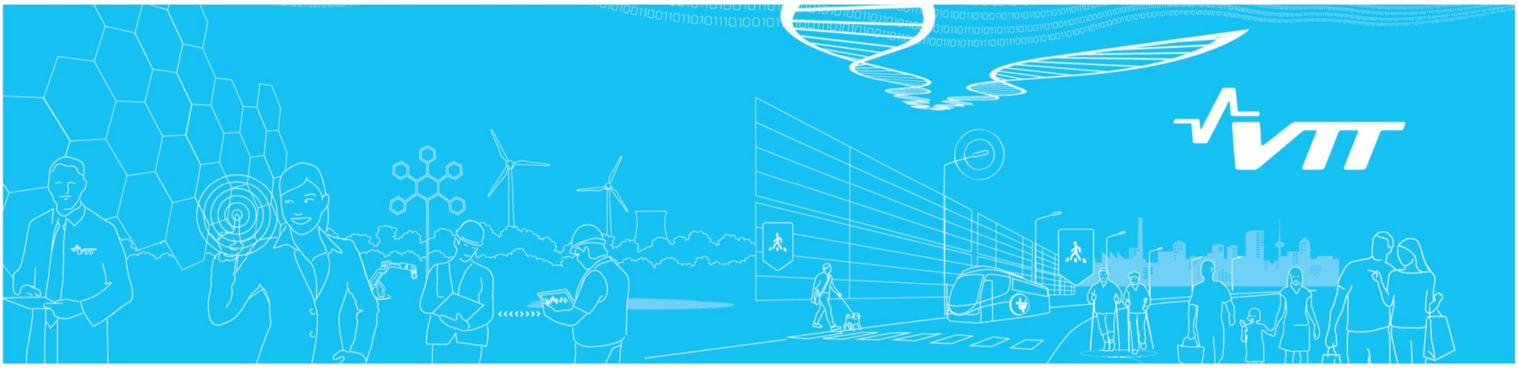
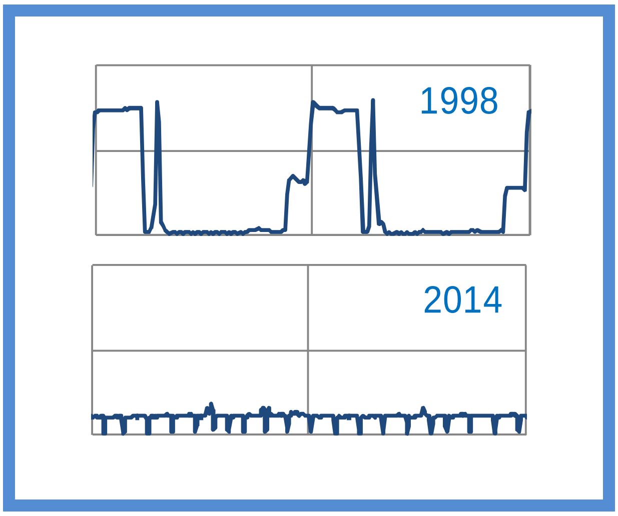


RESEARCH REPORT

VTT-R-02516-14



Comparing Ground Source Heat Pump System with Full Storage Heating System used in Detached House in Helsinki

Author: Marja-Leena Pykälä

Confidentiality: Public

Report's title	
Comparing Ground Source Heat Pump System with Full Storage Heating System used in Detached House in Helsinki	
Customer, contact person, address VTT BA 213, Tuula Mäkinen	**Order reference** Tuula Mäkinen
Project name IND BA213 Pienet pera 2014 - Lämpöpumppumittaukset	**Project number/Short name** 86237-1.5
Author(s) Marja-Leena Pykälä	**Pages** 50 + 3
Keywords full storage heating system, ground source heat pump system, electric power and power quality measurement	**Report identification code** VTT-R-02516-14

Summary

The heating system of a detached house was changed from a full storage electric heating system to a ground source heat pump system. The location of the building is in Southern Finland. The building itself has remained the same with both heating systems. Some electrical household appliances have quite possibly been renewed during the measuring period from 1996 to 2014. The housing practises and the weather conditions have varied to some extent from year to year during the measuring period. Still, the electric energy used for heating is dominating the measuring results in both cases.

The electric power and the related quantities of the full storage heating system have been measured during the years 1996 – 1998. In April 2013 the heating system was renovated. After the change the measurements were repeated and additionally some power quality measurements were performed. The measured results show a clear reduction of active power and electric energy consumption. The active power is 44% and the yearly electricity consumption is 35% in the new heating system compared to the earlier system. Still, it has to be noted that only one year's experience of the new system is available. During the first year the control of the indoor temperature was not ideal. The weather conditions refer to only one year and there was only one cold week in January 2014.

Power quality measurements did not show any problems in the operation of the ground source heat pump system.

Confidentiality	Public

Espoo 16.9.2014

Written by	**Reviewed by**	**Accepted by**
Marja-Leena Pykälä, Senior Researcher	Tiina Koljonen, Research Team Leader	Tuula Mäkinen Head of Research Area

VTT's contact address

VTT, P.O. Box 1000, 02044 VTT, Espoo, Finland

Distribution (customer and VTT)

VTT
Yrjö Rantanen, Uurtajantie 4, 00340 Helsinki

Preface

The analysis of these measurements was originated by Pekka Koponen from VTT, who already had measuring history of the detached house in Uurtajantie 4, Helsinki from other projects. The measuring results from previous heating system (1996-1998) and the new system (2013-2014) were available. Yrjö Rantanen, formerly working at VTT and the owner of the detached house in question, provided the background information of the building and technical data of the heating systems. He also gave the access code to his information in the Sävel-service of Helsingin Energy. Seppo Vehviläinen from MX Electrix Oy explained the details of the power quality monitoring meters used in the new heating system and gave the user identification for the measuring data collected by the company.

Thank you all for the co-operation.

Espoo 16.9.2014

Authors

Contents

1. Introduction

The electric power and the related quantities have been measured for the detached house during the years 1996 – 1998. At that time the full storage electric heating system was in use, the size of heat storing tank was 3.7 m^3 and the heating elements were resistors with maximum power of 27 kW at 220/380 V. The heat storing tank provided also domestic hot water.

In April 2013 the heating system was changed to ground source heat pump system with an integrated hot water tank. After the change the measurements were repeated and additionally some power quality measurements were performed.

The building itself has remained the same as in earlier measurements. Household electric appliances have quite possibly been renewed, but it has not been studied in this case. The housing practises and the weather conditions vary to some extent during the measuring period. Still, the heating energy is dominating the electricity consumption in both cases.

The measurements were done as a part of different projects:

1996-1998 ENETE (Promoting Energy Efficiency by Energy Companies) funded by TEKES (the Finnish Funding Agency for Innovation) and the ENETE partners.

2013-2014 SGEM (Smart Grids and Energy Markets), Work Package(WP) 3.2 Demand response funded by TEKES (the Finnish Funding Agency for Innovation) and the SGEM WP 3.2 participating companies.

In this report the results of electric power measurements of the old system, full storage electric heating system will be compared to the new one, the ground source heat pump heating system. Differences in total electric energy consumption, typical loading cycles are studied. In the latter case also power quality quantities are emphasised.

2. Goal

The goal of this study is to compare different heating systems of a detached house. The heating system was changed from a full storage electric heating to a ground source heat pump system. Electric power was measured both before (1996-1998) and after change work (05/2013 - 04/2014). The continuous energy consumption 2013-2014 is measured and reported by Helsingin Energia Sävel-services.

In this case the building itself has remained the same while the weather and operation conditions may vary from year to year. The following quantities will be analysed and reported here.

A. overview of the measured active (P) and reactive power (Q) along the measuring periods before and after the heating system change
B. examples of the quantities P, Q and phase voltage U_v during the maximum consumption, both one week and 24 h duration
C. comparison of energy consumption before and after the renovation based on the service of the distribution network operator
D. power quality quantities measured only after the renovation will be analysed as far as practical.

3. Descriptions

3.1 Background information of the building

The main field test was performed in a large, single family detached house located in Helsinki. The house consisted of three floors. The electric appliance mixture in the house is very extensive and besides this the house is heated with an accumulating electrical heating system until April 2013. The electrical heating load is dominating in electric consumption, (Pihala 1998).

The most important properties of the building are as follows (Pihala 1998), (Rantanen 2014):

- building is a single family detached house
- external surface area of the building is 99 m^2
- gross floor area is 275 m^2, the gross indoor volume 690 m^3
- detailed areas and room heights are as follows: heated space of the basement - height 2.09 m, volume 251 m^3; lower residential floor - room height 2.46 m, volume 283 m^3 and the upper residential floor - room height 2.43 m, floor area 63 m^2, volume 153 m^3
- number of residents: 2
- location of the building is in Southern Finland, address: Uurtajantie 4, Helsinki
- distribution network operator: Helsingin Energia, Helen Sähköverkko Oy.

The time-of-day distribution tariff with controlled night-time load was in use until April 2013: The daytime distribution is valid from Monday to Saturday, from 07 to 21 o'clock. The night-time distribution is valid at other times. This tariff requires a control system for load approved by Helen Sähköverkko Oy (Helsingin Energia) and allows Helsingin Energia to control the electric storage heating load. The electric energy and distribution prices before April 2013 are given in Table 1.

The full storage electric heating system was changed to the ground source heat pump system on 6.4.2013. At that time the distribution tariff type was changed from 'Time-of-day distribution tariff with controlled night-time load' to 'Time-of-day distribution tariff'. The daytime distribution is valid from Monday to Friday from 07 to 20 o'clock. The current electric energy and distribution prices are given in Table 2.

The prices in these two tables have been valid in January 2013 before the renovation of the heating system and in January 2014 after the renovation. In 2014 some fees have been increased and some decreased, resulting practically the same total price. The defined daytime has also changed while the distribution tariff was changed, from Mon-Sat 07-21 to Mon-Fri 07-20.

During these periods the electricity consumption has been divided into 5% daytime and 95% night-time with the full storage system and with the ground heat pump heating system into 32% and 68% proportions respectively. The total electric energy consumption has decreased 60-65%.

Table 1. Time-of-day distribution tariff with controlled night-time load, invoice 8.1.2013 Uurtajantie 4, (Helsingin Energia).

Description	**Charge**	**Unit**
Electric energy: Time-of-day electricity A		
Basic charge	0,00	€/month
Daytime electricity, Mon-Sat 07-21	7,24	c/kWh
Night-time electricity*	5,77	c/kWh
Distribution:		
Basic charge	16,40	€/month
Daytime, Mon-Sat 07-21	3,32	c/kWh
Night-time*	1,27	c/kWh
Electricity taxes	2,09469	c/kWh
Controlled night-time load	27,00	kW
Contracted power charge	9,37	€/kW, year

Table 2 Time-of-day distribution tariff, invoice 9.1.2014 Uurtajantie 4, (Helsingin Energia).

Description	**Charge**	**Unit**
Elecric energy: Time-of-day electricity A		
Basic charge	3,30	€/month
Daytime electricity , Mon-Fri 07-20	6,39	c/kWh
Night-time electricity*	5,65	c/kWh
Distribution:		
Basic charge	16,53	
Daytime, Mon-Fri 07-20	3,32	c/kWh
Night-time *	2,19	c/kWh
Electricity taxes	2,11172	c/kWh

* The price of night-time distribution and electricity is in force at other times, as well as on the eve of May 1, Midsummer's Eve, Christmas Eve and New Year's Eve (Helsingin Energia).

3.2 Full storage electric heating

3.2.1 Heating system

The most important properties of the full storage heating detached house:

- volume of the heat storing water tank 3,7 m^3
- the heat storing tank provided also domestic hot water
- max power of the resistors in the heat storing tank was originally 27 kW at 220/380 V with switching in two steps, first 9 kW and then 27 kW.

The load was controlled by Helen Sähköverkko Oy for so called night time load. The heating load has been switched on in two steps, first 9 kW and then 27 kW, the loads at 230/400 V are 10 kW and 30 kW. In the evenings one third of the heating power is switched on slightly after 21:00 and then full heating power turns on about 4 hours later (Koponen, 2010). The room temperature was controlled by the outdoor sensor regulating the radiator supply water, device Danfoss ECT. The control of the old system operated really well (Rantanen 2014).

3.2.2 Measuring system

The measurements were performed with the Mittrix kWh-meter, type MXPQ manufactured by the Finnish company Mittrix Oy for Non-Intrusive Load Monitoring NIALM-recorder. No current transformers were needed. The meter was calibrated specially: at the no load situation, the phase angle between voltage and current was 8 degrees. The sampling rate was 128 samples/phase during a time interval of 940 ms and the accuracy class Cl. 1.0. The recording interval was 15 minutes, (Pihala 1998).

The following power quantities were recorded:

Pk	total active power
Qk	total reactive power (Fryze's reactive power)
Urk, Usk, Utk	line to neutral voltage, RMS value, phases L1, L2, L3
Prk, Psk, Ptk	active power, phases L1, L2, L3
Qrk, Qsk, Qtk	reactive power, phases L1, L2, L3.

3.3 Ground Source Heat Pump System

3.3.1 Heating system

The heat pump system is Danfoss DHP-H 12. The rated power or heat capacity is 12 kW. The technical data of DHP-H is shown in Appendix A, Table A1. The performance values are defined according to standard EN 14511-2 based on both B0W45 and B0W35 conditions, i.e. brine 0 °C to radiator supply water 35 °C or 45 °C and including circulation pumps. The heat power or capacity is 11.0 kW, COP (Coefficient of Performance) 4.2 and electrical input power 2.6 kW (B0W35). The rated values of the compressor is 4.4 kW, 400 V and the auxiliary heater 3/6/9 kW, 400 V to be switched in three steps. The compressor is equipped with a soft starter with two phases connected via triac and one phase straight. This reduces the start current to the value 14 A. The total power of circulating pumps is about 500 W (450 W and 80 W). The depth of the ground well is 225 m (Danfoss 2014), (Rantanen 2014).

Standard EN 14511-2 defines also higher outlet temperatures, 55 °C and 65 °C for the heat pump performance tests. These results were not available. Now the maximum setting for outlet temperature is 56 °C.

The room temperature is controlled by an outdoor temperature sensor and the internal temperature regulator of the ground heat pump. The outdoor sensor was located on the wall of the building. The owner of the house considers that the control of the new heating system is of poor quality. The hysteresis of the room temperature is large when increasing or decreasing the temperature. During the first operating year there have been no problems with the domestic hot water heating system with volume 180 l (Rantanen 2014).

3.3.2 Measuring system

Two power quality monitoring meters EDF3GL 4605, manufactured by MX Electrix Oy, were installed to meter simultaneously the total electricity consumption of the building and the ground heat pump electric energy including the compressor and circulating pumps. The meters were delivered for the tests by VTT. The heat pump system has been installed in April 2013. No current transformers are in use. One meter is recording the total energy of the building and the other the heat pump system including the circulating pumps. The sampling rate of voltage and current is 409 Hz or 2.4 ms. These values are used for instance in the calculation of average RMS (root-mean-square value or effective value) values like *Umin/max* over 100 ms and *Imin/max* over 20 ms. Based on these values the average 5 min or 10 min RMS values are calculated for continuous recording of the quantities. The measuring accuracy class is 1.0 for active power and 2.0 for reactive power.

The measured quantities are:

P	total active power/ W
Q	total reactive power (Fryze's)/ VAr
f	frequency/ Hz
ULI-UL3	phase to neutral RMS voltage/ V
U12, U23, U31	phase to phase RMS voltage/ V
IL1-IL3 current/ A	I RMS current
Umax1, Umin1	max/min voltage 100 ms average/ V
Umax2, Umin2	max/min voltage 100 ms average/ V
Umax3, Umin3	max/min voltage 100 ms average/ V
Imax1, Imin1	max/min current 20 ms average/ A
Imax2, Imin2	max/min current 20 ms average/ A
Imax3, Imin3	max/min current 20 ms average/ A
PL1-PL3	active power, phase values/ W
QL1-QL3	reactive power, phase values/ VAr
SL1-SL3	apparent power, phase values/ VA
PstL1-PstL3	short time flickering, phase values
DL1-DL3	THD, total voltage distortion, phase values/%
U2U1, U0U1	U2/U1 voltage unbalance, U0/U1 zero component/%
	U2 negative, U1 positive and U0 zero sequence components
UdcLI-UdcL3	DC content of the voltage, phase values/%
PFL1-PFL3	power factor, phase values
Q1L1-Q1L3	fundamental frequency reactive power, phase values/ VAr
Dmax	total voltage distortion, maximum/%
U2U1max	*U2/U1* maximum negative sequence components/%
PFmin	minimum power factor
U0U1max	*U0/U1* maximum zero sequence component/%
S	apparent power/ VA
U3L1-U3L3	3rd harmonic voltage/%
U5L1-U5L3	5th harmonic voltage/%
U7L1-U7L3	7th harmonic voltage/%
EP, EP-	total active energy (+) and (-)/ Wh
EQ/ EQ-	total reactive energy (+) and (-)/ VArh.

Altogether 68 quantities were recorded. First 12 days have been measured at ten minutes interval and after that at five minutes interval. In this report the measuring data of electric power quantities was analysed until the end of April 2014.

3.3.3 Measuring service of the distribution network operator

The distribution operator provides nowadays yearly, monthly, weekly daily and hourly results of the electricity consumption metered with a smart meter which is remotely read. This SÄVEL service by Helsingin Energia has been available since 2010 for the building located in Uurtajantie 4. The owner of the building Yrjö Rantanen provided the user identification to this service to be used in this study. The meter gives electric energy readings separately for night-time and daytime; Sävel-service gives the total electric energy (Sävel service 2014).

4. Limitations

Only electric power and during 2013-2014 also power quality quantities were measured. Indoor/outdoor or circulating water temperatures were recorded. The maximum heating capacity of the new system was not measured or calculated for estimating the performance of the ground source heat pump in outdoor temperatures of -25 ° or even lower.

The outdoor temperatures shown in this report refer to general values in Helsinki Kaisaniemi or Helsinki-Vantaa Airport. The control of the ground source heat pump is based on outdoor temperature sensor located on the wall of the building, but this temperature has not been recorded.

There are some missing data in all measuring series. Reasons are for instance that the system was switched off during absences of the family; faults due thunderstorms or other reasons; change of the recording interval or change of the record file.

5. Measurements

5.1 Results of full storage electric heating system

Active (*P*) and reactive power (*Q*) measured in 1996-1998 for full storage heating system are shown in Figure 1 - 6 starting from the page 25. The results *Pk, Qk* and *Urk* to *Utk* are shown in a more detailed time scale for weeks having the minimum and maximum energy, see Figure 15. Additionally, 24-hour records are shown for the days with the minimum and maximum energy in Figure 16.

The results clearly show that the dominating load is the heating resistor of 30 kW. In the evenings 10 kW of the heating power is switched on usually at 21:00 and full load from 0:45 to 01:15. In the summertime only 10 kW heating has been in use. The duration of the heating period is controlled by the temperature limiting thermostat of the storage tank unless switched off by the utility ripple control system.

Table 3 shows the maximum and minimum measured active power, the reactive power phase to neutral voltages at the same instant and the maximum and minimum daily and weekly energy consumption values. Due to gaps in the measuring data not all daily or weekly values could be calculated. These values are compared to those obtained from the results of the new system.

The measuring data of full storage heating system has earlier been analysed in the reports (Pihala 1998), (Seppälä 2010) and (Koponen 2010). The main emphasis in these reports has been Non-intrusive appliance load monitoring (NIALM) system, Model for dynamic load control and Comparison of price control methods.

5.2 Results of ground source heat pump system

Active (P) and reactive power (Q) measured from April 2013 to April 2014 for ground source heat pump system are shown in Figures 7- 9 starting from the page 31. Additionally, the power of the compressor and circulating pumps was separately measured and recorded in Figures 10-12. The results P, Q and UL1 to UL3 are shown in a more detailed time scale for weeks having the minimum and maximum energy in Figure 17. Additionally, 24-hour records are shown for two days during the weeks with the minimum and maximum energy , see Figure 18. The separate measurements of the heat pump and circulating pumps are shown in Figures 19 and 20.

