SGC Rapport 2013:283

Installation and evlautation of gas heat pumps for medium-sized buildings

(Installation och utvärdering av gasvärmepump för medelstora fastigheter)

Mikael Näslund

"Catalyzing energygas development for sustainable solutions"

SGC Svenskt Gastekniskt CenterAB

INSTALLATION AND EVALUATION OF GAS HEAT PUMPS FOR MEDIUM-SIZED BUILDINGS (INSTALLATION OCH UTVÄRDERING AV GASVÄRME-PUMPAR FÖR MEDELSTORA FASTIGHETER)

Mikael Näslund

Denna studie har finansierats av:
Energimyndigheten
Dansk Gasteknisk Center A/S
E.ON Gas Sverige AB
Lund Energikoncernen AB
Göteborg Energi AB
Öresundskraft AB
Malmö Stad
Milton AB

Rapporten finns också publicerad av:
Dansk Gasteknisk Center A/S - med titeln ”Gas and renewable energy. Robur gas heat pump field test, Limhamn, Sweden”, av Mikael Näslund

Postadress och Besöksadress
Scheelegatan 3
212 28 MALMÖ

Telefonväxel
040-680 07 60

Telefax
0735-279104

E-post
info@sgc.se

Hemsida
www.sgc.se

Svenskt Gastekniskt Center AB, SGC

SGC är ett spjutspetsföretag inom hållbar utveckling med ett nationellt uppdrag. Vi arbetar under devisen *"Catalyzing energygas development for sustainable solutions"*. Vi samordnar branschgemensam utveckling kring framställning, distribution och användning av energigaser och sprider kunskap om energigaser. Fokus ligger på förnybara gaser från rötning och förgasning. Tillsammans med företag och med Energimyndigheten och dess kollektivforskningsprogram *Energigastekniskt utvecklingsprogram* utvecklar vi nya möjligheter för energigaserna att bidra till ett hållbart samhälle. Tillsammans med våra fokusgrupper inom *Rötning*, *Förgasning och bränslesyntes*, *Distribution och lagring*, *Industri och hushåll* och *Gasformiga drivmedel* identifierar vi frågeställningar av branschgemensamt intresse att genomföra forsknings-, utvecklings och/eller demonstrationsprojekt kring. Som medlem i den europeiska gasforskningsorganisationen GERG fångar SGC också upp internationella perspektiv på utvecklingen inom energigasområdet.

Resultaten från projekt drivna av SGC publiceras i en särskild rapportserie – *SGC Rapport*. Rapporterna kan laddas ned från hemsidan – www.sgc.se. Det är också möjligt att prenumerera på de tryckta rapporterna. SGC svarar för utgivningen av rapporterna medan rapportförfattarna svarar för rapporternas innehåll.

SGC ger också ut faktabroschyrer kring olika aspekter av energigasers framställning, distribution och användning. Broschyrer kan köpas via SGC:s kansli.

SGC har sedan starten 1990 sitt säte i Malmö. Vi ägs av EON Gas Sverige AB, Energigas Sverige, Swedegas AB, Göteborg Energi AB, Lunds Energikoncernen AB (publ) och Öresundskraft AB.

Malmö 2013

Martin Ragnar
Verkställande direktör

Swedish Gas Technology Centre, SGC

SGC is a leading-edge company within the field of sustainable development having a national Swedish assignment. We work under the vision of *“Catalyzing energygas development for sustainable solutions”*. We co-ordinate technical development including manufacture, distribution and utilization of energy gases and spread knowledge on energy gases. Focus is on renewable gases from anaerobic digestion and gasification. Together with private companies and the Swedish Energy Agency and its frame program *Development program for energy gas technology* we develop new solutions where the energygases could provide benefits for a sustainable society. Together with our focus groups on *Anaerobic digestion*, *Gasification and fuel synthesis*, *Distribution and storage*, *Industry and household* and *Gaseous fuels* we identify issues of joint interest for the industry to build common research, development and/or demonstrations projects around. As a member of the European gas research organization GERG SGC provides an international perspective to the development within the energygas sector

Results from the SGC projects are published in a report series – *SGC Rapport*. The reports could be downloaded from our website – www.sgc.se. It is also possible to subscribe to the printed reports. SGC is responsible for the publishing of the reports, whereas the authors of the report are responsible for the content of the reports.

SGC also publishes fact brochures and the results from our research projects in the report series *SGC Rapport*. Brochures could be purchase from the website.

SGC is since the start in 1990 located to Malmö. We are owned by EON Gas Sverige AB, Energigas Sverige, Swedegas AB, Göteborg Energi AB, Lunds Energikoncernen AB (publ) and Öresundskraft AB.

Malmö, Sweden 2013

Martin Ragnar
Chief Executive Officer

Authors' foreword

In the European Ecodesign labeling system, that most likely will be implemented in 2015, gas-fired heat pumps will be considered as one of the best technologies to utilize renewable energy. The gas heat pump is in itself using renewable energy from the air, ground etc. and can also use carbon neutral gaseous fuels, such as biogas from anaerobic digestion and gas from gasification of biomass.

On this background and due to the possibility for gaseous fuels to act as a bridge to a wider use of renewable energy is it the intention to demonstrate gas heating technologies that use or cooperate with renewable energy. The Danish gas distribution companies and the appliance suppliers cooperate in field tests within an overall program called "Total concepts for gas in cooperation with renewable energy" administered by the Danish gas companies' Technical Committee on Gas Utilisation and Installations (FAU GI). The demonstration reported in this study also includes Swedish gas companies through the Swedish Gas Technology Centre (SGC). In the current project, measurements are made on a gas heat pump installation in Limhamn (Malmö), Sweden. The gas heat pump is operated by the city of Malmö.

The field test was funded jointly by the Swedish Gas Technology Centre's R&D program and the Danish gas companies' Technical Committee on Gas Utilisation and Installations (FAU GI). The data acquisition was managed by SGC and E.ON Gas. The evaluation was done at Danish Gas Technology Centre (DGC). A reference group consisting of Mikael Näslund (DGC), Anna-Karin Jannasch (SGC), Theo Blom (E.ON Gas) and Joannis Ververidis (Malmö City) discussed the results during the field test. The report was written by Mikael Näslund and quality assurance within DGC was made by Karsten V. Frederiksen.

Summary

A Robur E^3 air-to-water gas heat pump was demonstrated in a day-care centre in Limhamn, Malmö. It covered the major part of the heating demand. A condensing gas boiler was used for peak loads. The operation and performance were studied in a field test during 2012. The results are summarized in Table 1[1]. The efficiencies are based on the lower heating value. The main observation is that the heat pump efficiency was not as high as anticipated. This is most likely caused by unsatisfactory integration of the gas heat pump and gas boiler in the heating system. Maintenance and service during the field test period were only related to the start phase and measures to improve the integration of the heating system parts.

Table 1. Field test results 2012, Robur E^3 in Limhamn, Malmö

(January 10, 2012 – February 1, 2013)

Parameter	**Value**
Total heat demand (kWh)	130,400
Heat pump production (kWh)	84,330
Gas boiler production (kWh)	55,650
Gas heat pump efficiency (%)	107
Gas boiler efficiency (%)	92
System efficiency (%)	105
Electricity consumption (kWh)	67,600 (2012 only)
Distribution heat loss, estimated (kWh)	2,000

The results indicate that the gas heat pump efficiency can reach 130 % after improvements of the control system and the heating system. Even though the efficiency was not as anticipated the gas savings were 25 %. If the installation could be improved the savings may reach 40 – 45 % compared to the original non-condensing gas boiler. No detailed economic evaluation was made in the report due to the non-optimized operation and performance. The pay-back time for a well operating installation with 130 % annual efficiency is estimated to 6 years.

