FINAL TECHNICAL REPORT

Swedish Energy Administration number: 4210-2001-1338

Pilot project number: P20138-1

SMART DISTRICT HEATING STATION

Document information

Issued by/ Sign: Peter Gummérus

Approved by/ Sign: Matts Lindgren Date: 2004-05-26

Contact information

Name: Peter Gummérus

Phone: +46 (0)303 979 40

Fax: +46 (0)303 979 41

E-mail: Peter.Gummerus@NordIQ.se

Copyright

Short summary

A pilot project in order to present the advantages with a model based control system designed on an innovation from the company NordIQ Göteborg AB was conducted during 2003-2004. The system was tested on 5 district heating stations in Gefle and 1 in Gothenburg. During the test period a 11 % reduction (normal year corrected) in energy consumption, 11,4°C increase in yearly average cooling and 34% reduction in primary heat carrier flow was attained. The system is thermo-hydraulic de-coupled from the distributing network condition and will therefore not require differential pressure controllers due to variations of the district heating network operating condition such as supply temperature and differential pressure. The maximum differential pressure is 10 bar and maximum supply temperature 120°C. Thanks to the model based operating principle, the system will not require any tuning and can be said to have plug-and-play properties. Several other utility functions have been implemented as well.

Security

NordIQ information classification system:

(P) Public information:

Information which is intended for common distribution inside and outside the company.

(I) Internal information:

Information that is intended for internal uses only.

(F) Company secret information:

Information of great value for NordIQ Göteborg AB and which by disclosure, loss or change would signify negative consequences to the company's business. This information shall only be distributed to people who need it to be able to fulfil their work.

Document updates

This document can be updated and appear in several revisions. A revision is a separate version of a document and is assigned the status "Draft" or "Issue".

A "Draft" status is entered when the document is ready for review. The draft is not approved. The draft status can appear between issues, and will in that case be indicated together with the new issue number e.g. "Draft 2".

An "Issue" status is entered when the document is approved, in most cases after review and corrections. Each issue is given a number and a date, and a history record shall be kept over all issues.

Revision History

Issue No:	Date:	Change description:
1.0	2004-05-16	
2.0	2004-06-27	English Translation

Content

1 SUMMARY

By using state-of-the-art knowledge in combination with a new patented method for energy control a function integrated substation recently has been developed by NordIQ Göteborg AB. The purpose with this project has been to demonstrate and evaluate the benefits with this intelligent substation.

The pilot project has been based on field measurement of heat supply, circulated water, forward and return temperatures in 6 substations with a 12 month reference period with the previous conventional but automated substations and another 12 month evaluation period with the new intelligent substations.

The results from the evaluation show that:

- The annual heat consumption was reduced by approximately 10 %.

- The annual cooling of the district heat fluid increased by 9-10ºC giving lower return temperatures in the district heating systems.

- The total heat carrier demand (pumped volume) decreased 34 %.

- The daily variation of the customer heat demand decreased. The morning peaks decreased and heat demand moved to evenings and nights.

The results are expected to be better in future installations as the current project was disturbed by anomalies such as late sensor installations etc. The study shows that the performance/adjustment of the heat distribution system of the buildings is far from optimal. In spite of this, major improvements regarding primary cooling and reduced energy consumption has been achieved without adjustment of the building installations. The future will tell what savings that can be made in buildings with well adjusted radiator systems.

One 7nth building was run with alternating control methods. First conventional well adjusted state-of-the-art control was run and then the new function integrated control algorithm, and so on switching control method several times. The result clearly demonstrated the new method lowers energy consumption and temperature levels compared to conventional control. During April ’04, with the new algorithm, the reduction in energy consumption was 26% compared to the year before. The building was well adjusted and had a low specific energy consumption of 112 kWh/m^2 during 2003 (Swedish average is 158 kWh/m^2 for buildings with same age).

The pilot project also shows that the new technology fulfils the expectations regarding de-coupling of network conditions, plug-and-play behaviour and the possibilities for standardisation of district heating stations. The new system is not sensitive to over-sizing of components in the district heating station that is very common today.

2 INTRODUCTION

A pilot project have been launched in order to evaluate new technology for heat supply in district heating connected buildings. The project are a cooperation between the originator of the technology, NordIQ Göteborg AB, the heat distributing companies, Gothenburg Energy AB, Gefle Energy AB and the housing companies Gavlegårdarna AB and Familjebostäder in Gothenburg. The financing of the projects have been made possible by shared contributions of the originators, the consumers and by the Swedish Energy administration. We like to thank all involved contributors for a well needed support throughout the project and specially to Robert Engström at Gefle Energy AB and Jan Karlsson at Familjebostäder in Gothenburg for their competence, knowledge and support that have contributed to a smooth realization of the project.

2.1 Goals

The aim with the pilot project has been to show that a better utilization of resources can be reached by the application of system integration and integrated functions. The application has been constituted by the information system of a district heating consumer station. The selection of the application depends on the fact that a waste part of energy is utilized through these system in a global point of view. In Sweden the district heating is accounted for 10,6% of the entire energy consumption (transports included), Ref. 5

2.2 Project accomplishment

The pilot project have embodied field operation of six prefabricated district heating stations equipped with new control technology for heat supply of residential buildings during one climatic year. The district heating house stations have been constructed and manufactured by NordIQ Göteborg AB. The entrepreneur of the energy distributing company has installed the systems. NordIQ Göteborg AB has done the commissioning and surveillance through Internet. Two evaluations have been performed. This evaluation, performed by NordIQ Göteborg AB is based on debiting information supplied by the energy distribution company and corrected by using the degree-day correction method. The other evaluation, performed by FVB AB by directions of the Swedish District heating association, performed by using the energy signature method based on hourly average values is scheduled to be presented in the beginning of October, 2004.

3 LIFE-CYCLE-COST

With the aim of presenting the economic benefit of this pilot project over the technical lifespan of the system, a cost analysis is performed for a type-system over the 25-year lifecycle. The result is presented in Figure 1. The calculations are described in APPENDIX V – LCC calculation. The reconstruction of the district heating station (DHS), reduces the operating cost by 9200 Euro/year when the initial consumption was 1100 MWh/year, energy-price 34,1 Euro/MWh, flow-cost of 0,2 Euro/ m3 and a effect-cost of 31 Euro/kW. The yearly cooling of the primary heat carrier prior to the reconstruction was 41°C . After reconstruction the yearly cooling was increased to 53°C , the average heat demand was reduced 20% based on a utilisation time of 2300h (heating and hot service-water demand).

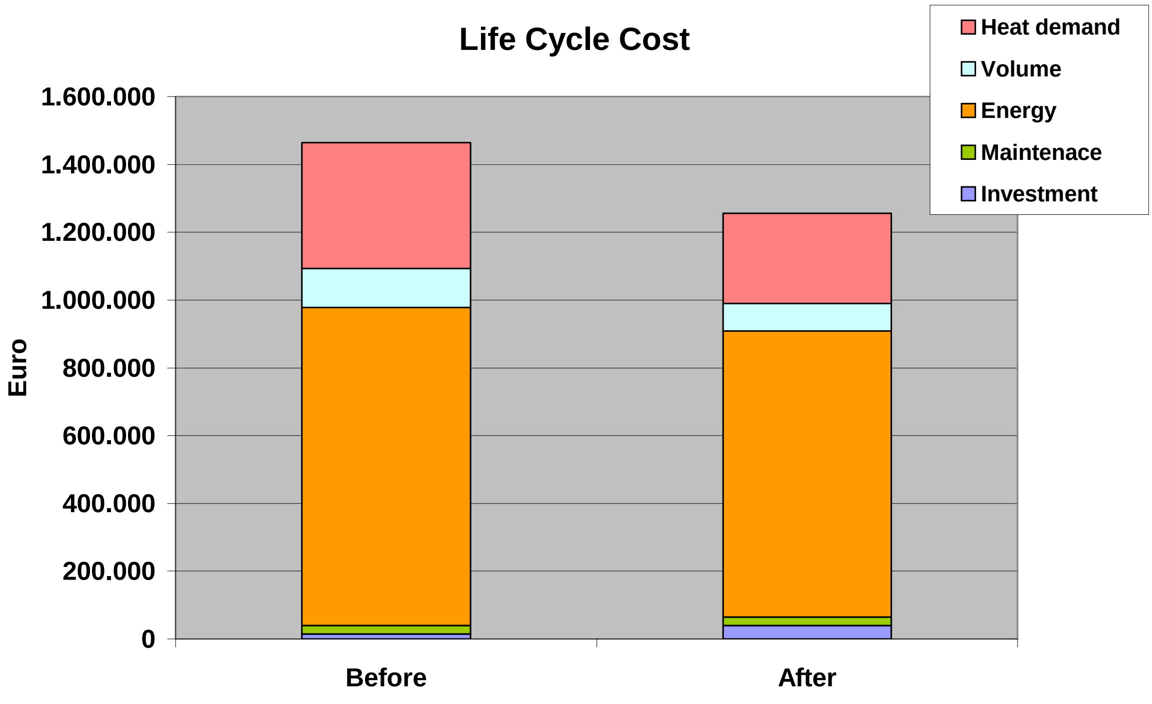

Figure 1: LCC – With or without the Enabler

4 DESCRIPTION OF PROJECT RESULTS

In order to show the impact of the new control method in the district heating application, six district heating stations was replaced (1 in Gothenburg and 5 in Gefle) with by NordIQ prefabricated stations equipped with the technology. The station was taken into operation during the period March-April ’03 and the evaluation period was decided to be one climatic year. A description of the test objects is presented in chapter APPENDIX IV – Description of field objects.

4.1 Field operation: May ‘03 – May ‘04

A characterisation of the six objects within the study , Table 1:

Table 1: Field objects within the study

Name	Yearly consumption	Heated surface	number of apt.
	kWh/m^2	m^2	-
Rävpasset, Gefle	141	6570	60
Jökelvägen, Gefle	156	5950	76
Jägargatan, Gefle	177	2300	28
Kaplansgatan, Gefle	172	3936	47
S. Köpmannag. Gefle	112	3125	39
Gröna Vallen, Gothenburg	192	5981	120

A wide variety regarding size and consumption can be seen in Table 1. The residential houses represents a broad spectrum of, in Sweden, frequently occurring types of residential buildings such as terrace-houses, compact multi-apartment buildings, stone- and wood-houses. No measures regarding adjustment or modifications on the house installations was made prior to the replacement of the district heating station. No replacement of the heat meter was made as well. According to an investigation, Ref. 1, no correlation regarding cooling of primary heat carrier can be made depending on the size, age or category of the district heating stations in Sweden.

