Methods, processes and practices to ensure high availability of heat pumps

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Abstract

Heat pumps have been sold for more than three decades. Today 730 000 heat pumps are collecting more than 5 TWh of renewal energy every year in Finland. Heat pumps have been most popular heating method in new residential buildings for several years. One of the fastest growing segment is exhausted air heat recovery systems in large apartment buildings. Also in commercial buildings heat pumps have started to play significant role, especially when renovating old heating systems.
In most cases heat pumps are running in stand-alone basis. This means that in case of error there are no immediate and automatic detection mechanisms that would trigger required corrective actions such as adjusting parameters or sending serviceman on-site to fix the problem. When the heat pump error occurs, it may take hours, days or even months before someone notices that. While the heat pump is not running there are back-up energy sources such as oil, gas, electricity or district heating. Back-up power capacity may be also limited causing drop of temperature inside the building.
Heat pump errors are not that rare and usually causes loss of energy savings and dissatisfaction to people living in the building. In some cases, the financial losses have been more than 20 000 euros. This presentation describes what kind of methods, processes and practices should be taken in to use to minimize the downtime of heat pump, prevent loss of money and to maximize the satisfaction of building owners and people living in the building.

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Keywords: heat pumps; supervision; control; optimization; methods

1. Introduction

Heat pumps have been one of the most popular solution for providing heating in new detached houses in Finland. In renovation market heat pumps are used to replace oil burners, district heating or direct electricity. By the end of 2015 more than 730 000 heat pumps have been installed [1].

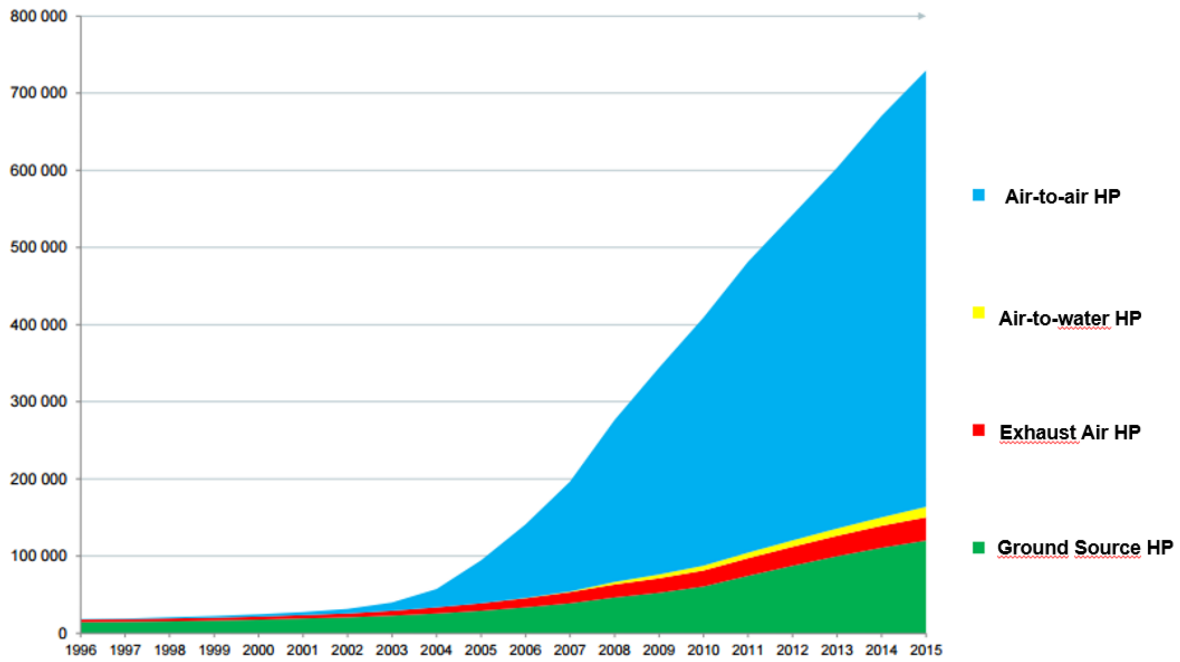

Fig. 1. Heat pump installations in Finland

These heat pumps collect more 5 TWh of renewal energy from different sources. Ground source heat pumps uses geothermal energy, Air-to-Water and Air-to-Air heat pumps extracts energy from the outside air and Exhaust Air Heat Pump recovers the energy from exhausted air that would we otherwise wasted.