The coldest days during the measuring period from May 2013 to April 2014 were during 23-24.1.2014, 18-20 °C. Depending on the time and location the heating cycle has been two and half hours with 90-95% operating time ratio. The average power of the heat pump system during these operating cycles has been 4050 W including the circulating pumps. Between the heating cycles the measured power was 145 W. When both pumps are running their rated power is 500 W and the input power of the compressor is 3.55 kW, 30% above the compressor input power in the test conditions (B0W45). Indoor, local outdoor and radiator supply water temperatures were not recorded. So, the actual performance of the heat pump is not known. The auxiliary heaters, steps 3/6/9 kW, have not been switched on during the cold days in January 2014. If the room temperature was too low, at least the settings shall be checked.

The auxiliary heater 9 kW has been switched on for 5-15 minutes every other week in order to heat the domestic hot water to at least 65 °C, which is called the legionella function.

5.3 Comparison of the electric power quantities between the two heating systems

The measuring results of full storage heating system and ground source heat pump system are compared in Table 3. The separately measured results of the heat pump system including the compressor and two circulating pumps are shown too. The values in the table are common for both heating systems. It shows the maximum measured active power and at the same instant the reactive power. Maximum and minimum phase to neutral voltages are single values of all readings over each heating system measuring results. The maximum and minimum weekly electric energy consumption values and the corresponding daily values are shown in Table 3. Due to the gaps in the measured data not all daily or weekly values could have been calculated.

Table 3 Measured maximum and minimum quantities during 1996-1998 and 2013-2014

Electric power quantity	**Full storage heating**	**Ground source heat pump**	**Heat pump system separately**
Interval of readings	15 min	(10 min) 5 min	(10 min) 5 min
P/W max min	33038 311	14471 32.50	10643 45.50
Q/VAr max min (at the same time as P)	1279 -478	3199 12.85	2538 -61.92
Uv1/V max min	240.2 218.7	235.3 224.5	235.5 224.1
Uv2 V max min	240.2 202.0	237.6 227.1	237.3 226.8
Uv3/V max min	239.6 193.9	236.7 225.9	236.6 225.6

The maximum measured active power of the building heated with the ground source heat pump system is 45% compared to that of the full storage heating system. The proportion of the separately measured active power of heat pump and circulating pumps to the total maximum power is 72%, during simultaneous measurements at maximum power.

The power factor (*PF*) is calculated based on Fryze's reactive power, which is available for both measuring periods. The power factor values vary a lot at different loadings, actually from zero to one. Highest loadings during the full storage heating period with resistive load from 10 kW to 30 kW resulted in *PF* 1.0. During measurements of the heat pump system the highest loading having the auxiliary heater on results in *PF* 0.98. The normal operation of the heat pump and domestic appliances results into the active power of 4-5 kW and *PF* 0.85. Low active power values are mostly single phase loadings and PF can vary a lot. Low *PF* at low active power values is not as significant because of the relative low reactive power value.

5.4 Comparison of electric energy by Sävel-service

The electric energy was measured or calculated from the power measurements before and after the renovation. This comparison is based on the measurements of Helsingin Energia because of the gaps in the power measurements in order to get the overall behaviour of the two heating systems. Sävel-service gives one hour average values.

Monthly and weekly measuring results are shown in Figure 21 and Figure 22 starting from the page 45. The full storage heating system was in use until 04/2013 and the ground source heat pump system after that. The daily results of 01/2013 and 01/2014 are shown in Figure 23. The results are summarized in Table 4. The electricity consumption of the full storage heating system during the year 2012 represents the measured consumption during the year 1997 having the minimum outdoor temperature conditions close one another.

Table 4 Maximum and minimum electric energy 2010-2014 (Sävel-service 2014)

Measuring period 2010 – 3/2013	**Full storage heating, electric energy, W/kWh**	**Measuring period 5/2013 – 4/2014**	**Ground source heat pump, electric energy, W/kWh**
Year 2010	39964	-	-
Year 2011	34432	-	-
Year 2012	37469	05/2013 – 04/2014	13652
Month 12/2012, max 6/2012, min	5190 1350	Month 1/2014, max 6/2013, min	2305 452
Week 05/2012, max 30/2012, min	1518 277	Week 03/2014, max 23/2013, min	637 21.8
Day 5.2.2012, max 8.7.2012, min	252 9.45	Day 23.1.2014, max 9.6.2013, min	101 3.09

The total electricity consumption of the building with the heat pump system was also measured by the power quality monitoring meter (Electrix). The electric energy was 13221 kWh during 1.5.2013 – 19.4.2014. Some readings were missing in the end of April 2014, so, the total electricity consumption was estimated using the average daily value of 32 kWh for the end of April. The consumption calculated for the whole year 05/2013 – 04/2014 was 13567 kWh, which differs -0.6% from that of the Sävel-service.

The renovation of the heating system resulted in a remarkable reduction of energy consumption. On the yearly level the electric energy consumption of the heat pump system is 34% to 40% compared to the full storage heating system. However, it should be noted that there is only one year's experience and measuring results of the new heating system.

Both old and new electricity consumption values include the household electric energy consumption and the electric energy for the heating and the domestic hot water system.

5.5 Household energy

Helsingin Energia (SÄVEL) meters the total electric energy of the building, i.e the heating system and the household energy. The Electrix-meters measure practically simultaneously the total electric energy of the building and separately the energy of the heat pump system including the circulating pumps. The household electric energy consumption ($W_{household}$) was calculated by subtracting the heat pump energy ($W_{heat\ pump}$) from the total energy (W_{total}). The results are shown in Table 5 and Figure 24.

Table 5. Household electric energy during 05-2013 and 04-2014 calculated as a subtraction of the heat pump energy from the total energy.

Month	W_{total} Sävel **(kWh)**	$W_{heat\ pump}$ Electrix (kWh)	**Household** W_{total}-$W_{heat\ pump}$ (kWh)	Note
Jan-13	4908			Full storage
Feb-13	4558			Full storage
Mar-13	5007			Full storage
Apr-13	1410			Change to heat pump
May-13	699	261.5	437,5	
Jun-13	452	192.7	259,3	
Jul-13	596	197.4	398,6	
Aug-13	665	256.0	409,0	
Sep-13	915	456.7	458,3	
Oct-13	1105	742.5	362,5	
Nov-13	1117	920.9	196,1	
Dec-13	1766	1189.4	576,6	
Jan-14	2305	1822.8	482,2	
Feb-14	1497	1140.7	356,3	
Mar-14	1301	1106.2	194,8	
Apr-14	1234	836.6	397,4	
12 months	**13652**	**9124**	**4528**	

Heat pump and Electrix energy meters switched off 31.5-10.6.2013 and 18-20.12. 2013

The reference consumption for a detached house having similar properties is minimum 4500 kWh, average 6100 KWh and maximum 9100 kWh presented by Fortum Customer Service (Fortum 2014). The building properties were given as in Cl. 3.1: floor area 275 m^2, gross volume 690 m3, building year 1970 and for comparison of the household consumption only, no electric heating. The realized household electricity consumption is close to the lower limit.

Supposing that the household electric energy has been practically the same in recent years 1996-2014 the comparison of heat pump system to full storage heating systems will result into 26% - 31%.

6. Power quality measurements during 2013-2014

6.1 General

Low-voltage supply characteristics defining power quality were measured applying standard SFS-EN 50160 (2010). The standard makes distinction between continuous phenomena and voltage events. For some continuous phenomena, limits are specified, but for voltage events, only indicative values are given. The standard nominal voltage is *Un* = 230 V. The nominal frequency of the supply voltage is 50 Hz (SFS-EN 50160:2010).

Limits for the continuous phenomena are given for supply voltage and frequency. The fundamental frequency measured over 10 s shall be within a range of 50 Hz ± 1% during 99,5% of a year and 50 Hz + 4% / - 6% during 100% of the time. Supply voltage variations should not exceed ±10% of the nominal voltage *Un*. Under normal operating conditions:

- mean RMS. values of the supply voltage shall be within the range of *Un* + 10 during each period of one week 95% of the 10 min mean RMS values of the supply voltage shall be within the range of *Un* ± 10%; and
- all 10 min%/ - 15% (SFS-EN 50160:2010).

The measuring results and SFS-EN 50160 limits for the voltage events are given in the next item case by case.

The requirements for the current harmonics for low-voltage systems and current ≤ 25 A are given in the standard IEC 61000-4- 4, the distribution company Helsingin Energia specifies the limit values for generating systems in Table 6.

Table 6 Recommended limit values for current harmonics at the network connection point (Helsingin Energia 2009)

<table>
<tr><th>Reference current</th><th colspan="2">Recommended limit values</th></tr>
<tr><td>≤ 25 A</td><td colspan="2">Equipment complying with relevant standards may be used</td></tr>
<tr><td>25 A ... 200 A</td><td colspan="2">Max total current distortion may not exceed 10% of the reference current</td></tr>
<tr><td rowspan="7">> 200 A</td><td colspan="2">Max total current distortion may not exceed 8% of the reference current. Minimum current distortion of 20 A is accepted. Moreover, for individual harmonics, the following limits exist:</td></tr>
<tr><td>Order of harmonics, n</td><td>Acceptable value from the reference current</td></tr>
<tr><td>< 11</td><td>7.0%</td></tr>
<tr><td>11–16</td><td>3.5%</td></tr>
<tr><td>17–22</td><td>2.5%</td></tr>
<tr><td>23–34</td><td>1.0%</td></tr>
<tr><td>> 34</td><td>0.5%</td></tr>
</table>

Main supply fuse links are 25 A. Actually no requirements are given for the current distortion of the heat pump system in question. In the range 25 A-200 A the maximum total distortion would be 10% of the reference current.

6.2 Measuring results of low-voltage supply characteristics

6.2.1 Supply voltage and frequency

During 2013-2014 the voltage was measured both as phase to neutral and phase to phase values, mostly five minutes interval is used. In earlier measurements 1996-1998 phase to neutral voltages were measured with 15 minutes interval. Measured maximum and minimum values were within:

2013-2014 *Un* +3%/ - 2%
1996-1998 *Un* +4%/ -16% (all) and + 4%/ -10% (mostly).

The voltage variation in heat pump measurement was well within the limits. The values measured right after the interruptions are ignored. In full storage measurements only one single value was less than -15%, most of the values were within the limits.

The power frequency was measured only during 2013-2014. All measured five minute values were within the limits 50 Hz +0.4% / -0.5%.

6.2.2 Rapid voltage changes

For low voltage, under normal operating conditions, rapid voltage changes generally do not exceed 5% Un, but changes of up to 10% Un with a short duration of the sustained level might occur some times per day under some circumstances. Close 10% changes are normally classified as dips and swells (SFS-EN 50160 2010).

Single rapid voltage changes of the supply voltage changes were calculated from the samples as 100 ms RMS values. Maximum and minimum values of each five minute measuring interval have been recorded. Thus the duration of the voltage change cannot be evaluated. *Umax and Umin* values for each phase are shown in Table 7.

Table 7 Maximum and minimum 100 ms voltage values during 2013-2014.

100 ms RMS values	**L1**	**L2**	**L3**
Δ Umax/%	3%	4%	4%
Δ Umin/%	-15%	-25%	-13%

The minimum values could be classified as dips if the duration is known.

6.2.3 Flicker severity

Intensity of flicker annoyance evaluated by the following quantities:

- short term severity (*Pst*) measured normally over a period of ten minutes;
- long term severity (*Plt*) calculated from a sequence of *N Pst*-values over a two hour interval, according to the following expression:

$$Plt = \sqrt[3]{\sum_{i=1}^{N} \frac{Psti^3}{N}}$$

Under normal operating conditions, during each period of one week the long term flicker severity *Plt* caused by voltage fluctuation should be less than or equal to 1 for 95% of the time (SFS-EN 50160 2010).

The short term severity was measured during 2013-2014, during the first week over ten and after that over five minute periods. The highest flicker severity values are given in Table 8.

Table 8 Flicker severity. Long term severity for two hour periods having Plt > 1,0.

Long term severity, *Plt*	**L1**	**L2**	**L3**
Total energy measurement			
18.5.2013 (20-22)	1.1	1.2	1.1
11.6.2013 (02-04)	1.1	1.1	1.3
Jan-Feb 2014	< 1.0	< 1.0	< 1.0
Separately measured heat pump			
21.4.2013 (10-12)	1.1	0.5	1.8
11.6.2013 (02-04)	1.2	1.1	1.3
Oct-Dec 2013	< 1.0	< 1.0	< 1.0
Jan-Feb 2014	< 1.0	< 1.0	< 1.0

Only few long term severity values exceeded the limit 1.0. The duration of these two hour periods represent only 0.1% of the total measuring period 2013-2014.

6.2.4 Supply voltage unbalance

Under normal operating conditions, during each period of one week, 95% of the 10 min mean RMS. values of the negative phase sequence component (fundamental) of the supply voltage (*U2/ U1*) shall be within the range 0% to 2% of the positive phase sequence component (fundamental). Only values for the negative sequence component are given because this component is the relevant for the possible interference of appliances connected to the system (SFS-EN 50160 2010).

The measured negative phase sequence component values *U2/ U1* were 0.1 to 0.8% of the positive phase sequence. The maximum value *U2/U1max* was also measured and only one single value was 7.1%. First 140 measurements were not reasonable, the readings were thousand%. There was no supply voltage unbalance defined as given in the standard.

6.2.5 Harmonic voltage

Under normal operating conditions, during each period of one week, 95% of the 10 min mean RMS values of each individual harmonic voltage shall be less than or equal to the values given in given in the standard. Resonances may cause higher voltages for an individual harmonic. Moreover, the *THD* (total harmonic distortion) of the supply voltage (including all harmonics up to the order 40) shall be less than or equal to 8% (SFS-EN 50160 2010).

The power quality monitoring meters measured 3rd, 5th and 7th harmonic voltages. The maximum limits given in the standard are 5,0%, 6,0% and 5,0% respectively. The measured values are very low and so are the THD values. As an example some diagrams of harmonic voltage are shown in Figure 25. Three diagrams are shown for both total energy measurement and separate heat pump measurement: at maximum harmonic values, at maximum power and at heat pump running without auxiliary heater. All measured individual 10 minute RMS harmonic voltage values were less than 2%, mostly less than 0.5%. THD values were also less than 2% including only three harmonic order numbers. Maximum *value of distortion during each five or ten minute periods was normally between 2 and 3%,* however, some single values from 15 to 55% have been measured. There was no harmonic voltage problem in the building.

Heffernan reports about Harmonic performance of heat-pumps (Heffernan 2013). It compares air-source air heat pumps mostly driven by a frequency converter with heating capacity from 2.5 kW to 5 kW. Harmonic currents are studied and quite high, single harmonic values were recorded or simulated, 10-15%.

6.2.6 Interruptions of the supply voltage and Supply voltage dips/swells

This study does not include assessing interruptions or voltage dips/swells. Missing measurement data does not give indication of interruptions. Other reasons exist like cases when the system was switched off during absences of the family or faults due thunderstorms or faults of the measuring system.

6.3 Current harmonics

The current harmonics were not measured but estimated using the other measured quantities. Supposing that *Uh* voltages are low and phase to neutral voltage is close the fundamental frequency voltage value the harmonic current, total current distortion *THDI*, was calculated as follows for each phase separately

$$Ih = \frac{\sqrt{Q^2 - Q1^2}}{U}$$

in which	*Ih*	harmonic current, total current distortion
	Q	total reactive power (Fryze's)/ VAr
	Q1	fundamental frequency reactive power / VAr
	U	phase to neutral RMS voltage/ V

The current harmonics were calculated for the separate measuring data of the heat pump system. The readings represent five minutes average value. The RMS reference current used in the calculations was selected according to the main fuse value 25 A. Only a single phase radiator circuit circulating pump is running between the compressor running cycles. The compressor is equipped with the soft starter which reduces the starting current and the current distortion. A complete heating cycle in winter time with current distortion values is shown in Table 9 and Figure 26 as an example. The maximum total current distortion value occurred on phase L1 when the heat pump was switched on or off.

Table 9 Examples of current distortion estimations for the separately measured heat pump system, reference current 25 A.

Date	P(W)	THDI L1	THDI L2	THDI L3	Note
23.1.14 8:30	4 143	1.4%	0.7%	0.8%	
23.1.14 8:35	4 147	1.6%	0.9%	1.0%	
23.1.14 8:40	986	2.5%	0.1%	0.2%	Compressor off
23.1.14 8:45	140	1.3%	0.0%	0.0%	
23.1.14 8:50	141	1.2%	0.0%	0.0%	
23.1.14 8:55	2 945	2.7%	0.6%	0.9%	Compressor off
23.1.14 9:00	3 882	1.5%	0.8%	1.0%	
23.1.14 9:05	3 908	1.6%	0.9%	1.1%	
23.1.14 9:10	3 937	1.7%	1.0%	1.1%	
23.1.14 8:30	4 143	1.4%	0.7%	0.8%	

Helsingin Energia does not recommend any limit values for current harmonics for ≤ 25 A systems and max total current distortion may not exceed 10% of the reference currents from 25 to 200 A. The calculated current harmonics are clearly below the 10% limit.

7. Summary

Based on this study a remarkable reduction in electric energy consumption has been realized by changing the heating system from a full storage heating system to a ground source heat pump system. The measured reductions compared to the full storage heating system are:

<u>Total electric energy</u>

Maximum power	-65%
Yearly energy	-63%
Weekly energy, winter time	-58%
Daily energy, winter time	-69%.

<u>Electric energy for heating including the domestic hot water</u>

Yearly energy for heating	- 72%.

During the summertime the relative differences are even higher. Local outdoor temperature and other weather conditions bring some differences between the years. These conditions have not been recorded, only general temperature values in Helsinki area were available. In these measurements the ground source heat pump operated its first complete year. No long duration minimum temperatures occurred during that period. In the winter 2013/2014 the minimum temperature was -18 °C for one week, in these conditions the maximum operating time was not needed and no auxiliary heaters were in use. So, the maximum performance of the ground heat pump was not realized.

Indoor temperatures have not been recorded in this study. The resident mentioned that the control of the heat pump has now remarkable hysteresis in temperature regulation, which was not the case with the full storage heating system.

The power quality measurements did not indicate any problems in the building with the ground source heat pump system. The building is situated close the distribution transformer and the network can be regarded as rigid. On the other hand the loads are relatively low, which result in low disturbances.

In the future it would be interested to get measuring data in really cold outdoor conditions in order to ensure that the heating capacity of the ground source heat pump system is sufficient.