4.1.1 Energy consumption

A reduction of the energy consumption can be determined during the period May’03-April’04 compared to the period May’02-April’03. Detailed diagrams is found in Appendix I – Monthly Energy consumption. The principle with the model based control system was tested in field operation for the first time during this project. The control system had only been in actual operation in the thermo-hydraulic laboratory before this project. Before the optimal adjustment of the new system could be performed, a knowledge base had to be established first with real operating conditions. When the systems was taken into operation during the late spring ’03, no real operating conditions in the radiator system was obtained until the fall ’03. Adjustment of the hot service-water circulation flow was not made until the beginning of April ’04.

In general, it can be said that in no buildings, the thermostatic valves were working even though they was installed. The radiator circulation flow was unchanged independent of the variations in outdoor temperature and radiator supply temperature, Figure 2. From the figure it can be seen that the radiator flow is constant for variations in supply temperature and heat demand. A comparison with a reference building not within the pilot project with functioning thermostatic valves had a different behaviour,

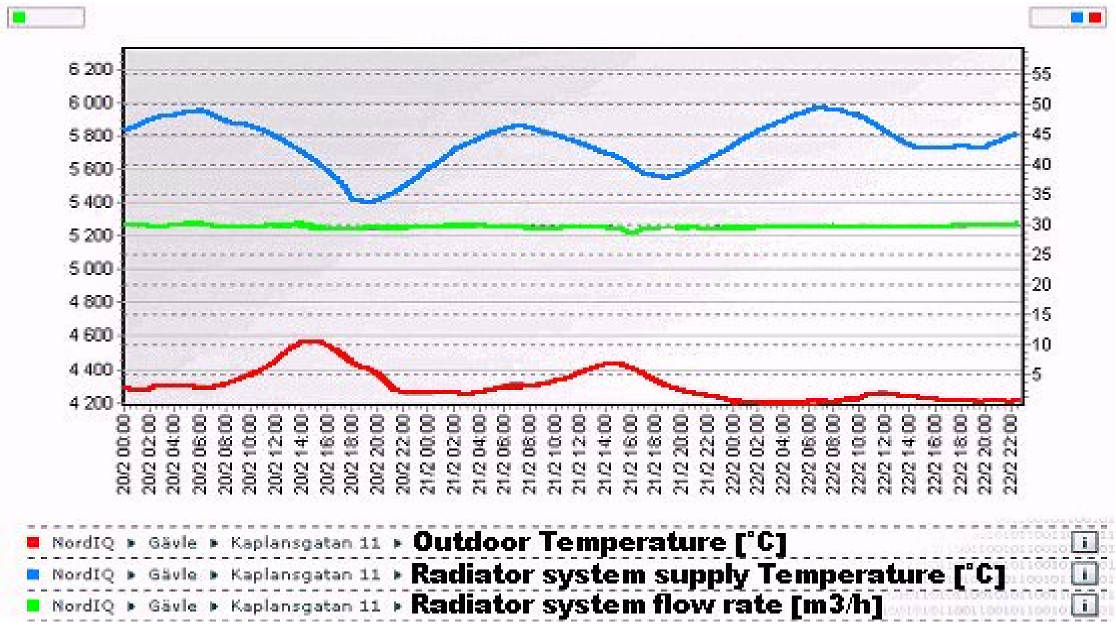

Figure 2: Faulty thermostatic radiator valves, Kaplansgatan, Gefle

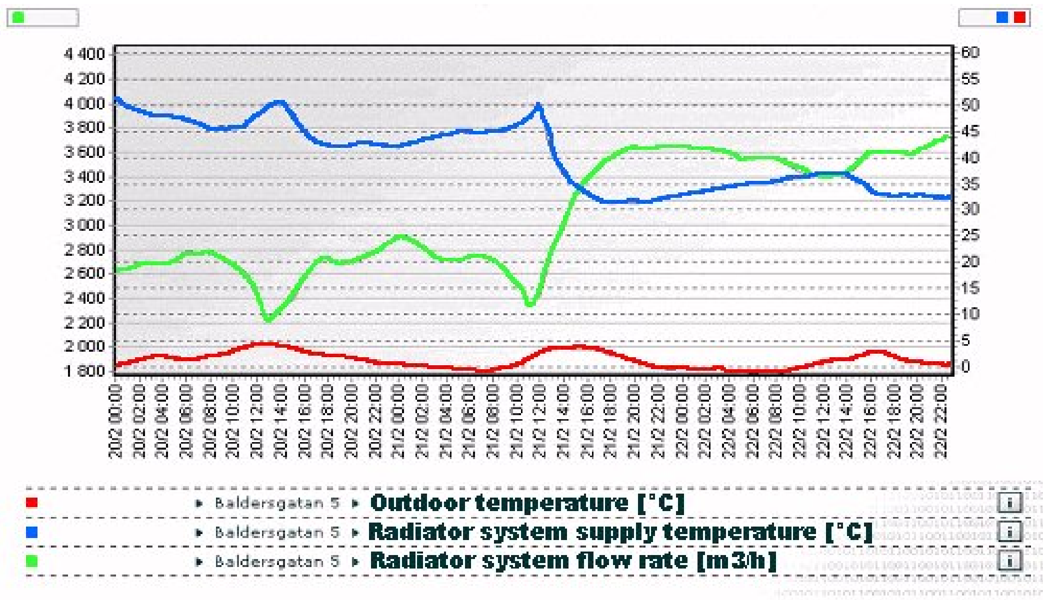

Figure 3: Functioning thermostatic radiator valves, Baldersgatan, Gothenburg

Table 2: Normal-year corrected energy consumption before and after replacement

Object	Reference period MWh	Enabler MWh	Spec. consumption kWh/m^2	Difference %
Rävpasset	935	894	136	-4.4
Jökelvägen	965	929	156	-2.5
Jägargatan	409	360	157	-12
Kaplansgatan	677	589	150	-13
S.Köpmannagatan	359	318	102	-12
Gröna Vallen	724	599	167	-17

One reason to explain the reduction in energy consumption is that the room temperature, by utilisation of the Enabler® Softcontrol™, have been kept more stable. Due to this, an increased room temperature set point can be avoided in order to compensate for dynamic variations in indoor temperature caused by a deficient control system. Normally the downswing in room temperature cause the set point temperature to become increased.

Another reason for the reduction in energy consumption is that the Enabler control system is taking the correct action instead of correcting an error (PID-control) which can be seen in the cooling ability. Two of the field objects did not reach the same level in reduction of energy consumption compared with the other objects. The likely explanation to this depends on combined effects of ; unexpected flow restriction in the DHS, heat locks due to insufficient flow rate (0,9 litre/h m^2) and insufficient / not representative knowledge of the actual room temperature in the building.

It must be pointed out that no alterations of the secondary systems in the building was performed prior to the replacement. It is necessary to have the knowledge concerning the actual condition in the building in order to reduce the energy consumption.

4.1.2 Cooling of primary heat carrier

The yearly average cooling of primary heat carrier have been improved in all buildings, Table 3. From the table it can be determined that a significant increase has been achieved depending on that the performance of the radiator system have been optimised by the use of the Enabler-system, Ref. 2, Ref. 3, Ref. 4. This lead to a reduction in energy consumption and a increased cooling of the primary heat carrier. Detailed diagrams are presented in Appendix II – Monthly average cooling of heat carrier.

During several years, a major unexplained difference between calculations in cooling ability, Ref. 5, and measurements of cooling ability on field objects, Ref. 6. The explanation to the big difference, as mentioned above, have been unclear, but many practitioners believe that the cause can be found in inadequate adjustment of the radiator system. The result from this project exhibit several similarities between calculated and measured performance which imply that the cause can be found in the conventional control of the heating system.

Table 3: Yearly average cooling[1]

Object	Reference period °C	Enabler °C	Difference °C
Rävpasset	33,4	39,1	-5,7
Jökelvägen	31,4	40,9	-9.5
Jägargatan	22,5	37,1	-14,6
Kaplansgatan	22,4	43	-20,6
S.Köpmannagatan	29,2	37,5	-8,3
Gröna Vallen	40,4	47,7	-7.3

4.1.3 Reduction of primary heat carrier flow

The combined effect of the improved performance in the radiator system that lead to reduced energy consumption and the improved cooling of primary heat carrier will reduced the primary flow rate considerably. The specific heat consumption is calculated for the two periods and will result in the volume of heat carrier in order to heat 1 kWh. The normal-year corrected heat consumption for the two periods has been used in order to calculate the required volume, Table 4. With maintained volume of heat carrier and improved specific energy consumption, 62% increased surface can be heated.

Table 4: Required volume primary heat carrier during the two periods.

Object	Reference period m^3	Enabler m^3	Difference %
Rävpasset	24371	19909	-18
Jökelvägen	26725	20042	-25
Jägargatan	15807	8461	-46
Kaplansgatan[2]	26488	12001	-55
S.Köpmannagatan	10483	7399	-29
Gröna Vallen	15582	10935	-30

[1] Yearly average cooling Gothenburg = 41,4°C , Gefle = 27,6°C (NordIQ Gbg = 47,7°C, NordIQ Gefle = 39,9°C)
Yearly average primary supply temperature Gothenburg = 87,6°C , Gefle = 76°C
Yearly average primary return temperature Gothenburg = 46,2°C , Gefle = 48,3°C

[2] The result from measurements during June, July and August '03 was missing and therefore the same consumption as the year before has been assumed during these three month.

4.2 WEB-connection

All buildings has been connected to internet via RS232-, GSM- or IP-modem. Through this connection the diagnostic, parameter variations, alarm and remote measurements has been performed, Figure 5. The heat meter, belonging to the utility company was connected through M-bus communication so that debiting of the consumer could be performed without visiting the building for meter reading. A quick glance of the system is given by the flow scheme, Figure 4.