[1] The gas heat pump performance is often stated as efficiency instead of COP which is used for electric heat pumps.

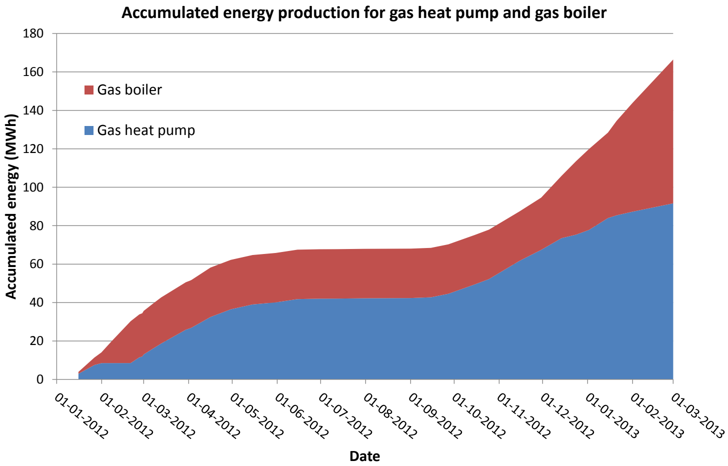
Sammanfattning på svenska

Uppvärmning med hjälp av kondenserande gaspannor har länge ansetts som det fossila uppvärmningsalternativ med lägst miljöpåverkan, med beaktande av såväl koldioxid som andra skadliga utsläpp såsom partiklar, svavel- och kväveoxider. Denna teknik kan idag också på många håll med fördel kombineras med förnybar energi (biogas, solenergi), och därmed bli helt eller delvis koldioxidneutral. Verkningsgraden har dock nått sitt praktiska maximum (ca 105 % på årsbasis relaterat till bränslets undre värmevärde) och effektivare lösningar efterfrågas nu av kunderna. Detta kan nu erbjudas av gasdrivna värmepumpar, som nu för första gången i Sverige har demonstrerats i Limhamns gamla brandstation i Malmö, idag använt som dagcenter. Demonstrationen har pågått under drygt ett år med kontinuerlig insamling av driftdata. Föreliggande rapport presenterar och diskuterar uppmätt prestanda som funktion av drifttid, omgivningstemperatur och last samt erhållna praktiska installationserfarenheter. Förhoppningen är att demonstrationen skall kunna bidra till att fler miljövänliga och energibesparande gasvärmepumpar börjar installeras i Sverige. De primära skillnaderna mellan en gasvärmepump och en konventionell värmepump består av att man ersatt en förädlad energiform (el) med en primär energikälla (gas) samt att man ersatt kompressorn med en termisk krets, varav det senare resulterar i billigare underhållskostnader.

Aktuell gasvärmepump som installerats och utvärderats i denna studie är en s.k. on-off arbetande luft-vatten pump av modell Robur E^3, som i brist på utrymme i byggnaden placerades utomhus i tillhörande trädgård, se figur nedan. Värmepumpens designeffekt (35 kW_v) täcker nästintill den aktuella fastighetens totala värmebehov, som präglas av en större än vanligt andel av värme och bara en liten andel varmvattenbehov (ca 10 % av det totala värmebehovet). En kondenserande modulerande gaspanna (Milton Topline 80, 19-85 kW_v) installerades också med syfte att användas som back-up och för att täcka tillfälliga toppar i värmebehov. Behövligt varmvatten producerades separat i en elektriskt uppvärmd tank. Justeringar av diverse inställningar hos kontrollsystem samt utbyte av cirkulationspump har genomförts under testtiden. Det aktuella värmesystemet har ersatt en tidigare installerad icke-kondenserande gaspanna (160 kW_v), inkluderande en tvåstegs Bentone brännare, från 1986, med en uppskattad årlig verkningsgrad på som mest 80-85 %.

Figur 1. Foto på gasvärmepumpens placering utanför dagcentrat där aktuell fältstudie ägt rum.

Grafen i figur 2 visar den sammanlagda energin tillförd av värmepump respektive kompletterande gaspanna under fälttestet. Som förväntat står värmepumpen för den större delen av den totala energitillförseln för merparten av tiden, och dess drift har konstaterats vara tillförlitlig under hela testperioden.



Figur 2. Ackumulerad energi tillförd av gasvärmepump respektive gaspanna under fälttestet.

Vidare visar dock utvärderingen att den genomsnittliga prestandan varit betydligt lägre än vad som kan förväntas. Enligt leverantören Robur bör så pass höga verkningsgrader såsom 140-150 % kunna uppnås vid optimala driftförhållanden, i detta fall uppmättes i genomsnitt enbart 107 % i genomsnitt, se tabell 1 nedan. Samtidigt observerades att vid de tidsperioder gaspannan ej varit i drift uppnås betydligt bättre prestanda för värmepumpen, motsvarande verkningsgrader 125-130%, vilket i sin tur tydligt indikerar på brister i befintlig integration mellan de båda gasapparaterna. Ett annat delvis återkommande problem under fälttestet var isbildning på värmepumpen, vilket sannolikt också uppkommit till följd av inkorrekta kontrollinställningar. Nästa steg är därför att ytterligare justera och optimera kontrollinställningarna av ingående komponenter i aktuellt värmesystem. Man står även i begrepp i skrivandets stund att installera ett nytt kontrollkort som förväntas avsevärt kunna förbättra kommunikationen mellan gaspanna och värmepump, och därmed inom kort kunna uppnå signifikant högre effektiviteter.

Tabell 1. Huvudsakliga resultat uppmätta vid ett 12 månaders långt fälttest av en luft-vatten gasvärmepump (Robur E^3, 35 kWv) i kombination med en kondenserande gaspanna (Milton Topline 80, 19-85 kW_v) installerad vid ett dagcenter i Malmö.

Parameter	**Uppmätt Värde**
Totalt värmebehov (kWh)	130400
Gasvärmepumpens produktion (kWh)	84330
Gaspannans produktion (kWh)	55650
Verkningsgrad gasvärmepump (%, LHV)	107
Verkningsgrad gaspanna (%, LHV)	92
Systemverkningsgrad (%)	105
Elkonsumption (kWh)	67600 (OBS! under enbart år 2012)
Uppskattad distributionsvärmeförlust (kWh)	2000

Då driftsförhållanden för systemet inte varit optimerade har heller ingen djupare ekonomisk utvärdering genomförts. Man kan dock ändå enkelt konstatera att trots detta har signifikanta gasbesparingar (25 %) kunnat göras i jämförelse med tidigare befintligt värmesystem. Efter att ovan beskrivna justeringar genomförts förväntas denna besparingssiffra kunna stiga till hela 40-45 %, vilket i sin tur visar på teknikens potential.

Content

1. Introduction

A Robur GAHP air-to-water gas heat pump was evaluated regarding operation and performance. The heat pump is located in Limhamn old fire station, now owned by the city of Malmö and used as day care centre for disabled people. It is used during normal working hours on week days only.

The thermal energy demand is characterized by a larger than usual share of space heating and only a small hot water demand. The heating system consists of a radiator system and a floor heating system. Ventilation air is also heated. The main heating source is the Robur air-to-water gas absorption heat pump. A condensing gas boiler is used for peak demand. Hot water is produced separately in an electrically heated tank.