Large apartment buildings built between 1960's and 2002 has mechanical ventilation without heat recovery [2]. This means that major part of energy used for heating is lost through ventilation. Study made by VTT indicates that 46% of heating energy loss is through mechanical ventilation if no heat recovery is used [3]. During the four decades' total of 38 500 apartment buildings were built, representing 62 million square meters of space heating [4]. All these buildings have an opportunity to install Exhaust Air Heat Pump (EAHP) that recovers the energy from exhausted air which will cut the energy bill by 30-40%.

No matter what is the application used, it is essential that planned annual running hours are met and heat pump can work on the conditions it has been designed by the manufacturer. Each heat pump type has its own optimal operational range where the best efficiency (i.e. COP) is achieved. In case the heat pump operates outside of designed optimal range, it will consume more electricity and COP will suffer. Additionally, heat pump lifetime will be shorter.

Main reason for selecting heat pump is the low running costs, although the investment is typically higher than in most of other heating solutions. Customers are expecting that higher investment will pay back as soon as possible and give a good return on investment over the time.

There is, however, a significant risk due various reasons that heat pump application will not run as planned or it runs outside of optimal range. In such case, investment does not pay back in a designed timeframe and best possible return on investment is not realized, unless the system is under continuous supervision and control.

There are plenty of examples where the customer has been surprised negatively about the heat pump operational failures and loss of expected savings. In some extreme cases, there has been so severe problems in the heat pump operations that the case has been taken to court. It is clear that every player on the field (customer, contractor, manufacturer) would not like to see such a low performance.

2. Reasons for heat pump running failures

Optimal performance of heat pump depends on various issues. Some of them are related how the system is designed and installed. However most common reasons for low performance are not related to poor design or installation but rather the operational conditions that change over the time. This is the author's view based on 7 years of experience with heat pump design, installation, supervision and control.

As a starting point, heat pump systems should be always designed by qualified designer who has necessary experience and knowledge of heat pumps. Same applies to installation. Following basic requirements should be met from system design and installation perspective:

- Heat pump power dimensioning is done correctly
- Bore hole dimensioning is done correctly (in case of geothermal heat pump)
- Additional power source and back-up system is dimensioned correctly
- Proper HVAC, automation and electrical design is made
- Installation is made by qualified persons and by following the design
- Installation is supervised by qualified person
- System is fully tested and commissioned before handed over to customer

Even if the design, installation and commissioning is done properly, there are still numerous of issues that may cause system malfunction or failure during the operation. The following list includes the most common issues that are affecting heat pump operation:

- filters in pipelines getting muddy and causing lower flow of liquid
- air filters getting dirty and causing less air flow through heat recovery unit
- fault in water circulation pumps outside of heat pump
- heating radiator thermostats prevent water circulation through condenser of HP
- pressure drop in pipelines
- leakage in pipelines
- fuse tripped
- safety switch not turned back on after service is completed
- emergency stop switch turned off accidentally (e.g. by house cleaner)
- human mistake by serviceman (e.g. setting parameters incorrectly)
- annual maintenance activities not done.

Following issues are typical faults seen in heat pumps:

- heat pump low pressure switch (pressostat) triggered (due to low flow through evaporator in brine circuit)
- heat pump high pressure switch (pressostat) triggered (due to low flow through condenser in heat medium circuit)
- heat pump refrigerant leakage
- fault in expansion valve of heat pump refrigerant circuit
- fault in soft starter or contactor/relay of heat pump
- fault in circulation pump inside heat pump
- faults in software of heat pump.