References

Danfoss 2014	Technical brochure Danfoss DHP-H, referred August 2014, http://lampo.danfoss.com/PCMPDF/dhp-h_fi.pdf Data sheet Danfoss DHP-H, referred August 2014, http://danfoss.ipapercms.dk/Heating/AutoGen/30558_33782/?ForceLanguage=fi
EN 14511-2:2013	Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling. Part 2: Test conditions. CENELEC 2013, 20 p.
Fortum 2014	Comparison to the consumption of similar buildings. Fortum asiakaspalvelu/customer service 2014, access data of the author
Heffernan 2013	W.J.B Heffernan, N.R. Watson, R. Buehler, J.D. Watson, Harmonic performance of heat-pumps. The Journal of Engineering, September 2013, 10 p.
Helsingin Energia 2009	Generaattorilaitteiston aiheuttamat sallitut yliaaltovirrat suhteessa tuottajalle varattuun siirtokapasiteettiin (Recommended limit values for current harmonics of generators) http://www.helen.fi/Documents/Suunnittelijat%20ja%20urakoitsijat/HSV/HSV-yleistä-generaattorilaitteiston-yliaaltovirrat-SU40309L1.pdf
IEC/TS 61000-3-4:1998	Electromagnetic compatibility (EMC) - Part 3-4: Limits - Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A
Koponen 2010	Koponen Pekka VTT, Seppälä Joel Helen Electricity Network Ltd. Comparison of price control methods for electrical heating, simulation study. Research Report VTT-R-04982-10, Espoo 2010, 17 p.
Pihala 1998	Pihala, Hannu. Non-intrusive appliance load monitoring system based on a modern kWh-meter, Espoo VTT Publications 356, 1998, 68 p.
Rantanen 2014	Rantanen Yrjö, e-mails on14.2-31.3.2014
Seppälä 2010	Joel Seppälä Helen Sähköverkko Oy, Pekka Koponen VTT. AMM-järjestelmällä toteutetun varaavan sähkölämmityksen dynaamisen kuormanohjauksen toimintamalli ja kenttäkokeet. Tutkimusraportti VTT-R-09756-10 in Finnish, Espoo 2010, 24 p.
SFS-EN 50160:2010	Voltage characteristics of electricity supplied by public electricity networks, CENELEC - SESKO 2010, 67 p.
Sävel-service 2014	Electric energy measurements (2010-2014) by Helsingin Energia, user name provided by Yrjö Rantanen
Vehviläinen 2014	Seppo Vehviläinen, MX Electrix, Web page http://www.electrix.fi/ and e-mails 20.2-3.3.2014

Figures

Measuring results:

A. Overview of the measured active (*P*) and reactive power (*Q*) along the measuring periods before and after the heating system renovation

Figures 1 to 6 Full storage heating system, years 1996-1998
Figures 7 to 9 Ground source heat pump system, total energy April 2013-April 2014
Figures 10 to 12 Separately measured heat pump power April 2013-April 2014
Figures 13 to 14 Outdoor temperatures1996-1998 and 2013-2014

B. Examples of the electric quantities *P, Q* and phase to neutral voltage U_v during the maximum and minimum electricity consumption, both one week and 24 h durations

Figure 15 Full storage heating. During maximum and minimum weekly energy consumption
Figure 16 Full storage heating. During maximum and minimum 48 h energy consumption
Figure 17 Ground source heat pump system, total energy. During max and min weekly energy consumption
Figure 18 Ground source heat pump system, total energy. During max and min 48 h energy consumption
Figure 19 Separately measured heat pump. During max and min weekly energy consumption
Figure 20 Separately measured heat pump. During max and min weekly energy consumption

C. Comparison of electric energy consumption before and after the renovation based on the SÄVEL-service of Helsingin Energia from Jan 2010 to May 2014
Figures 21-23 Electric energy from 2012 to2014 on monthly, weekly and daily level

D. Household electric energy from May 2013 to April 2014
Figure 24 Calculation from total energy and separate heat pump values

E. Power quality quantities measured only after the renovation will be analysed as far as practical.
Figure 25 Example of harmonic voltage values
Figure 26 Current Distortion, calculated from a heating cycle during the winter

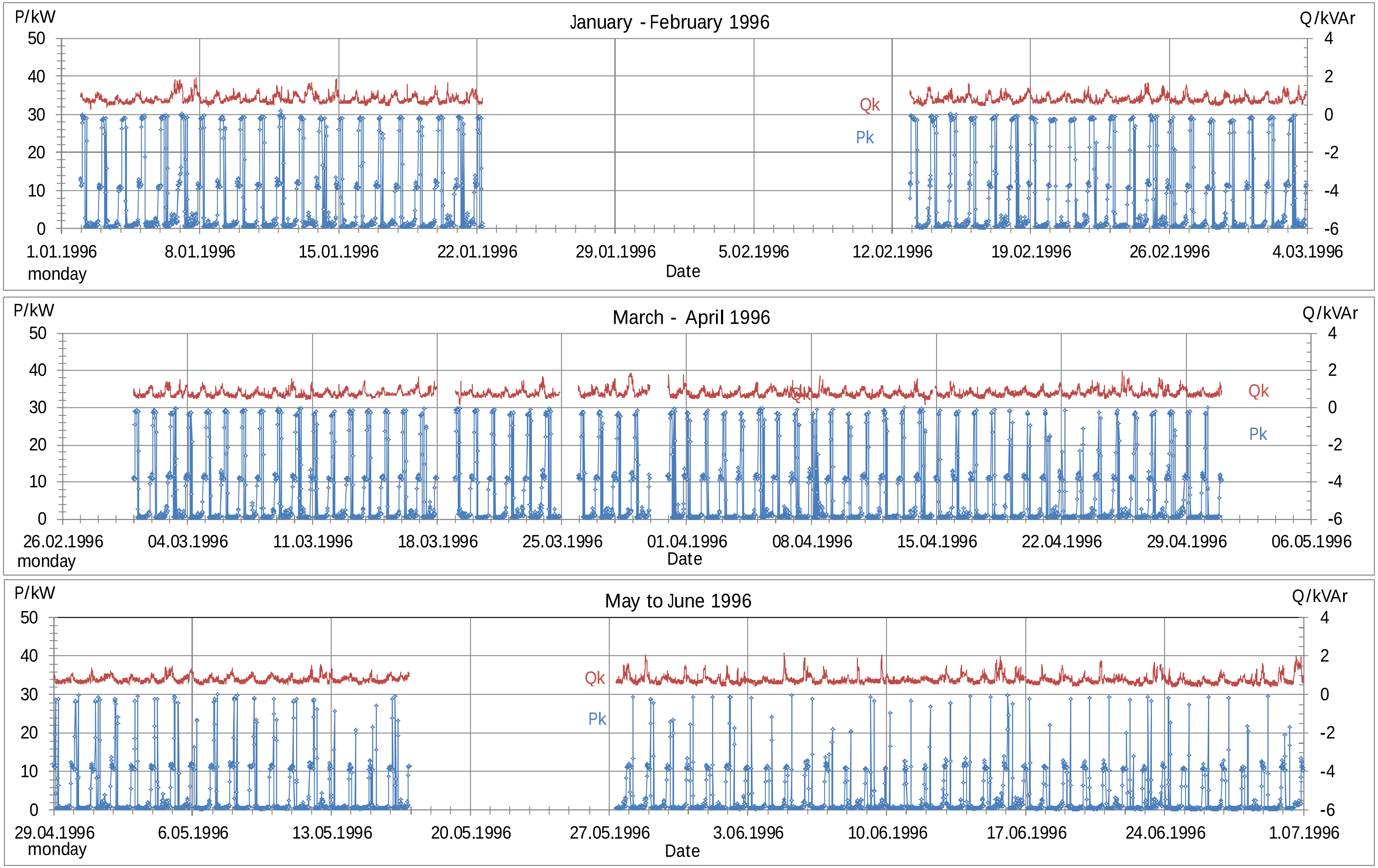


Figure 1 Full storage heating. Pk and Qk from January to June 1996. Major unit of horizontal axis: one week, starting on Monday, interval 15 min.

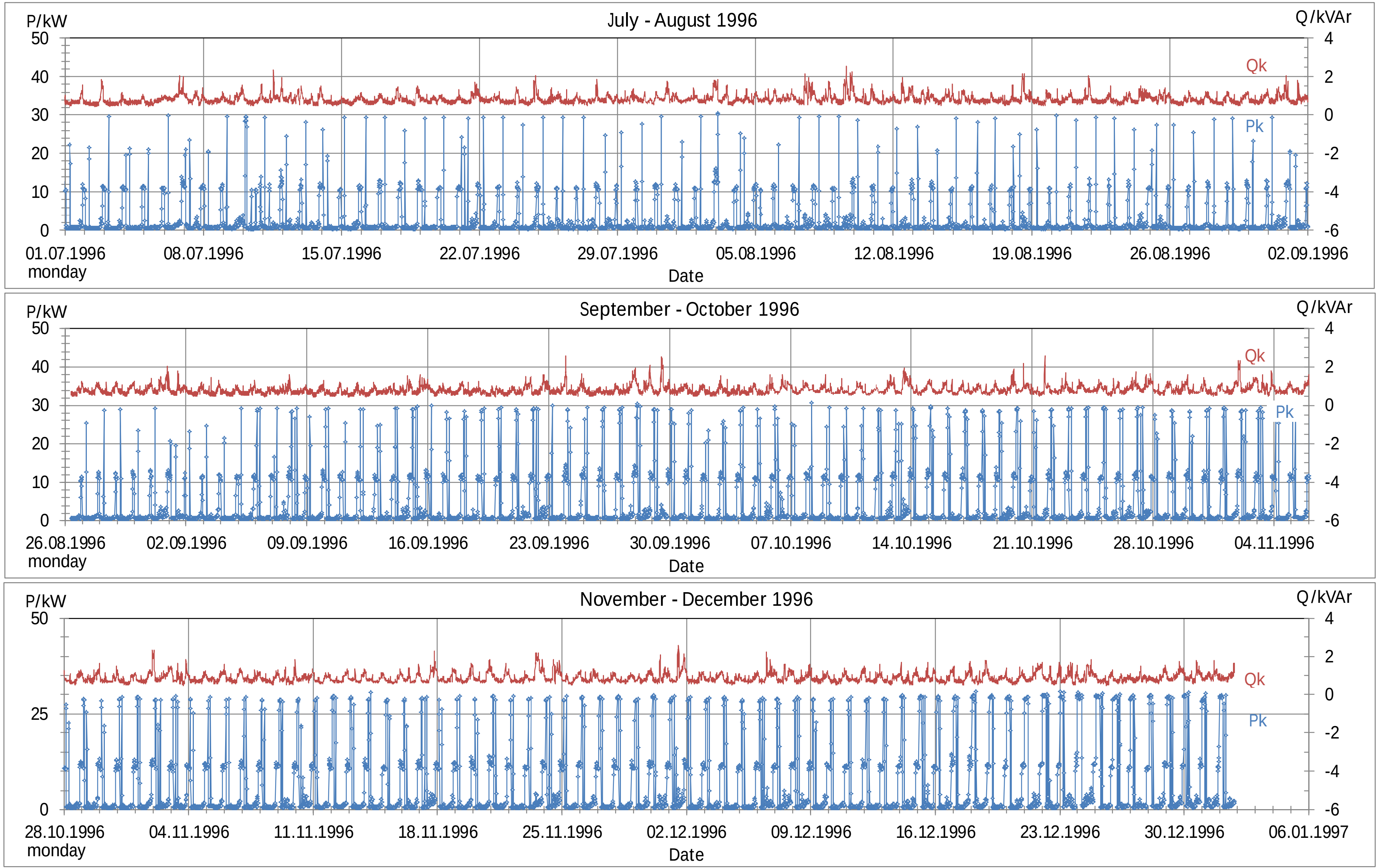


Figure 2 Full storage heating. Pk and Qk from July to December 1996. Major unit of horizontal axis: 1 week, starting on Monday, interval 15 min.

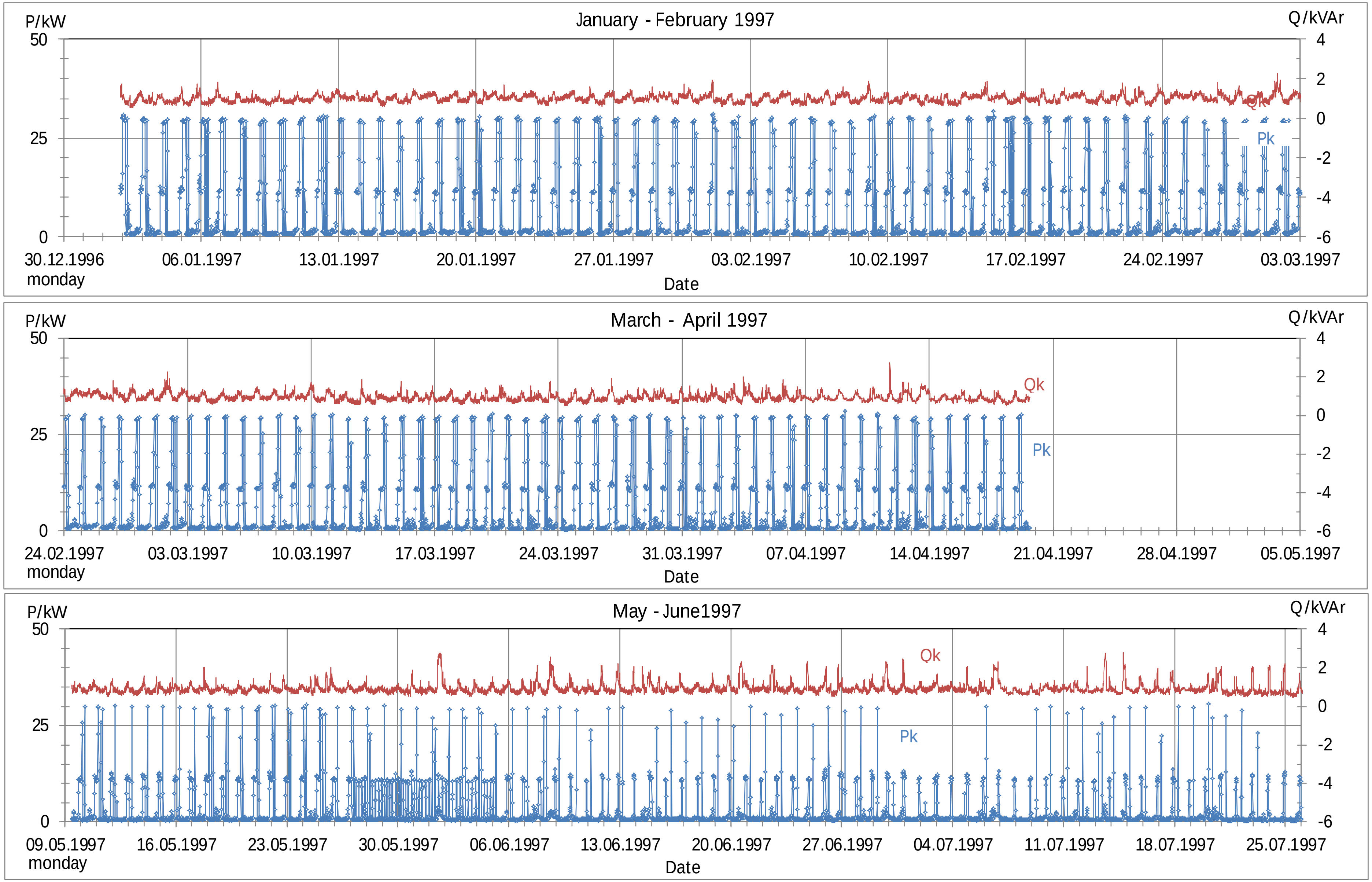


Figure 3 Full storage heating. Pk and Qk from January to June1997. Major unit of horizontal axis: 1 week, starting on Monday, interval 15 min.

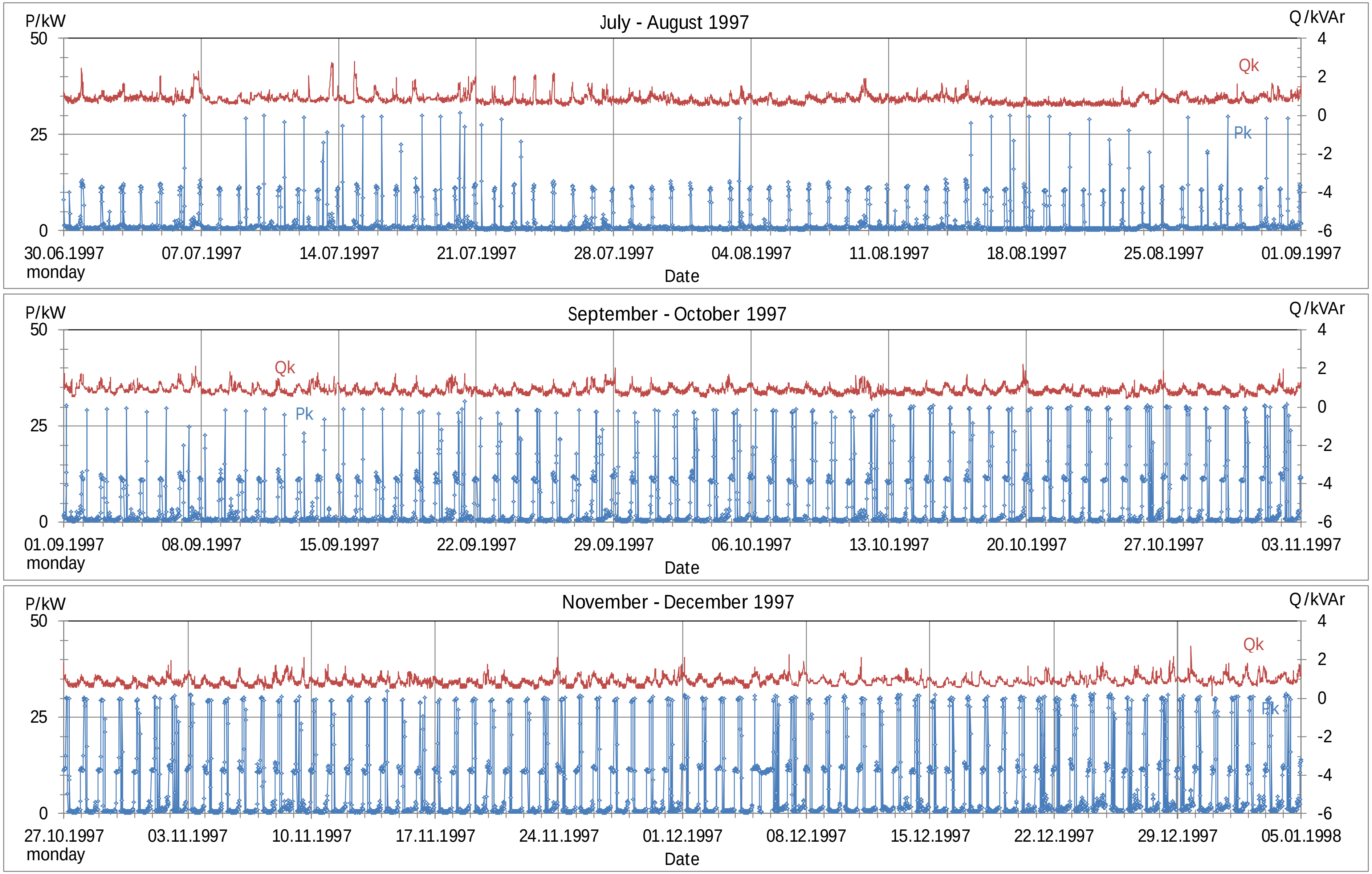


Figure 4 Full storage heating. Pk and Qk from July to December 1997. Major unit of horizontal axis: 1 week, starting on Monday, interval 15 min.

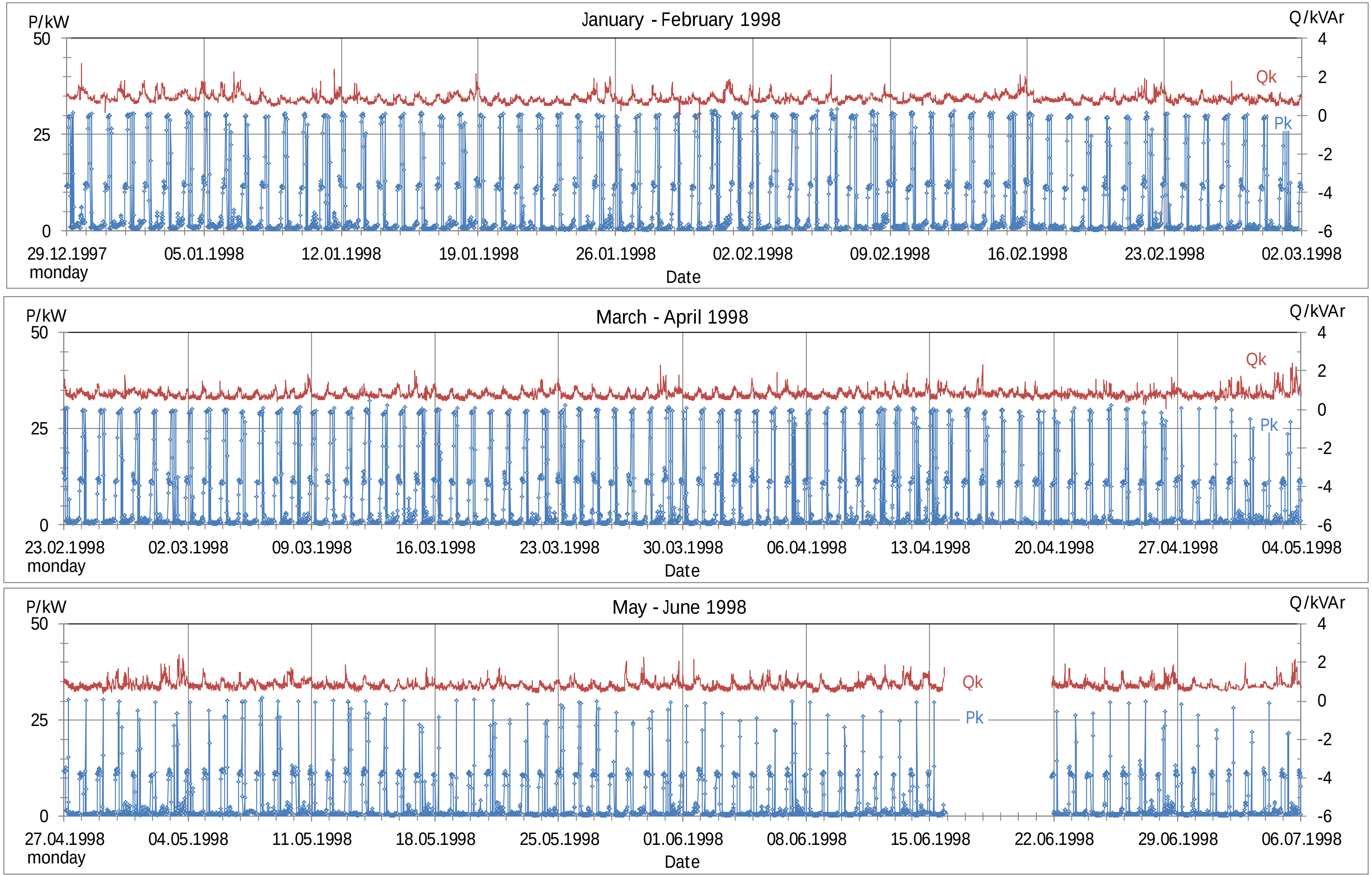


Figure 5 Full storage heating. Pk and Qk from January to June 1998. Major unit of horizontal axis: one week, starting on Monday, interval 15 min.