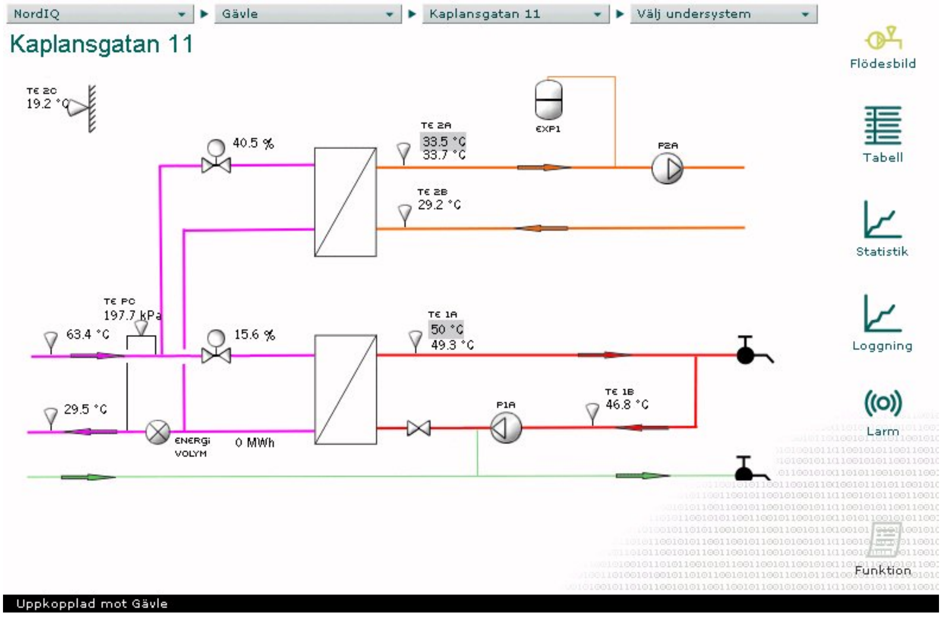

Figure 4: Flow scheme of the DHS with momentary sensor readings

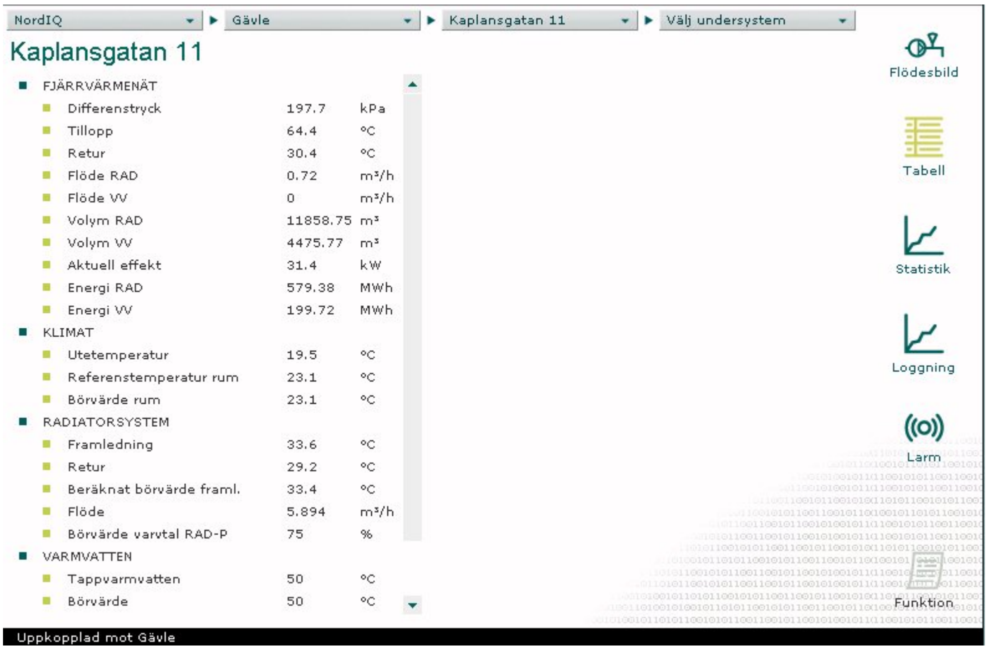

Figure 5: System overview through the WEB-interface

4.3 Integrated heat metering

Each circuit has, on the secondary side, been equipped with flow meter and temperature sensors on the in- and outlet pipe. In the Enabler software, service functions have been implemented so that heat and flow rate are integrated to energy and volume in the same manner like the integrating unit in the heat meter. The numbers are stored in the flash-memory of the Enabler so that no loss of information will occur during power failure.

4.4 Miscellaneous utilities

Several utility functions have been added into the software of the Enabler in order to facilitate/enhance diagnosis, service, preventive maintenance, energy optimisation, availability and to increase the security of delivery during loss of production capacity.

Some of these service functions are described below.

4.4.1 Heat demand limitation

The maximal delivered heat in each subsystem can be limited to a static value, Figure 6. The limitation can be used as a safeguard against over-consumption or even better, in combination with the Primitation™ function, see section 4.4.4. By keeping the delivered heat at a low level, the efficiency in the production plants can be increased and an optimal utilisation of the distributing network achieved.

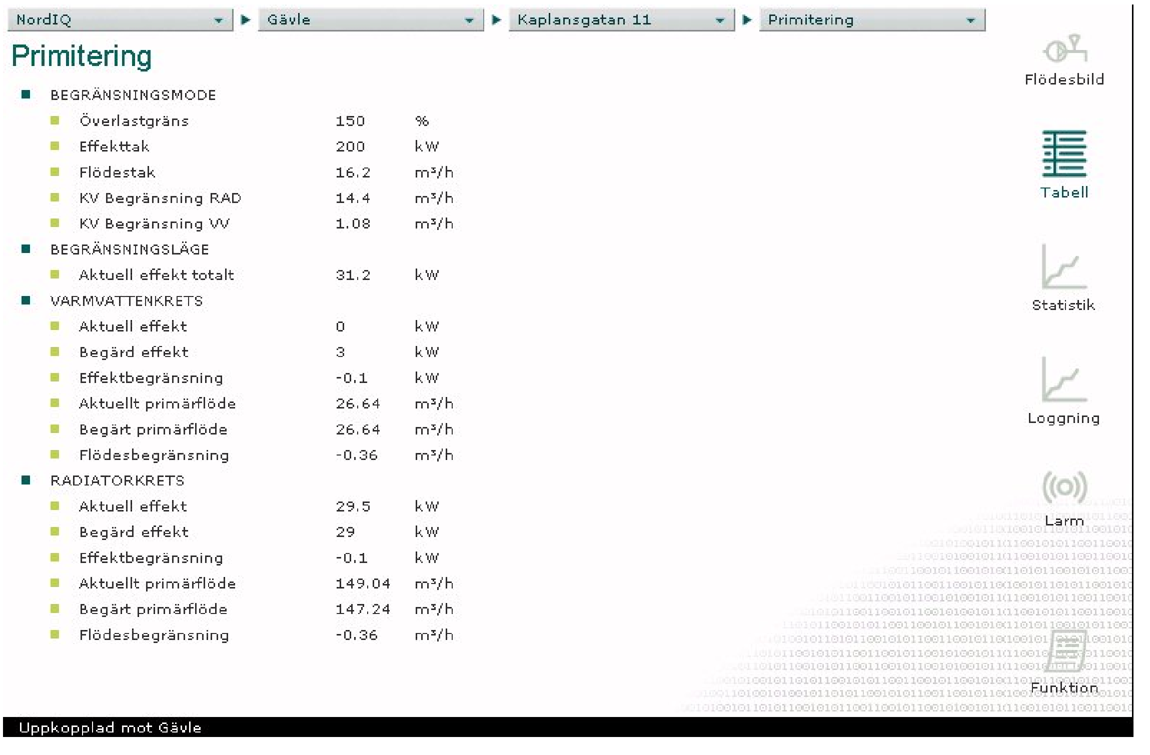

Figure 6: Limitations and activated states

4.4.2 Flow limitation

Flow limitation is used today by some district heating companies in the same manner as electric fuses in order to limit the maximum current. The limitation is implemented as a separate device connected between the heat meter and the heat regulator. The consumer subscribe for a specified maximum flow rate and pay a fee in proportion to the size of the subscribed primary flow rate. In the Enabler system the flow limitation can be used in similarity with such a device or as a safeguard against high flow rates when the heat demand limitation cannot be used, i.e., during heat supply cut off when the supply temperature becomes low. When a breakdown in a production unit occurs, the supply temperature will decrease and the flow rate in the distributing network will increase in pace with increased flow demand in the district heating stations. An advantage with the Enabler flow limitation is that the start-up time will decrease significantly after a production unit break-down.

4.4.3 Limitation of control valve size

Another form of flow limitations is given by the control-valve flow coefficient limitation. When dimensioning a DHS, there are always an uncertainty during selection of valve size regarding actual consumption and the district-heating network operating conditions.

With the Enabler system the valve size can be set from the software given that the valve is big enough. The valve size can be adjusted remotely through Internet or through the HMI at the DHS. It is always possible to reduce the valve size...

A better cooling of the primary heat carrier of the hot service water system can be achieved if the valve size is chosen so that there is almost a “shortage-of-supply” during high flow demands. If the valve size is limited, the required heat is withdrawn through an increased primary temperature difference and a smaller primary flow rate. From Figure 8, it can be seen that high flow rates occur but also that they are not very frequent. When they occur, the duration is very short.

A study where the dynamic behaviour of the hot service-water was analysed, Ref. 8, showed that very large flow demands occurs in similarity to earlier investigations, Ref. 9, Ref. 10, but it’s frequency is very low. The Swedish district heating association now recommend a dimensioning flow-rate corresponding to a cumulative relative frequency of 7 %. This is a dimensioning based on a shortage of supply as long as the dimensioning flow rate is smaller than 1,7 l/s. The recommended dimensioning flow rate of 7% cumulative relative frequency corresponds to 0,6 l/s and all flow rates above 0,6 l/s translates to a shortage of 7 % of all occurring flow rates.

In order to demonstrate the valve limiting function, a very small value of 0,7 m3/h was set on the hot service-water control valve at Kaplansgatan in Gefle (50 apartments) Figure 7. The hot service-water temperature set point was 50°C and not until 10:10, the temperature starts to drop. In order to find the correct valve size, the accumulated time during one day when the requested valve position exceed a certain time determines the size.

