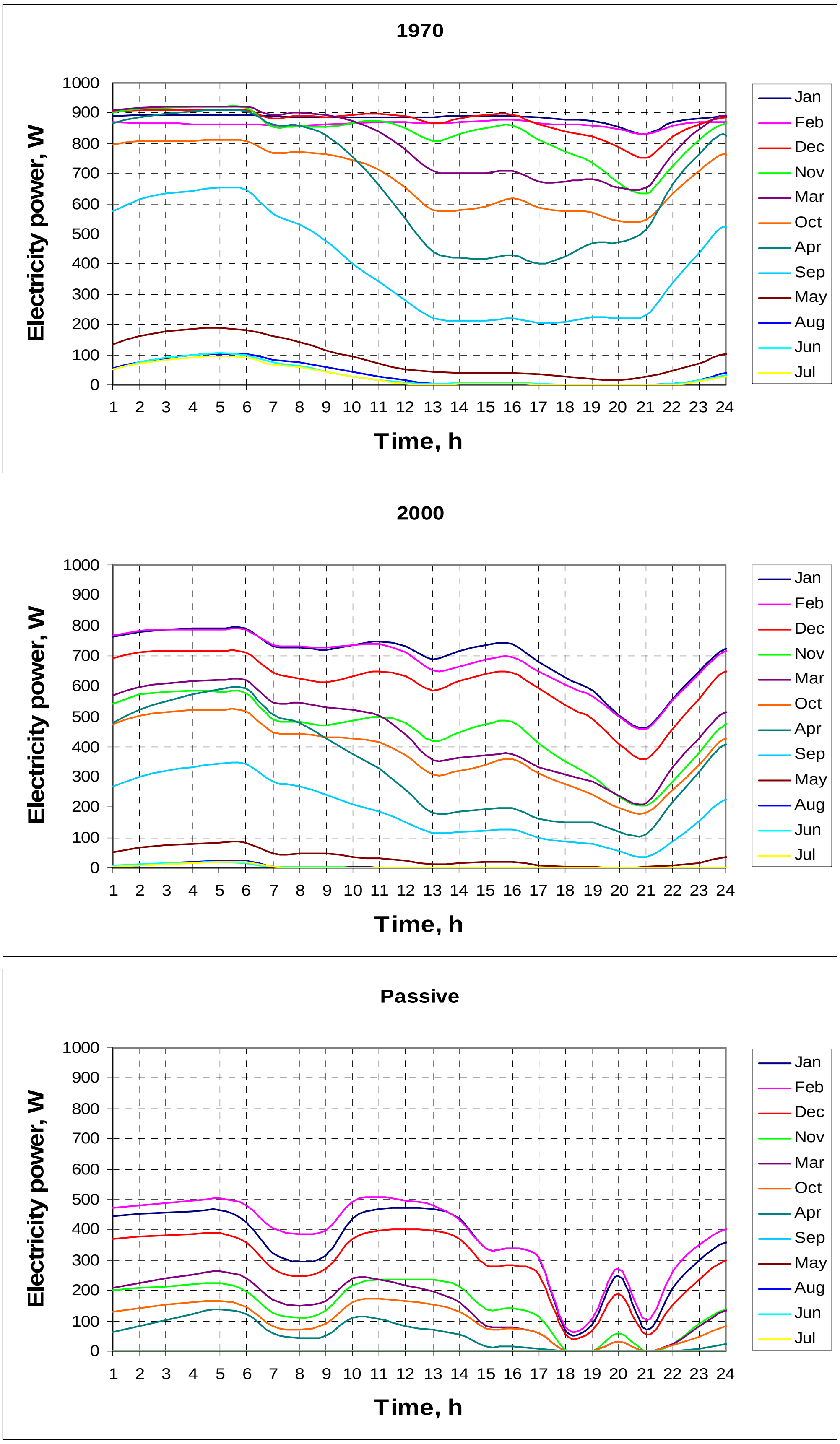


Figure 61. Average electrical power of the air/air heat pump of each hour in the type houses.

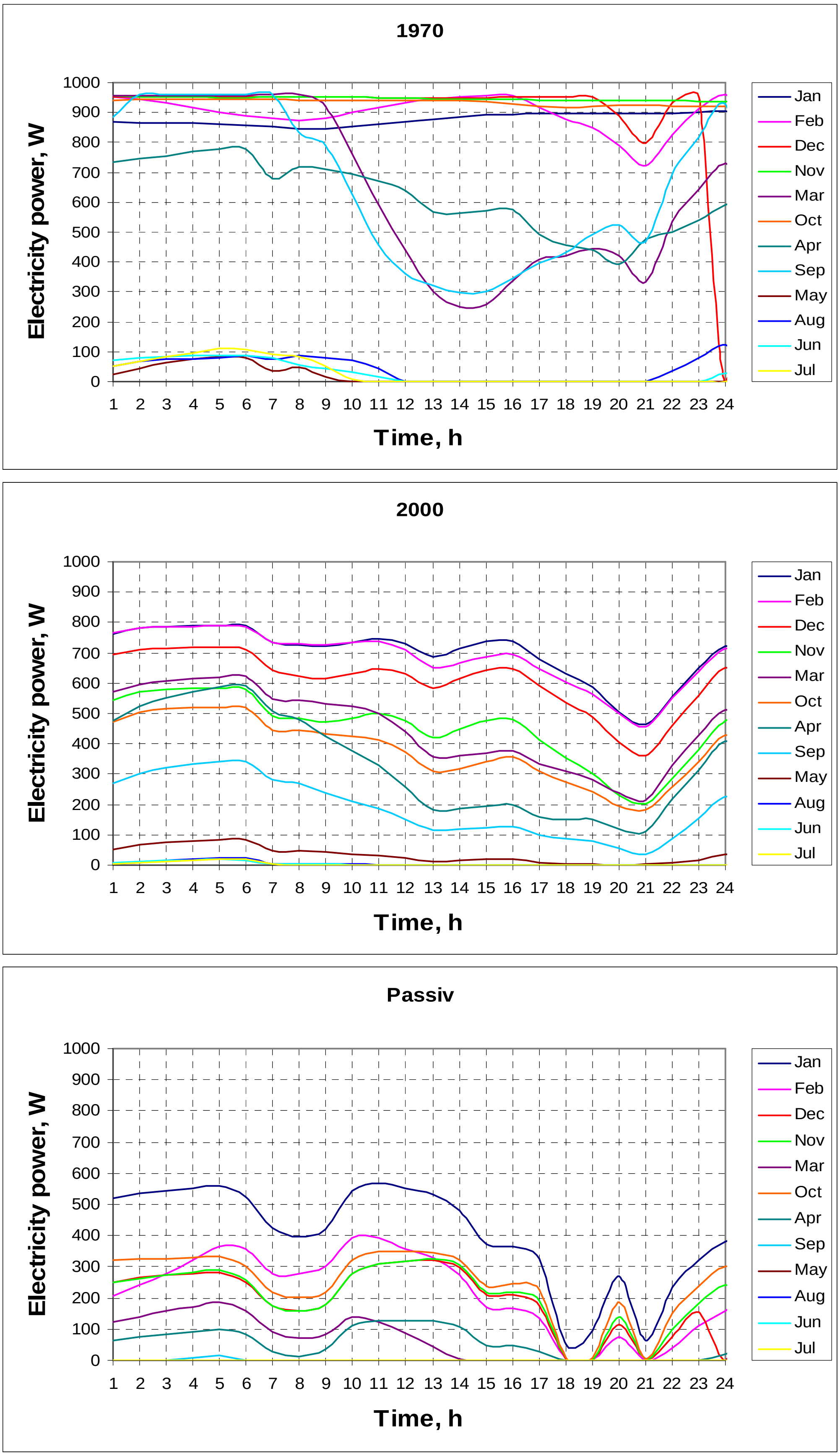


Figure 62. Electrical power of the air/air heat pump on the last day of each month in the type houses.

6.3 Ground source heat pump

The load curves for ground source heat pumps were created for two dimensioning cases and three building types. The two dimensioning cases were 100 % and 50 % which means that in the first case the heat pump is supposed to produce all the heating need (100 %) whereas in the second case the heat pump heating power covers only half (50 %) of the demand. The three building types were the same as with air/air heat pumps i.e. 1970's house, 2000's house and passive house.

The characteristics of the simulated heat pumps are presented in chapter 4.2.2.

The simulated hour by hour electricity power is presented in Figures 63 and 64 for 100 % and 50 % case respectively. Although the heat pump is dimensioned for the full heating demand (100 %) there are occasional need for the auxiliary resistance heater in the winter time during peak domestic hot water consumption.

Month by month hourly data of the power demand are shown in Figures 65 – 68.

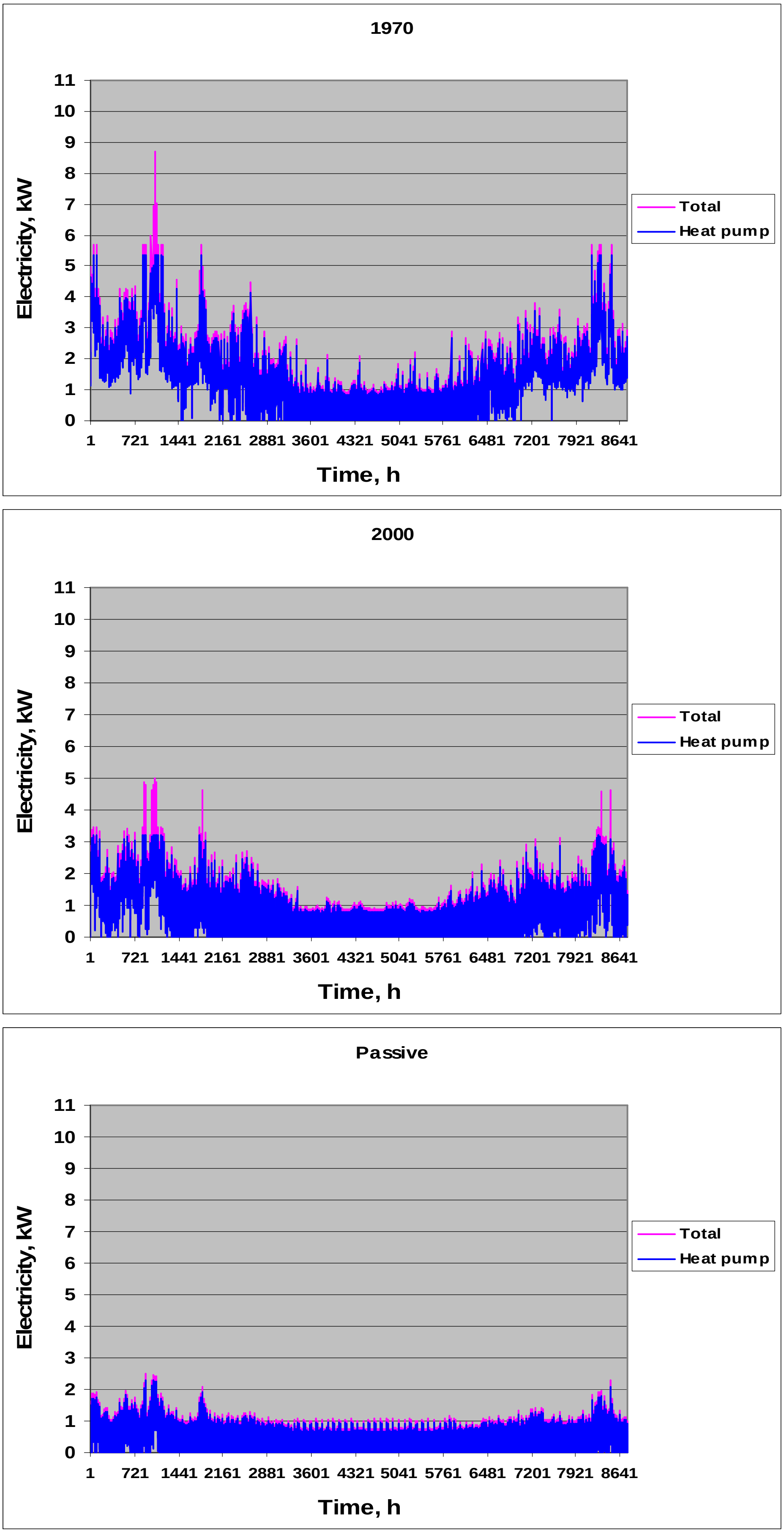


Figure 63. Hourly heating electricity (Total = HP+Pumps+auxiliary heat), HP dimensioned for full power = 100 %.