3. Financial impact of heat pump running failures

Depending on the size of heat pump system any of the faults described in previous chapter may cause significant financial losses to the heat pump owner, if they are not detected on time. It can be said that the larger the system is the higher is the financial loss in case of failure. Also, the longer the time between failure and detection is, the higher is the loss. Every time heat pump fails to run there is a back-up power taken in use automatically. Since the back-up power energy is typically 2-4 times more expensive financial impact realizes immediately when the fault occurs.

Therefor the essential question is that are there adequate methods, processes and practices in place to minimize the delay of detecting the fault situation, identifying the root cause of failure and implementing corrective actions.

3.1. Financial losses of 180 kW Ground Source Heat Pump system

Building with 70 apartments and located in southern part of Finland consumes 500 MWh of energy for space and tap water heating. If the building owner makes a ground source heat pump investment and disconnects from DH network, owner can expect to save 41 000 euros in annual heating costs.

Table 1. Parameters of 180 kW GSHP system

Parameter	Value
Building:	Building with 70 apartments
Heat pump application	180kW Ground Source Heat Pump
Heat Pump energy cost	36,14 € per MWh
Back-up energy source	Electricity
Back-up energy cost	120,00 € per MWh
Building annual energy consumption	500 MWh
Degree of power coverage	81 %
Degree of energy coverage	99,6 %
Running hours per year	3000 h
runnning ratio of full year (8760h)	34,2 %
SCOP	3,32
Expected annual saving in heating costs	41 760 € per year

Depending on the length of heat pump downtime the financial loss varies from 800 euros up to 41 000 euros per year.

Table 2. Financial loss during 1 year in different downtime periods

Downtime period	Annual Downtime (h)	Annual Downtime (%)	Energy supplied to HP (MWh)	Energy produced by HP (MWh)	Supl. energy needed (MWh)	Total energy needed (MWh)	Total purchased energy (MWh)	Back-up energy needed (MWh)	One year financial loss
100% runtime	0	0	150,0	498	2,0	500	152,0		
Downtime 1 week/year	57,5	1,9 %	147,1	488,4	11,6	500	158,7	6,7	**-801 €**
Downtime 2 weeks/year	115,1	3,8 %	144,2	478,9	21,1	500	165,3	13,3	**-1 602 €**
Downtime 1 month/year	246,6	8,2 %	137,7	457,1	42,9	500	180,6	28,6	**-3 432 €**
Downtime 3 months/year	739,7	24,7 %	113,0	375,2	124,8	500	237,8	85,8	**-10 297 €**
Downtime 12 months/year	3000,0	100,0 %	0,0	0,0	500,0	500	500,0	348,0	**-41 760 €**

3.2. Financial losses of 120 kW Exhaust Air Heat Pump system

Building with 110 apartments located in southern part of Finland consumes 1400 MWh of energy for space and tap water heating. Building has been built on 1980's and has mechanical ventilation without heat recovery. Building owner makes an exhaust air heat pump investment where supplementary energy is provided by DH network. In this case the expected saving is 37 000 euros in annual heating costs.

Table 3. Parameters of 120 kW EAHP system

Parameter	Value
Building:	Building with 110 apartments
Heat pump application	120kW Exhaust Air Heat Pump
Heat Pump energy cost	31,58 € per MWh
Supplementary energy cost (DH)	65,00 € per MWh
Back-up energy source	DH
Back-up energy cost	65,00 € per MWh
Building annual energy consumption	1400 MWh
Degree of power coverage	21 %
Degree of energy coverage	56,0 %
Running hours per year	6404 h
running ratio of full year (8760h)	73,1 %
SCOP	3,80
Expected annual saving in heating costs	37 115 € per year

Depending on the length of heat pump downtime the financial loss varies from 700 euros up to 37 000 euros per year.