Figure 1. Limhamn old fire station now used for day care activities

1.1 Site description – old installation

The original gas boiler was installed in 1986. The boiler was a cast iron Parca Wirbex mini G rated at 160 kW. A two-stage Bentone burner adjusted to 113 kW and 176 kW was used. The flue gas temperature at the low and high burner input was 159°C and 176°C. The efficiencies were 92 % and 91 % for the low and high fuel input, respectively. The annual efficiency was assessed not to be larger than 80 – 85 %. The average degree day corrected annual gas consumption during 2008 – 2010 was 191,000 kWh. The old boiler is seen in Figure 2.

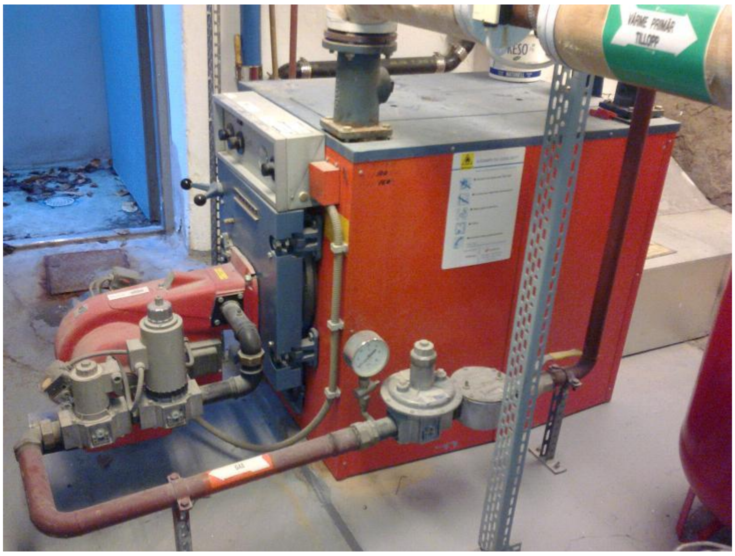


Figure 2. Old gas boiler with two-stage fan assisted burner

Hot water is produced in an electrically (13 kW) heated tank and hydraulically separated from the heating system. The tank has a volume of 300 l and was installed in 2004. The hot water tank is seen in Figure 3.

Figure 3. Hot water tank with electric heater (red)

1.2 Gas heat pump process and site description

Gas heat pumps are either of the compression type, where a gas engine operates the compressor, or thermally driven. In the latter designs, absorption or adsorption processes, a burner is used to raise the temperature of the source energy (air, ground energy etc.). In this field test, a thermally driven absorption gas heat pump has been evaluated.

Gas heat pumps have a lower COP (Coefficient of Performance) than electric heat pumps. The gas heat pump has a COP of 1.3 – 1.7 depending on source temperature and operating conditions. Electric heat pumps have a COP in the 3 – 5 range. However, when the primary energy consumption for the power generation is considered the heat pump COP is to be divided by a factor of 2.5 if a traditional fossil fuelled power plant is used. The performance difference is then not as large as it may look at a first glance.

Often the gas heat pump performance is expressed as efficiency rather than COP. A gas heat pump COP of 1.5 equals 150 % efficiency. Following the convention within the gas industry this report uses the efficiency to describe the gas heat pump performance.

1.2.1 Gas heat pump process

In the basic absorption process, ammonia is evaporated in an evaporator and flows to an absorber where it forms a solution with water. The absorption process is exothermic, and energy has to be transferred from the absorber. The ammonia and water solution is pumped to the generator where energy is added (for example from a gas burner or from steam). The vapour formed in the generator flows to a condenser and further on to the evaporator. A lean ammonia-water liquid solution flows from the generator back to the absorber. Other working pairs are also possible, for example Lithium-Bromide. The basic absorption cycle is shown in Figure 4.

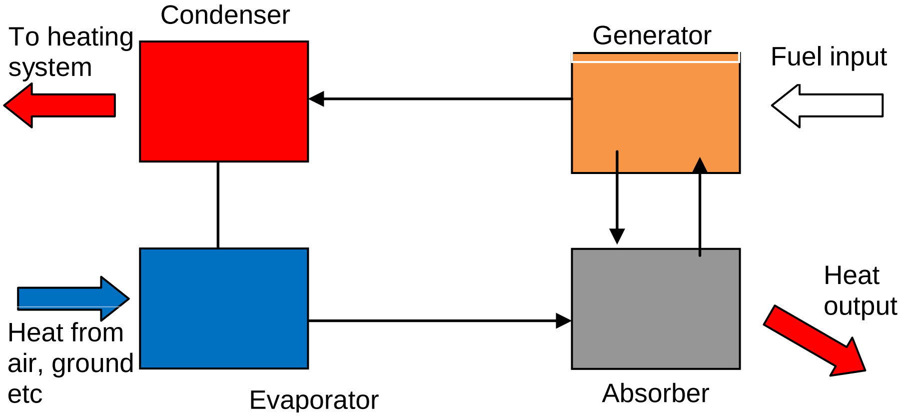


Figure 4. Basic gas heat pump absorption process

Among the advantages of gas-fired absorption heat pumps claimed by manufacturers and the gas industry are:

- Gas-fired heat pumps are the next step in efficiency improvement.
- The CO_2 reduction may be larger than for electric heat pumps when the primary energy consumption is considered.
- The lower COP for gas-fired heat pumps means that the heat exchanger for the heat source can be smaller and at a lower cost than the source heat exchanger for electric compression heat pumps with equal heat output.

- Some heat pump designs can be made without moving parts, i.e. there is a potential for low maintenance and long lifetime. Also, a very low noise level is possible.
- No CFC is used in the heat pump process.

Gasterra in the Netherlands has published a book covering most aspects of gas heat pumps [1].

1.2.2 Site description

The old gas boiler was replaced by the absorption gas heat pump working as base load and a condensing gas boiler for peak heat demands. The system layout is illustrated in Figure 5.

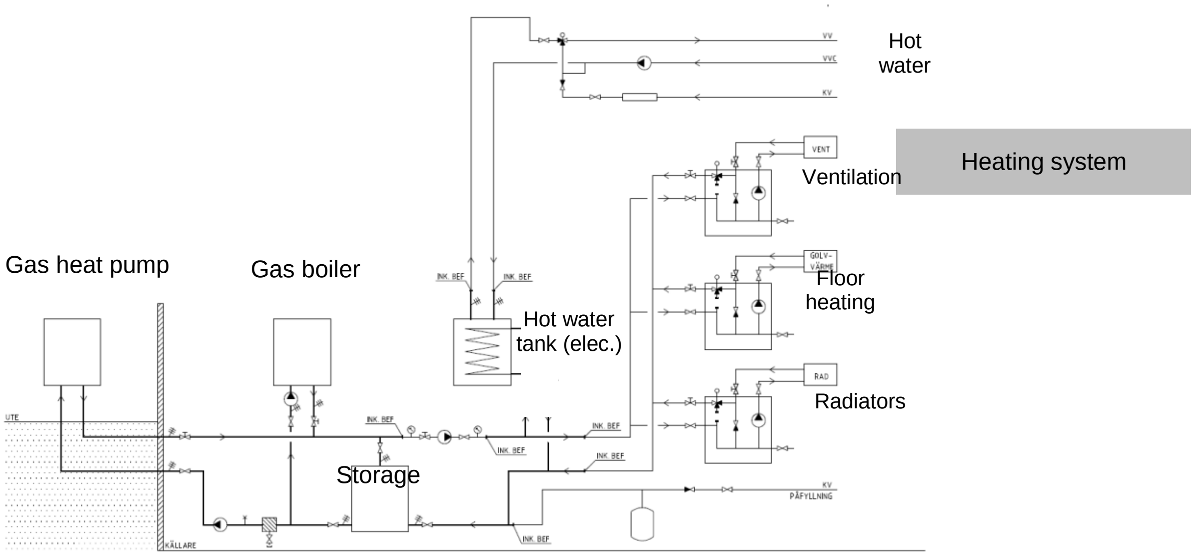


Figure 5. System layout with gas heat pump, gas boiler and heat storage

The heat pump is adjusted to operate in an on-off mode. Modulating mode is an option not used in this installation.