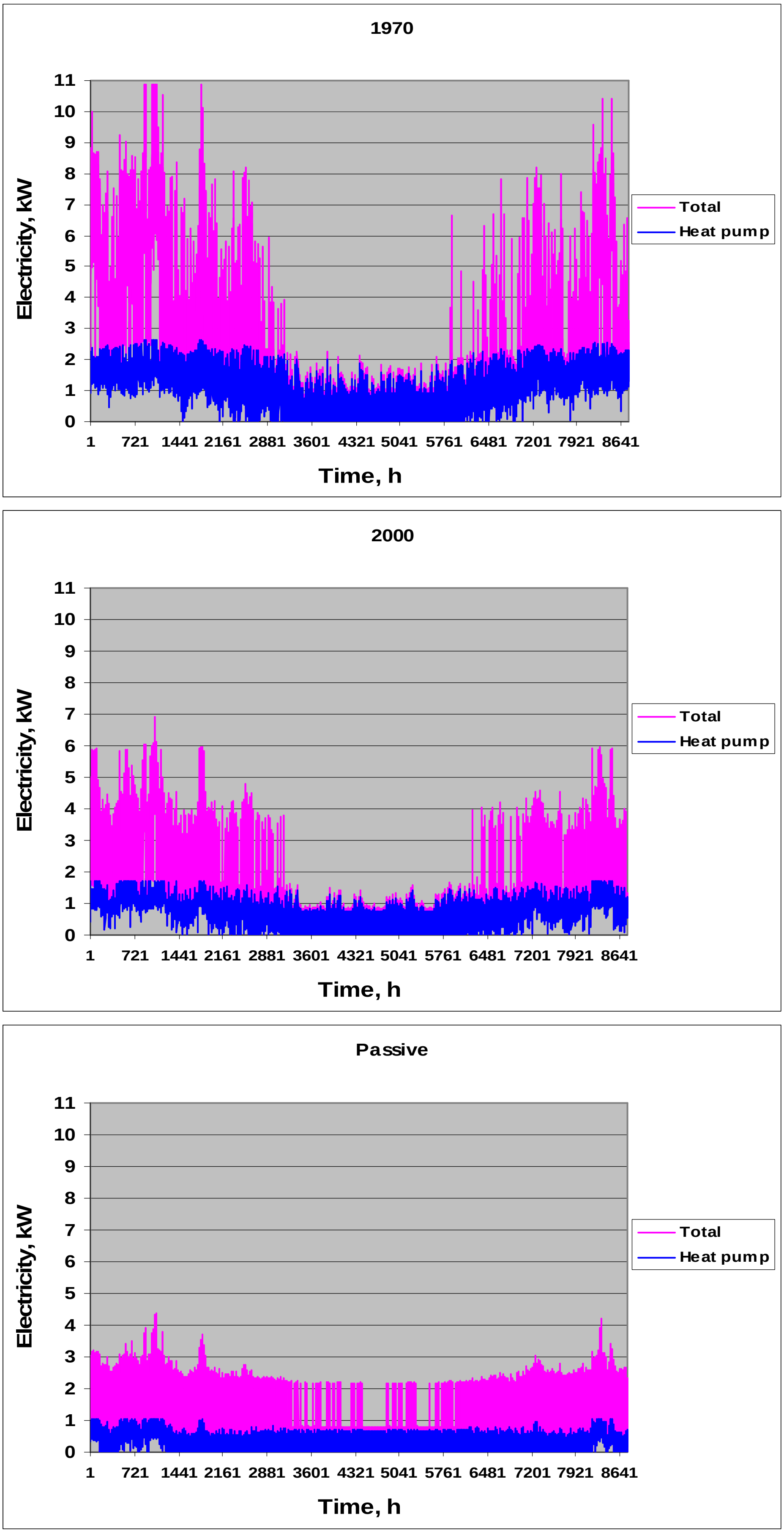
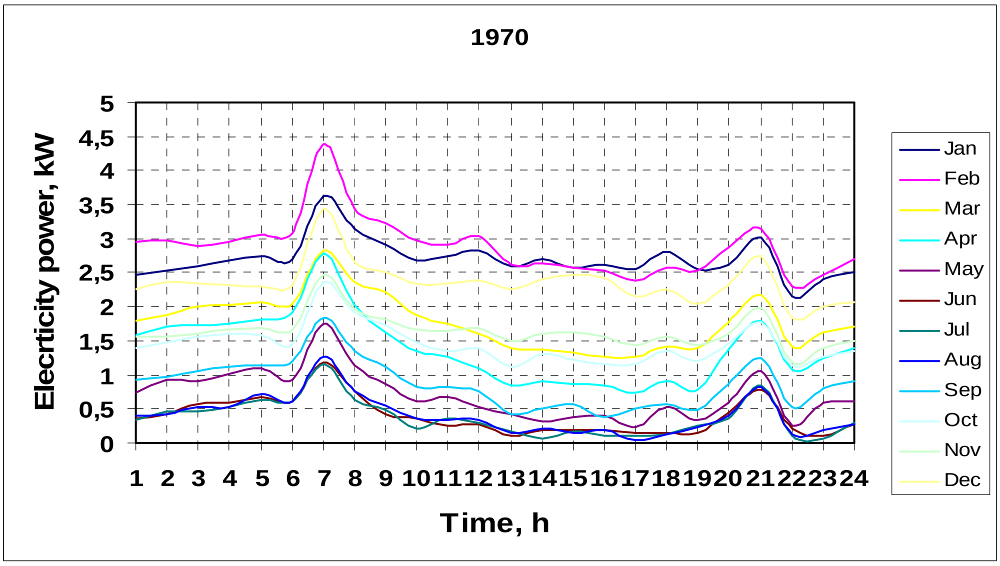
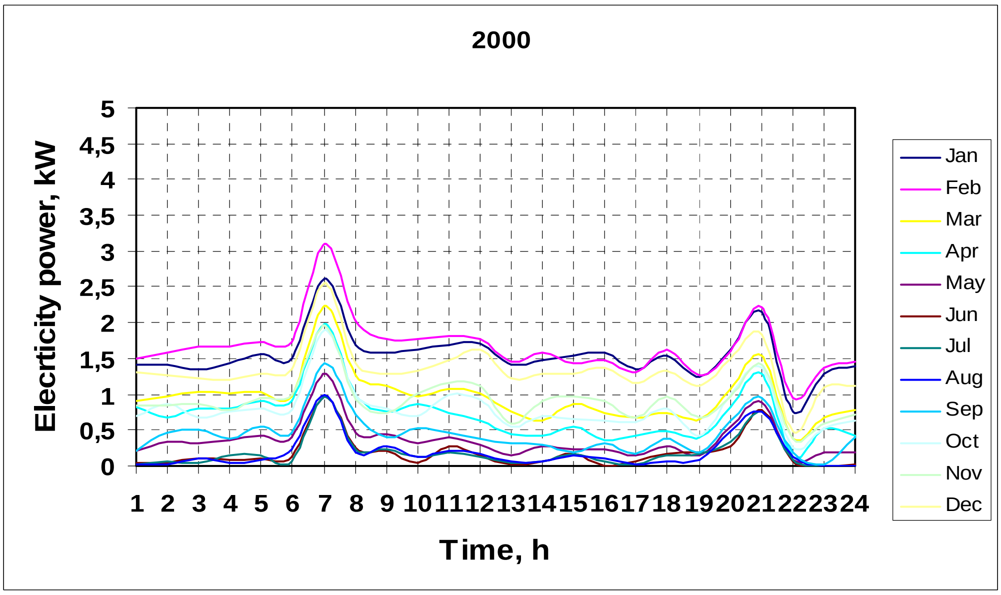


Figure 64. Hourly heating electricity (Total = HP+Pumps+auxiliary heat), HP dimensioned for full power = 50 %.





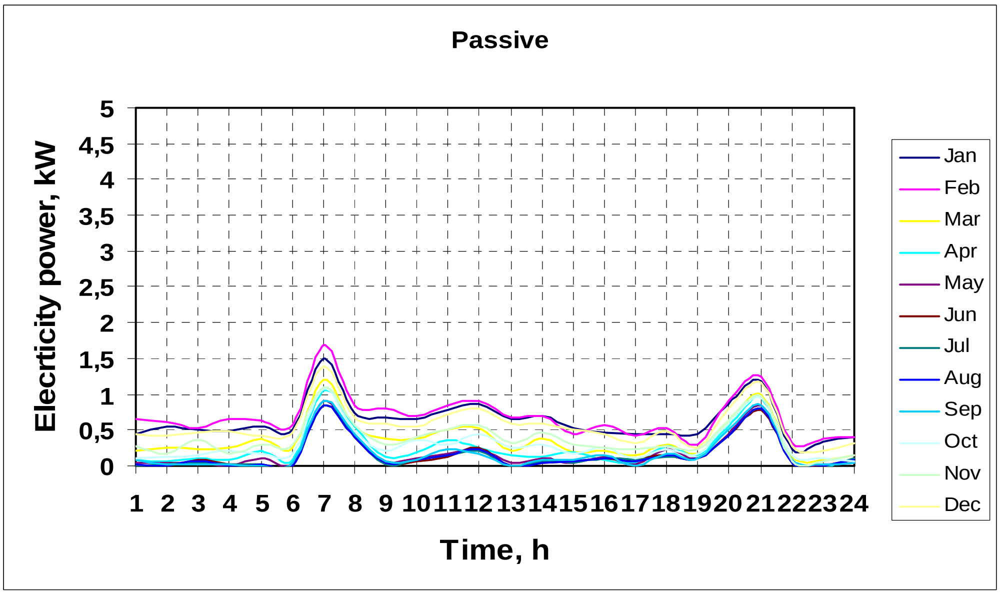
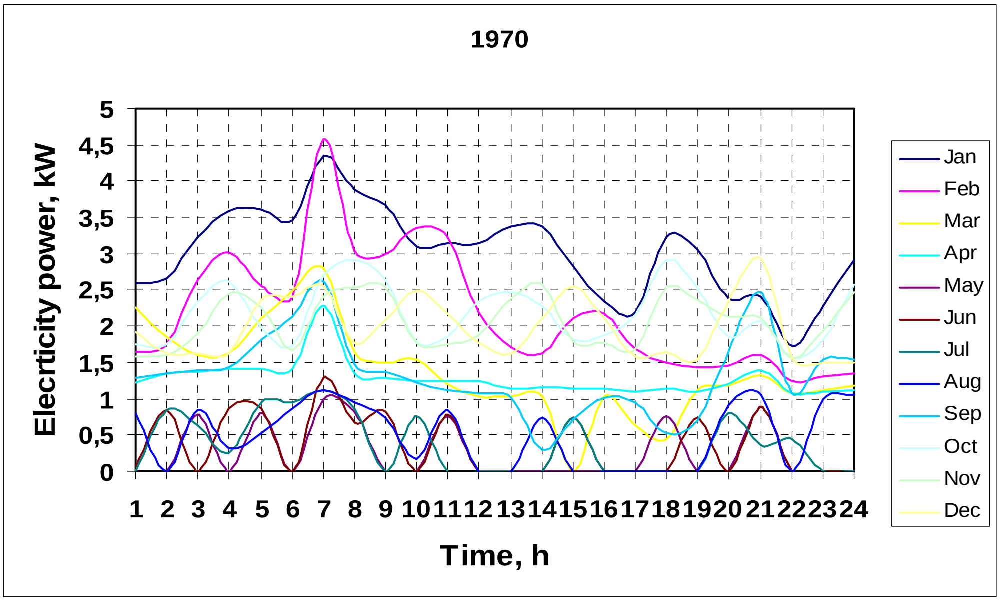
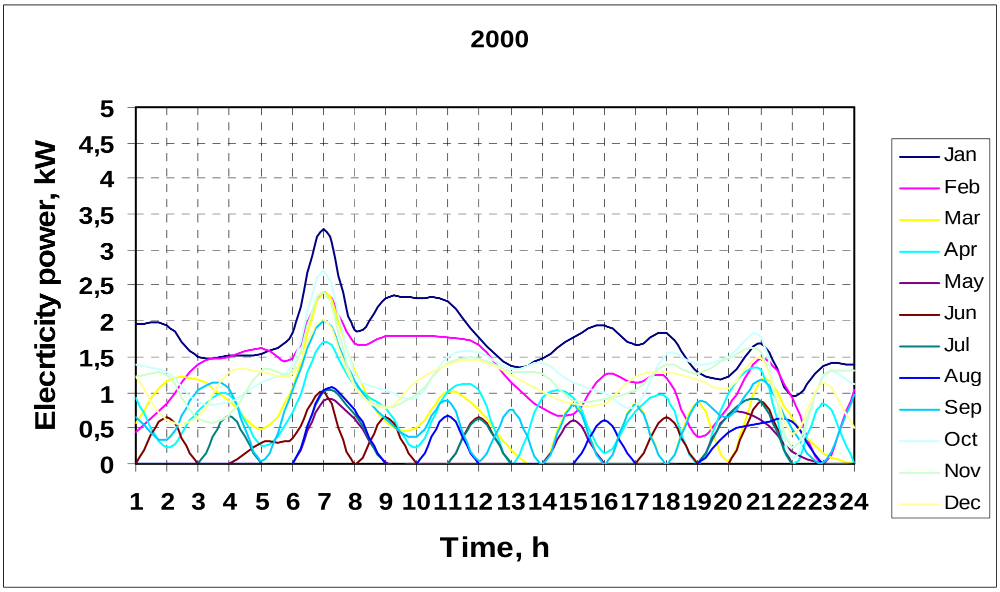