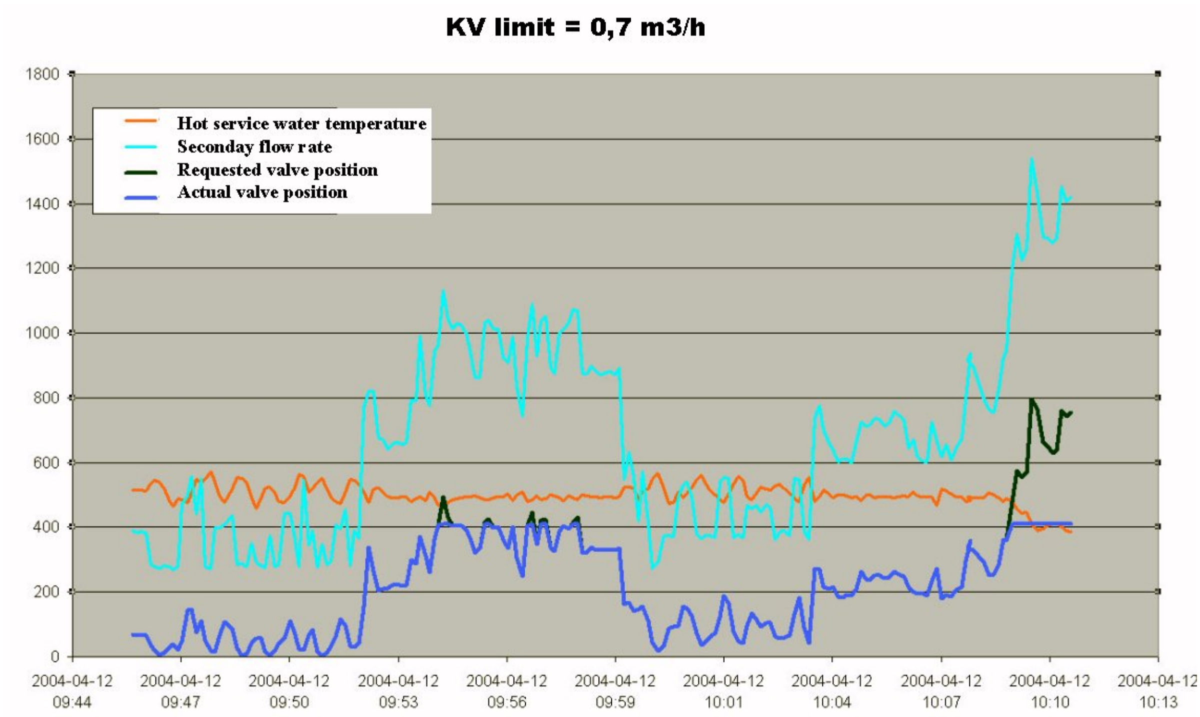

Figure 7: Limitation of control valve flow coefficient

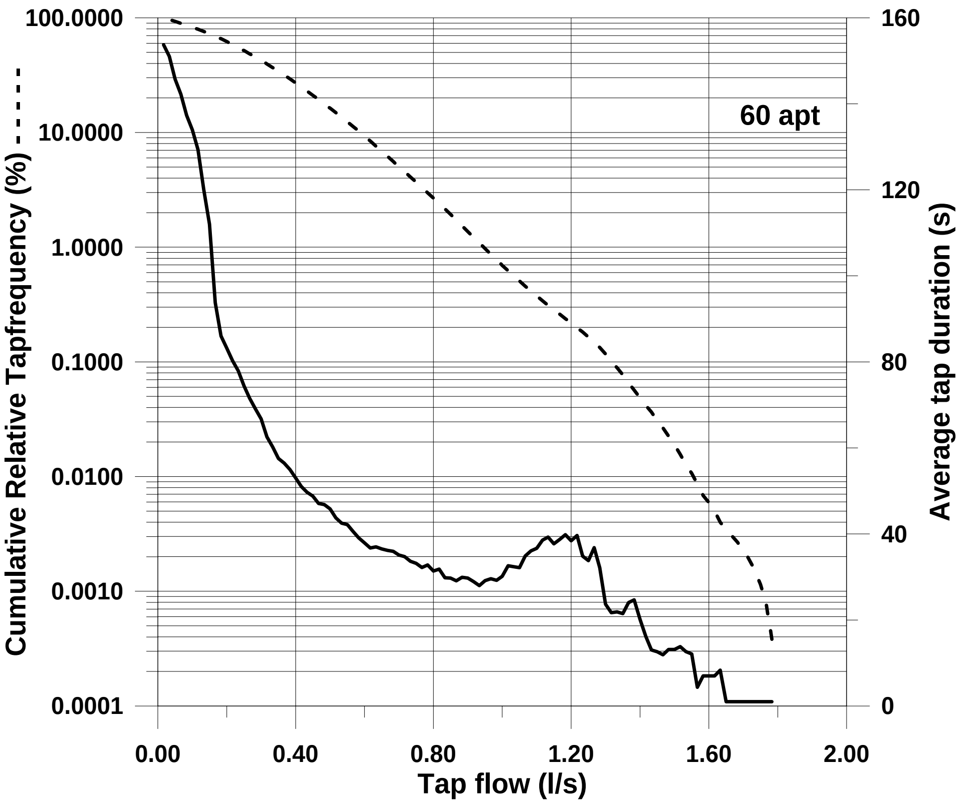

Figure 8:The Cumulative relative frequency of hot service-water flow, Ref. 8

4.4.4 Primitation™

Primitation constitute the combination of priority and limiting. The limiting part is the restriction of the total heat demand and priority means that heating of hot service-water has higher priority than space heating. The function is activated when a limit for the total heat demand has been reached. The limit for the total heat demand is from the beginning not a static limit, an over-consumption will be allowed for a shorter period of time depending on how the consumption pattern have behaved earlier. When the limit has been exceeded some period of time, the supplied heat to the radiator system will become reduced in favour for the hot service-water system until the limit is reached.

The reduction in supplied heat to the radiator system will not be noticed by the inhabitants due to the fact that a large heat buffer is stored in the building and that the high heat demands in the hot service-water system are short, Figure 8. In this way the maximal heat demand of the building can be limited in favour for the energy distributing company. The principal method behind the Primitation can be seen in Figure 9.

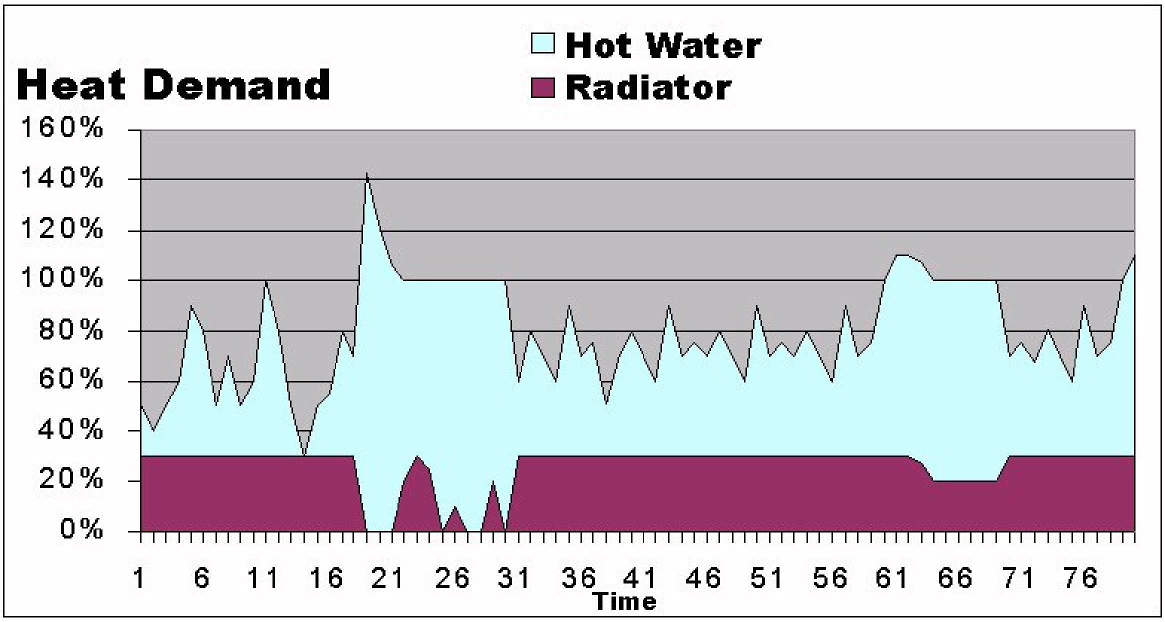

Figure 9: The principle behind the Primitation function

From Figure 9 it can be seen that when the limit is reached, the limitation function is activated after a short period of time. By reducing the heat supplied to the radiator system and transfer this amount to the hot service-water system, the maximum heat demand will be kept at the required limit. The limitation function is deactivated when the total heat demand of the radiator- and hot service-water system is less than the required limit.

Several flow peaks occur in residential buildings during the day. The most well known peak is therefore called the morning peak. The phenomenon is caused by deactivation of night setback in heating system controllers in combination with an increased demand of hot service-water for the consumers. The “morning peak” can be seen from a sampling of the Enabler system in Gefle, Figure 10.

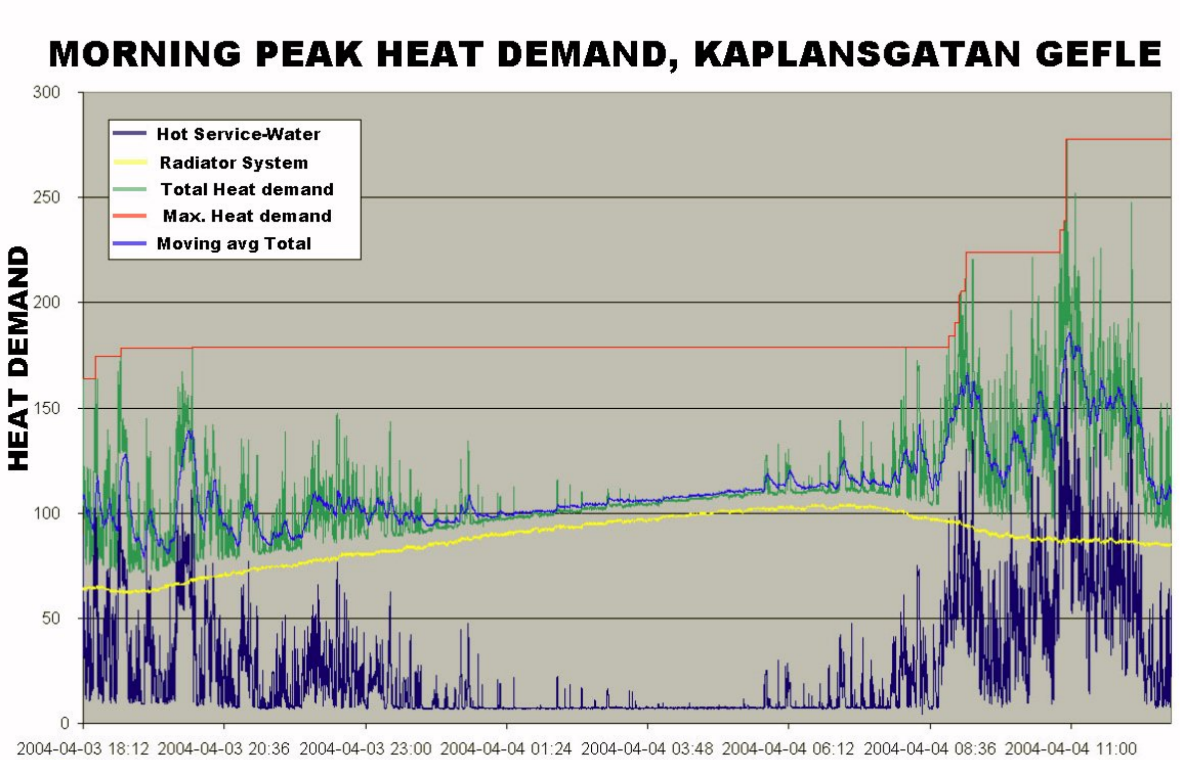

Figure 10: Morning peak, Kaplansgatan, Gefle

The yellow line represents the heat demand in the radiator system that slowly increase during the night. The blue line represents the heat demand in the hot service-water system. As can be seen, the tap water system is nearly inactive during the night but starts to increase around 6 am. The green line represents the total heat demand and the light blue constitutes a 5:minute moving average of the total delivered heat. The red line is the reached maximum value of the heat demand. The maximum radiator heat demand is 100 kW and the average value of the total heat demand is 175 kW. When the Primitation function has been activated and the limit set to 110 kW, we see that the delivered heat to the radiator system is reduced between 20:52 and 21:10 and that the delivered average heat never exceed 110 kW. In this manner the morning peak can be reduced significantly in the entire system without any consumer noticing.