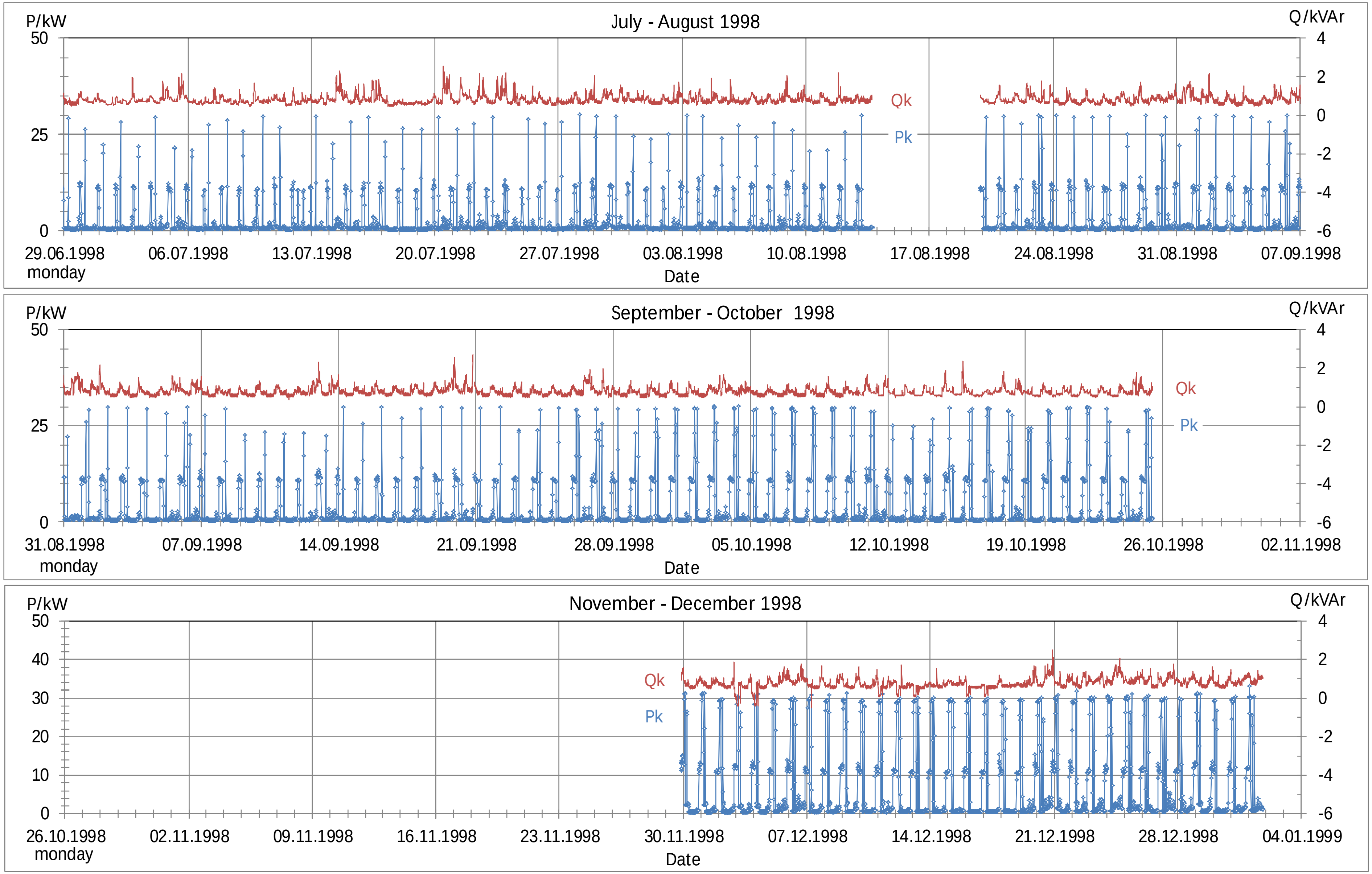


Figure 6 Full storage heating. Pk and Qk from July to December 1998. Major unit of horizontal axis: 1 week, starting on Monday, interval 15 min.

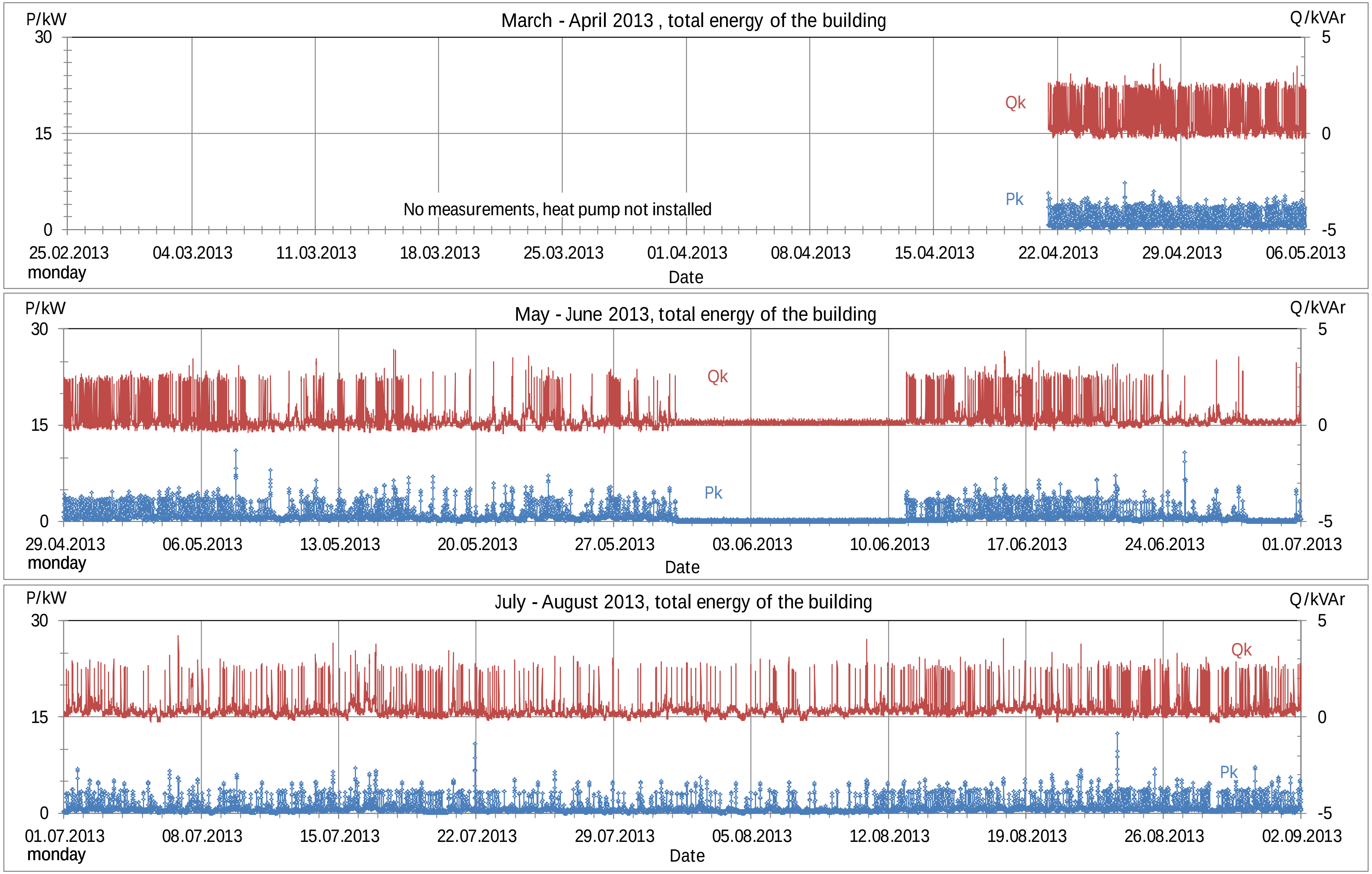


Figure 7 Ground heat pump system. Pk and Qk from April to August 2013. Major unit of horizontal axis: 1 week, starting on Monday,recording interval 10-5 min

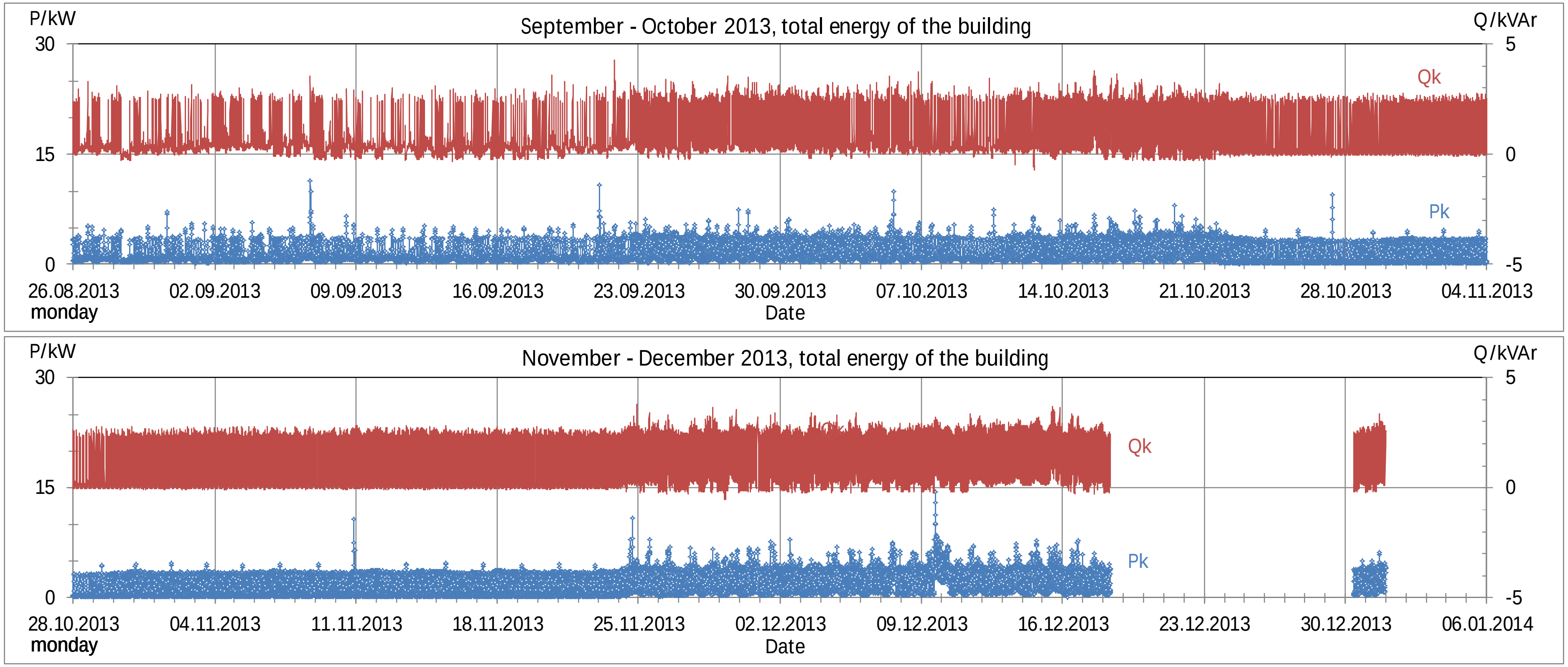


Figure 8 Ground heat pump system. Pk and Qk from September to December 2013. Major unit of horizontal axis: one week, starting on Monday, recording interval 5 min.

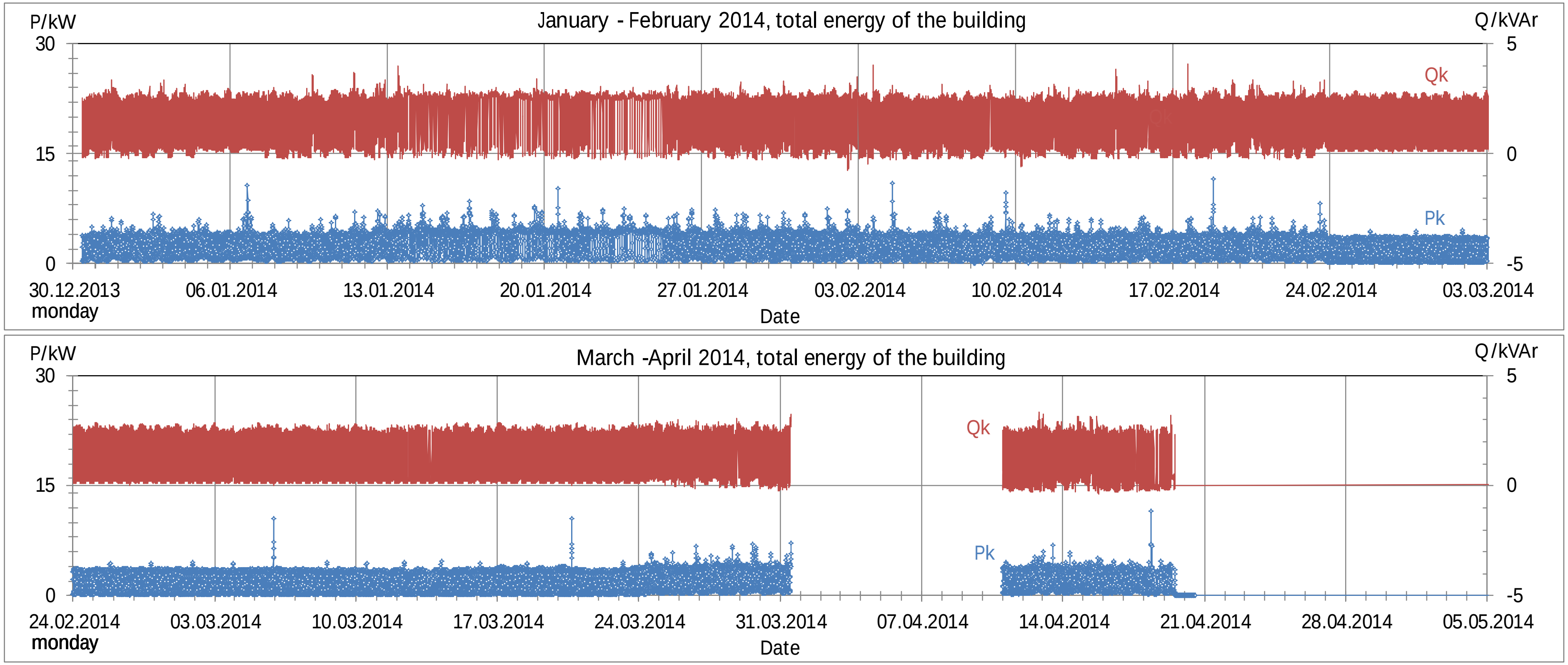


Figure 9 Ground heat pump system, total energy. Pk and Qk from January to April 2014. Major unit of horizontal axis: one week, starting on Monday, recording interval 5 min.

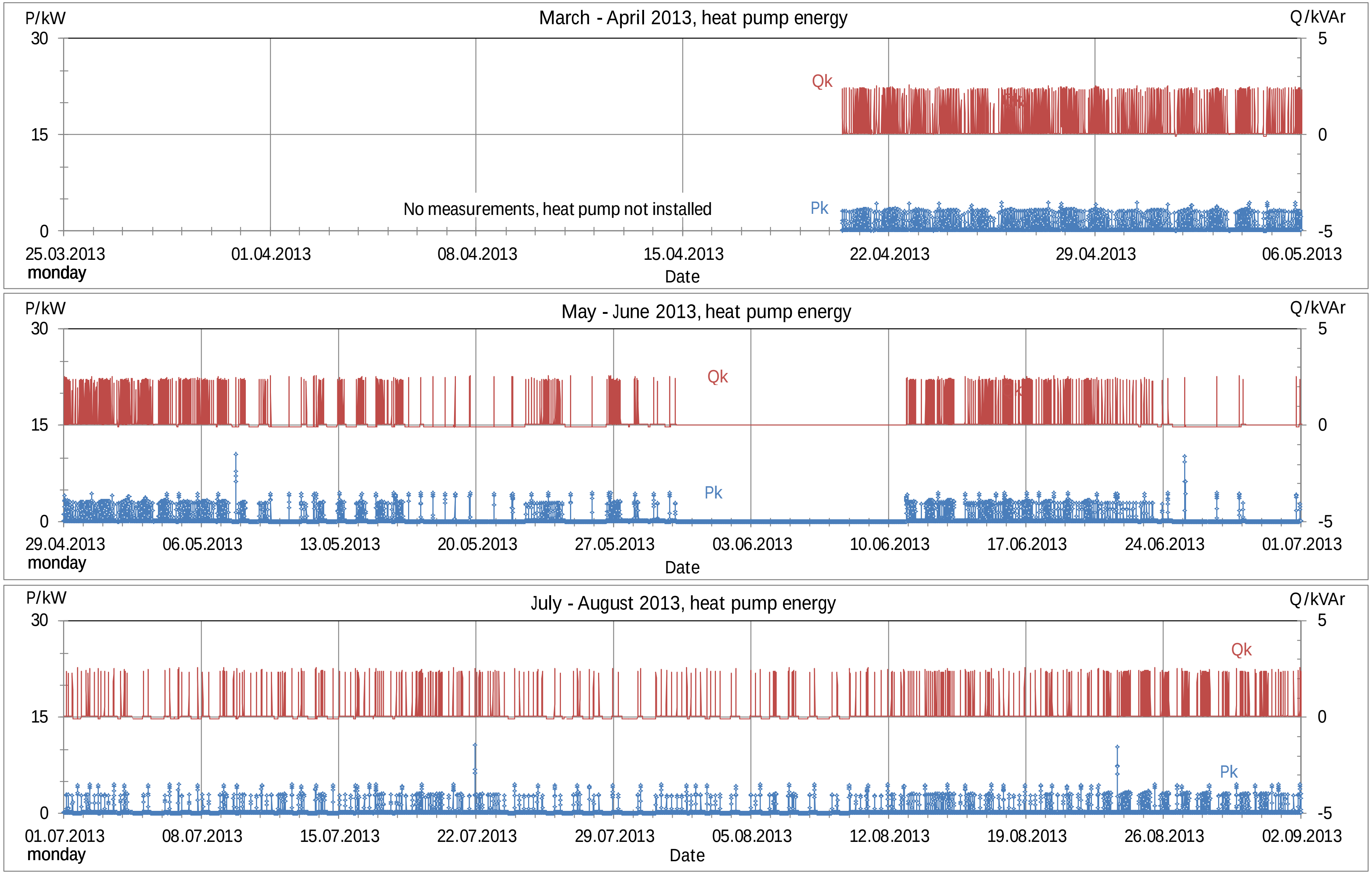


Figure 10 Separate heat pump power. Pk and Qk from April to August 2013. Major unit of horizontal axis: one week, starting on Monday, recording interval 5 min.