Figure 65. Average hourly heating electricity (HP+Pumps+auxiliary heat), HP dimensioned for full power = 100 %.





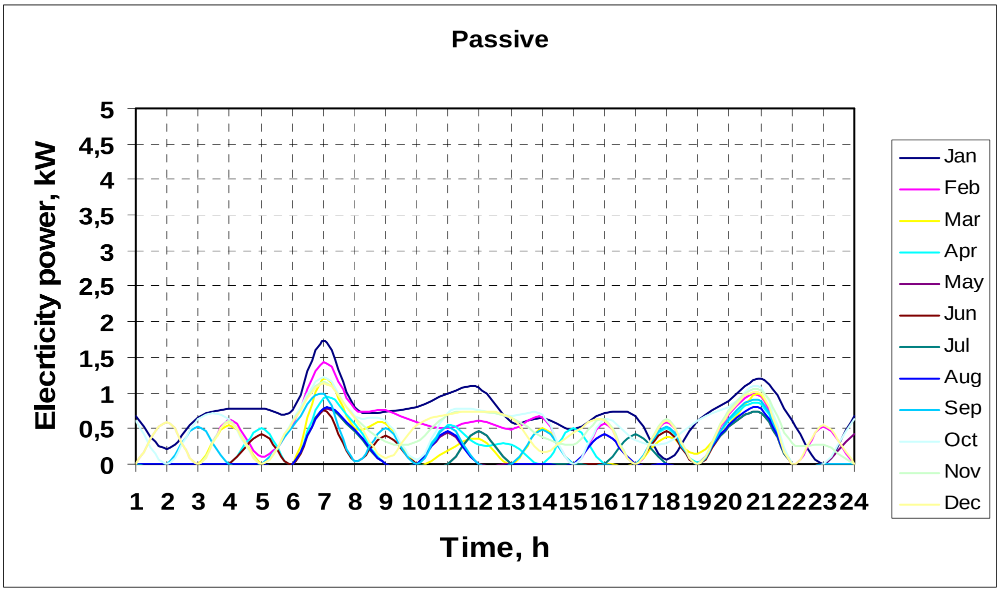


Figure 66. Hourly heating electricity (HP+Pumps+auxiliary heat) for the last day of each month, HP dimensioned for full power = 100 %.

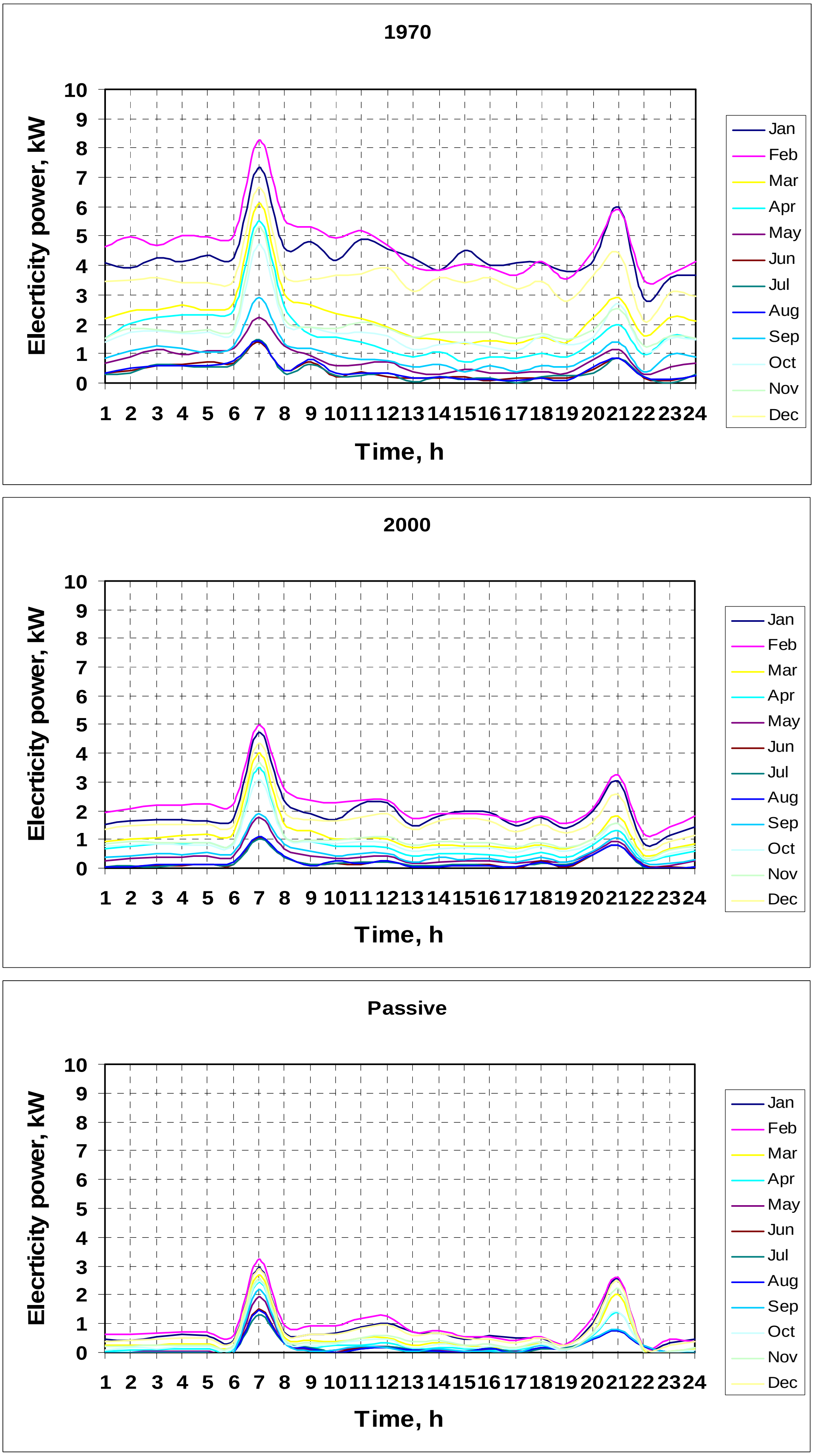


Figure 67. Average hourly heating electricity (HP+Pumps+auxiliary heat), HP dimensioned for full power = 50 %.

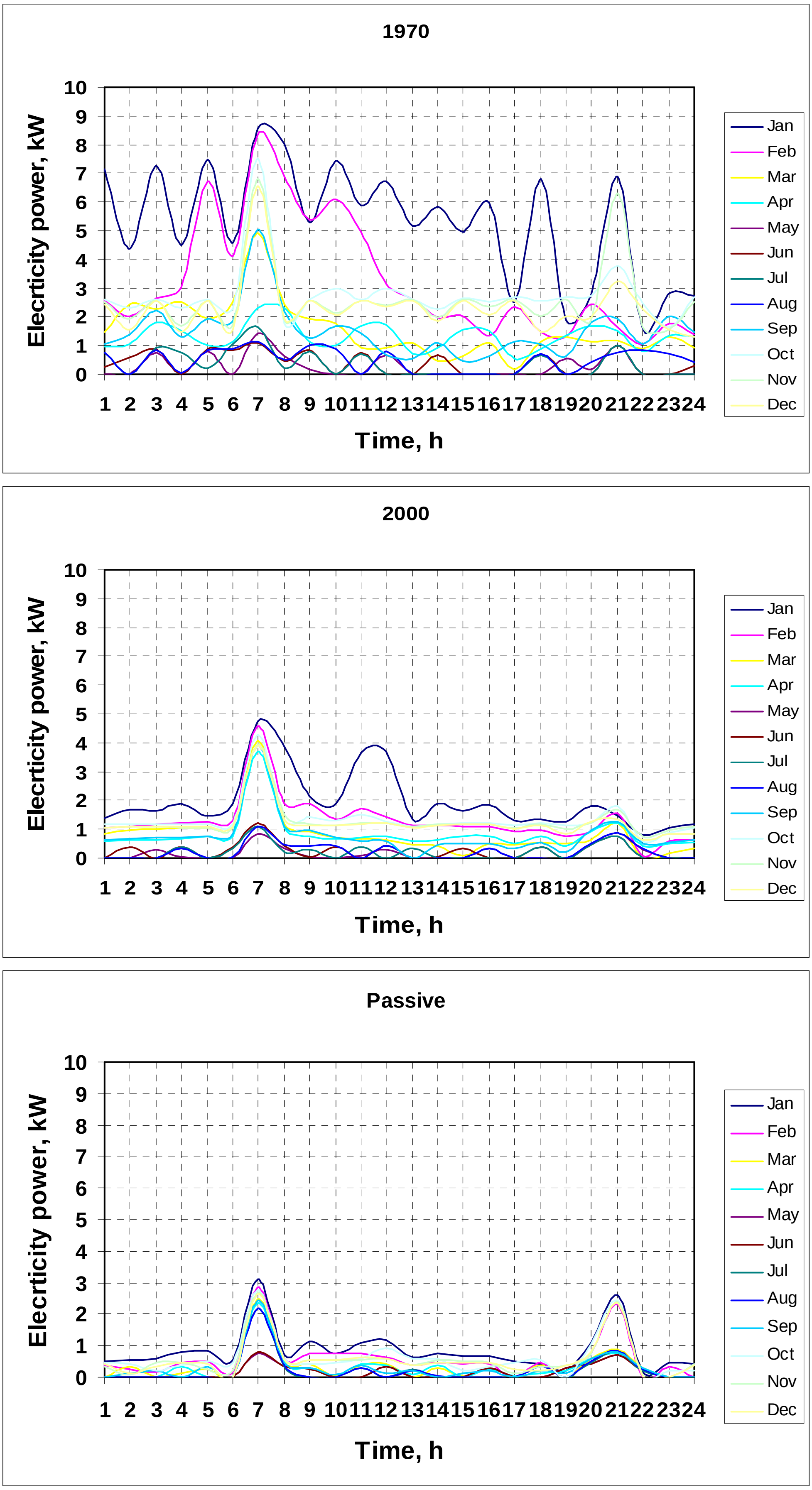


Figure 68. Hourly heating electricity (HP+Pumps+auxiliary heat) for the last day of each month, HP dimensioned for full power = 50 %.