The gas boiler is a Milton (Nefit) Topline 80 with a modulating input between 19 kW and 85 kW. It is installed with open combustion (Type B), i.e. combustion air is taken from the boiler room, see Figure 6. A plastic flue lining is located in the old chimney.

Figure 6 Boiler room after installation of new gas boiler and heat storage

The heat pump is located on the lawn outside the house as seen in Figure 7. The fence prevents damages to the heat pump due to activities such as soccer and other outdoor activities performed by the day care centre visitors. The energy from the heat pump is transferred through an 18 m pre-insulated pipe, Uponor Ecoflex Twin. The heat loss is estimated to 11 W/m, i.e. 200W.

Figure 7. Heat pump location outside the day-care centre

The heat pump and the gas boiler are controlled separately. The heating curve for the heat pump is set slightly higher than the heating curve for the gas boiler. This is done to maximise the gas heat pump operation time. A 300 litre storage tank is used and connected as shown in Figure 8.

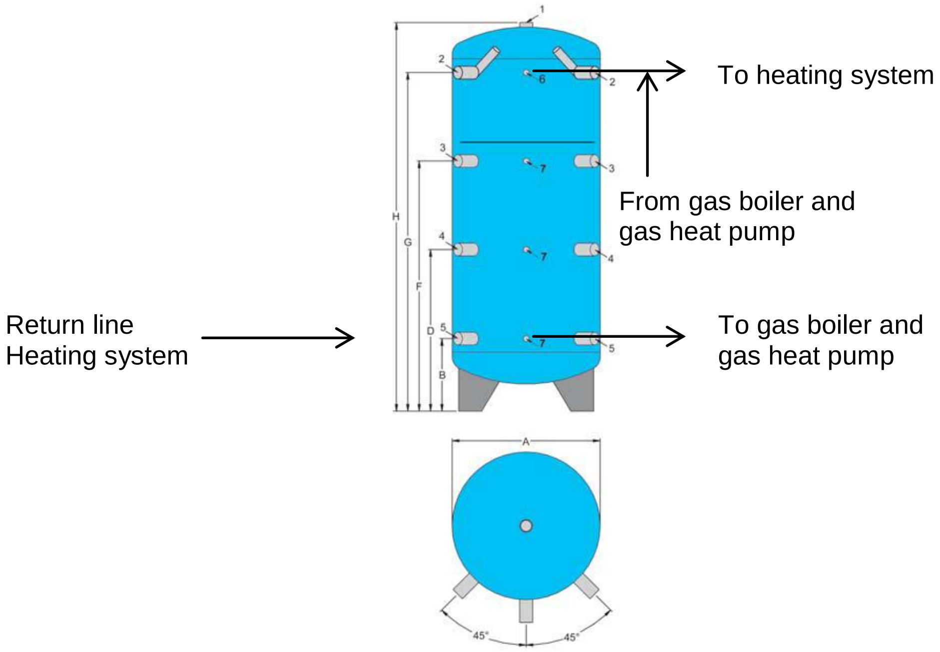


Figure 8. Storage tank with connections used

Hot water accounts for only a small part, 15,000 - 20,000 kWh per year, which is 10 % of the energy demand in the building. The hot water production is managed by electric heating. This makes it possible to have lower supply temperatures from the gas heat pump and to get a high efficiency. The hot water demand is not a topic for this project and heat pump evaluation.

1.3 Data acquisition

The performance of the gas heat pump, the gas boiler and the entire heating system are measured by three energy meters and two gas meters. The two gas meters are diaphragm gas meters. One meter measures the total gas consumption, while the second gas meter measures the heat pump gas consumption. The gas boiler consumption is calculated as the difference between the gas meter readings. Gas and heat meter data is shown in Table 2.

Table 2 . Gas and heat meters used in field test

	Comment
Gas meter	
Actaris G16, 0.25 – 16 m^3/h	Total gas consumption for heating Output corrected to 15°C and 20 mbar Output 1 pulse/1 m^3
Kromschröder BK-G4T G4, 0.04 – 6 m^3/h	Heat pump gas consumption Output corrected to normal conditions Output 1 pulse/0.01 m^3
Heat meter	
3 Armatec Pollustat E	Heat meter with ultrasonic flow meter and Pt500 temperature sensors

2. Results

The gas heat pump began operation January 10 2012. Data was collected since the start until February 2013. Adjustments were made during the field test period in order to improve the system performance.

2.1. Overall field test results

The test results for the period from January 10, 2012 until February 1, 2013 are summarized in Table 3. The efficiencies are based on lower heating value.

Table 3. Overall field test summary for Robur E3 gas heat pump in Limhamn (January 10, 2012 – February 1, 2013)

Parameter	**Value**
Total heat demand (kWh)	130,400
Heat pump production (kWh)	84,330
Gas boiler production (kWh)	55,650
Gas heat pump efficiency (%)	107
Gas boiler efficiency (%)	92
System efficiency (%)	105
Electricity consumption (kWh)	67,600 (2012 only)
Distribution heat loss, estimated (kWh)	2,000

The data in the table are field test results and are not to be used as general key data for a gas heat pump performance. Firstly, the gas heat pump efficiency varied considerably during the test period due to icing and unsatisfactory adjustment. During periods of reasonably proper operation the efficiency was in the 115 – 130 % range. There is probably also a potential of improving this efficiency through system adjustments. Secondly, there is an uncertainty in the energy measurements. Table 3 shows a 5 % difference between the gas heat pump and gas boiler heat production, and the heating demand. The difference is too large to be explained as heat loss from the new, well insulated pipes and storage tank. There is no clear indication whether the heat production or heat demand measurements are the source of the difference. It may for example increase the heat pump efficiency by 5 %.

The heat pump was operating in the summer as well, although it was not necessary, leading to unnecessary gas consumption. If the gas consumption during the period beginning May 31 and ending September 15 is deleted it means an energy saving of approximately 3,200 kWh. This corresponds to 2.5 % of the field test gas consumption and does not have a noticeable impact on the system efficiency.

The heat pump operated reliably. Adjustments and other measures were made to the gas heat pump and the heating system in order to improve the efficiency during the field test period. These measures are shown in Table 4. The heat pump and the gas boilers have been separately controlled during the entire test period. A control card that should allow a common control of these appliances has been ordered but not delivered and installed. This control card will probably solve some of the problems described later.

Table 4. Adjustments, observations and other measures to the Limhamn Robur gas heat pump

Observation/Measure	**Date**
Field test start	January 16, 2012
Heat pump not operating due to circulation pump problem. Gas boiler temperature constantly at 70°C	February, 2012
De-icing and software reprogramming	April 2-3, 2012
Boiler shutdown for the summer	April 30, 2012
Main circulation pump in operation during the summer	September 4, 2012
Severe ice formation	end of October 2012
Gas boiler started	November 29, 2012
De-icing, temperature sensor moved, service	December 2012

The overall energy supplied by the heat pump and the gas boiler to the heating system is shown in Figure 9. The gas heat pump delivered the major part of the heating energy except for a few periods.