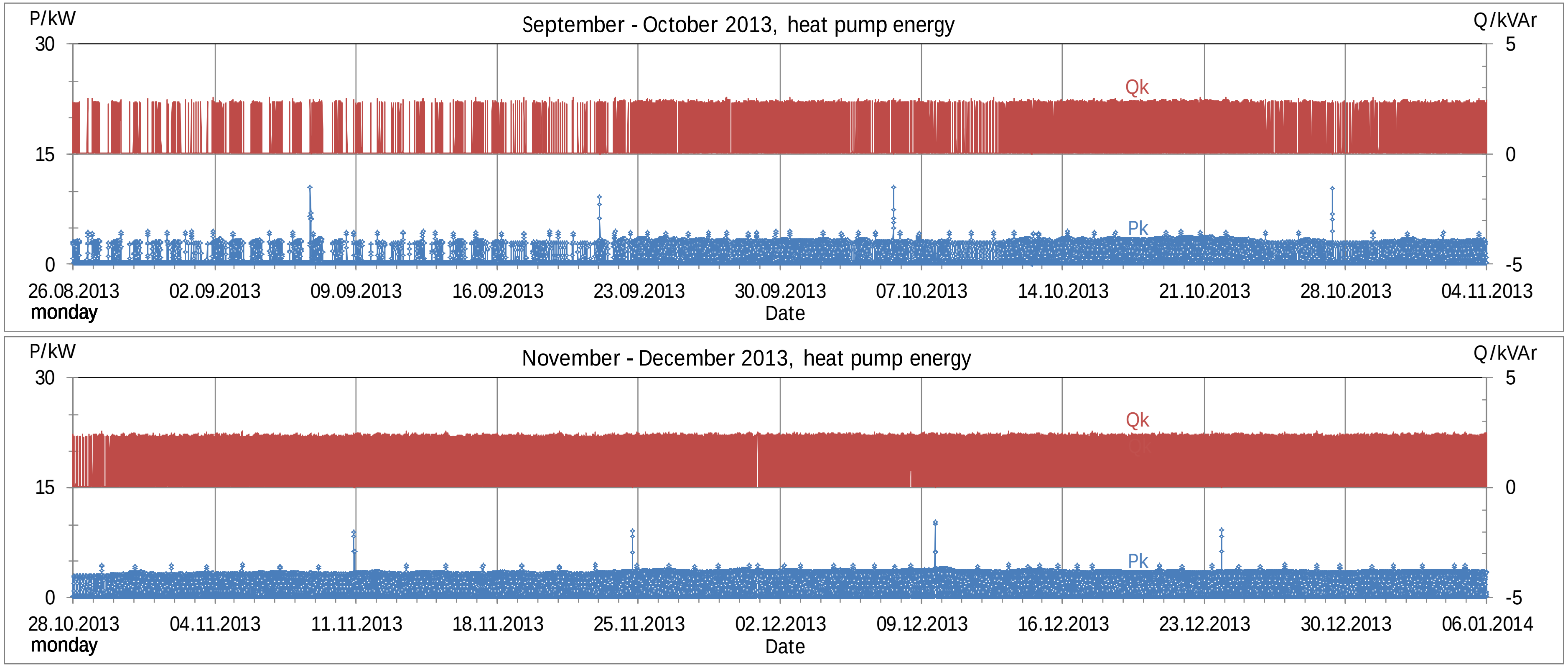
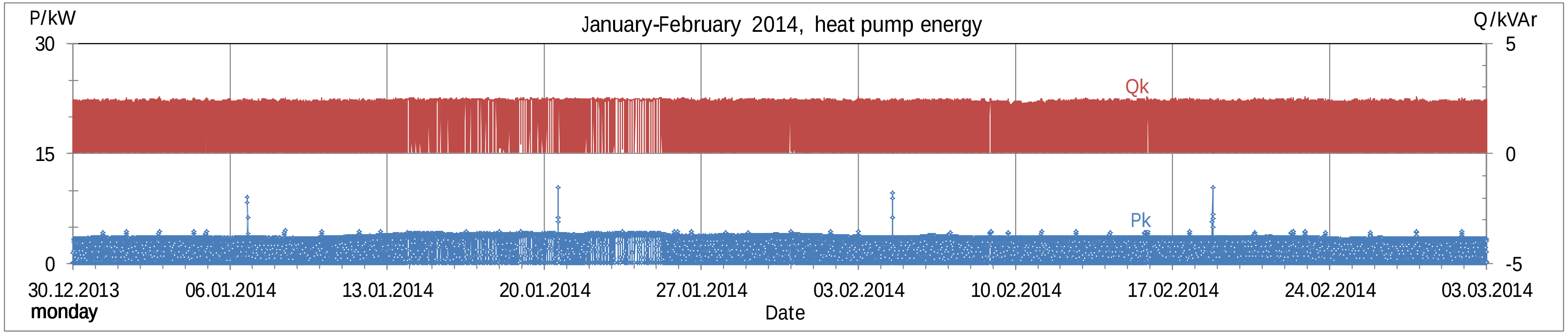


Figure 11 Separate heat pump power. Pk and Qk from September to December 2013. Major unit of horizontal axis: one week, starting on Monday, recording interval 5 min.



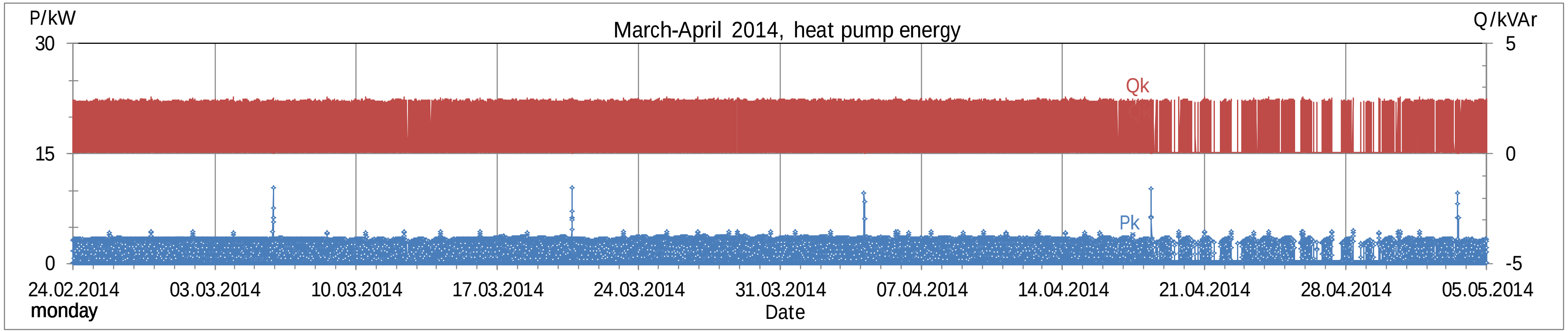


Figure 12 Separate heat pump power. Pk and Qk from January to April 2014. Major unit of horizontal axis: one week, starting on Monday, interval 5 min.

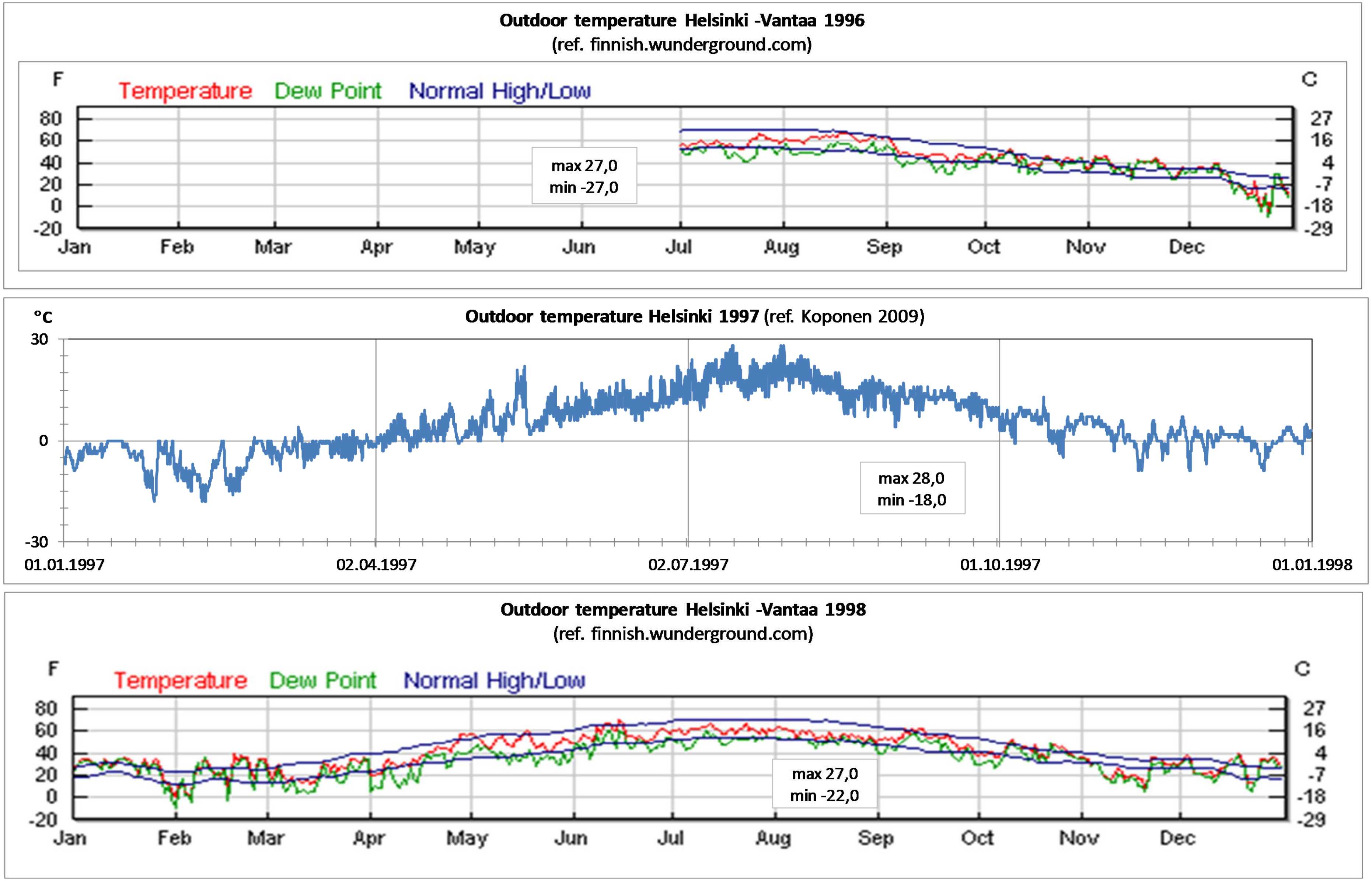
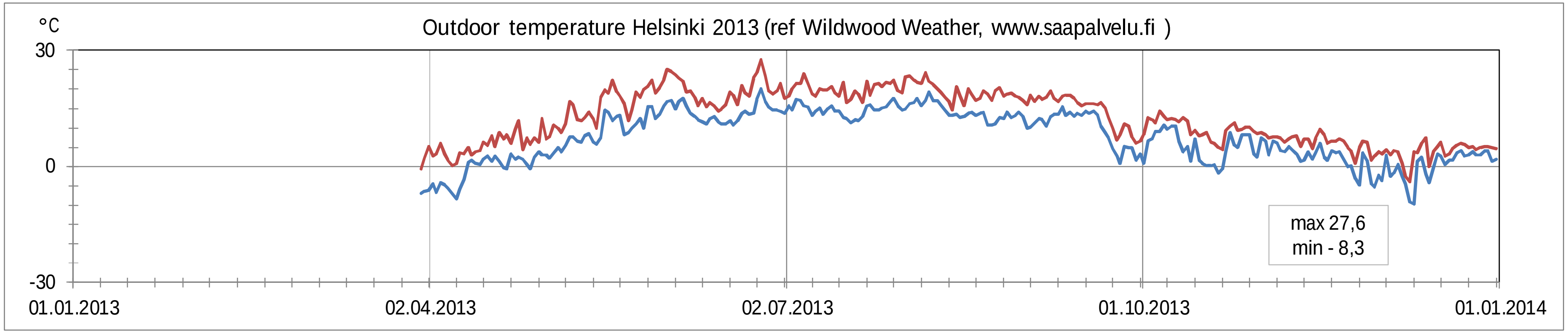


Figure 13 Outdoor temperatures during power measurements1996-1998



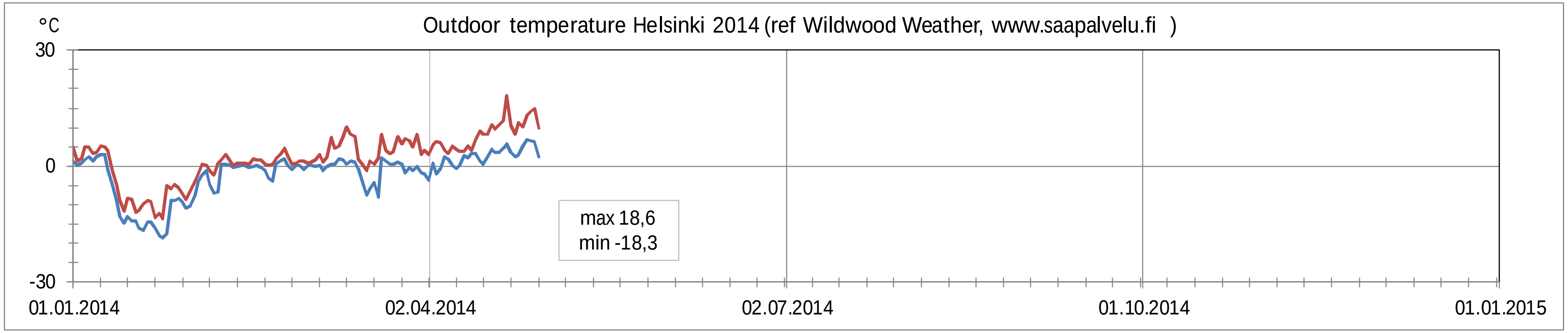
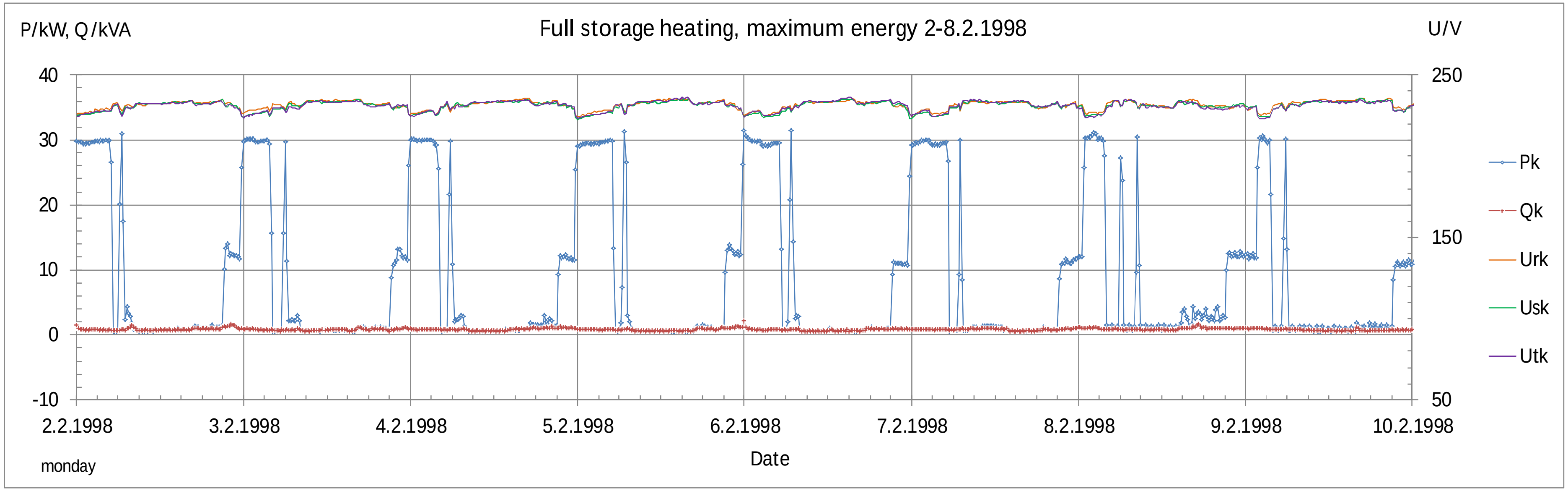


Figure 14 Outdoor temperatures during power measurements 2013-2014



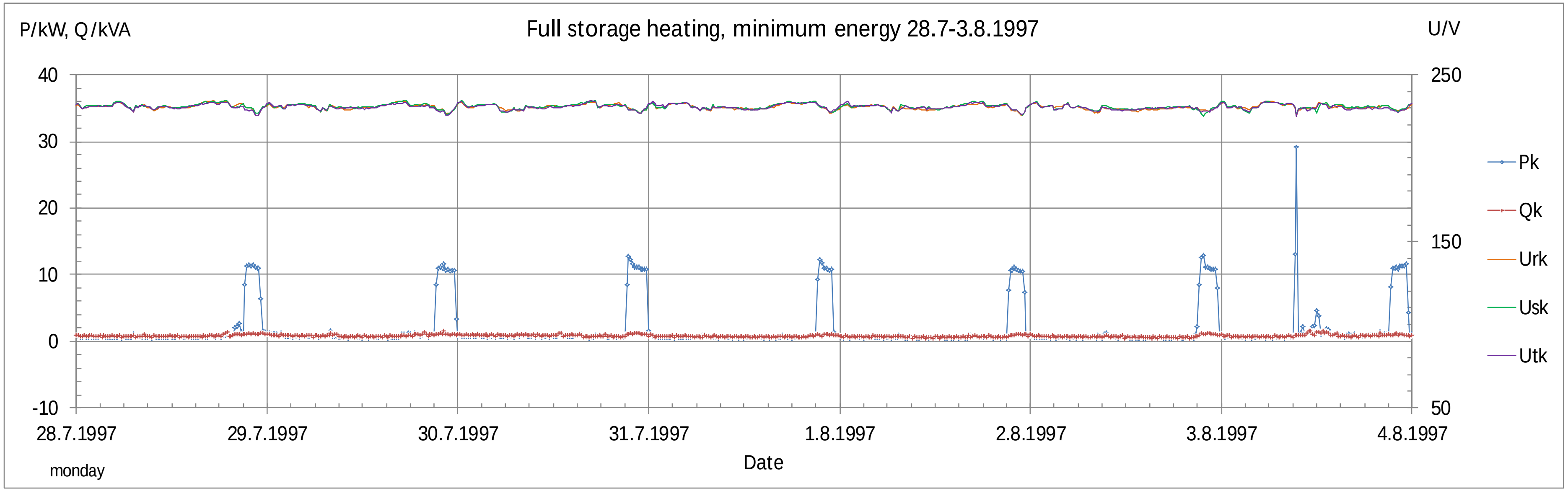
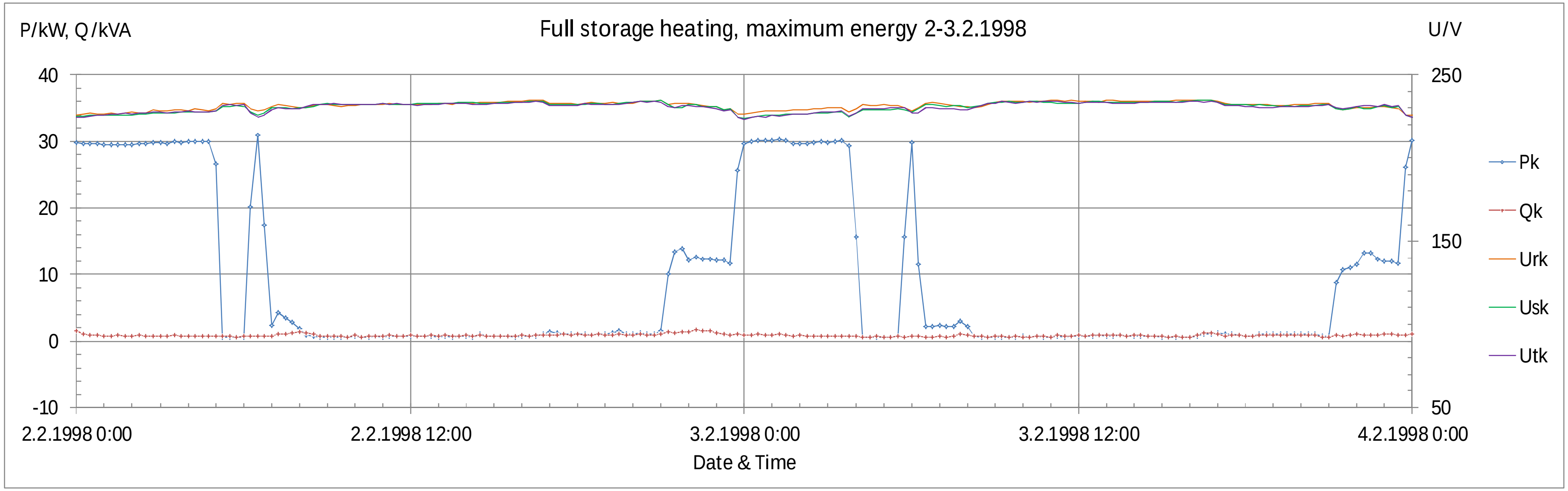


Figure 15 Full storage heating. Pk , Qk and phase to neutral voltages during 2-8.2.1998 (top) and 28.7-3.8.1997(bottom).