6.4 Impact on Finnish peak load in 2020

The load curves presented were used to estimate what effect the changes in the heating systems might have on the national peak load. A similar approach was done by Koreneff et al (2010) in the SEKKI-project, where the impacts of large step changes as examples were analysed.

Using the load curves for the different house types and heat pumps as well as an approximation of a direct electric heated house, the effects of the forecasts from Chapter 5 on a peak load week were estimated. The peak load week from year 2006 was used as basis. The load curves were scaled using estimated change in annual energy. As not all load type/heat pump type combinations have load curves, the most suitable ones from those available were used.

The changes in annual energy from the increase of the heat pumps on one side, and from the decrease of electric heating on the other side, even out. The estimated change to the peak load in Finland using the load curves turns out to be quite difficult to notice, see Figure 69. This can be explained partly by here having only direct electric heating as being replaced by other sources. Direct electric heating has a high peak correlation with the national load, whereas a house with a heat accumulator would fare better. Another noticeable discrepancy is the modeling of free-time residences using detached house load curves. As can be seen in Figure 55, free-time residences are expected to have a strong impact on the peak demand by 2020, but not so here.

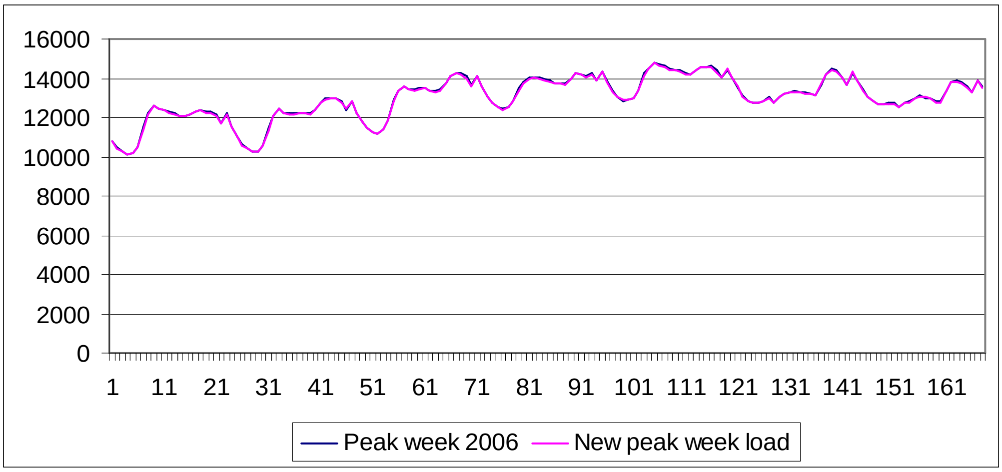


Figure 69. The effect of heating solutions in 2020 on the peak load. Free-time residences are not modelled using a very suitable load curve, as their impact alone is expected to be only near 500 MW.

7 Summary

This study covers the impacts of large penetration of heat pumps on the electricity use of residential buildings. The impacts are evaluated for the coming 20 years perspective. The analysed house types include detached houses, attached houses, blocks of flats and free-time residences.

Today there are slightly over 390 thousand heat pumps in Finland according to the statistics of Finnish heat pump association SULPU. Ground source heat pumps are 47 thousand, exhaust air heat pumps 17 thousand, air/water 6 thousand and air/air 320 thousand. The growth has been nearly five-fold in 5 years and the vision is that the market continues to increase. By 2020 the number of heat pumps will be about 1 million of which nearly 60 % is air/air heat pumps and 25 % ground source heat pumps. By 2030, it is estimated that the number of heat pumps totals 1.6 million, of which 44 % are air/air heat pumps and 32 % ground source heat pumps. The popularity of heat pumps is contributed to the rising energy prices, tightening energy regulations and subsidies given when changing the heating system.

The impacts of large penetration of heat pumps on the electricity use are of two kinds. Firstly, the heating electricity consumption of residential houses is estimated to decrease compared to the BAU scenario. Secondly, the heating electricity power demand will rise compared to the BAU scenario.

The total heating electricity consumption of residential buildings is 9.8 TWh today and it is estimated to rise to 10.4 TWh by 2030 with BAU scenario and with heat pump scenario the heating electricity will be 9.6 TWh.

The total power demand of residential building heating at present is 7.9GW and it is expected to rise to 8.8 GW by 2030 with BAU scenario and with heat pump scenario the power demand will be 9.3 GW.

This study presents also hourly load curves for the most common types of heat pumps namely air/air and ground source heat pumps. The load curves are calculated for typical detached houses of the 1970’s and the 2000’s and for a modern passive house.

Using these load curves together with estimates of changes in annual heating electricity usages, the net effect of all the assumed changes on the total Finnish peak load seems to be well below the previously estimated 1.5 GW. The preliminary simulations show the net effect to be negligible, as the reductions in direct electric heating counterbalance the introductions of new heat pumps. However, as the used load curves were restricted in number, this meant a lot of simplifications, especially when looking at the peak load. For example, using load curves for detached houses when estimating the heating load of summer cottages doesn’t work so well, as the heating operation is quite different and the use of domestic hot water even more so. All in all, the net effect of switching to heat pumps on the system peak load is, at most, only a few three percents by 2030.

References

Ecoheatcool 2005-2006. The European Heat Market. Ecoheatcool Work package 1. Final report. A Euroheat & Power Initiative. Available: http://www.euroheat.org/files/filer/ecoheatcool/documents/Ecoheatcool_WP1_Web.pdf

EC 2009. Directive on the promotion of energy from renewable sources (RES-directive). 2009/28/EC.

EHPA 2008. European Heat Pump Action Plan. European Heat Pump Association. Available:

EHPA 2011. Outlook 2010. European Heat Pump Statistics. European Heat Pump Association. Available: http://www.ehpa.org/fileadmin/red/Heat_Pump_Statistics/2010_EHPA_Outlook_executive_summary.pdf

EN 14511:2007 (all parts), Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling.

Energimyndigheten. Luf/luft värmepumpar. Available: http://www.energimyndigheten.se/Hushall/Testerresultat/Testresultat/Luftluftvarmepumpar/

EU 2010. Directive on energy performance of buildings (EPBD). 2010/31/EU

Hirvonen J., Heat pumps in Finland: market report. IEA Heat pump centre newsletter, volume 28 – No. 2/2010.

Koreneff, G., Ruska, M., Kiviluoma, J., Shemeikka, J., Lemström, B., Alanen, R. & Koljonen, T. Future development trends in electricity demand. VTT Research Notes 2470. VTT 2009

Odyssee 2011. ODYSSEE Database on energy efficiency indicators. http://odyssee.enerdata.net/nrd_web/site/ . Last visited 3.5.2011..

Perrels, A., Berghäll, E. ja Sahari, A. 2008. Mökkikannan kehityspolku vuoteen 2025 asti. VATT Keskustelualoitteita no. 455.

Rytkönen A,. Kirkkari A.-M. Vapaa-ajan asumisen ekotehokkuus. Suomen ympäristö 6/2010. Ympäristöministeriö, Helsinki 2010.

Statistics Finland. Buildings and Free-time Residences 2009. Helsinki 28.5.2010.

Statistics Finland 2011. Energy Statistics. Yearbook 2010. Helsinki 2011. ISBN 978–952–244–289–5 (pdf). (Used: CD-version)

SULPU 2011. Finnish heat pump association (Suomen lämpöpumppuyhdistys ry). http://www.sulpu.fi/ Visited 31.1.2011.

Vehviläinen I., Pesola A., Heljo J., Vihola J., Jääskeläinen S., Kalenoja H., Lahti P., Mäkelä K., Ristimäki M., Rakennetun ympäristön energiankäyttö ja kasvihuonepäästöt. Sitran selvityksiä 39. Sitra Helsinki 2010.

Appendix 1 Load profiles

Load profiles are done using an outer and an inner index. The outer index shows the normalised average hourly power for 26 two-week-periods. As shown here, the average of the outer indices will be 100%. The normalised inner index for each two-week-period shows 3*24 hour values; 24 hours for working days, 24 hours for eves, and 24 hours for holidays. The average hour value for each two-week-period is also 100%. The index matrix is altogether of the dimension 26 ·73, where the first column is the outer index. The normalised load for a given hour is the product of the respective outer and inner indices. The normalised load is converted to a nominal load using the factor (annual energy/8760 h).

The inner indices are here graphically simplified and given as averages of the four seasons:

1. winter = two-week-periods 1 to 4, 25, and 26
2. spring = two-week-periods 5 to 10
3. summer = two-week-periods 11 to 18
4. autumn = two-week-periods 19 to 24

The load profiles do not follow the normalised temperature, but instead the temperature from Jyväskylä 1979, here as averages for each two-week period:

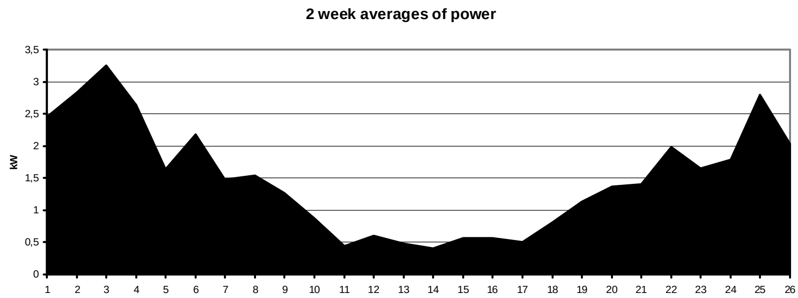
2 week indices

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
-7,7	-11,5	-15,3	-9,4	-0,1	-6,1	0,5	-1,4	4,2	9,6	16,2	13,5	15,6	16,6	14,0	14,4	15,7	10,6	7,0	3,8	4,0	-3,2	0,3	-1,1	-10,2	-5,3

The following load profiles are presented here:

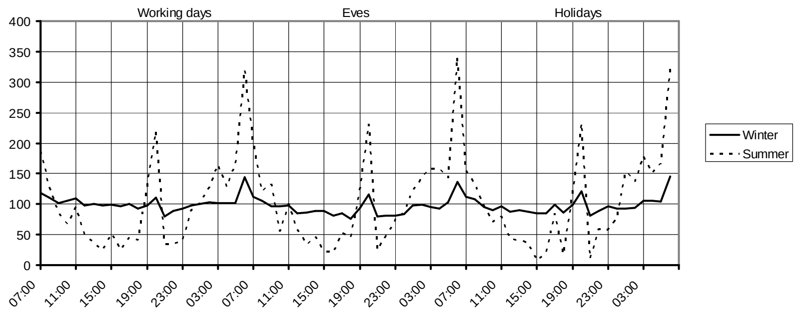
1. GSHP with a heat capacity measured for 100% of the heat peak demand, traditional technique, used in a 1970's house.
2. GSHP (capacity 100%), traditional technique, used in a 2000's house.
3. GSHP (capacity 100%), traditional technique, used in a passive energy house.
4. GSHP (capacity 70%), modern technique, used in a 1970's house.
5. GSHP (capacity 70%), modern technique, used in a 2000's house.
6. GSHP (capacity 70%), modern technique, used in a passive energy house.
7. GSHP (capacity 50%), modern technique, used in a 1970's house.
8. GSHP (capacity 50%), modern technique, used in a 2000's house.
9. GSHP (capacity 50%), modern technique, used in a passive energy house.
10. AAHP, used as auxiliary heat source in a 1970's house.
11. AAHP, used as auxiliary heat source in a 2000's house.
12. AAHP, used as auxiliary heat source in a passive energy house.