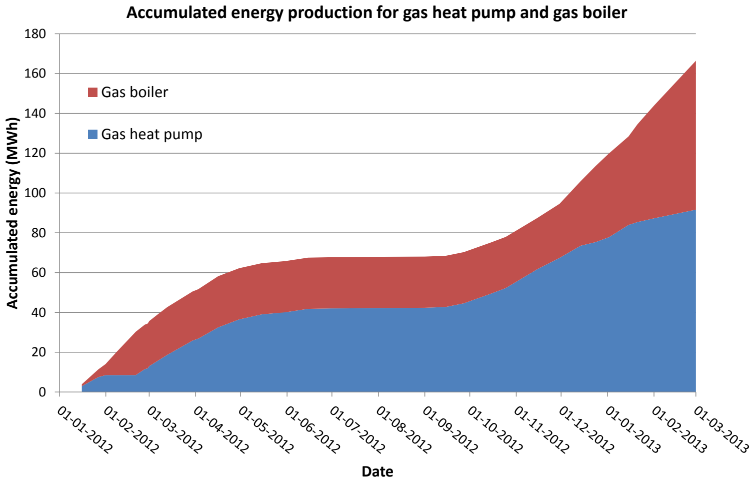
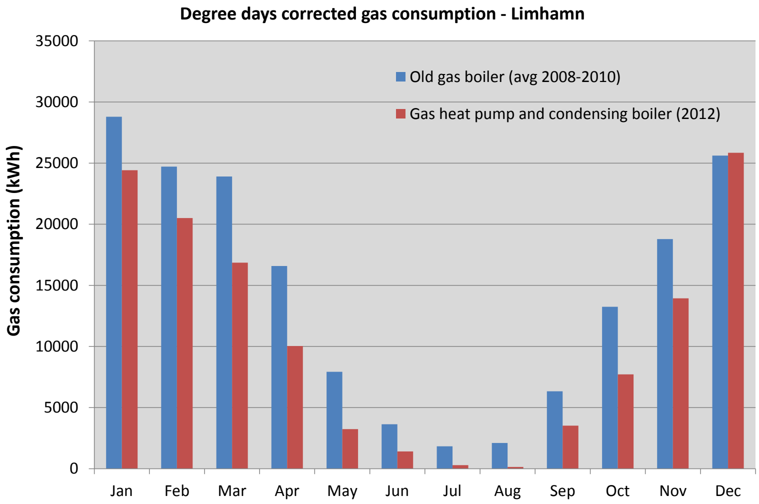


Figure 9. Overall energy supply to the heating system

The graph shows that the gas boiler was used for heating mainly in January, February and from December 2012.

The energy consumption before and after the heat pump was installed is illustrated in Figure 10. Monthly gas consumption with the old gas boiler are the average values during 2008 – 2010. The data is supplied by the Malmö City office for public buildings.



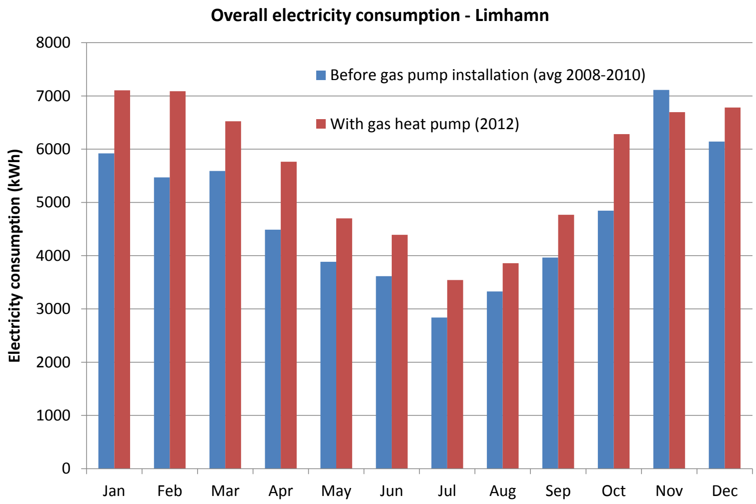


Figure 10. Comparison between gas and electricity consumption before and after the installation of the gas heat pump

The gas consumption 2012 was 30 % lower than the 2008 – 2010 average value. Increased electricity consumption due to hot water production reduced the energy savings to 25 %.

2.2. Appliance performance

The unexpectedly low heat pump efficiency is studied in this section and possible explanations presented. The gas boiler efficiency of 92 % is reasonable considering the average low load and not further investigated. In Figure 11 the heat pump output and efficiency are plotted for periods of approximately 2 weeks. It is obvious that the heat pump efficiency decreases at higher heating demands, i.e. when the gas boiler is also in operation. The highest heat pump efficiency is close to 130 % despite a low heat load.

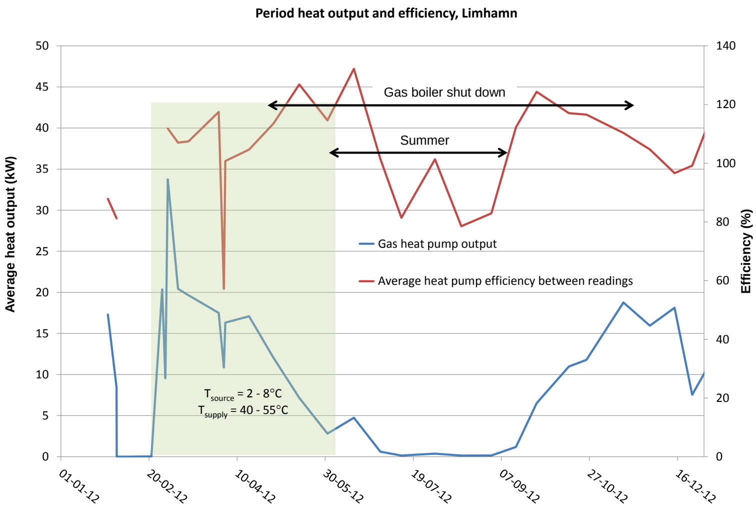


Figure 11. Gas heat pump period heat output and efficiency

The gas heat pump efficiency depends on the source temperature (ambient air) and load. Period efficiencies are plotted against the average heat pump output in Figure 12. The field test time is divided into periods of approximately 2 weeks. The ambient temperature was not collected during the field test. The graph confirms that the highest efficiencies are obtained at low loads.

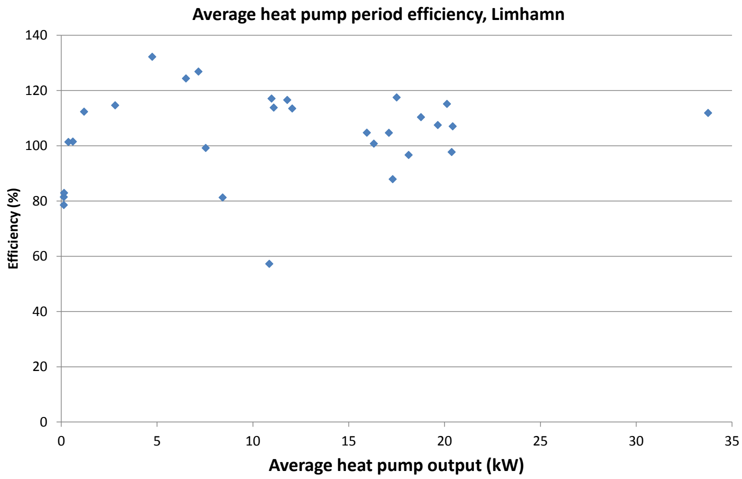


Figure 12. Gas heat pump period efficiency as a function of average heat output

The graph shows that the top average efficiency during a two-week period is slightly above 130 %. The lowest efficiencies were observed during periods of very low load, i.e. during the period from late spring until late summer. The gas heat pump should be shut down during this period since there is no real heating demand. However, the gas energy consumed during this period did not have any significant impact on the overall heat pump efficiency for the entire field test period.