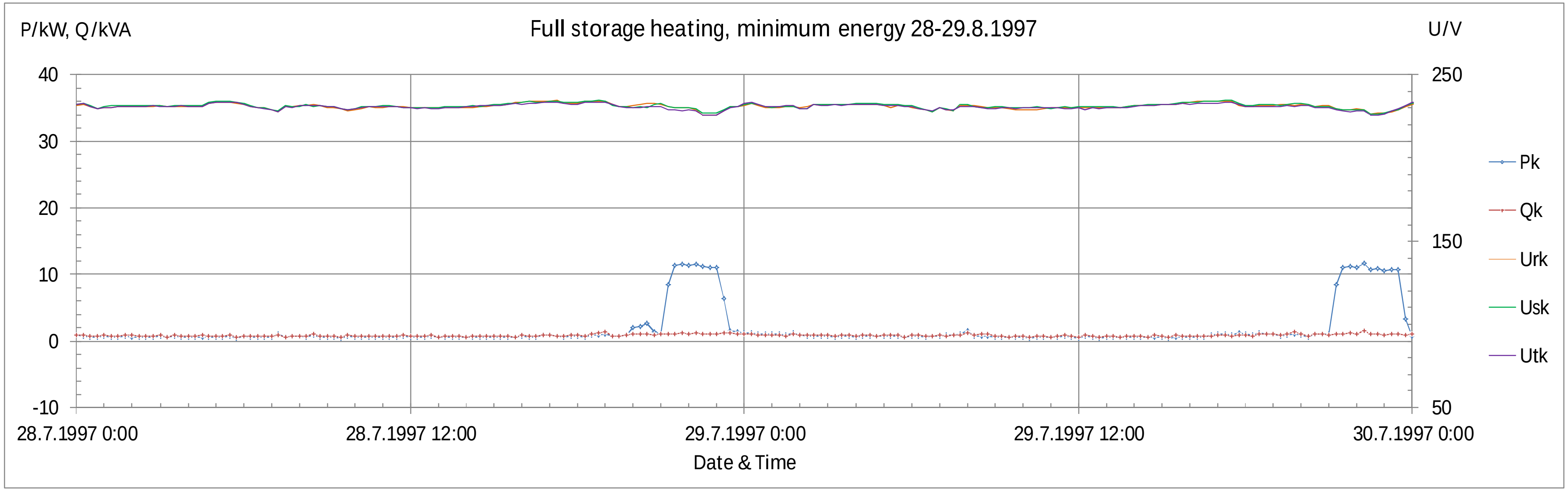
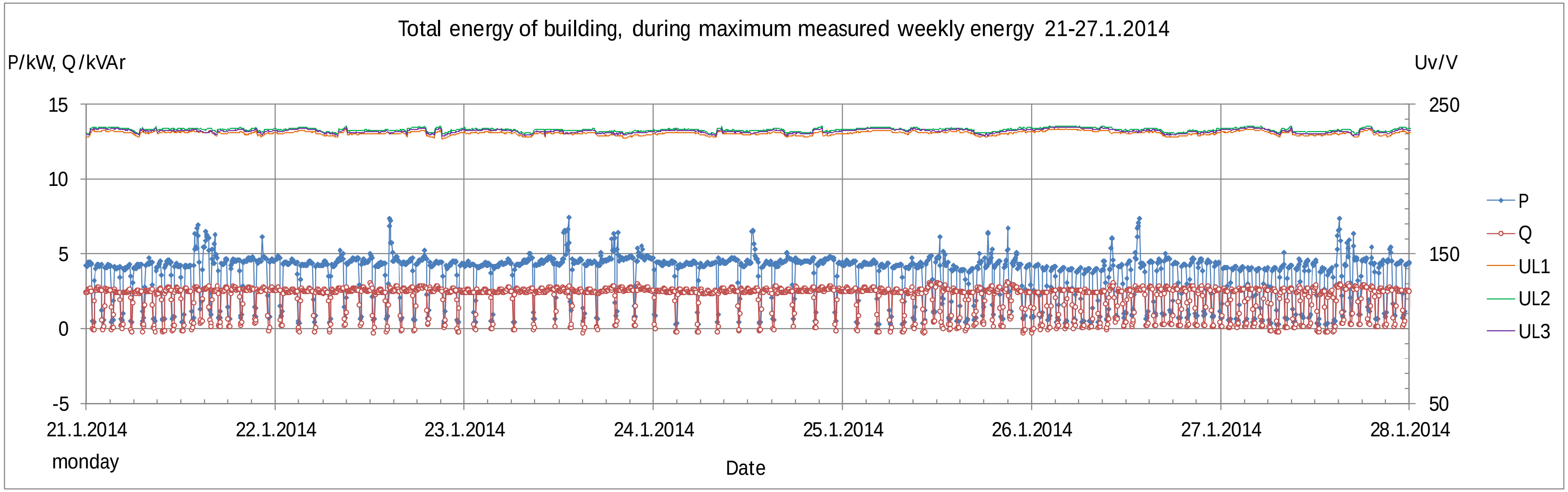


Figure 16 Full storage heating. Pk ,Qk and phase to neutral voltages, 48 h during maximum energy consumption, 2-3.2.1998 (top) and during minimum energy consumption, 28.7-29.7.1997(bottom).



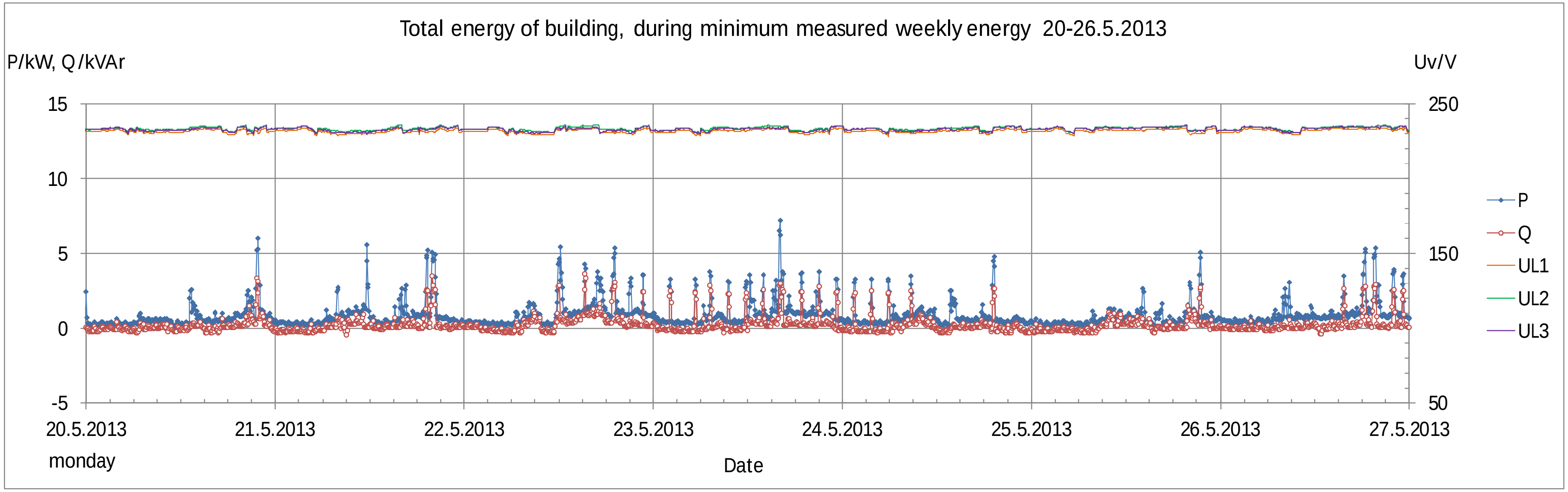
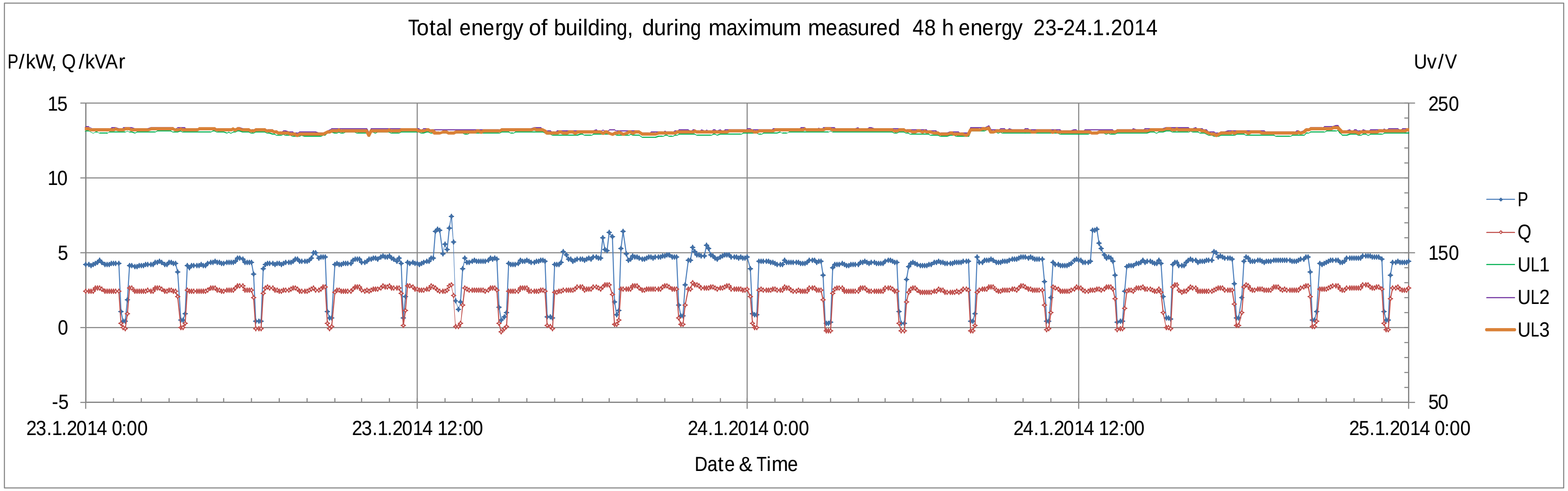


Figure 17 Ground source heat pump system, total energy. Pk ,Qk and phase to neutral voltages, during maximum energy consumption week 21-27.1.2014 (top) and during minimum energy consumption week 20-26.5.2013 (bottom).



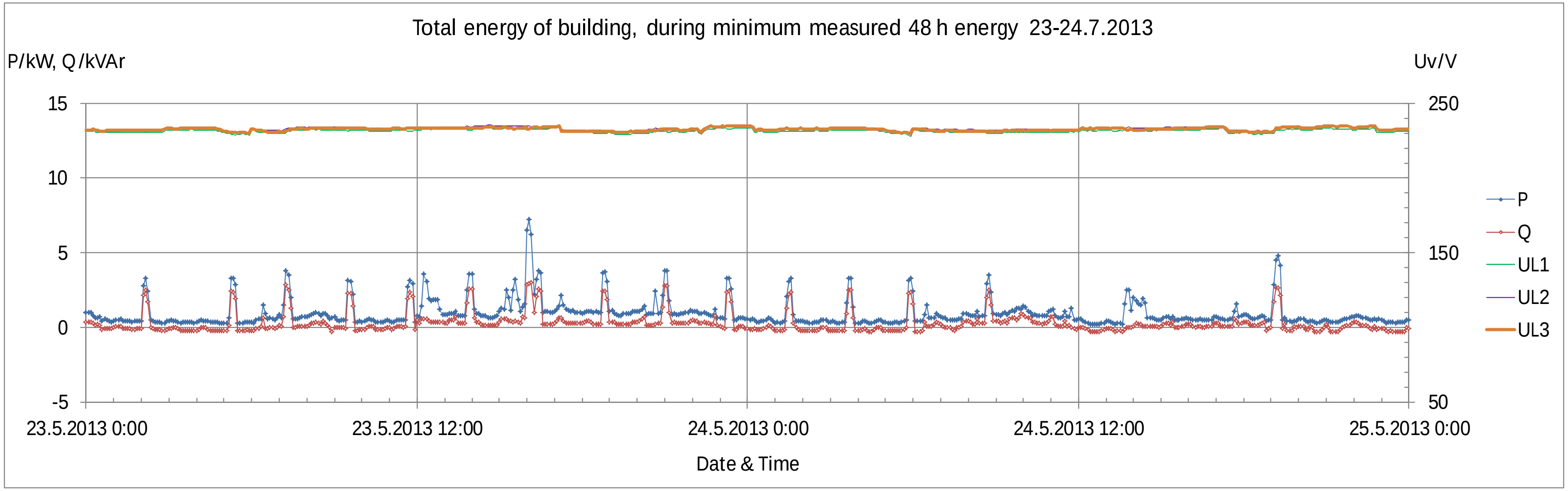
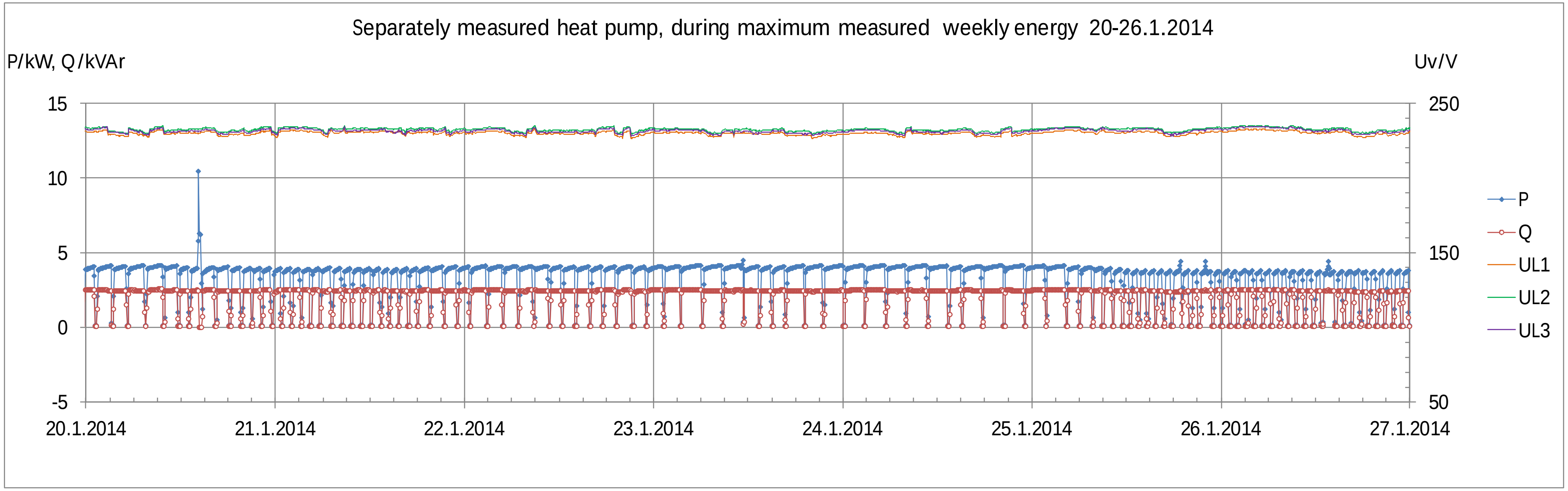


Figure 18 Ground heat pump system, total energy. Pk ,Qk and phase to neutral voltages, 48 h values during maximum energy consumption week 23-24.1.1998 (top) and during minimum energy consumption week 23-24.5.2013 (bottom).



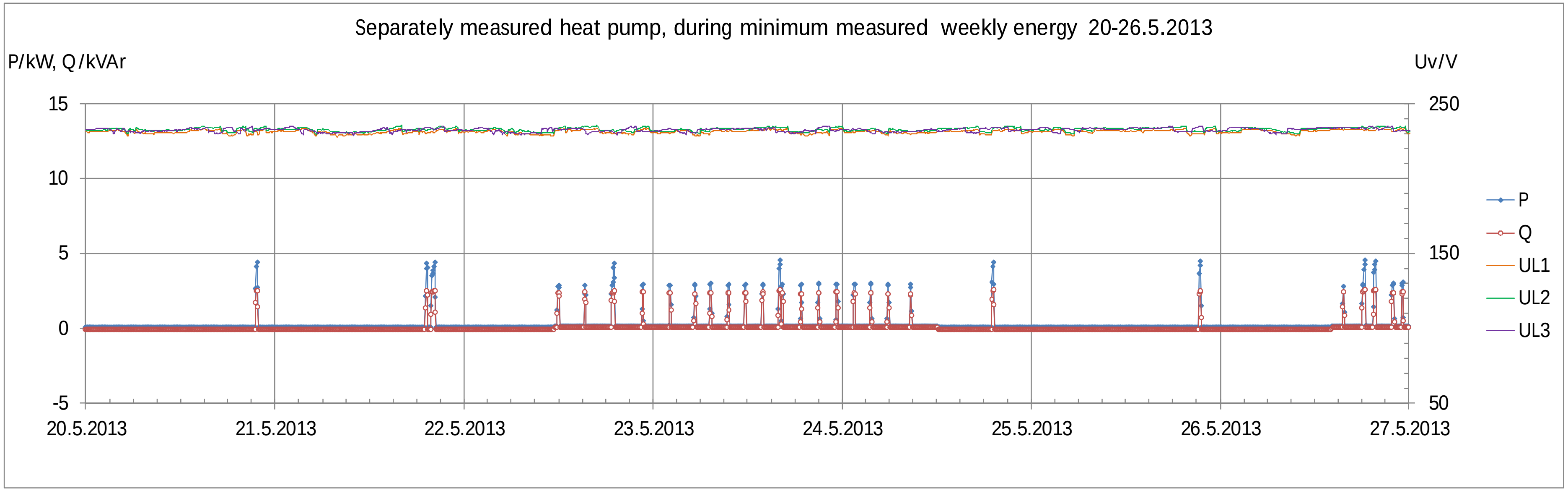
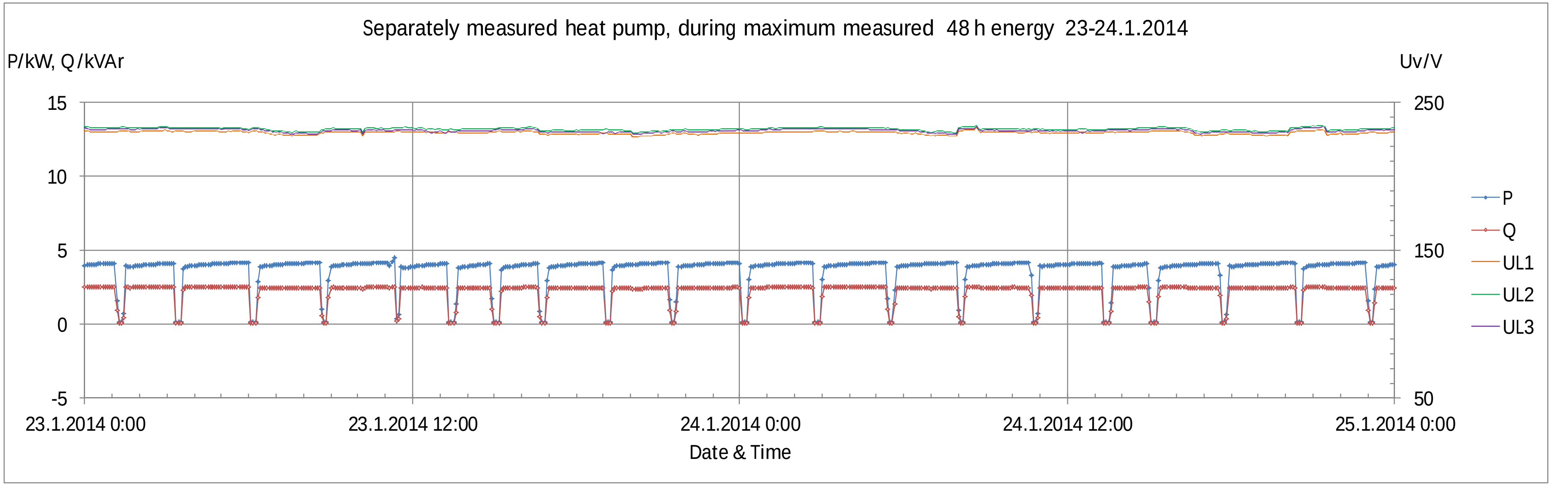


Figure 19 Separately measured heat pump. Pk , Qk and phase to neutral voltages during maximum energy consumption week 20-26.1.2014 (top) and during minimum energy consumption week 20-26.5.2013 (bottom).