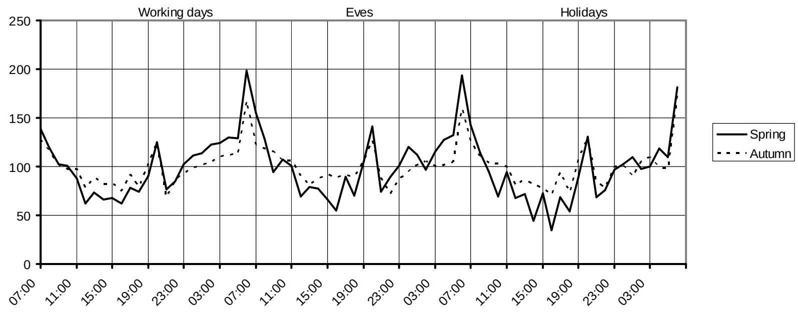
Profile: GSHP 100% capacity. Detached house from the 70's. Annual electricity use: 13 000 kWh

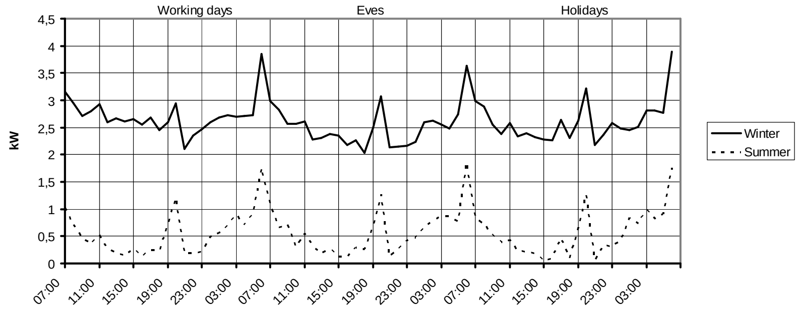


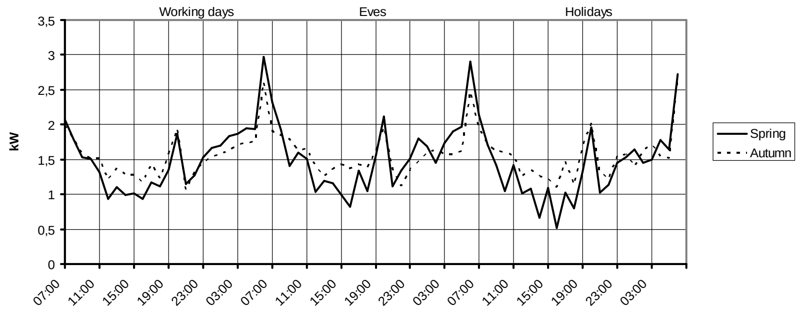
2 week indices

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
165	191	219	177	110	147	99,2	104	85,3	58,5	29,4	40,8	32,2	27	38,1	37,9	33,9	54,8	76,6	91,7	94,6	133	111	120	188	137

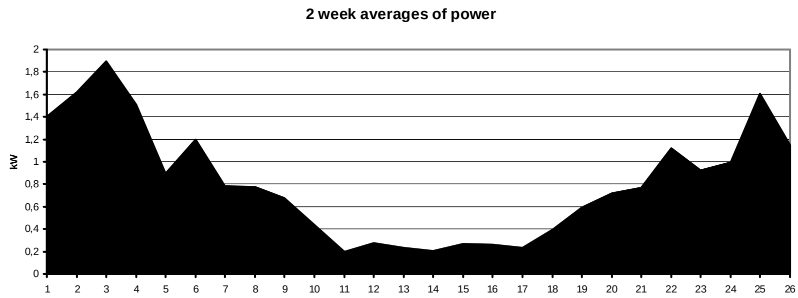






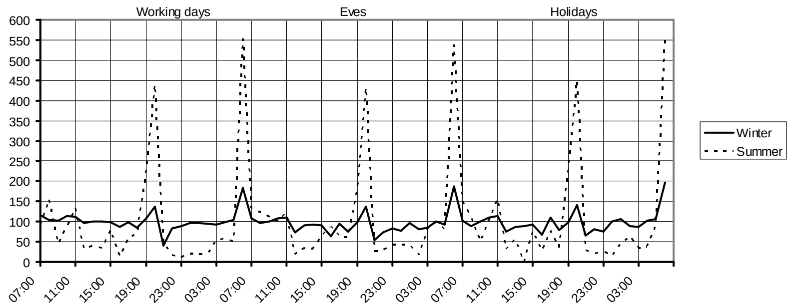


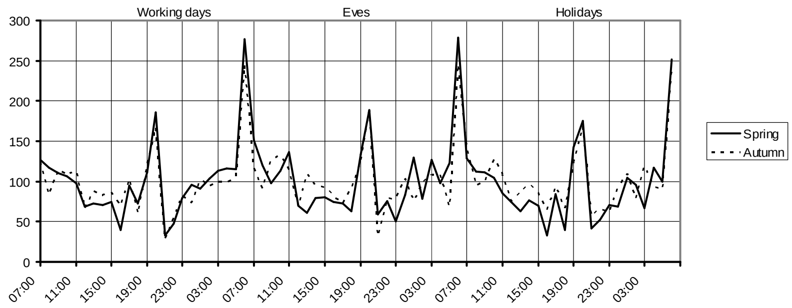
Profile: GSHP 100% capacity. Detached house from the 2000's. Annual electricity use: 7 000 kWh

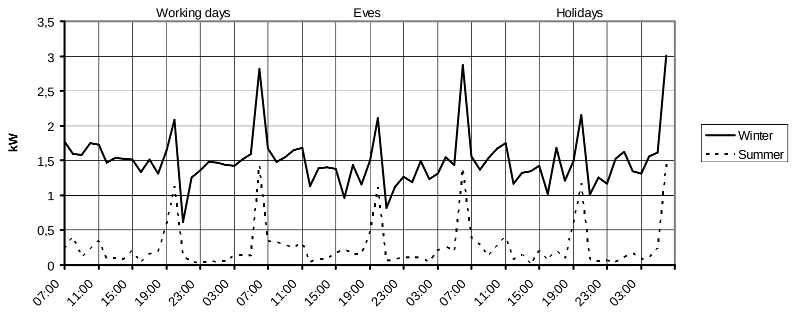


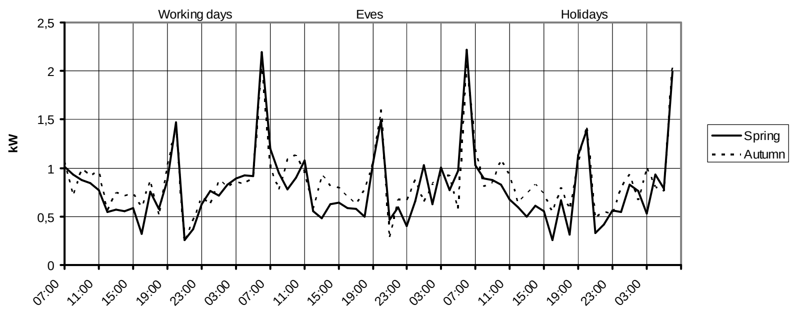
2 week indices

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
173	199	233	186	110	147	95,8	95,5	83,5	53,9	24,1	34,2	29	25,3	33,1	32,2	28,8	48,5	72,9	88,6	94,9	138	113	122	197	141

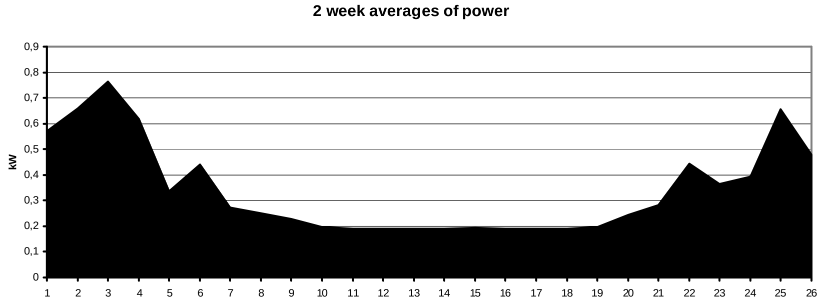






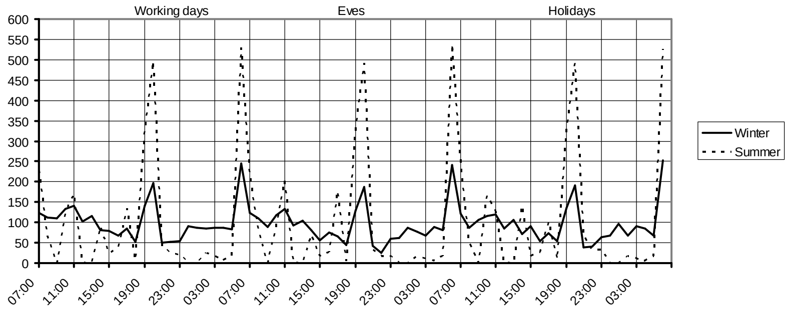


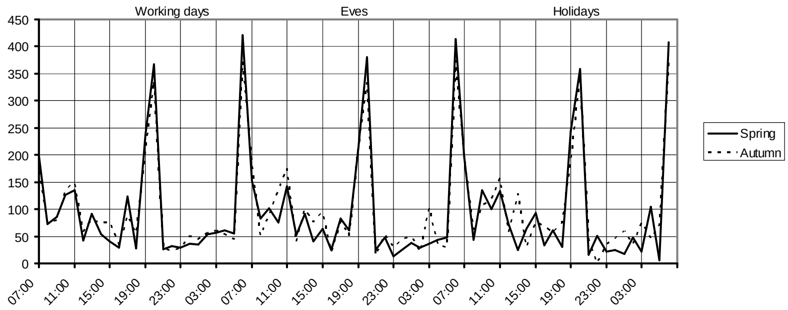
Profile: GSHP 100% capacity. Detached passive house. Annual electricity use: 3 000 kWh

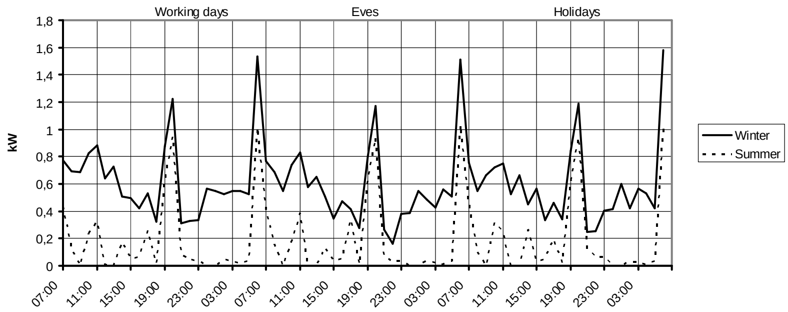


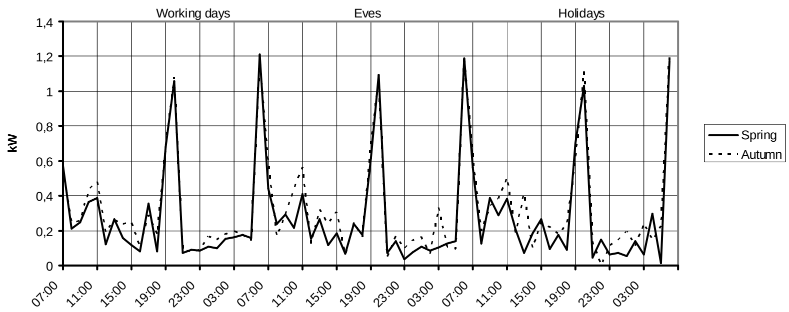
2 week indices

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
166	192	223	180	97,7	129	79	73,2	66,3	57,7	55,6	55,6	55,5	55,7	55,9	55,6	55,6	55,6	57,5	71,1	81,9	129	106	115	191	139