2.3. Result analysis and suggested improvements

A comparison between the results from this field test and results from German field tests indicates the potential for improvements. German field test results for five installations are shown in Figure 13 /2/. At low loads, the measured efficiency can vary within a wide range, but it is always more than 130 % when the monthly energy demand exceeds 6 MWh.

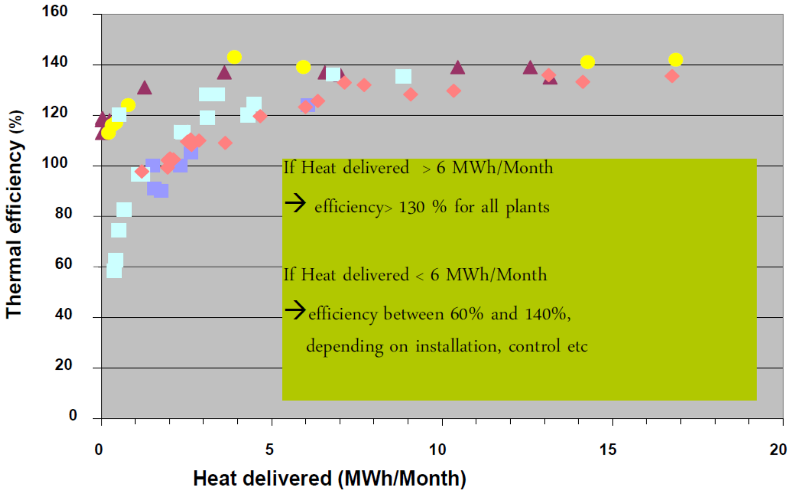


Figure 13. German Robur heat pump field test results [2]

The average heat output for a monthly energy production of 6 MWh is approximately 8 kW. The historical data in Figure 10 show that it is clear that the monthly heat demand exceeds 6 MWh during a large part of the heating season. Figure 12 shows that 130 % efficiency is reached only on a few occasions. In the following text the operating conditions are analysed in order to find the explanation and suggest adjustment for improved efficiency.

2.3.1. Examples of high- and low-load days

Sunday December 23, 2012 is chosen to illustrate a high-load day. The heat production and system temperatures are shown in Figure 14. The gas boiler (blue line in upper graph) operated close to the minimum output and covered most of the heating demand despite the fact that the heat pump was not operating at nominal load. A correct operation would be the opposite with the heat pump as base load and boiler operation in case the heat load exceeds the heat pump output.

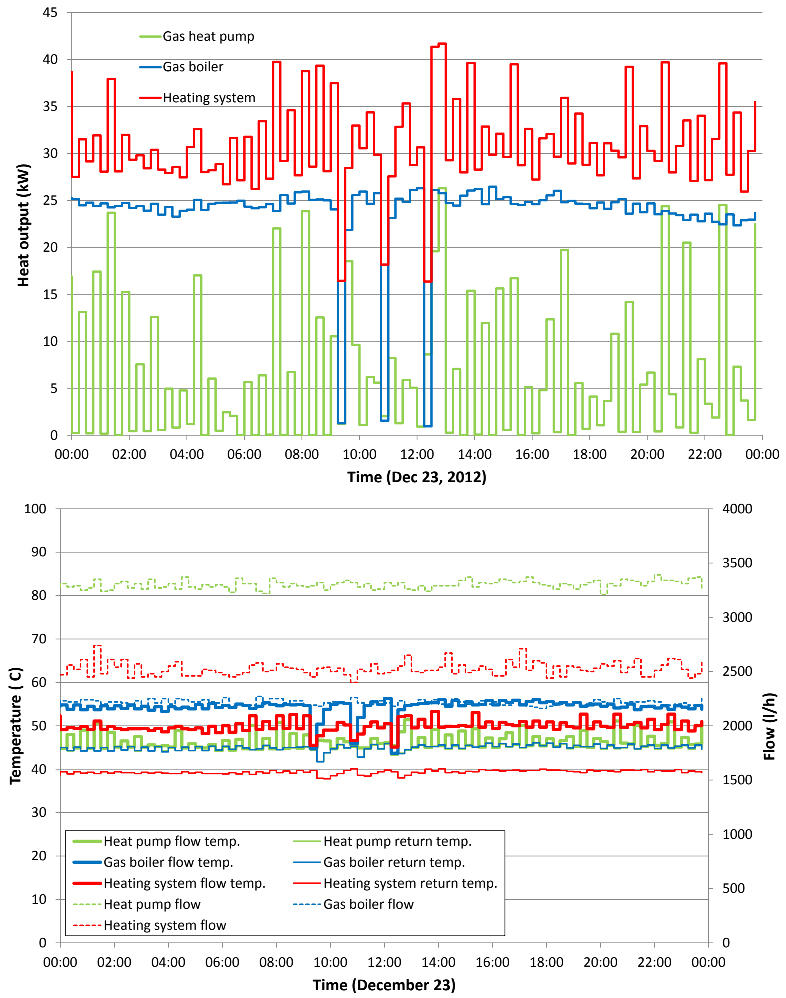


Figure 14. Heat output, heating demand during a high load day

Tuesday May 15, 2012 is chosen to illustrate a low-load day, and when the gas boiler is shut down, see Figure 15. The gas heat pump was in operation during the night only. The temperature reached 18 °C during the day and the sun shone for 5 hours[2]. The system operation seems to be as expected.

[2] Data for Copenhagen from Danish Meterological Institute, DMI.

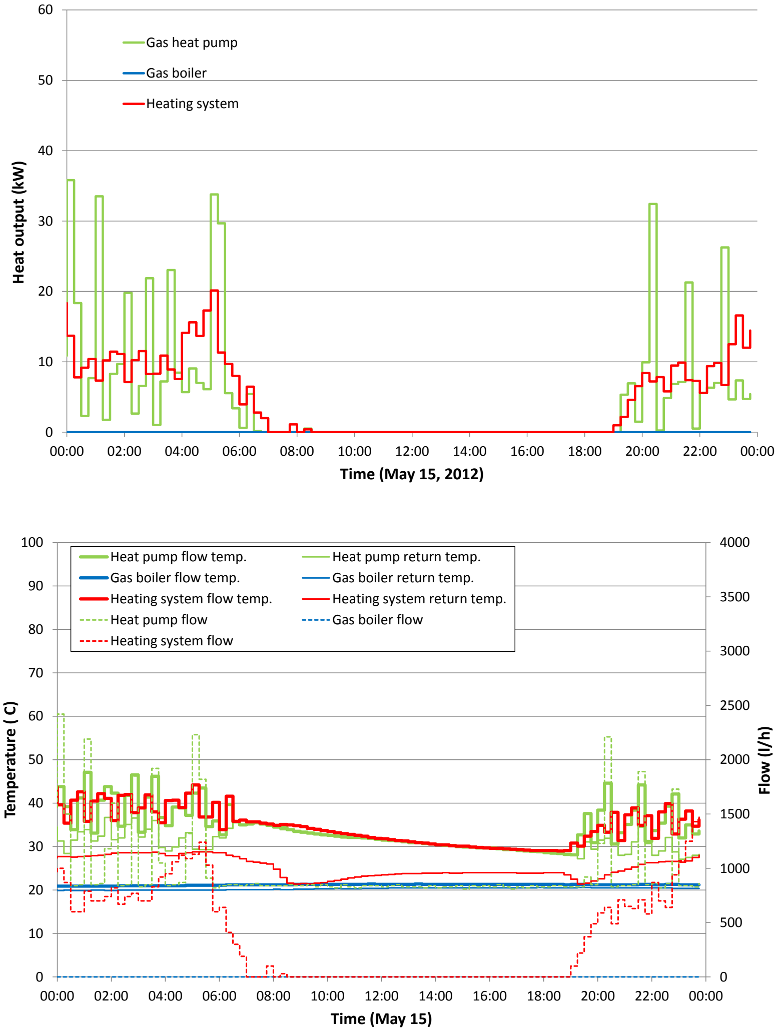


Figure 15. Flow and return temperature during a low-load day. The gas boiler is shut down.