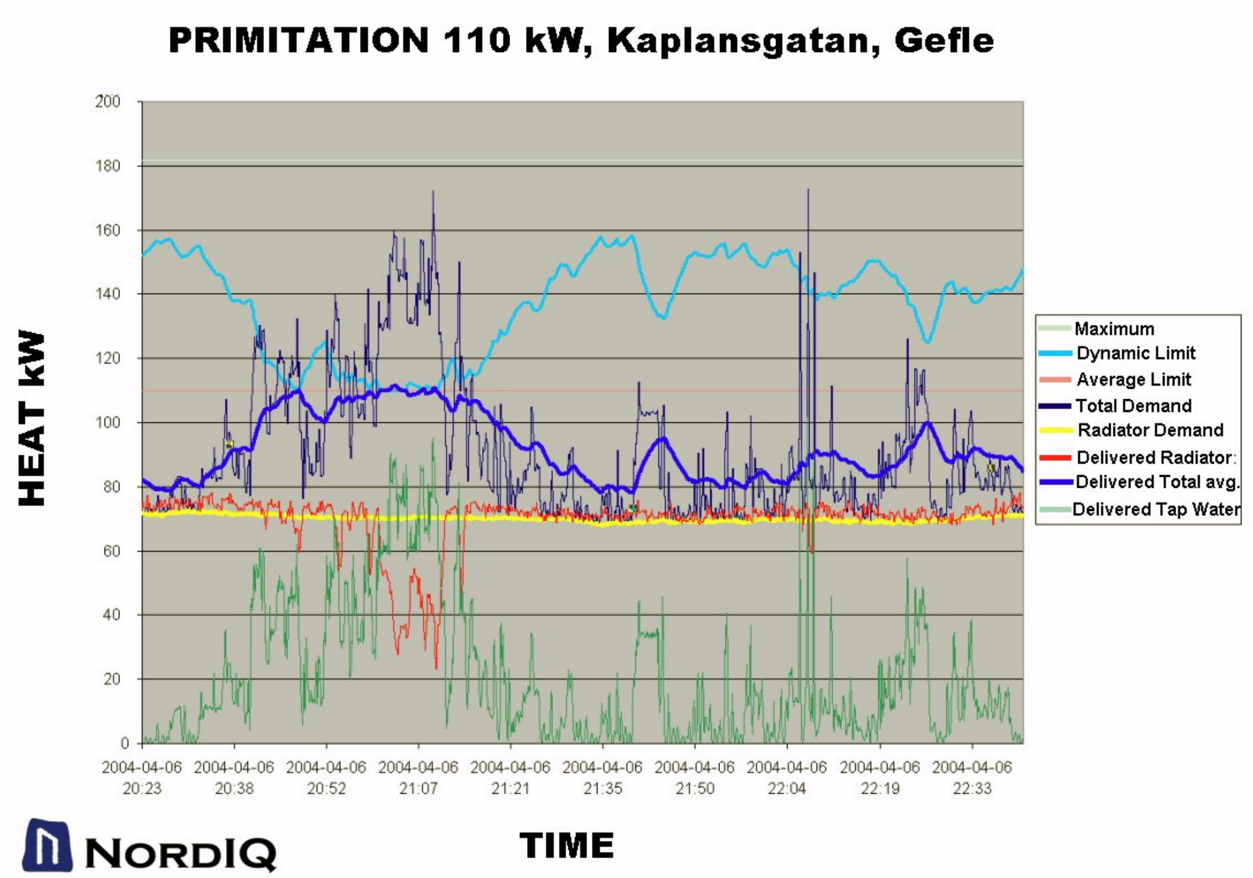

Figure 11: Primitation in operation, limit 110 kW, Kaplansgatan, Gefle

4.4.5 Heat-exchanger diagnostics

The Enabler continuously analyse the operating conditions at different load levels when stationary conditions prevails.

By measuring flow rates and temperatures, several evaluations of the system is made continuously such as heat exchanger performance. By establishing a signature in the initialization of the DHS, the variation in performance in different parts of the system can be discovered, sampled and a notification over Internet can be issued. These utility functions are established in the Enabler system but not yet analyzed.

4.4.6 Fault tolerant

Another function that has been established is “fault tolerance”, which means that the system will alter control algorithm when faulty sensors are detected in order to protect the consumer from hazard or increased operating costs. The Enabler system are equipped with more sensors compared to conventional DHS, therefore an increased redundancy is supplied for “Fail-safe-functions”.

4.4.7 Decoupling of district heating network conditions

One of the more important advantages of the Enabler-system is constituted by the thermo hydraulic decoupling of the control system from the distributing distribution network. By making the DHS more insensitive to variations in supply temperature and network differential pressure, a more stable system is achieved during extreme load conditions. Another advantage with this feature is that the DHS can have a more standardised design due to the fact that variations in network conditions in various district heating systems already have been taken care of by the control system. The feature allows the network operator to utilize the design pressure better. Normally the design network is PN16 and the maximum differential pressure that conventional DHS can manage is maximized to 6 bars. By adding the possibility to increase the network differential pressure more, the breakpoint between flow- and temperature control in the distributing network can be transferred to lower outdoor temperatures. This will lead to reduced network losses. The enabler system are less sensible to variations in network conditions which will lead to a minimal need for differential pressure controllers.

4.4.8 Plug-and-Play

The model based control principle will release capacity from commissioning and adjustment of the district heating station. In the case with the conventional PID-controller, the adjustment work will consume a lot of time in order to find suitable parameters. It is impossible to find suitable parameters that will fit all operating conditions in the district heating application depending on the fact that the controller amplification in the linear PID-algorithm require that the control object have a linear characteristic regarding static and dynamic behaviour. Variable system amplification is a characteristic property of a district heating system (supply temperature and differential pressure will vary during the climatic year). And further, the PID-algorithm require that the control object has a linear characteristic. The time constant of a heat exchanger is not linear but it will vary with the load (nonlinear). The interaction between the opening degree and the transferred heat in the heat exchanger seldom follow a linear relationship. Therefore it is impossible to find the correct parameters for the PID controller, and in particular to find the correct setting for the system six month ahead of time.

During the evaluation period no adjustments have been performed regarding the hot service-water system on any of the Enabler pilot plants.

4.5 Product concept

4.5.1 Electronic platform

The Enabler consists of a module based PLC-system with analogue and digital in- and output channels. The PLC is equipped with RS232- and RS485-loop for communication inside and outside the building. Through the RS485-loop it is possible to connect other devices such as heat meters and dispatch units. Heat meters can be read remotely through the PLC via M-bus connection. The solution is very flexible and other conventional routines except the dedicated Enabler functions are implemented as well such as pulse counters, PID-controllers, alarm signals in several layers, average, password sensitive hierarchy and so on.

4.5.2 Smart control valve

A development project with the aim to adapt certain central components for the developed DHS concept was initiated. Several components could be integrated into the control valve in order to take care of the advantages inherited in the Enabler concept regarding rationalisation. By doing so, this would reduce the complexity of the composed system. The components that could be integrated into the control valve were a differential pressure sensor and a temperature sensor.

The available contemporary technology within control-/operation and maintenance has progressed organically with a low degree of innovation or utilisation of research progress/products in the nearby technological sector. The available products on the market are similar and development co-operation between component-, system-manufacturers and customers is small or negligible.

Some of the key components in the new concept except from the control box is a control valve with integrated differential pressure sensor and a robust and fast flow sensor. The available components on the market are not adopted technological or economical for the patented technology. It is therefore important that these components are developed in order to match the Enabler concept regarding required performance and price and in full utilize the advantages regarding possibility for standardisation. The manufacturers of control equipment have there own assortment of controllers, control valves actuators and temperature sensors. With the Enabler technology a modification of the valve can be done in such a way that a simplified production and assembly in the end will produce a more cost effective and a technological improved system product.

The new control technology does not require a complex valve characteristic which in turn reduces the requirements on the manufacturer. The new technology does not require a wide range of valve sizes which will lead to a smaller assortment. Therefore the manufacturing- and logistic cost can be reduced.

4.5.2.1 Conventional components

A common component in the control valve and the flow meter could be the differential pressure sensor. In order to measure the differential pressure across an existing valve, the sensor must be connected on four places, up- and downstream the pressure restriction and on the sensor. The available sensors on the market are expensive and bulky. It is therefore desirable that a more adapted unit is developed. Available flow meters are normally developed for the heat meter industry to measure volume. The sensor emits a pulse when a specific volume has passed through the meter. The output consists of a pulse train. The pulses must be converted to flow rate in order to fit our application. The conversion constitutes an uncertainty regarding accuracy and dynamic behaviour.

4.5.2.2 Development of differential pressure sensor, valve

With a differential pressure sensor a continuous signal that is proportional to the square of the flow rate. The differential pressure sensor should fit into the valve and the flow meter application given that the dynamic range of the sensor will generate correct resolution for small flow rates. A sensor is available on the market with the right performance/price and size but unfortunately is sensitive to water due to galvanic corrosion problems. A development project was started in order to develop a housing for the sensor that would take care of the problem. There are still some problems left to solve before the product is ready for production. Prototypes for the valve and the differential pressure sensor are produced, Figure 12.