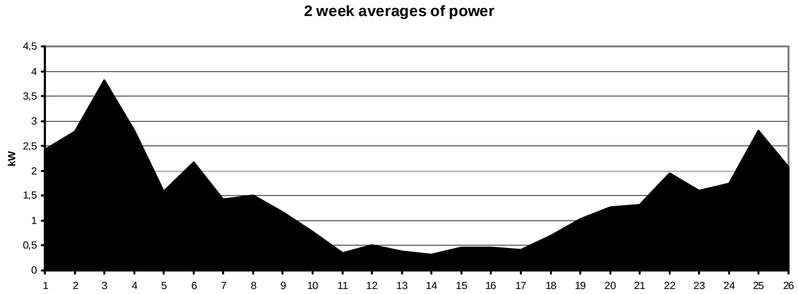






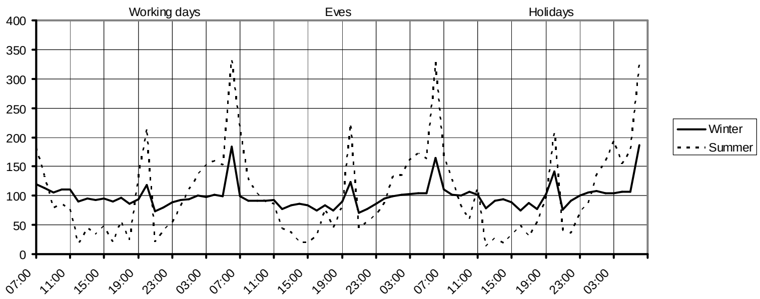


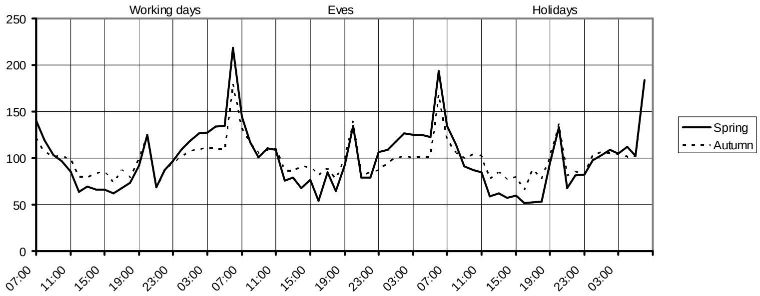
Profile: Modern GSHP 70% capacity. Detached house from the 70's. Annual electricity use: 12 700 kWh

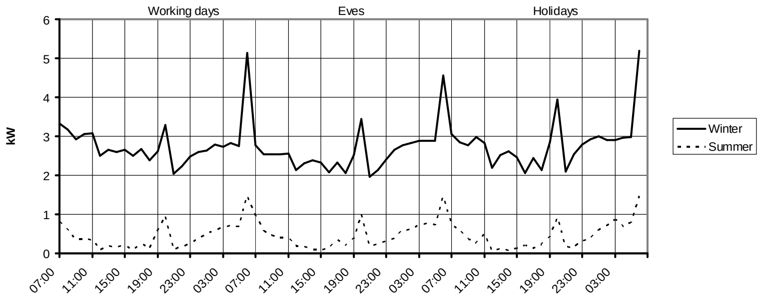


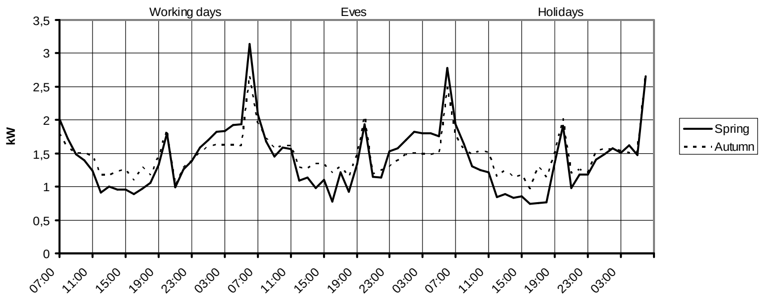
2 week indices

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
167	192	263	193	109	149	98	104	81	52,9	24,2	34,6	26,6	21,5	31,5	31,6	27,9	48,1	70,4	87,6	90,2	134	110	119	192	142

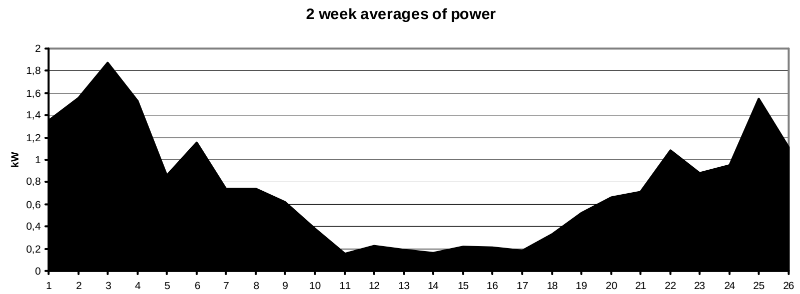






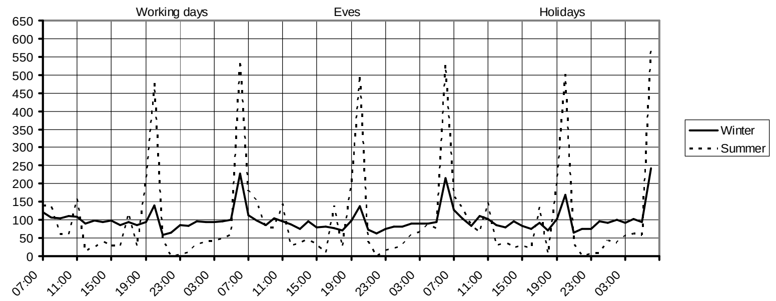


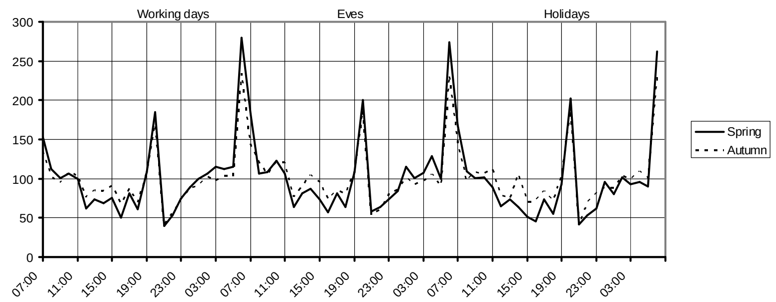
Profile: Modern GSHP 70% capacity. Detached house from the 2000's. Annual electricity use: 6 700 kWh

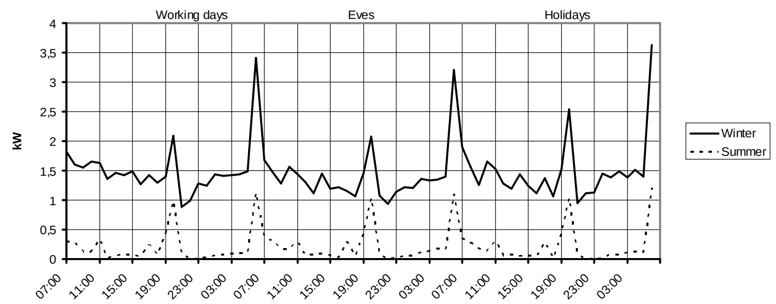


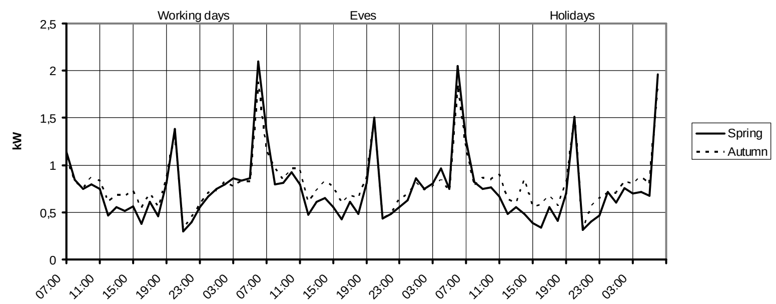
2 week indices

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
177	203	244	199	112	151	96,7	96,5	80,8	49,6	20	29,3	24,4	20,7	28,1	27,2	24,3	43	68,4	86,3	92,6	141	114	124	202	145

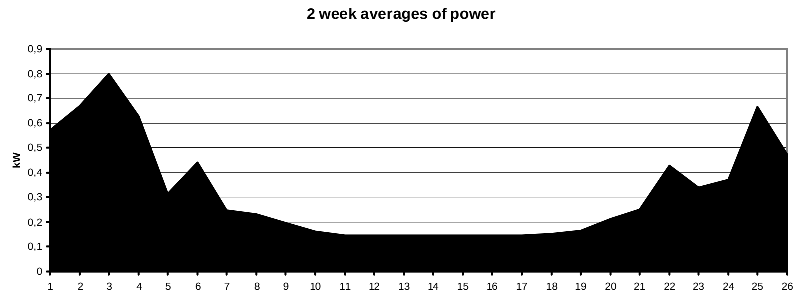






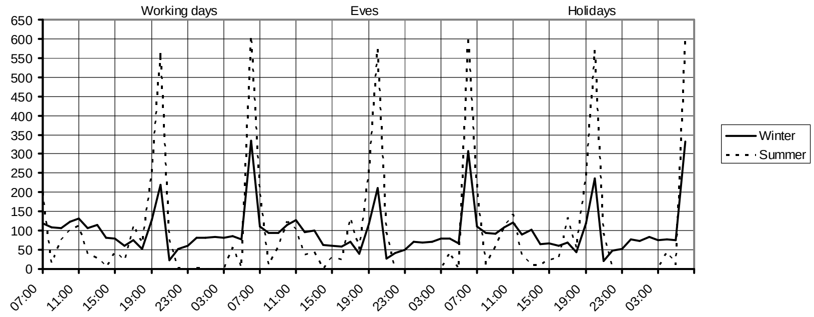


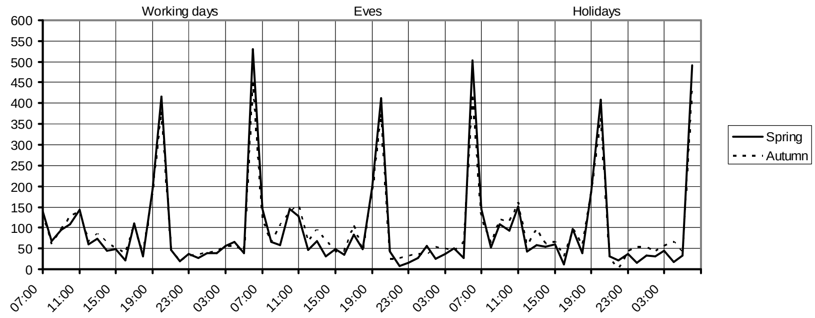
Profile: Modern GSHP 70% capacity. Detached passive house. Annual electricity use: 2 800 kWh