2.3.2. System temperatures etc.

The flow or supply temperature from the heat pump is an indication of the operating conditions. Figure 16 shows the flow temperature during the entire field test period.

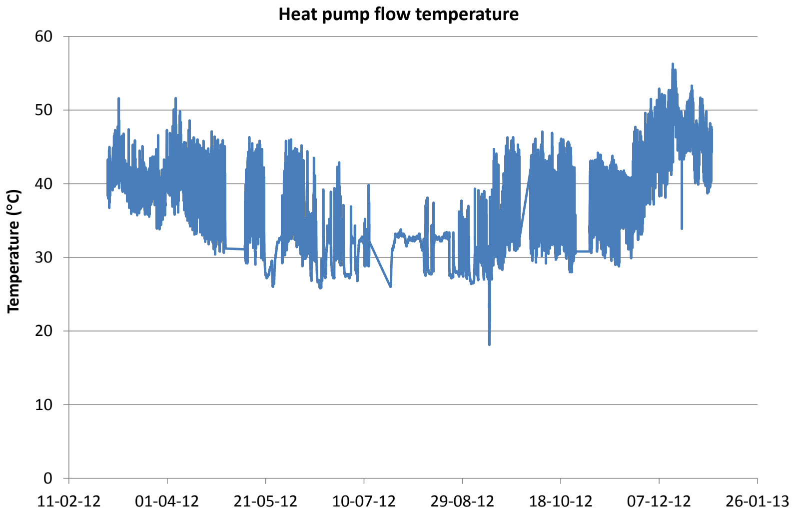


Figure 16. Heat pump flow temperature during the field test period

The flow temperature from the heat pump is moderate and should allow a high efficiency in the 140 – 150 % range when the outdoor temperature is around the freezing point.

The difference between the heat generator flow temperatures and the heating system flow temperature is shown in Figure 17. The data show that the flow temperature from the heat pump is higher than the heating system flow temperature most of the time. It means that the storage tank and the gas boiler have a significant influence on the operating conditions. In another DGC field test of a Robur heat pump[3] it is clear that this difference can be more or less prevented.

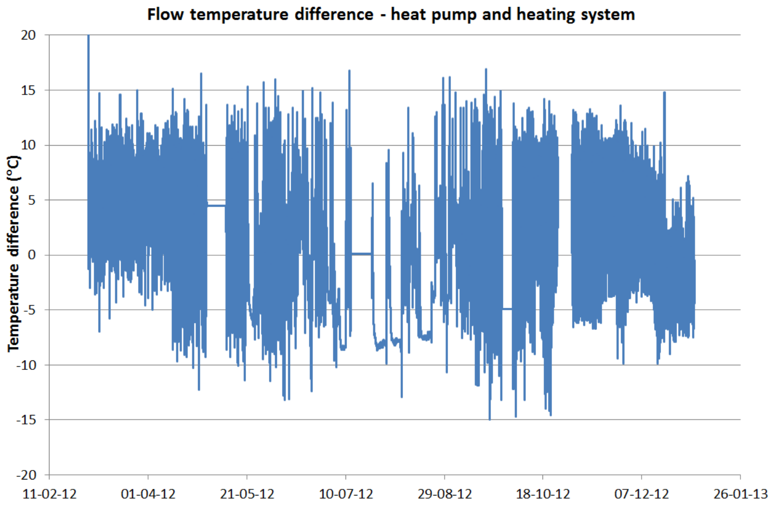


Figure 17. Difference between gas heat pump and heating system flow temperature

[3] Ongoing field test evaluation.

A similar graph showing the difference in return temperatures also indicates a difference. This is shown in Figure 18. These graphs show that the hydraulic system can be adjusted to improve the operating conditions for the gas heat pump.

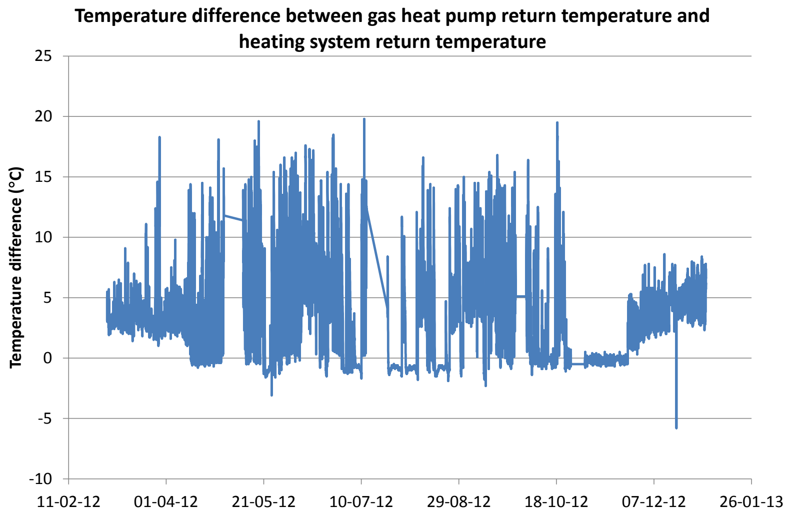


Figure 18. Temperature difference between the heating system return line and the heat pump return line

2.3.3. Heat pump operating times

The operation during December 23rd is an example showing an on/off operation for the heat pump, while the gas boiler operated constantly around the minimum burner input. The gas heat pump operated on/off with a low average output instead of being the major heat generation source.

The operating conditions also influence the gas heat pump operation time. There was no direct measurement of the operating time, but since the heat pump has an on-off operating one-stage burner it is possible to calculate the time the heat pump is operating between each gas meter reading. This approach shows the estimated full-load operating times as seen in Figure 19. It is clear that the heat pump operation cycles are very short. For example shall the heat pump must be in operation for at least 15 minutes before de-icing can begin. Figure 21 shows images with heavy ice formation on the evaporator. This supports the estimation of very short operating cycles.

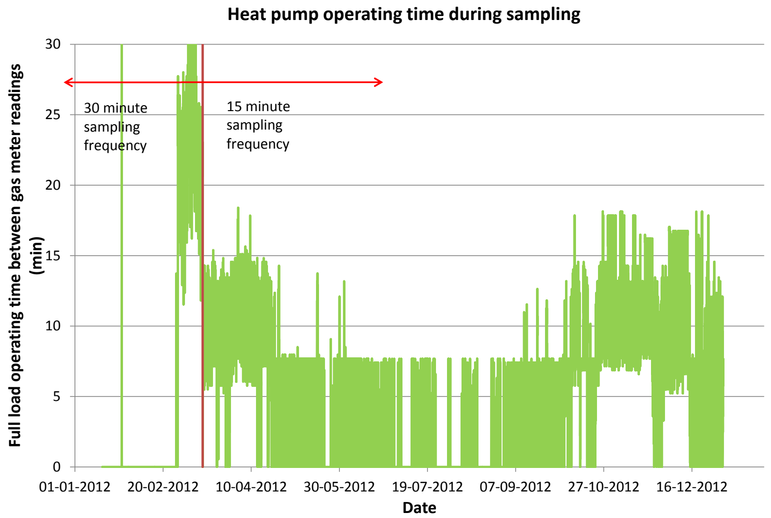


Figure 19. Calculated full load operating times for the gas heat pump

2.3.4. Discussion on the operating condition analysis

From the analysis of different operating conditions we have made the following observations regarding subjects that may cause low gas heat pump efficiency:

- The heat pump seems to obtain a high efficiency exceeding 125 – 130 % when the gas boiler is out of operation.
- The return temperature from the heating system is often approximately 5°C lower than the return temperature to the gas heat pump and the gas boiler. This lower temperature may increase the efficiency.
- The gas heat pump apparently operates for short periods. The operating time is not directly measured, but indirectly, calculated based on 15 minutes' gas consumption data.
- The after-run times of the circulation pumps are not really understood.