Table 4. Financial loss during 1 year in different downtime periods

Downtime period	Annual Downtime (h)	Annual Downtime (%)	Energy supplied to HP (MWh)	Energy produced by HP (MWh)	Supl. energy needed (MWh)	Total energy needed (MWh)	Total purchased energy (MWh)	Back-up energy needed (MWh)	One year financial loss
100% runtime	0		207,0	778	622,0	1400	829,0		
Downtime 1 week/year	122,8	1,9 %	203,0	763,1	636,9	1400	840,0	11,0	-712 €
Downtime 2 weeks/year	245,6	3,8 %	199,1	748,2	651,8	1400	850,9	21,9	-1 424 €
Downtime 1 month/year	526,4	8,2 %	190,0	714,1	685,9	1400	875,9	46,9	-3 051 €
Downtime 3 months/year	1579,1	24,7 %	156,0	586,2	813,8	1400	969,8	140,8	-9 152 €
Downtime 12 months/year	6404,0	100,0 %	0,0	0,0	1400,0	1400	1400,0	571,0	-37 115 €

4. Benefits of continuous supervision

Having continuous supervision and monitoring system together with required methods and processes to fix the faults ensures high availability of heat pump system. This does not only provide planned return on investment but also prolongs the heat pump lifetime. This will give additional financial benefit to building owner due lower maintenance costs.

Another benefit is that heat pump system performance is continuously under supervision and in case something starts to go wrong monitoring system identifies that proactively and problem can be solved before it impacts the heat pump behavior. This is called preventive maintenance.

4.1. Financial savings of 180 kW GSHP system with continuous supervision

As described in previous chapter, a building with 70 apartments consuming 500 MWh of energy can expect to save 41 000 euros in annual heating costs with 180 kW GSHP system. This saving is realized only if the system runs continuously as designed, year after year, without any disturbance.

In practice, during the year there may occur several incidents due various reasons (as described in chapter 2), that causes downtime for heat pump. Every time downtime occurs, there are financial impact involved. These financial impacts can be minimized with adequate supervision system, as described in table 5.

Table 5. Financial saving with supervision during 1 year in different downtime periods of 180 kW GSHP system

			No supervision		With Supervision	
Downtime period	Annual Downtime (h)	Annual Downtime (%)	Back-up energy needed (MWh)	One year financial loss	annual cost of supervision	1. year saving
100% runtime	0	0				
Downtime 1 week/year	57,5	1,9 %	6,7	-801 €	600,00 €	201 €
Downtime 2 weeks/year	115,1	3,8 %	13,3	-1 602 €	600,00 €	1 002 €
Downtime 1 month/year	246,6	8,2 %	28,6	-3 432 €	600,00 €	2 832 €
Downtime 3 months/year	739,7	24,7 %	85,8	-10 297 €	600,00 €	9 697 €
Downtime 12 months/year	3000,0	100,0 %	348,0	-41 760 €	600,00 €	41 160 €

4.2. Financial savings of 120 kW EAHP system with continuous supervision

Another example was a building with 110 apartments consuming 1400 MWh of energy. By investing to 120 kW exhaust air heat pump the expected saving is 37 000 euros in annual heating costs. Again, this saving is realized only if the system runs continuously as designed, year after year, without any disturbance.

Especially in this kind of application there can be many incidents causing downtime for heat pump. In many cases the reason is a simple human mistake made by janitor or serviceman due to the lack of understanding of the whole system behavior. Heat Pump downtime due these kinds of issues can be easily minimized with adequate supervision system. Financial benefits are described in table 6.