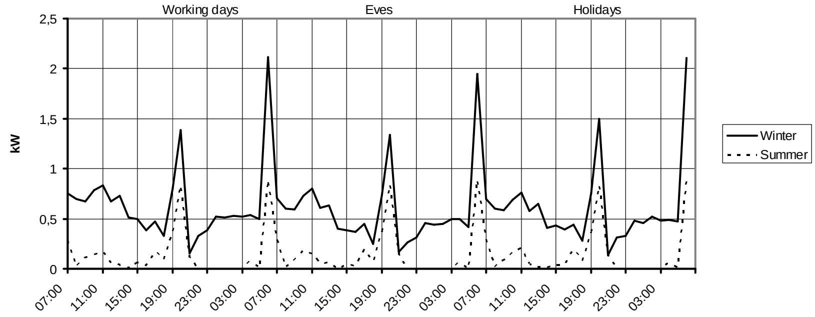


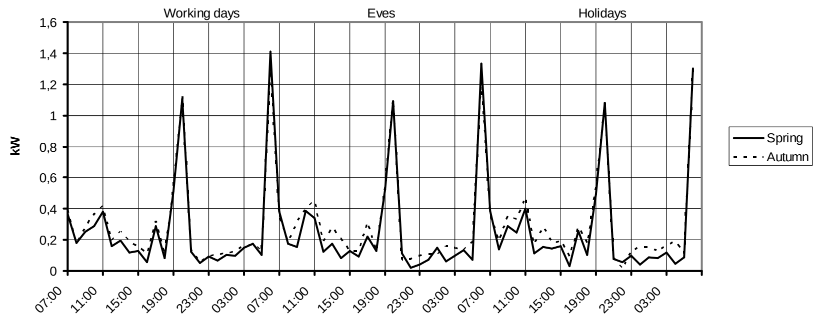
2 week indices

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
178	208	250	196	97,7	137	77,4	72,3	61,3	50	45,5	45,9	45,5	45,2	45,4	45,6	45,4	47,1	51,4	66,6	78	133	106	116	208	148

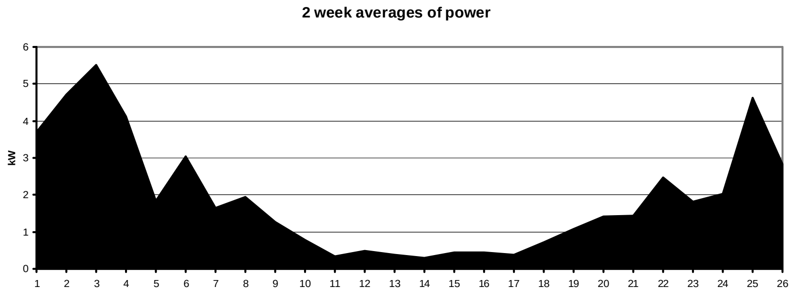






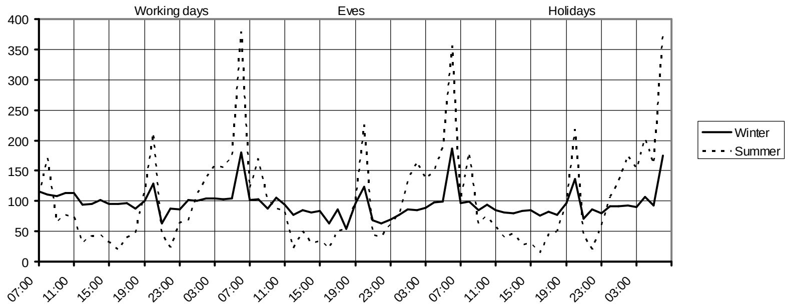


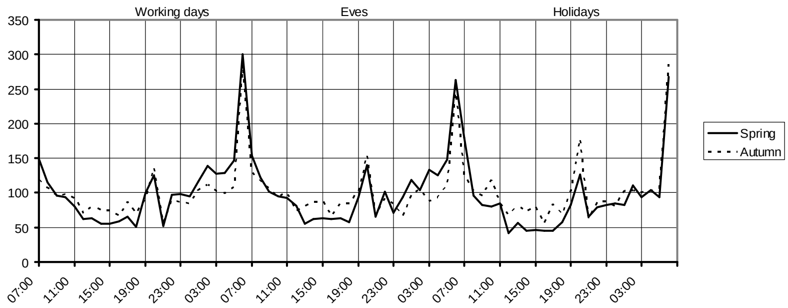
Profile: Modern GSHP 50% capacity. Detached house from the 70's. Annual electricity use: 16 700 kWh

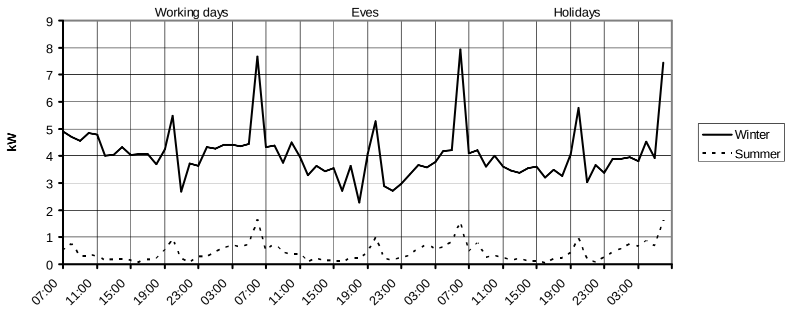


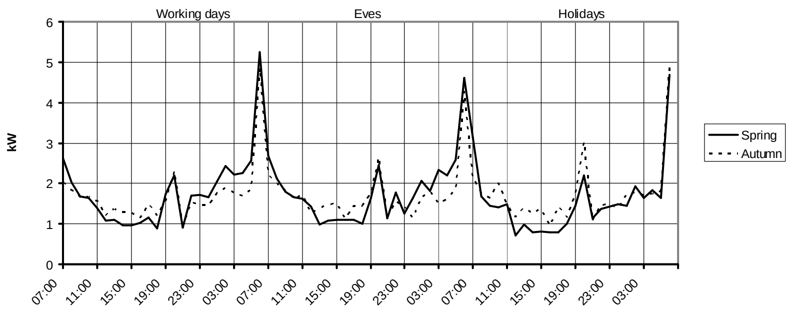
2 week indices

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
193	246	289	216	96	159	85,7	101	66	41,2	17,6	25,5	19,5	15,5	22,9	23	20,2	37,2	55,9	73,7	75,2	129	95,5	106	242	148

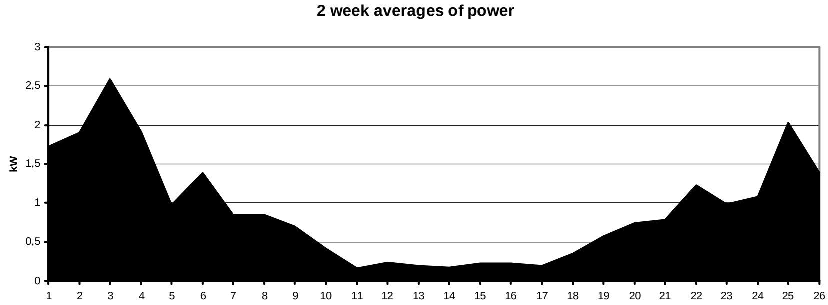






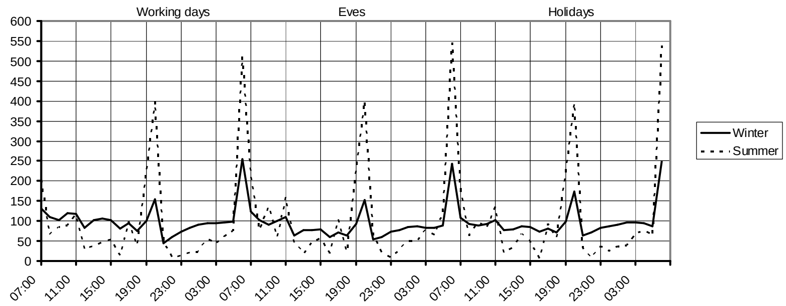


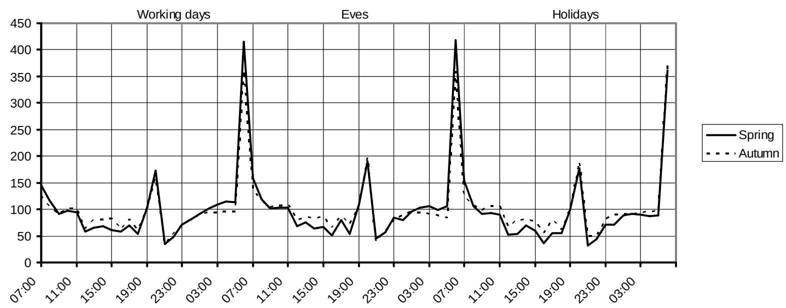
Profile: Modern GSHP 50% capacity. Detached house from the 2000's. Annual electricity use: 8 000 kWh

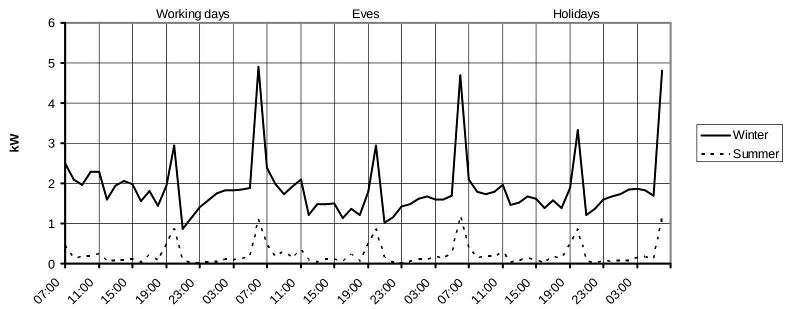


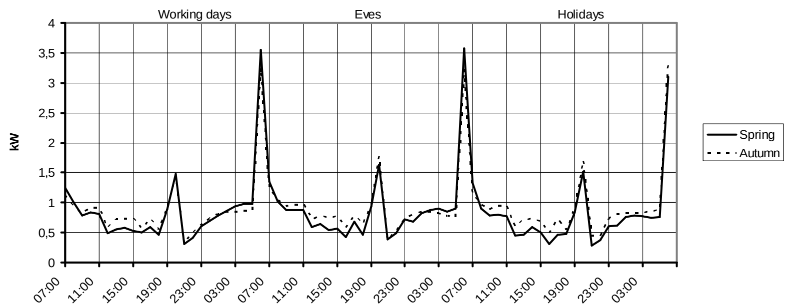
2 week indices

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
188	208	283	209	106	151	91,8	92	75,7	44,8	17,5	25,9	21,3	18,2	24,7	23,9	21,3	37,8	62,8	81,1	85,7	134	108	117	221	151

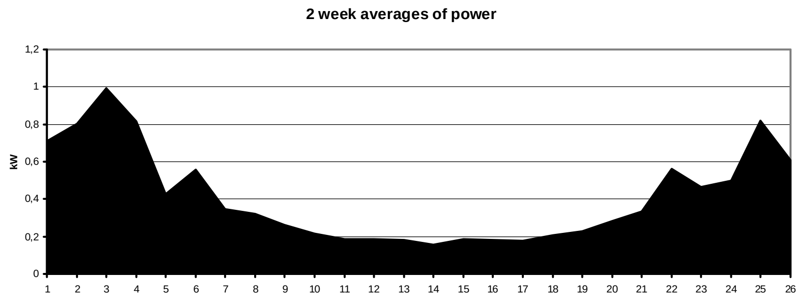






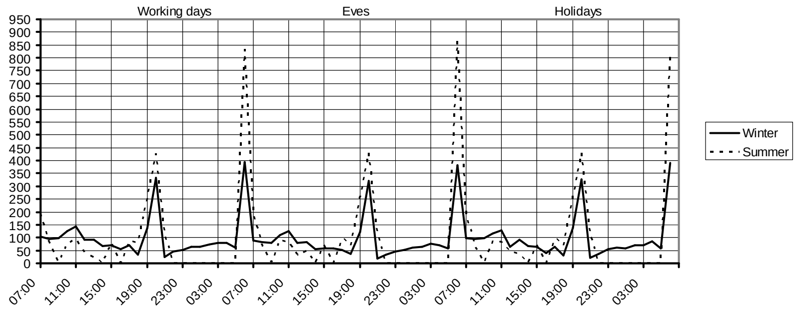


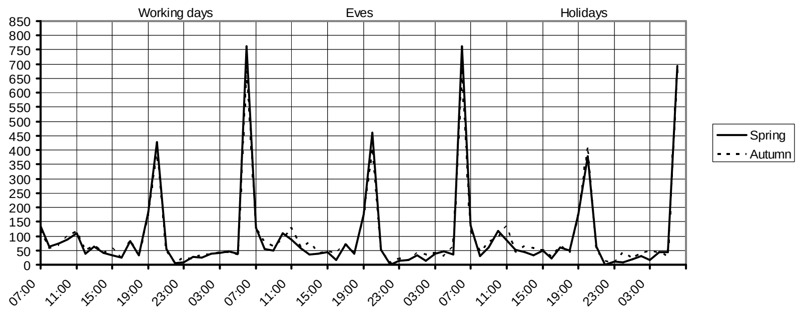
Profile: Modern GSHP 50% capacity. Detached passive house. Annual electricity use: 3 600 kWh