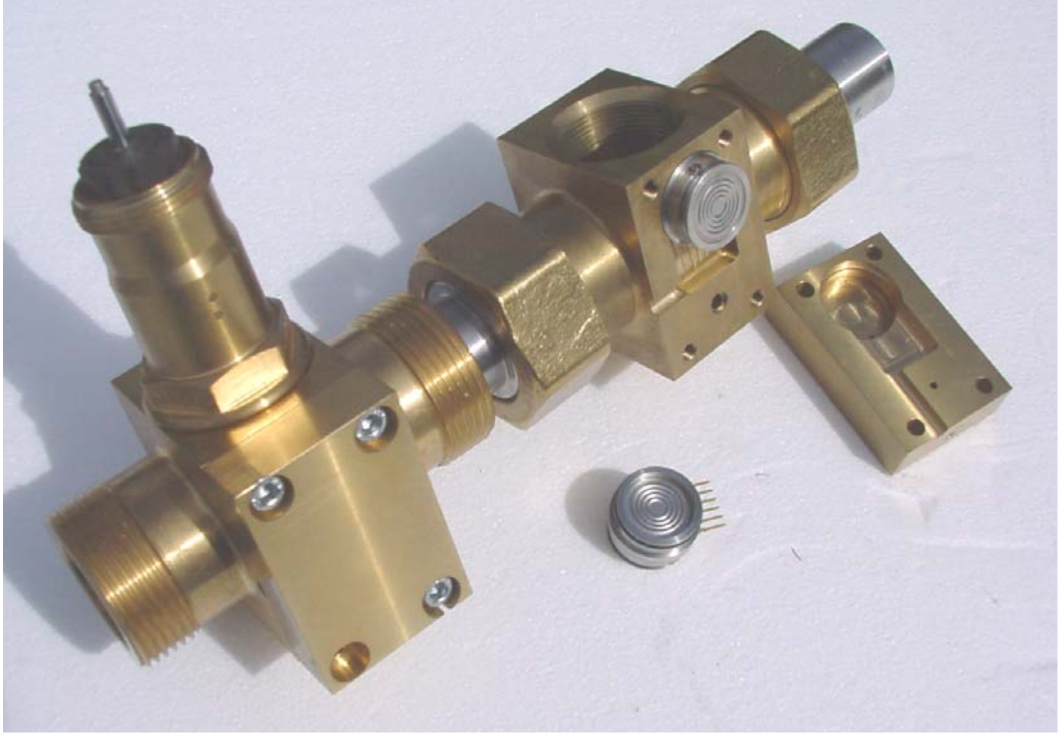

Figure 12: Control valve with integrated differential pressure sensor

4.5.3 Standardization of district heating station

A standardized concept for district heating stations have been developed based on Enabler technology, Figure 13, (right picture). The concept is based on variation of heat exchangers and pumps only. When the pilot plants was constructed, combination heat exchangers were used. A combination heat exchanger consists of two conventional exchangers brazed together back-to-back. The primary supply pipe are common for the 2 heat exchangers. During the project it was discovered that the heat leakage between the two circuits was significant. The leakage was quantified and amounted to 30% of the consumed energy during one summer month. Due to the leakage, the heat exchanger design was modified and now the system consists of 2 separate heat exchangers, Figure 13, (left picture).

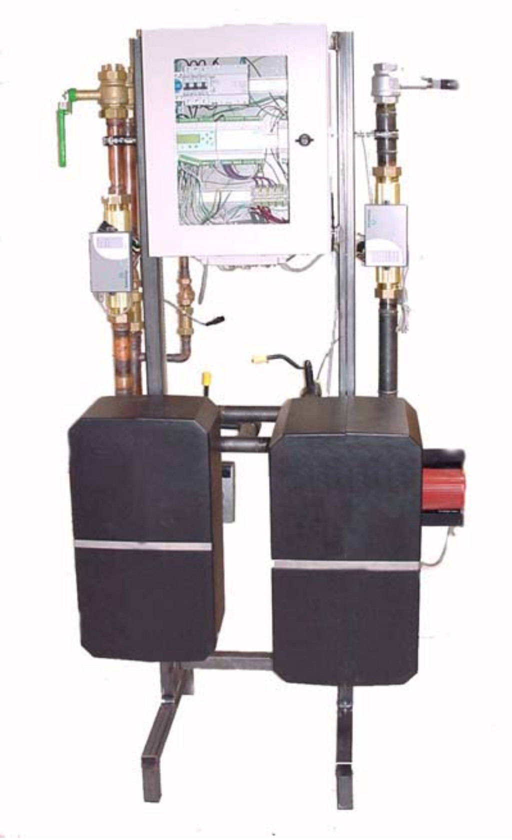

Figure 13: Standardized DHS pilot plant in Gefle

The pipe dimensions are the same, from the smallest DHS-size to the largest. A marginal cost reduction is obtained by reducing the pipe size for each size. On the other hand a simplification regarding revision and logistic effort is obtained for the manufacturer and customer. The thermo hydraulic design of the heat exchanger have been selected in order to be used with the several radiator systems and district heating network conditions. The over surface of the heat exchanger is of minor importance compared to problems with possible high secondary pressure drop. The over surface will contribute to reduced grädigkeit in favour for the energy supplier.

5 CONCLUSIONS

By replacing the conventional district heating stations with Enabler stations, several common problems in district heating stations can be avoided with the advantages the new technology offers through the NordIQ 5-point program :

1. Energy savings
2. Improved cooling of the primary heat carrier
3. Primitation
4. Operational supervision / Control
5. Plug-and-play

The operational cost are reflected in all of the five points above for the house owner as well as the energy distributor. The environmental impact is also reduced by utilisation of the Enabler technology. In the presented project energy consumption was decreased by 9 %, cooling of primary heat carrier increased by 11°C and circulated primary volume reduced by 34 %.