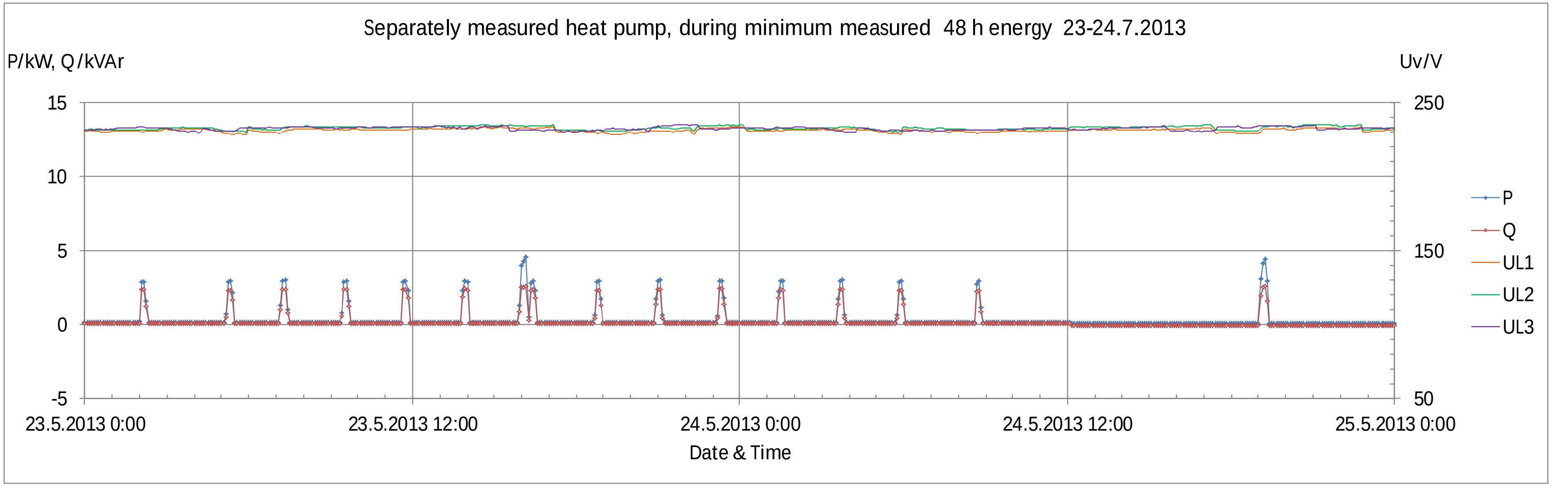
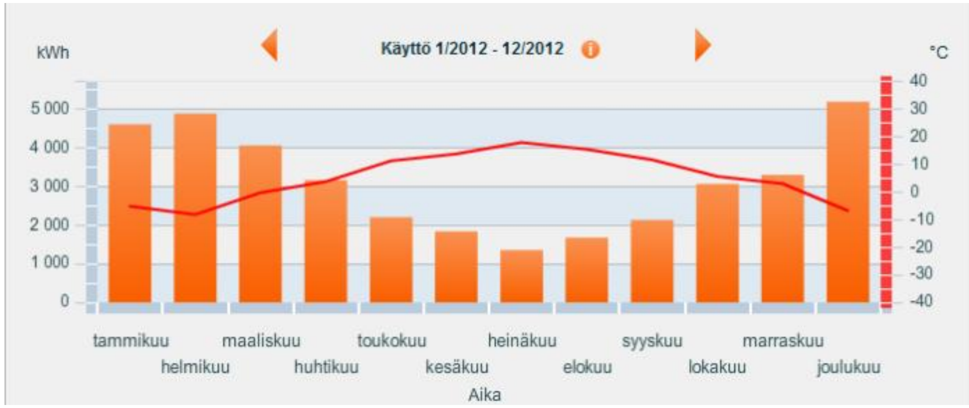
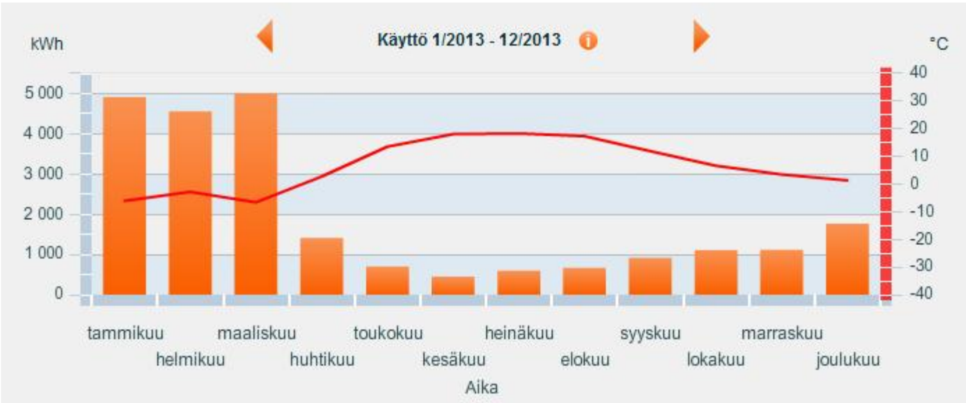


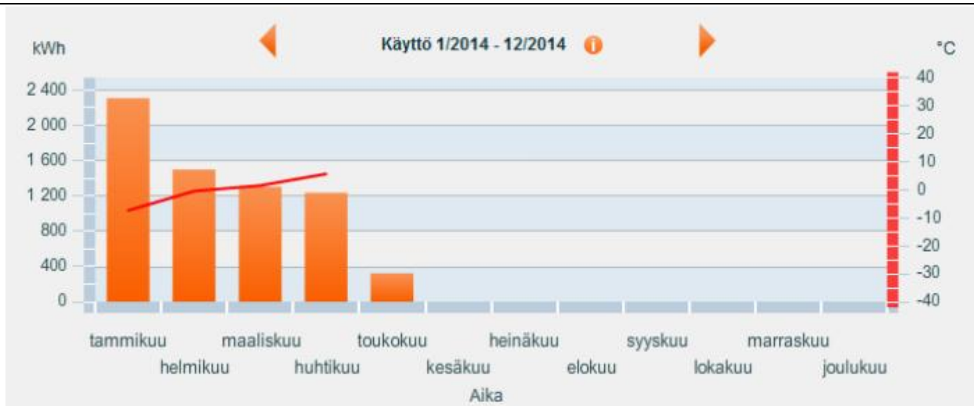
Figure 20 Separately measured heat pump. Pk , Qk and phase to neutral voltages, duration 48 h during maximum energy consumption week 23-24.1.1998 (top) and during minimum energy consumption week 23-24.5.2013 (bottom).



Full Storage heating system
Energy consumption, year 2012
Monthly results
Outdoor temperature
Helsingin Energia, SÄVEL Service, Uurtajantie, Helsinki

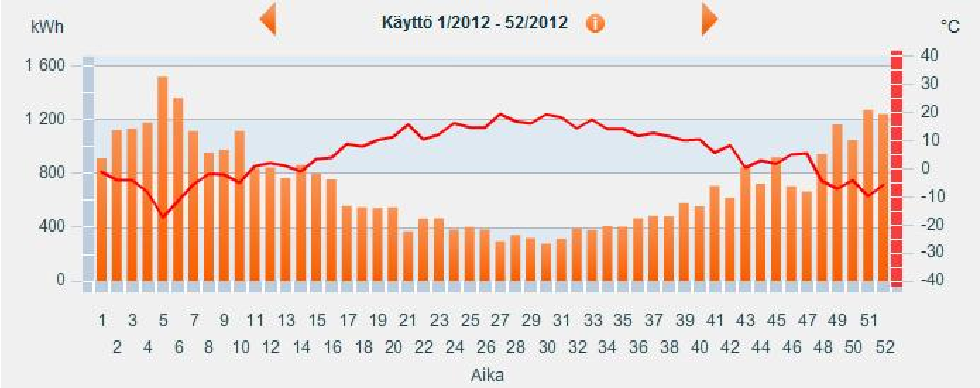


Full Storage heating changed to Ground source heat pump system in April 2013
Energy consumption, year 2013
Monthly results
Outdoor temperature
Helsingin Energia, SÄVEL Service, Uurtajantie, Helsinki

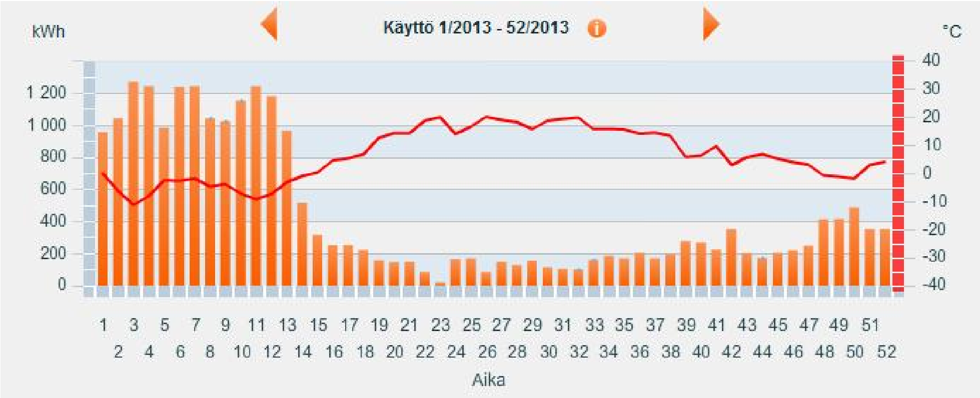


Ground source heat pump system
Energy consumption, from January to April 2014
Monthly results
Outdoor temperature
Helsingin Energia, SÄVEL Service, Uurtajantie, Helsinki

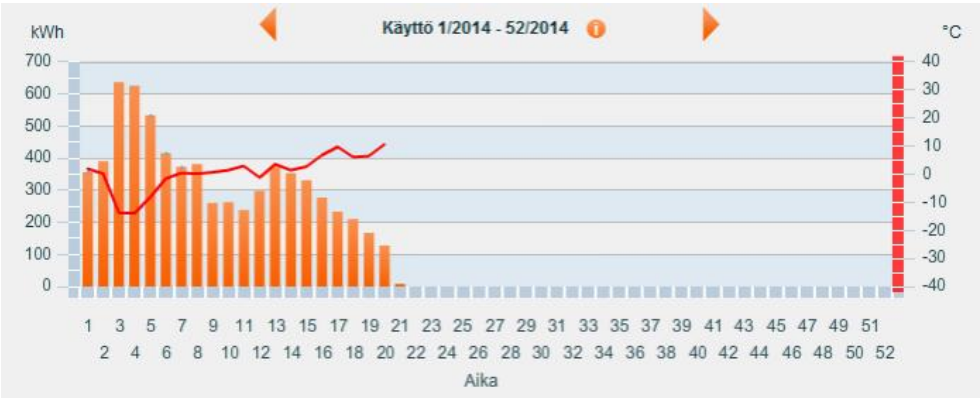
Figure 21 Energy consumption measured by Helsingin Energia, 2012-2014 monthly results (Sävel-service 2014)



Full Storage heating
Energy consumption, 2012
Weekly results
Outdoor temperature
Helsingin Energia, SÄVEL Service, Uurtajantie, Helsinki

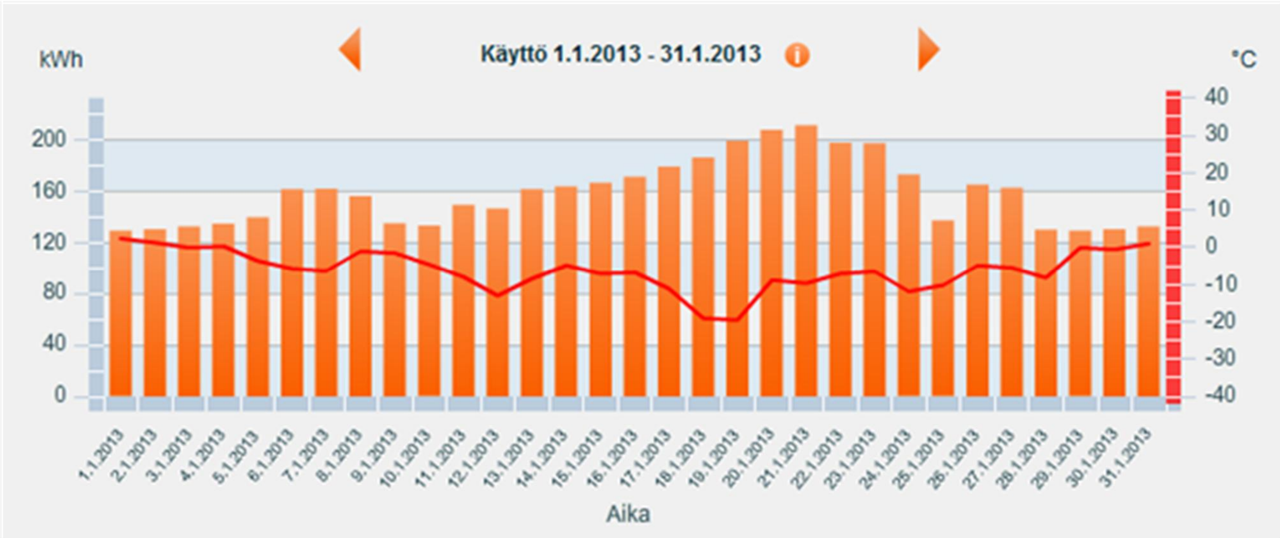


Ground source heat pump system
Energy consumption, January 2013
Weekly results
Outdoor temperature
Helsingin Energia, SÄVEL Service, Uurtajantie, Helsinki



Ground source heat pump system
Energy consumption, 2014 Jan to Apr
Weekly results
Outdoor temperature
Helsingin Energia, SÄVEL Service, Uurtajantie, Helsinki

Figure 22 Energy consumption measured by Helsingin Energia, 2012-2014 weekly results (Sävel-service 2014)



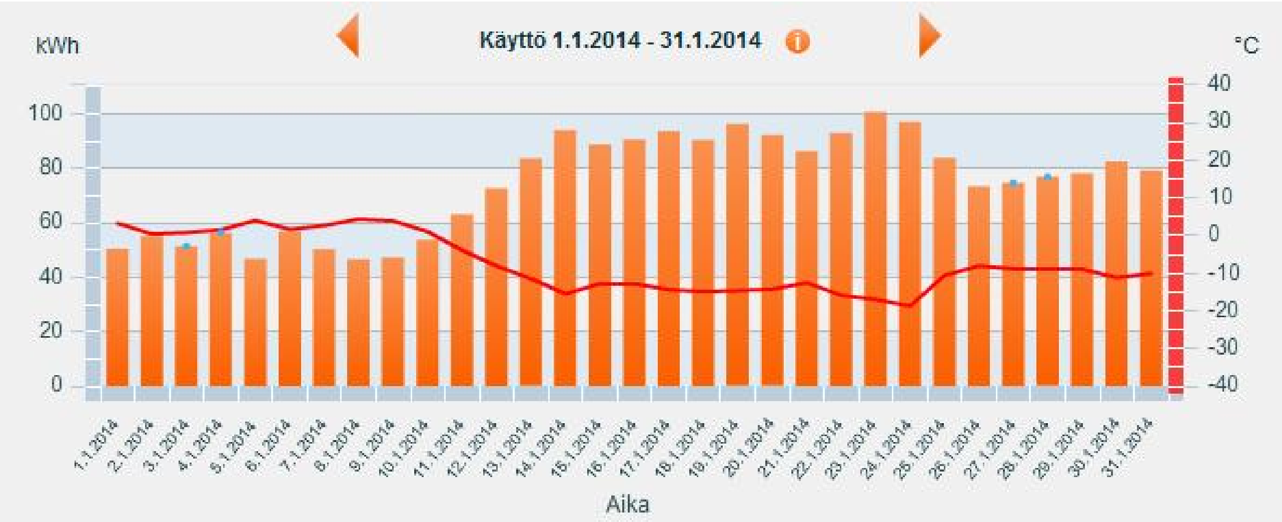
Full Storage heating

Energy consumption, January 2013

Daily results

Outdoor temperature

Helsingin Energia, SÄVEL Service, Uurtajantie, Helsinki



Ground source heat pump system

Energy consumption, January 2014

Daily results

Outdoor temperature

Helsingin Energia, SÄVEL Service, Uurtajantie, Helsinki

Figure 23 Energy consumption measured by Helsingin Energia, 01/2013 and 01/2014 daily results (Sävel-service 2014)