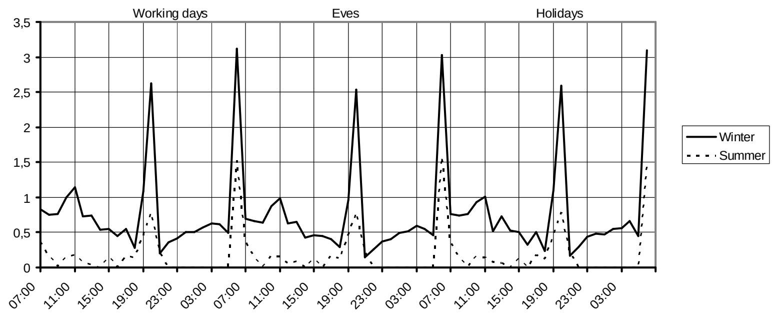


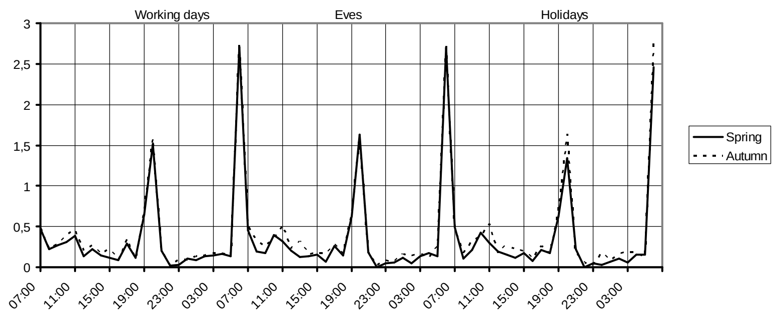
2 week indices

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
172	195	241	198	104	135	83,9	77,7	63,8	52,4	45	45,3	44,1	37,5	45	44,2	43,3	50,7	55	68,9	81,1	136	113	121	199	148

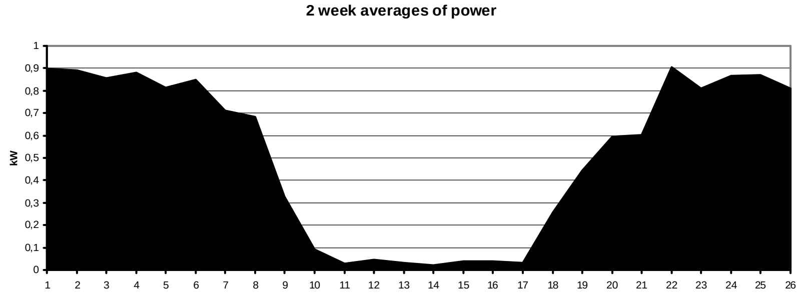






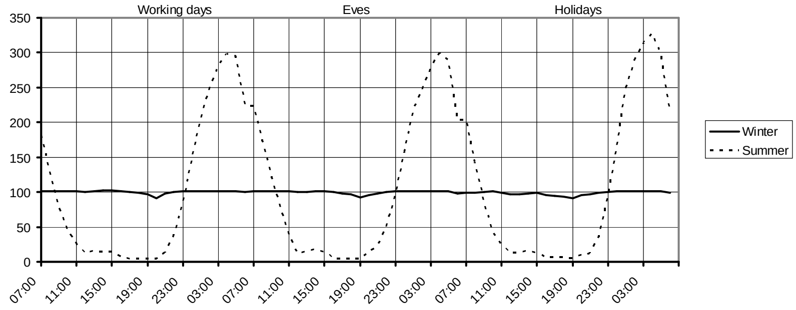


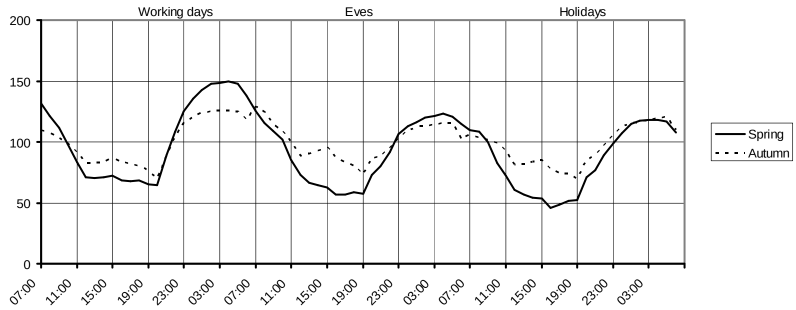
Profile: Auxiliary AAHP. Detached house from the 70's. Annual electricity use of HP: 4 500 kWh

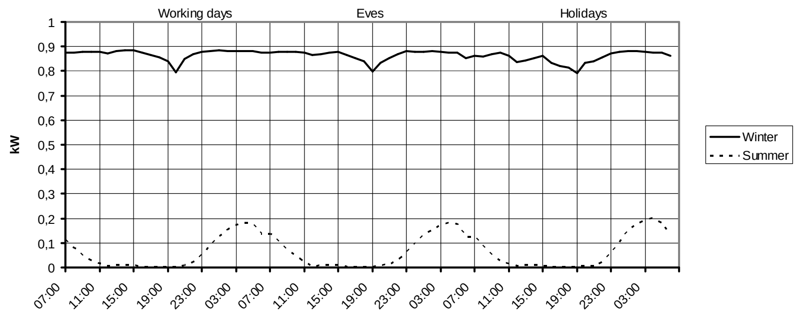


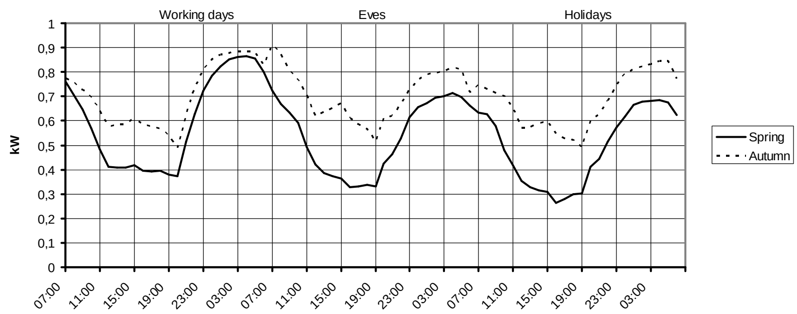
2 week indices

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
174	173	166	171	158	165	138	133	63,8	17,7	5,28	8,74	5,85	3,87	7,28	7,78	6,39	50,1	86,1	116	117	176	157	168	169	157



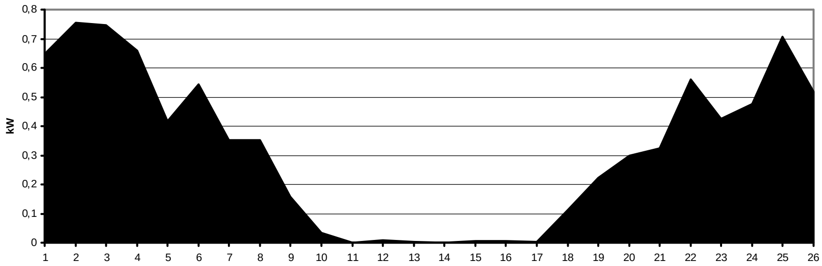






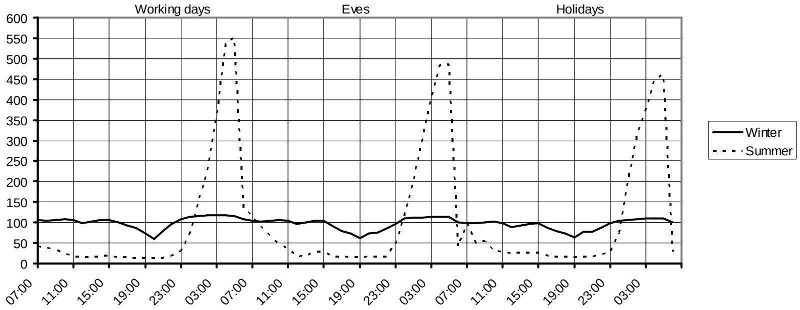
Profile: Auxiliary AAHP. Detached house from the 2000's. Annual electricity use of HP: 2 800 kWh

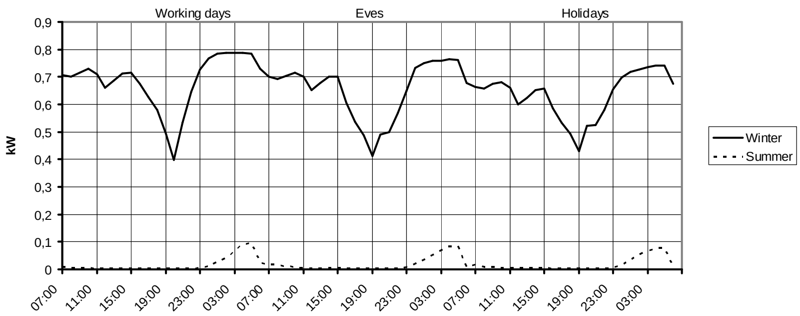
2 week averages of power

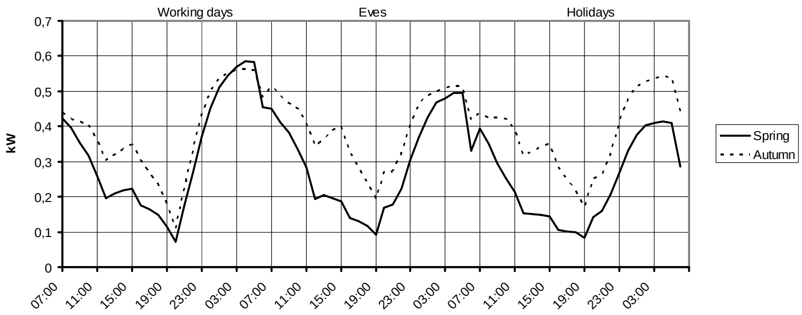


2 week indices

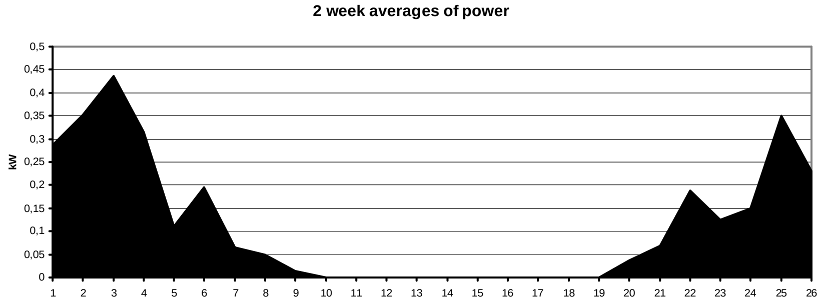
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
202	236	233	206	130	169	110	110	49,7	10,6	0	2,53	1,07	0,07	1,84	1,69	0,87	34,9	69	93	101	175	133	149	220	162







Profile: Auxiliary AAHP. Detached passive house. Annual electricity use of HP: 1 000 kWh



2 week indices

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
251	308	381	275	96,7	171	57,3	43,8	11,6	0	0	0	0	0	0	0	0	0	0	32,6	59,7	165	110	130	306	202