The conclusions from these observations are:

- The hydraulic system is not in balance.
- The gas boiler disturbs the heat pump operation and subsequently reduces the heat pump efficiency.

The Robur heat pump supplier in Sweden and Denmark, Milton Megatherm, suggested that the water flow from the gas heat pump and the storage is the source of the problem, and will try to improve the performance by changing the pump operation.

2.3.5. Distribution pipe heat loss

Heat from the heat pump is transferred to the building through an 18 m insulated pipe. The pipe is Uponor Ecoflex Thermo Twin. The manufacturer data for heat loss is 10 W/m (8°C soil temperature, size 2x50/200 mm, 50/30°C water temperatures). This gives a total distribution loss of 180 W.

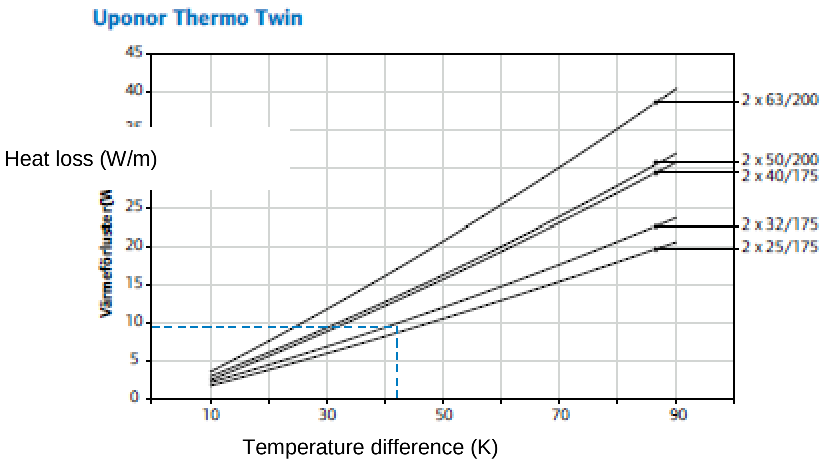


Figure 20. Heat loss for distribution pipes (Source: Uponor)

The overall heat pump operation time during the field test was 9,800 hours. The estimated heat loss in the distribution pipes between the heat pump and the building was then estimated to 1,760 kWh, which corresponds to approximately 2 % of the total heat pump heat production.

2.3.6. Heat balance and accuracy

An overall heat balance for the heat meters during the field test period shows a difference of 5,900 kWh between the energy delivered to the heating system and the sum of the gas and heat pump energy. Since the gas boiler efficiency seems reasonable it is suggested that the difference is caused by heat loss in the boiler room and either an overestimated energy delivered to the building or underestimated energy produced by the heat pump. There is no clear indication on the origin of the heat balance mismatch.

2.3.7. Electricity consumption

The electricity consumption increased due to the electricity based hot water production. Figure 9 shows the monthly values for the gas and electricity consumption before and after the replacement of the old gas boiler. The electricity consumption increased 20 % due to the electricity used for hot water heating. The hot water tank is planned to be connected to the gas boiler.

2.3.8. Noise level

Malmö City Environmental Department measured the noise level around the heat pump. The levels were 70 dBA at 1 m distance and 42 dBA at 9 m distance.

2.3.9. De-icing

Early in the operation phase heavy ice formation was observed on the evaporator, see the top left image in Figure 21 taken on March 7, 2012. It was later recognized that the de-icing settings were wrong and they were adjusted April 2. The de-icing function starts after 15 minutes of gas heat pump operation. Since the gas heat pump has short cycling times it will affect the possibility of de-icing. The problem of ice formation remained also later in the field test as the images from September 2012 show.


March 2012


September 2012


September 2012

Figure 21. Ice formation on the Robur heat pump evaporator

2.3.10. Economy

No in-depth economic evaluation was made in this report because the operation and performance were not as anticipated. In addition to this, the installation was more expensive than a standard gas heat pump installation. For example the gas heat pump is surrounded by a fence to protect the visitors at the day-care centre.

The gas savings were measured to 31 % and when the additional electricity consumption for the hot water production is accounted for the energy savings were 25 %. When the operation and performance is improved the annual efficiency for the gas heat pump may reach approximately 130 %. The estimated energy savings will then be 40 – 50 %.

A rough estimation of the payback time if a gas heat pump and a peak load boiler are chosen instead of a condensing boiler can be made since Malmö City obtained prices for a standard installation with a boiler only and one installation with a gas heat pump and a peak load boiler. Observe that the costs etc. are in Swedish currency (SEK). The following assumptions are made:

- The price difference is SEK 158,000 for the equipment. Any difference in installation cost is not included.
- Annual efficiency for a gas heat pump covering the entire heat demand, 130 %. This efficiency was observed during periods when the gas boiler was shut down.
- Annual efficiency with a condensing boiler, 100 %
- Annual heat demand of 120,000 kWh based on degree day corrected gas consumption and the measured system efficiency during 2012.
- Gas price paid by the city of Malmö, 0.76 SEK/kWh (excl. VAT)

This gives an annual energy saving of 28,000 kWh and a payback time of 6 years. There is no indication that the pay-back time would be much different In Denmark.

3. Conclusions

A Robur E^3 air-to-water gas heat pump was demonstrated in a day-care centre in Limhamn, Malmö. It covered the major part of the heating demand. A condensing gas boiler was used as back-up and for peak loads. Hot water is currently produced separately using electric heating. The gas heat pump operated without any significant problems. Control system settings and circulation pumps were adjusted and replaced during the demonstration. Ice formation was observed.

The gas heat pump performance was not as high as expected, while the gas boiler efficiency was as expected. The low gas heat pump performance was probably due to a less successful hydraulic integration of the gas heat pump and the gas boiler. The gas boiler operation seems to limit the gas heat pump operation time. The overall results for the field test period are shown in Table 5.

Table 5. Field test results for Robur gas heat pump in Limhamn/Malmö (January 10, 2012 – February 1, 2013)

Parameter	**Value**
Total heat demand (kWh)	130400
Heat pump production (kWh)	84330
Gas boiler production (kWh)	55650
Gas heat pump efficiency (%)	107
Gas boiler efficiency (%)	92
System efficiency (%)	105
Electricity consumption (kWh)	67600 (2012 only)
Distribution heat loss, estimated (kWh)	2000

The gas heat pump efficiency reached 130 % during short periods when the gas boiler was shut down. This value should be possible to reach during longer periods when the integration of the heat pump and the gas boiler is improved. The system improvements are mainly related to the control system. The payback time for a well operating installation with 130 % annual efficiency is estimated to 6 years.

References

[1] Gas Heat Pumps. Efficient heating and cooling with natural gas, Gasterra and Castel International Publishers, 2010, http://www.gasterra.com/$resource/800

[2] Schossig, P., Fuel driven heat pumps, Chillventa 2012, October 2012, Nürnberg, Germany

9771102737101