Table 6. Financial saving with supervision during 1 year in different downtime periods of 120kW EAHP system

			No supervision		With Supervision	
Downtime period	Annual Downtime (h)	Annual Downtime (%)	Back-up energy needed (MWh)	One year financial loss	annual cost of supervision	1. year saving
100% runtime	0					
Downtime 1 week/year	122,8	1,9 %	11,0	-712 €	600,00 €	112 €
Downtime 2 weeks/year	245,6	3,8 %	21,9	-1 424 €	600,00 €	824 €
Downtime 1 month/year	526,4	8,2 %	46,9	-3 051 €	600,00 €	2 451 €
Downtime 3 months/year	1579,1	24,7 %	140,8	-9 152 €	600,00 €	8 552 €
Downtime 12 months/year	6404,0	100,0 %	571,0	-37 115 €	600,00 €	36 515 €

5. Methods, processes and practices for ensuring high availability

To ensure that the heat pump system operates as planned, delivers the energy savings expected and gives the best possible return on investment, several topics needs to be addressed properly. First thing is to decide how the system will be taken under continuous monitoring and supervision. Traditionally this has been handled by serviceman who has visited the site in a regular basis and has looked after the heating system and in case of malfunction has repaired the system. This has worked rather well (although not very cost-effectively) with the heating systems that are simple from technical perspective such as district heating, oil burner or electric heating.

Heat pump systems, however, are more complex and requires more expertise to address different kind of malfunctions and even to identify that something in the system is wrong. Recommended approach for continuous supervision and monitoring is to take a SCADA (Supervisory control and data acquisition) system in use [5]. Onsite SCADA systems require high investments but there are also cloud based SCADA systems available on the market that lowers the monitoring costs significantly. One example of such an application is Talotohtori cloud based SCADA [6]. Figure 2 shows an example of heat pump diagram in SCADA.

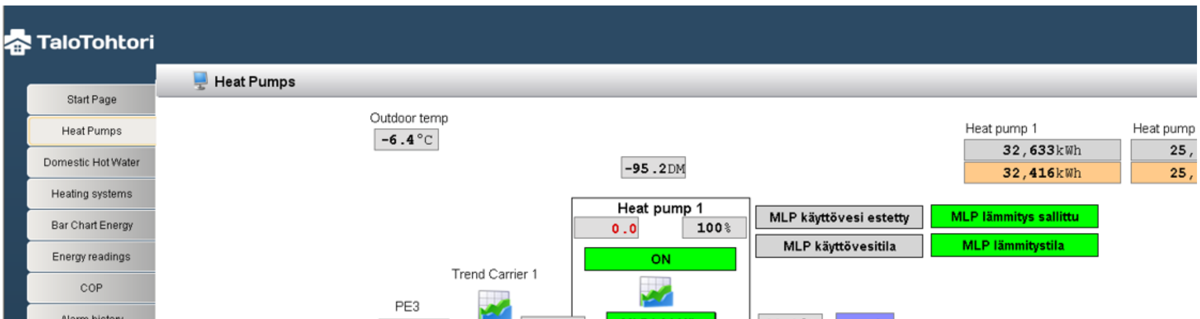

Fig. 2. Heat pump diagram in SCADA

More features of SCADA such as energy consumptions, COP, alarms and trends are showed in Appendix 1. With all these powerful features of SCADA, heat pump system can be remotely supervised and controlled which enable efficient and fast reaction for any kind of malfunction in a cost-effective manner.

Second topic to be addressed is the process knowledge of the supervision personnel. Those people who are monitoring the system remotely from SCADA, needs to have adequate skills about the heat pump processes. They need to be able to understand the process so well, that when something happens they can figure out the root cause by using the tools available on the SCADA. In case the root cause requires serviceman to go onsite, they need to be able to give precise instructions what to investigate.

Third topic is related to the practices on how the correction work is managed so that it can be tracked and ensured that correction was made properly and no side-effects has been occurred. There are two main guidelines for this:

- **Severity:** to understand and record the severity of the problem which helps to define the urgency of corrective actions. Highly severe issues need faster response times for correction than minor issues.
- **Status:** it is important to record the latest status of all problems identified. Intention of the status is to guide supervision staff to make right decisions in their daily work with handling problems. Some low severity problems may be open for quite long period while high severity issues need faster actions. Once the problem is fixed, it is important to verify it from the SCADA. Minutes of all taken actions and status changes should also be kept.