6 APPENDIX I – MONTHLY ENERGY CONSUMPTION

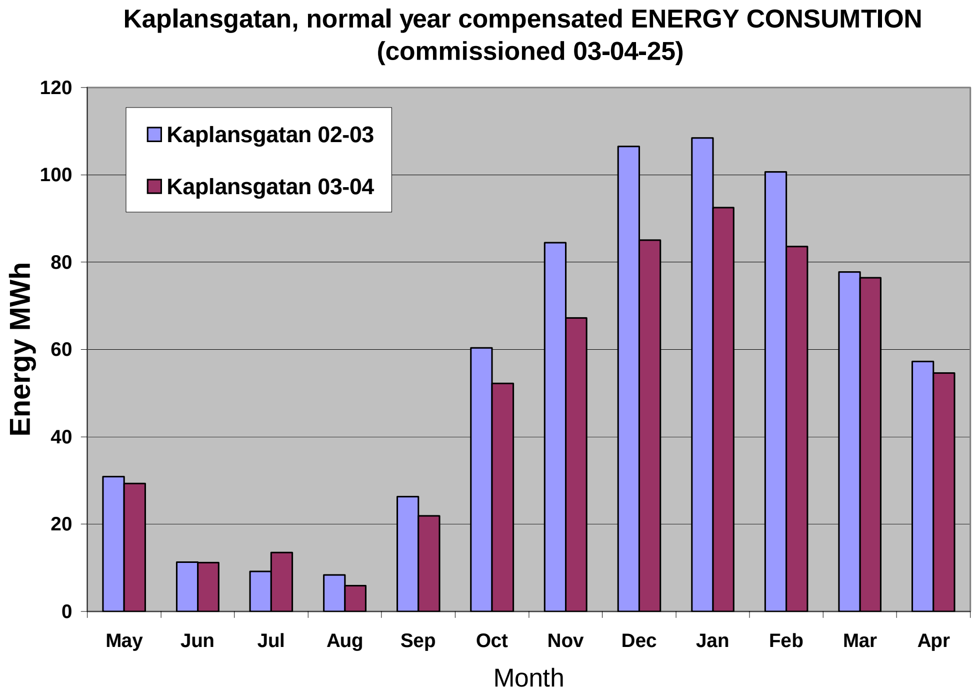

Figure 14: Energy consumption, Kaplansgatan, Gefle

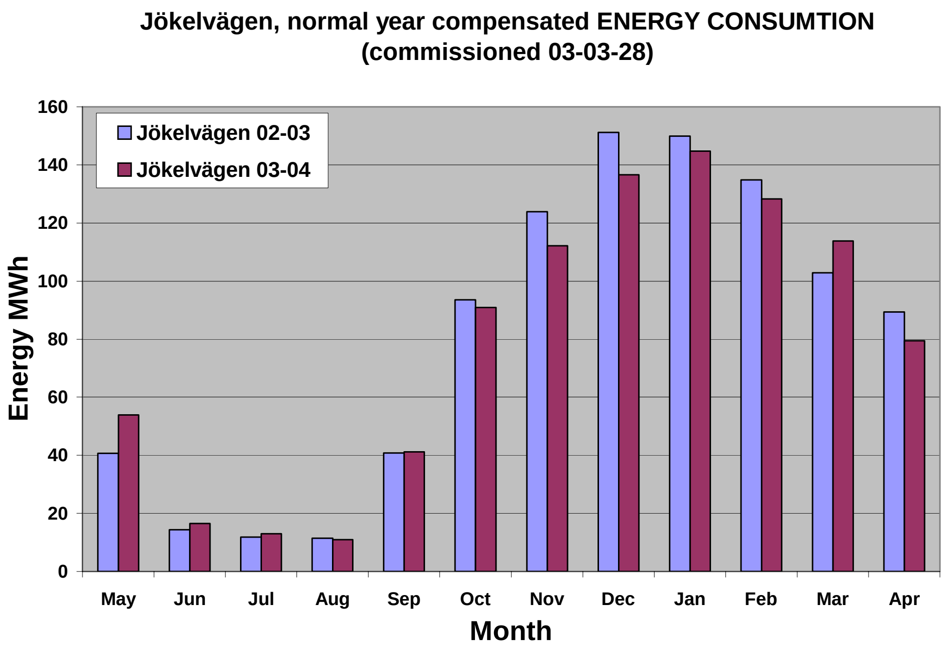

Figure 15: Energy consumption, Jökelvägen, Gefle

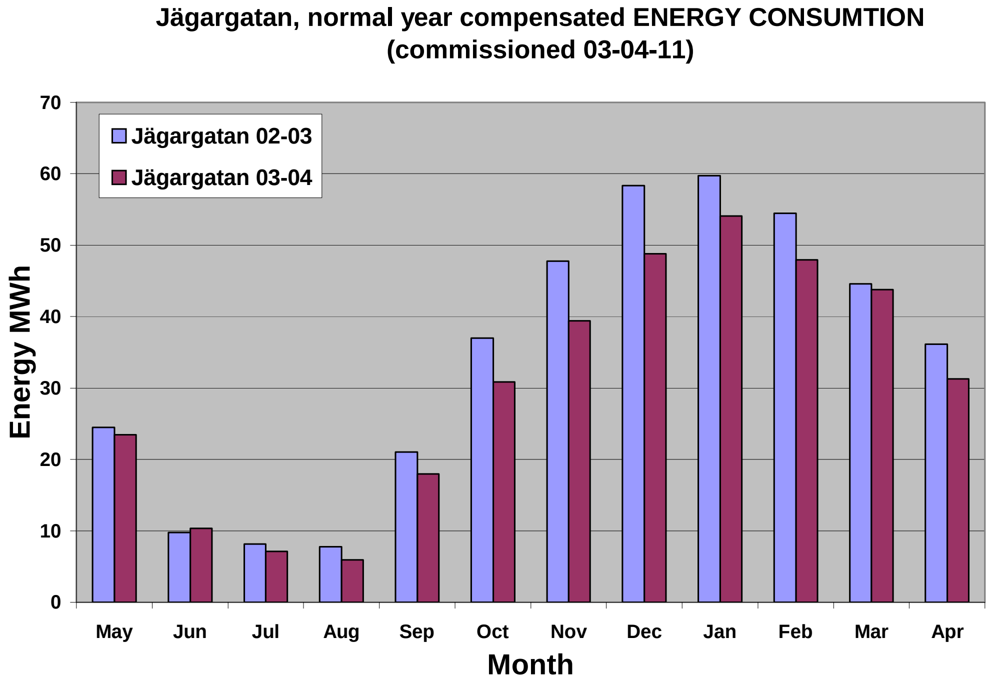

Figure 16: Energy consumption, Jägargatan, Gefle

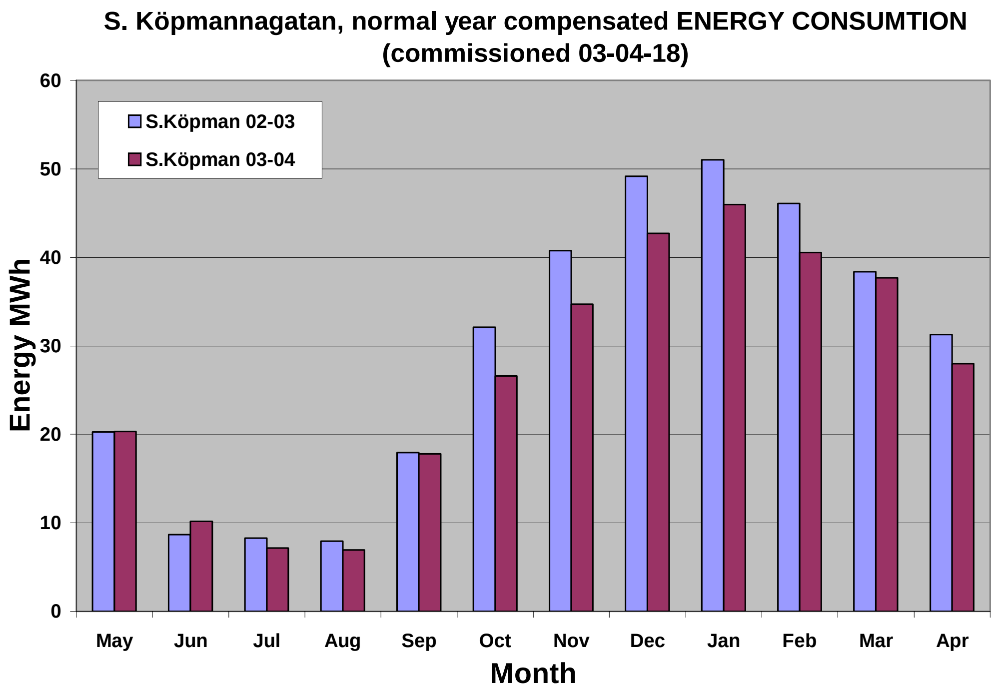

Figure 17: Energy consumption, S.Köpmannagatan, Gefle

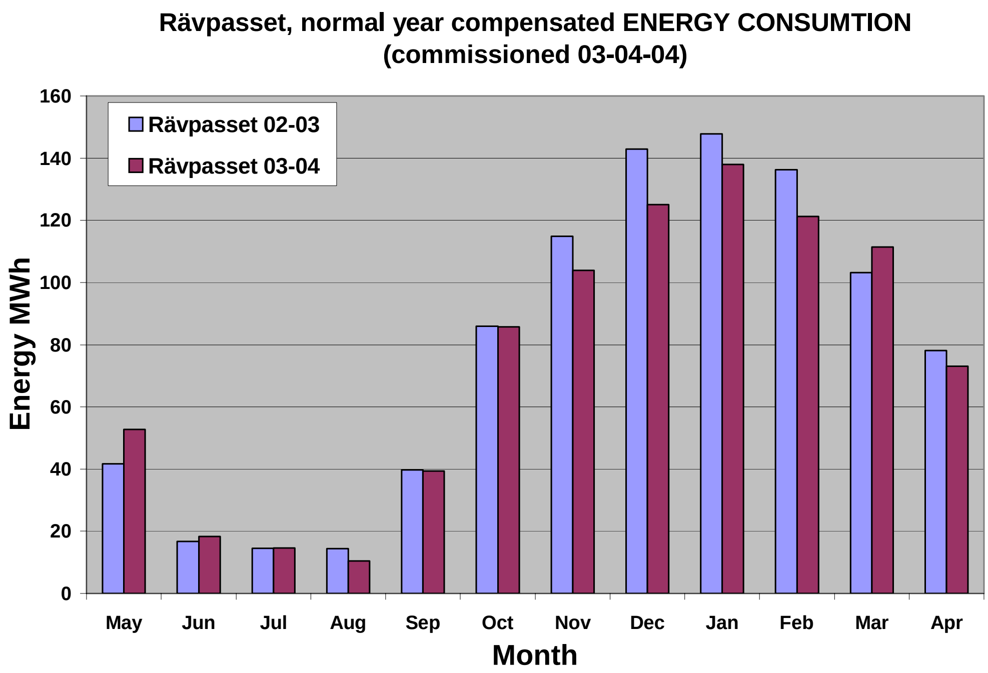

Figure 18: Energy consumption, Rävpasset, Gefle

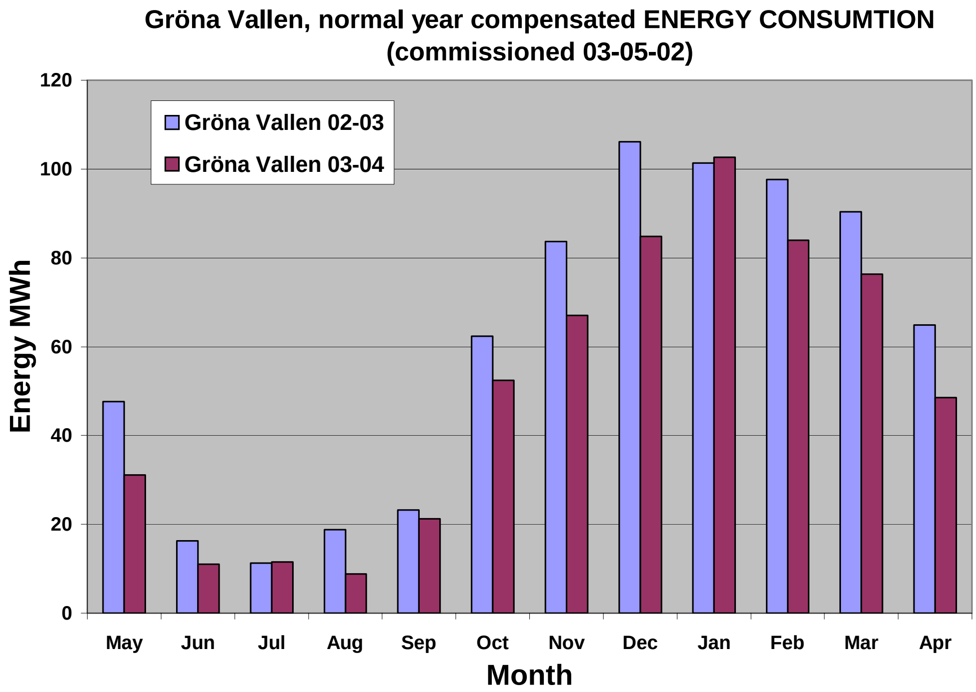

Figure 19: Energy consumption, Gröna Vallen, Gothenburg

7 APPENDIX II – MONTHLY AVERAGE COOLING OF HEAT CARRIER