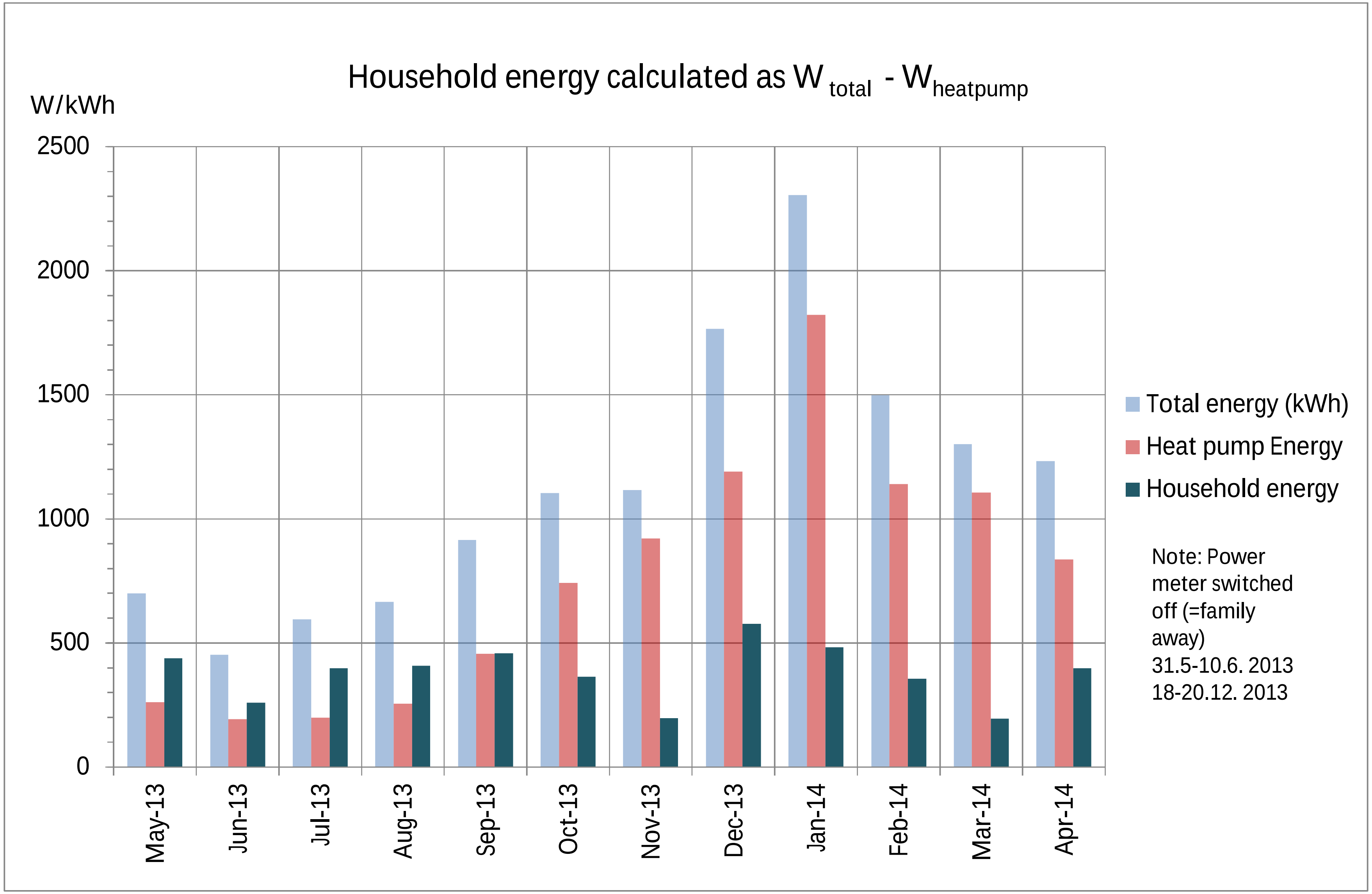
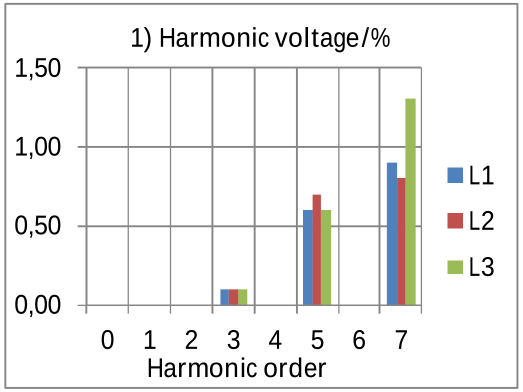
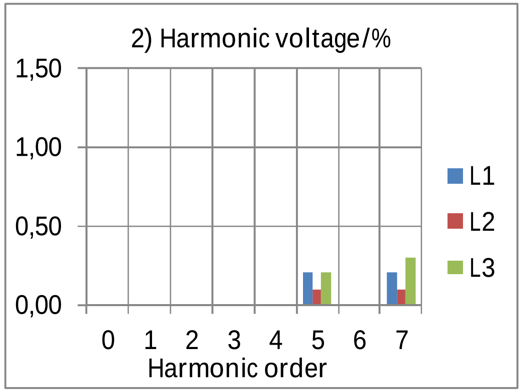


Figure 24 Household electric energy. Total energy is taken from Sävel-data and heat pump energy from Electrix -data. Household energy is calculated from these. Measurements are from May 2013 to the end of April 2014.

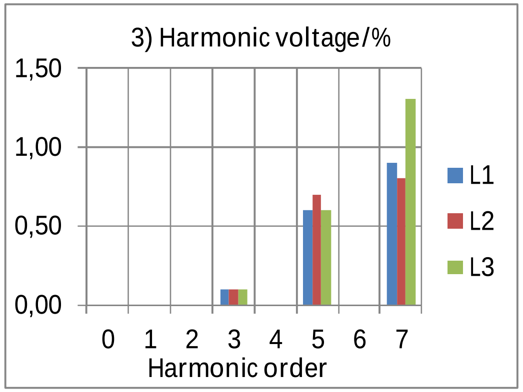
Total energy measurement



Measured at
low power
P 403.6 W
U7L3(%) 1.3 %

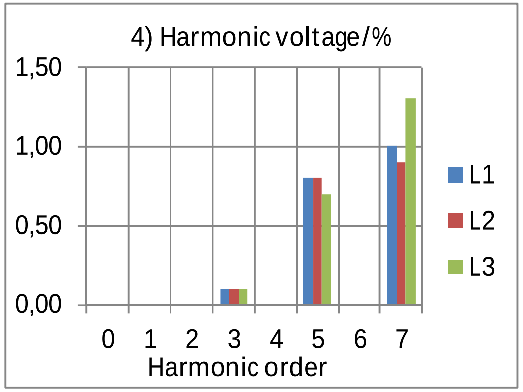


Measured at
maximum power
P 14470 W
U7L3(%) 0.3 %

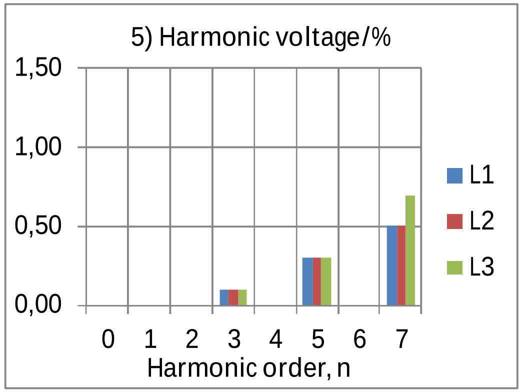


Measured when heat pump, circ. pumps and some appliances ON
P 4296 W
U7L3(%) 1.3 %

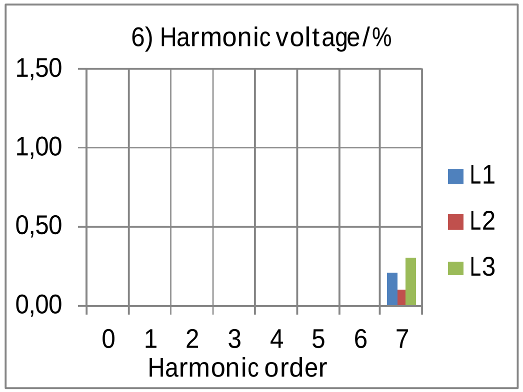
Separately measured heat pump



Measured at
low power
P 145.8 W
U7L3(%) 1.3 %



Measured at
maximum power
P 10564 W
U7L3(%) 0.7 %



Measured when heat pump and circ. pumps are running
P 4030 W
U7L3(%) 0.3%

Figure 25 Examples of harmonic voltages.

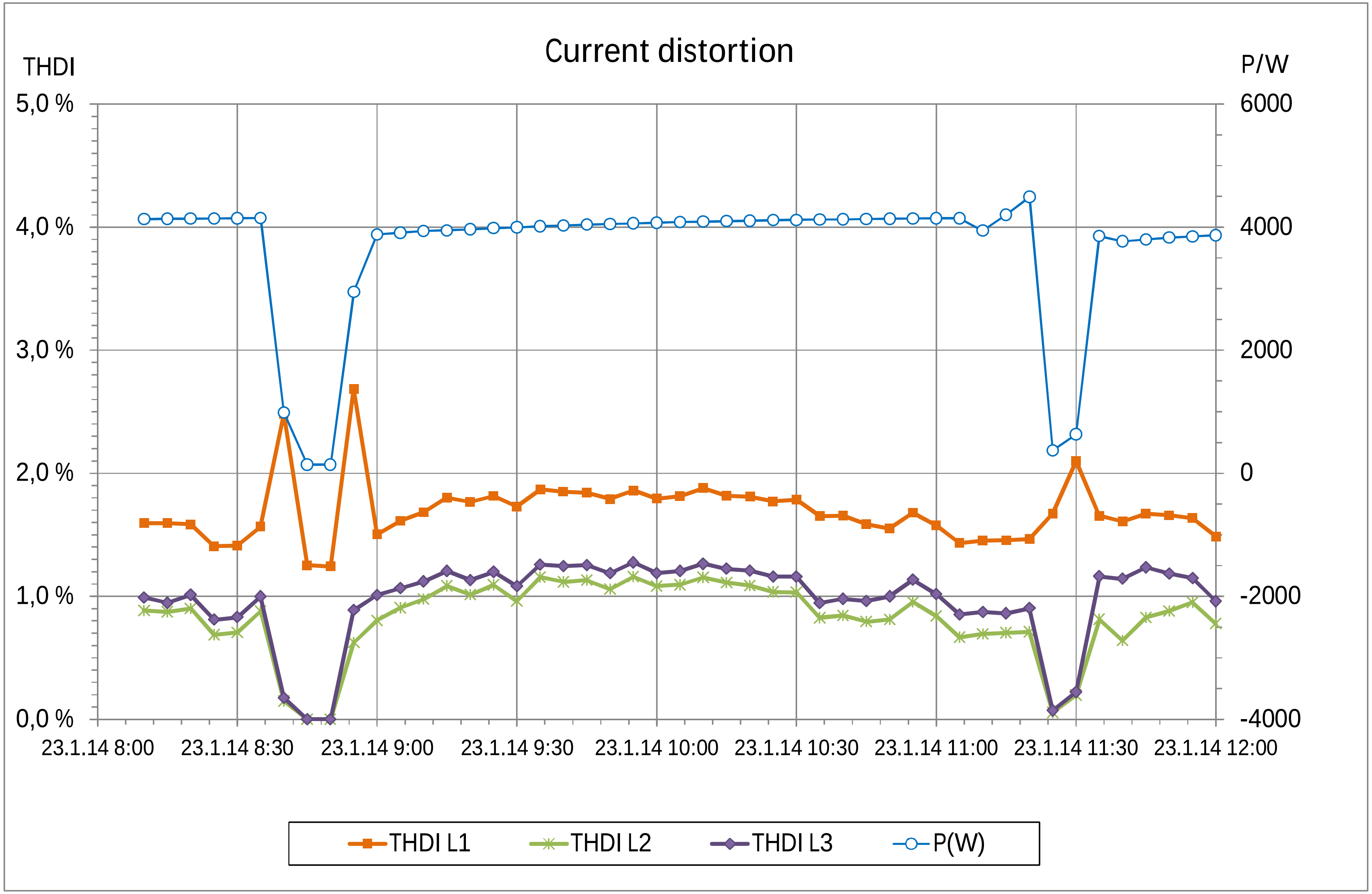


Figure 26 Current distortion calculated from one complete heating cycle of the ground source heat pump, during maximum energy in 2014

Annex A

Table A1 Technical data of the ground source heat pump Danfoss DHP-H 12 assembled to Uurtajantie 4 (Danfoss 2014).

a) Data sheet DHP-H, general

DHP-H			***6***	***8***	***10***	***12***	***16***
Refrigerant	Type		R407C	R407C	R407C	R407C	R407C
	Amount	kg	1.20	1.30	1.45	1.55	2.00
Compressor	Type		Scroll	Scroll	Scroll	Scroll	Scroll
Electrical data 3-N~50Hz	Main supply	Volt	400	400	400	400	400
	Rated power, compressor	kW	3.0	3.2	4.2	5.0	7.2
	Rated power, circulation pumps	kW	0.2	0.2	0.5	0.5	0.6
	Auxiliary heater, 3 steps	kW	3/6/9	3/6/9	3/6/9	3/6/9	3/6/9
	Start current[1]	A	9	10	12	14	20
	Fuse	A	10[4]/16[5]/20[6]	16[4]/16[5]/20[6]	16[4]/16[5]/20[6]	16[4]/20[5]/25[6]	20[4]/20[5]/25[6]
Electrical data 1-N~50Hz	Main supply	Volt	230	230	230	230	**
	Rated power, compressor	kW	3.2	3.6	4.5	5.5	**
	Rated power, circulation pumps	kW	0.2	0.2	0.5	0.5	**
	Auxiliary heater, 3 steps	kW	1.5/3.0/4.5	1.5/3.0/4.5	1.5/3.0/4.5	1.5/3.0/4.5	**
	Start current[1]	A	22	24	26	28	**
	Fuse	A	25[4]/32[5]/40[6]	25[4]/32[5]/40[6]	32[4]/40[5]/50[6]	32[4]/40[5]/50[6]	**
Performance	COP[2]		4.74	4.88	4.84	4.75	4.80
	COP[3]		4.04	4.34	4.24	4.20	3.99
	Heating capacity[3]	kW	5.33	7.51	9.40	11.0	16.4
	Power input[3]	kW	1.3	1.7	2.2	2.6	4.1
Max/min temperature	Cooling circuit	°C	20/-10	20/-10	20/-10	20/-10	20/-10
	Heating circuit	°C	60/20	60/20	60/20	60/20	60/20
Water volume	Water heater	l	180	180	180	180	180
Anti freeze media[7]			Ethanol + water solution with freezing point -17 ±2 °C				
Dimensions LxWxH		mm	690x596x1845	690x596x1845	690x596x1845	690x596x1845	690x596x1845
Weight empty		kg	229	229	229	238	242
Weight filled		kg	409	409	409	418	422
Sound power level[8]		dB(A)	47	44	46	49	57

NOTES:
The measurements are performed on a limited number of heat pumps which can cause variations in the results. Tolerances in the measuring methods can also cause variations.
*) TWS - Tap Water Stratification, our patented technology developed to ensure that the stored heat is always used optimally.
1) According to IEC61000.
2) At B0W35 Δ10K warm side (excluding circulation pumps).
3) At B0W35 according to EN 14511 (including circulation pumps).
4) Heat pump with 3 kW auxiliary heater (1-N 1.5 kW).
5) Heat pump with 6 kW auxiliary heater (1-N 3 kW).
6) Heat pump with 9 kW auxiliary heater (1-N 4.5 kW).
7) Always check local rules and regulations before using antifreeze.
8) Sound power level measured according to EN ISO 3741 at B0W45 (EN 12102).
**) Not available in this version.

b) Technical brochure DHP-H, general

Heat pump DHP-H			12
Refrigerant	Type		R407C
	Amount	kg	1.55
	Test pressure	MPa	3.2
	Design pressure	MPa	3.1
Compressor	Type		Scroll
	Oil		POE
Electrical data 3-N	Main supply	Volt	400V 3-N
	Rated power, compressor	kW	4.4
	Auxiliary heater, max 3 steps	kW	3/6/9
	Start current	A	32
	Circuit breaker	A	16[2]/20[3]/25[4]
Performance [1]	Output capacity	kW	10.7
	Heat factor	COP	3.1
Nominal flow [6]	Cooling circuit	l/s	0.6
	Heating circuit	l/s	0.3
External available pressure [5]	Cooling circuit	kPa	64
	Heating circuit	kPa	51
Max/min temperature	Cooling circuit	°C	20/-10
	Heating circuit	°C	55/20
Pressure switches	Low pressure	MPa	0.08
	Operating	MPa	2.65/2.85
	High pressure	MPa	3.10
Anti freeze media			Ethylene glycol/ Ethanol
Water heater volume		l	180
Weight		kg	238

NOTES:
1) At B0W45 according to EN 14511 (including circulation pumps)
2) Heat pump with 3 kW auxiliary heater
3) Heat pump with 6 kW auxiliary heater
4) Heat pump with 9 kW auxiliary heater
5) Presure drop that must not be exceeded outside the heat pump without the nominal flow being reduced
For the cooling circuit these values require a pipe of Ø 40x2 4
6) Nominal flow: heating circuit Δ10K, cooling circuit Δ3K

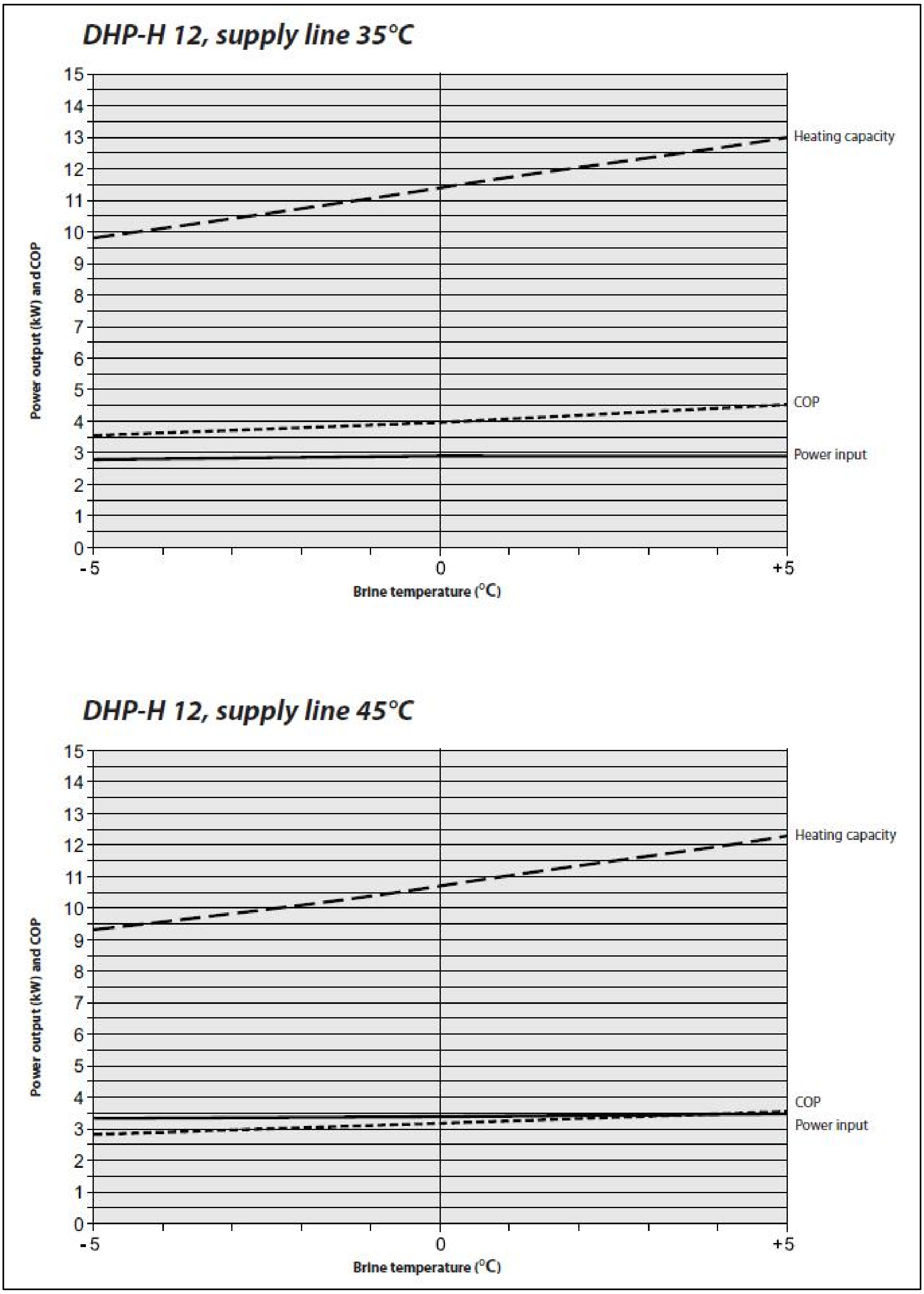


Figure A1 Power and COP (coefficient of performance) graphs of heat pump DHP-H 12. Heating capacity (kW), Power input (kW) and COP (factor) as a function of Brine temperature (°C). The data shown in the graphs is according to EN14511 including circulation pumps for B0W35 (top) and B0W45 (bottom). (Danfoss 2014).