6. Conclusion

Rationale for the need of continuous supervision and control of heat pump solutions to ensure high availability is obvious. Heat pumps are invested mainly for the one reason only; they consume less energy than other heating systems and thus provide low operating cost. On the other hand, they are rather complex and sensitive systems and may not always operate as planned, due to the various faults either in the heat pump itself or in the system environment.

When the malfunction happens, heat pump stops running and backup power is taken automatically in to use. Then the key question is that what is the time between the failure and correction. The longer this time is, the bigger is the financial impact to the owner. We could say that in this case the traditional phrase “Time is money” applies very well.

By having adequate tools (SCADA), processes and practices in place, downtime of heat pump systems can be minimized and return on investment maximized. Customers who are investing heat pumps should not only require professional design and implementation of heat pump system but also professional services that minimizes downtime and ensures the planned savings and return on investment over the lifetime of the system. This is beneficial for every stakeholder and to the whole industry as well.

7. References

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8. Appendices

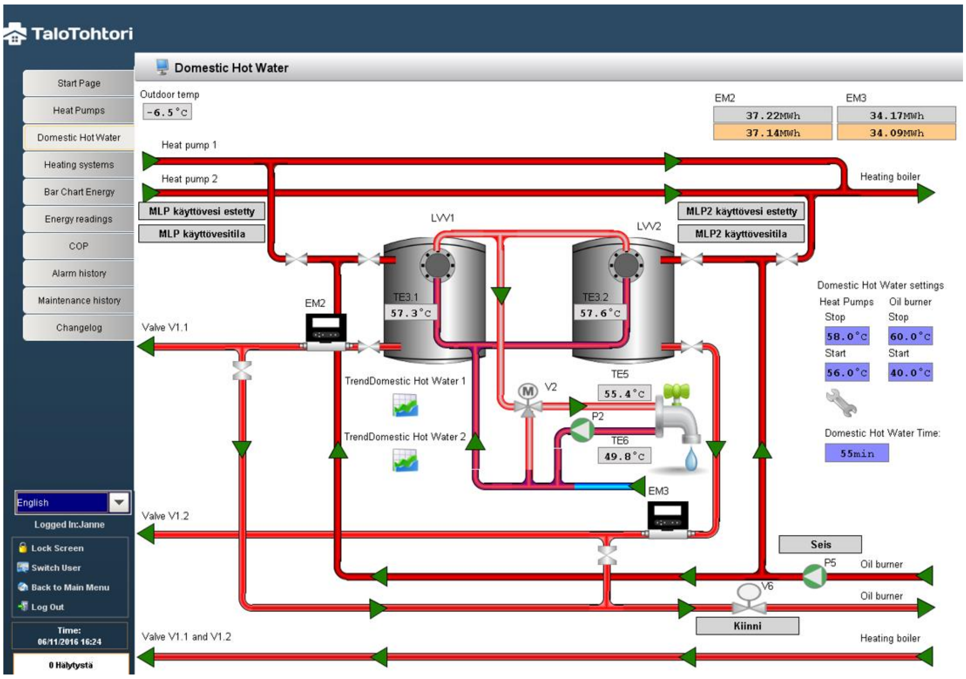

Fig. 3. Domestic hot water diagram in SCADA

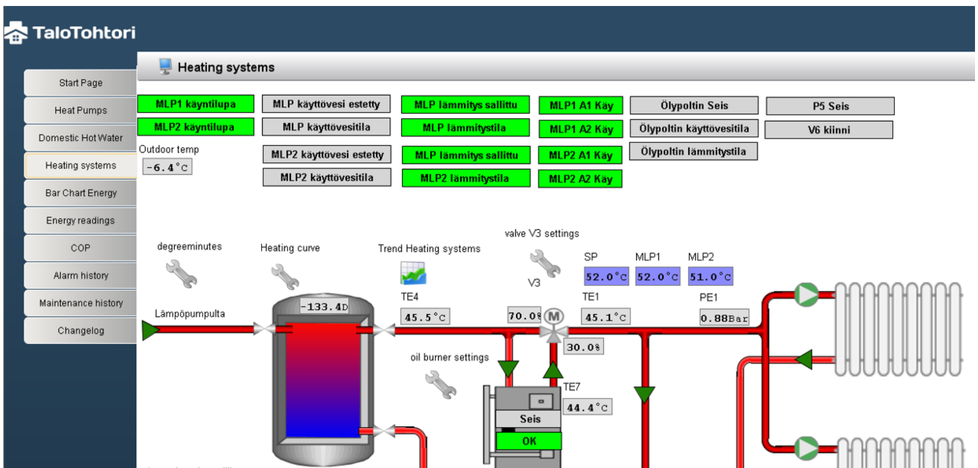

Fig. 4. Radiators and oil burner diagram in SCADA

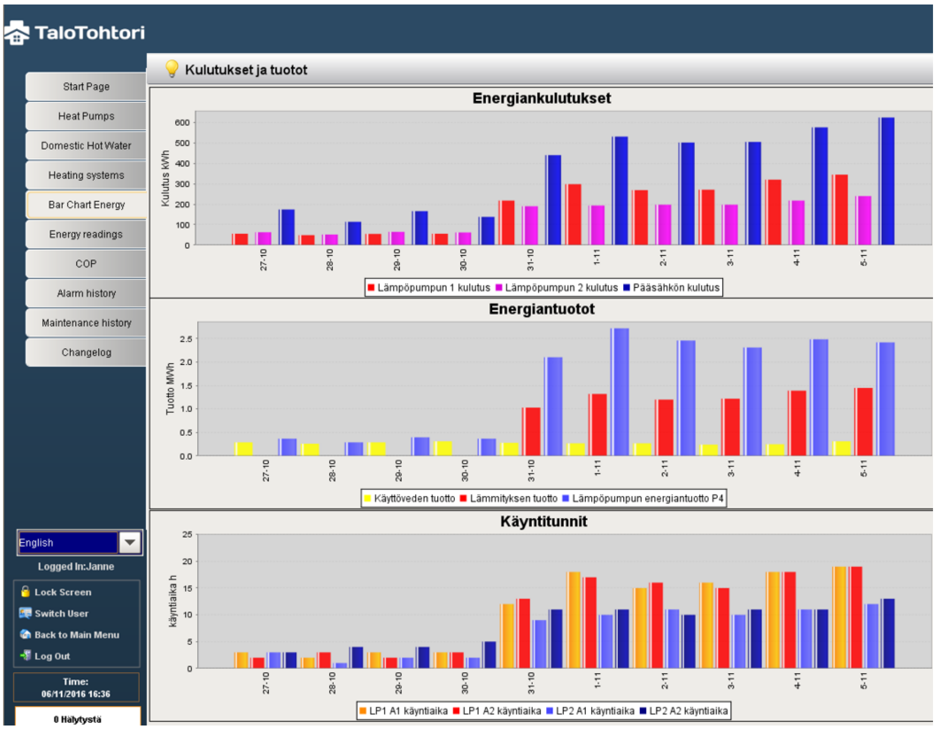

Fig. 5. Energy consumption in SCADA

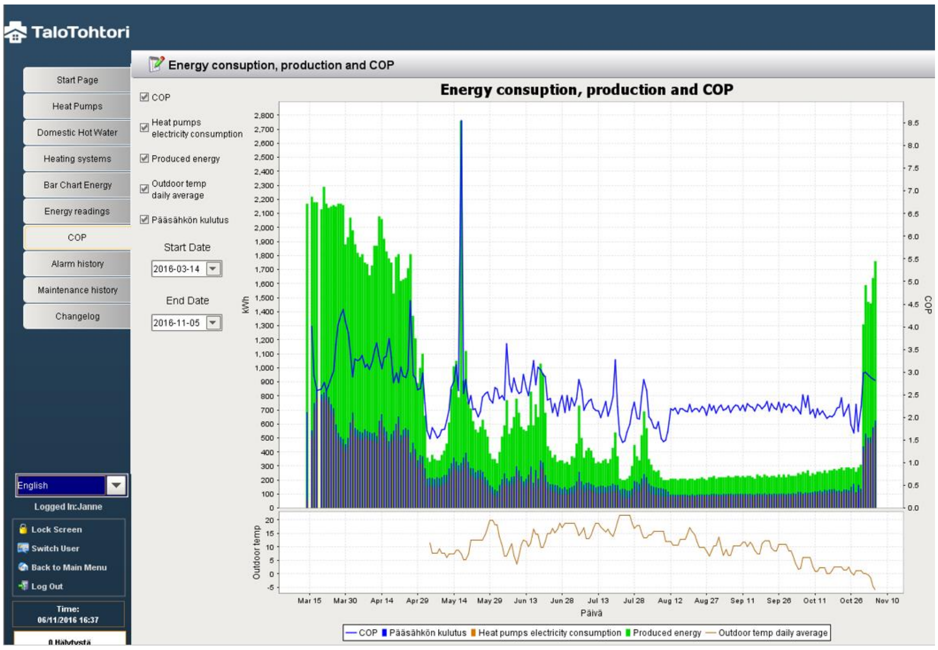

Fig. 6. Energy consumption, production and COP in SCADA

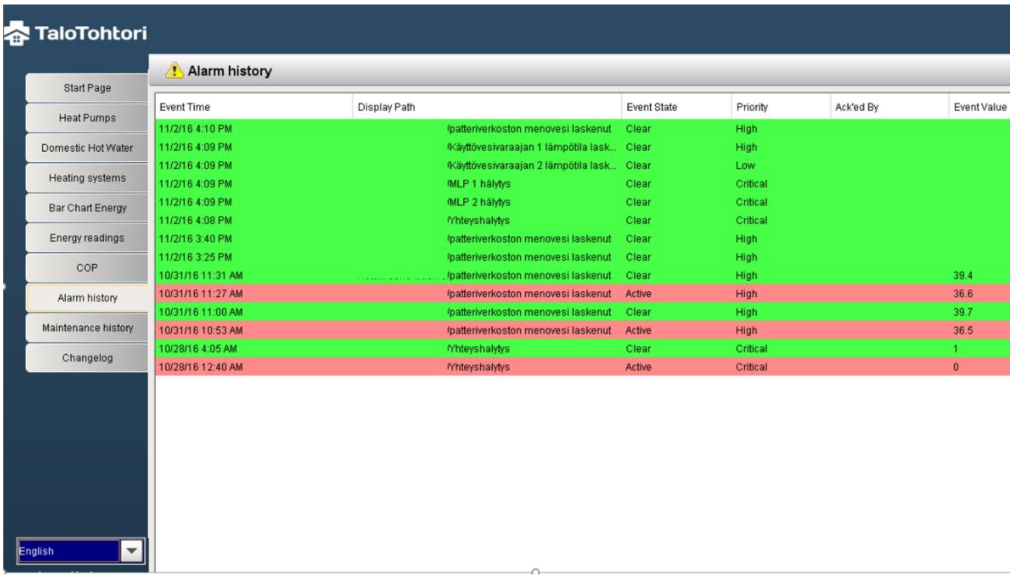

Fig. 7. Alarm history in SCADA

Fig. 8. Trend group in SCADA