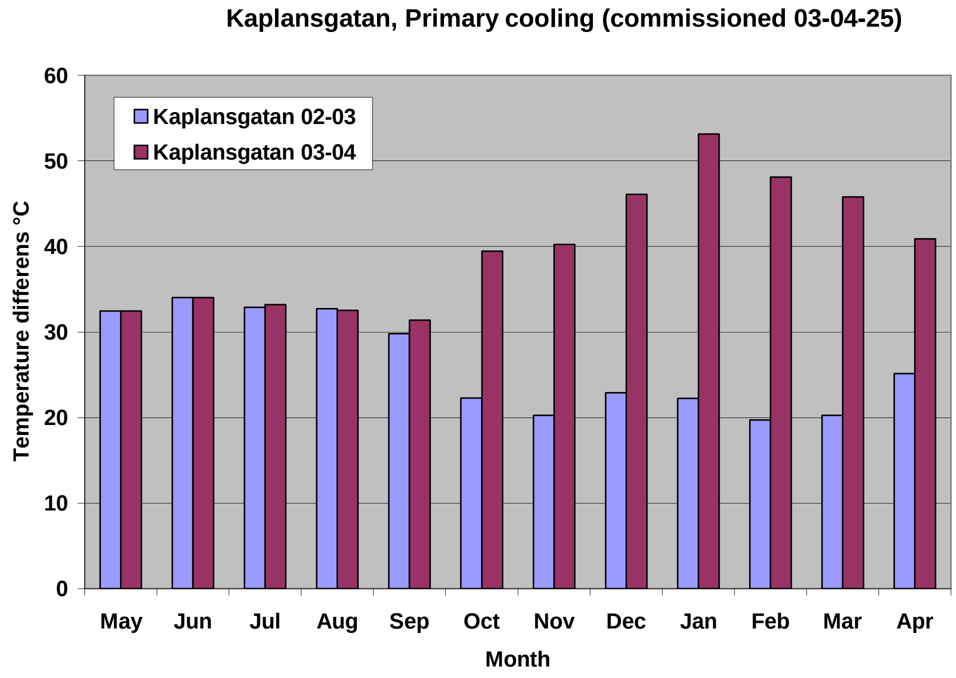

Figure 20: Cooling of primary heat carrier, Kaplansgatan, Gefle

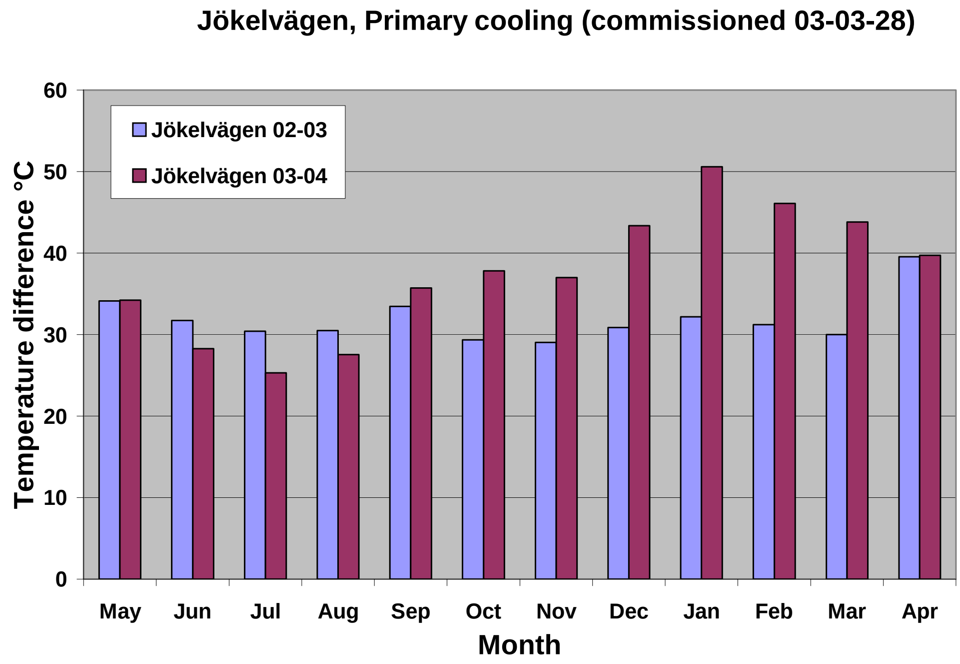

Figure 21: Cooling of primary heat carrier, Jökelvägen, Gefle

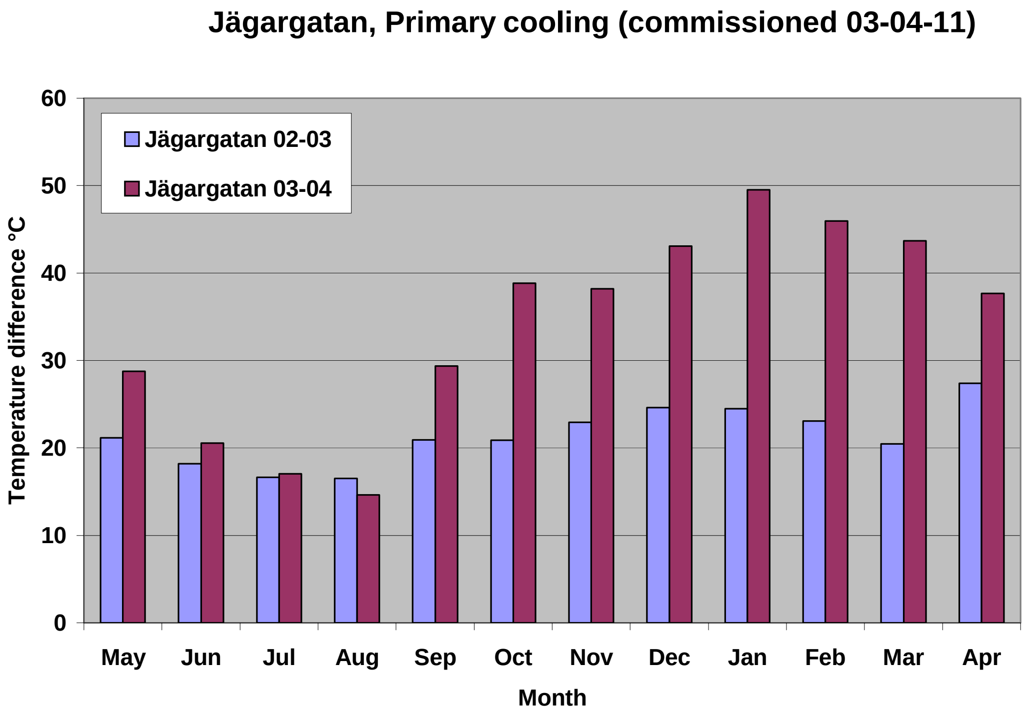

Figure 22: Cooling of primary heat carrier, Jägargatan, Gefle

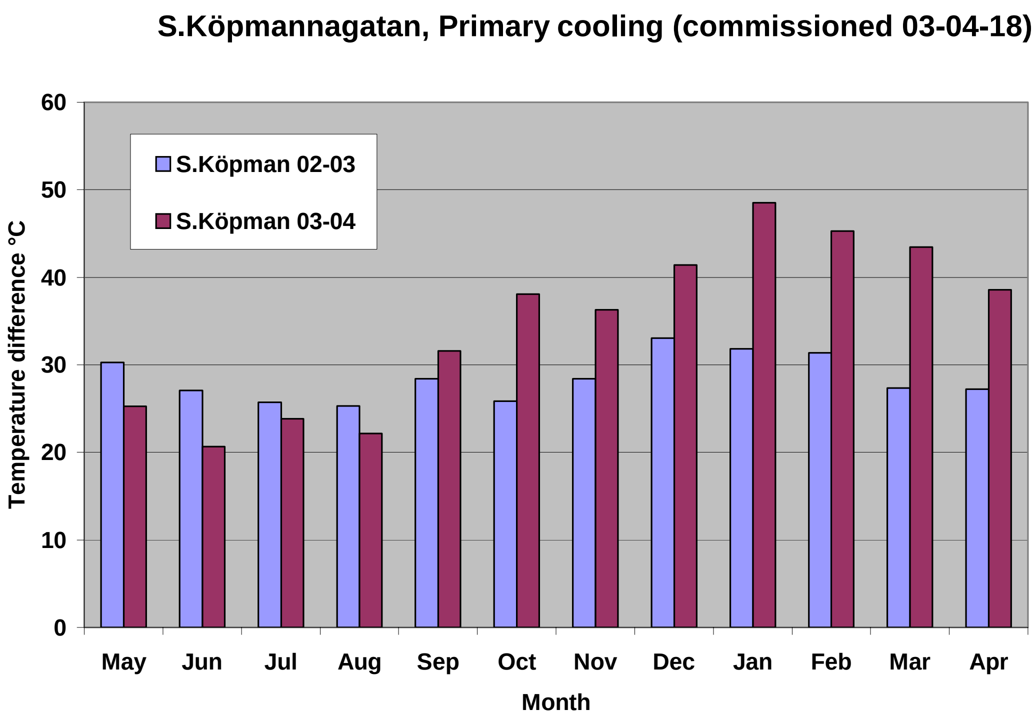

Figure 23: Cooling of primary heat carrier, S. Köpmannagatan, Gefle

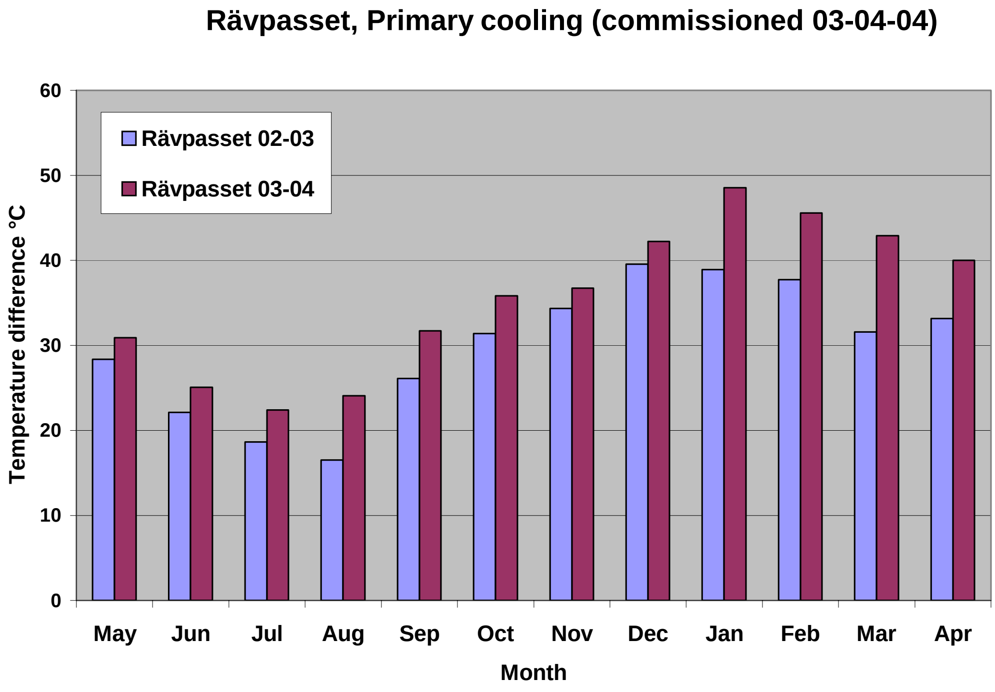

Figure 24: Cooling of primary heat carrier, Rävpasset, Gefle

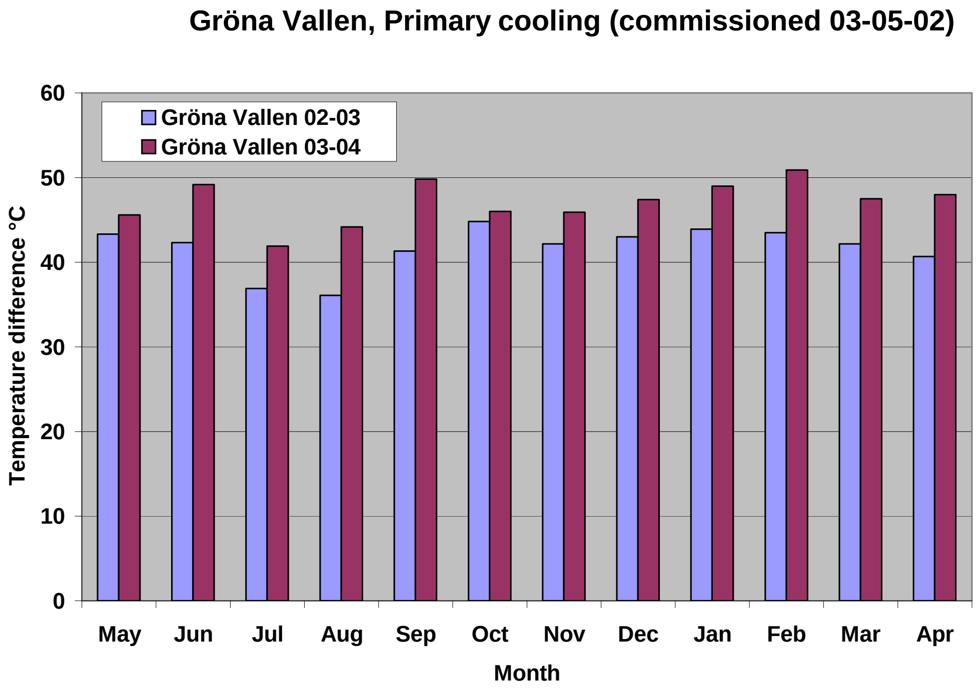

Figure 25: Cooling of primary heat carrier, Gröna Vallen, Gothenburg

8 APPENDIX III – MONTHLY VOLUME OF PRIMARY HEAT CARRIER

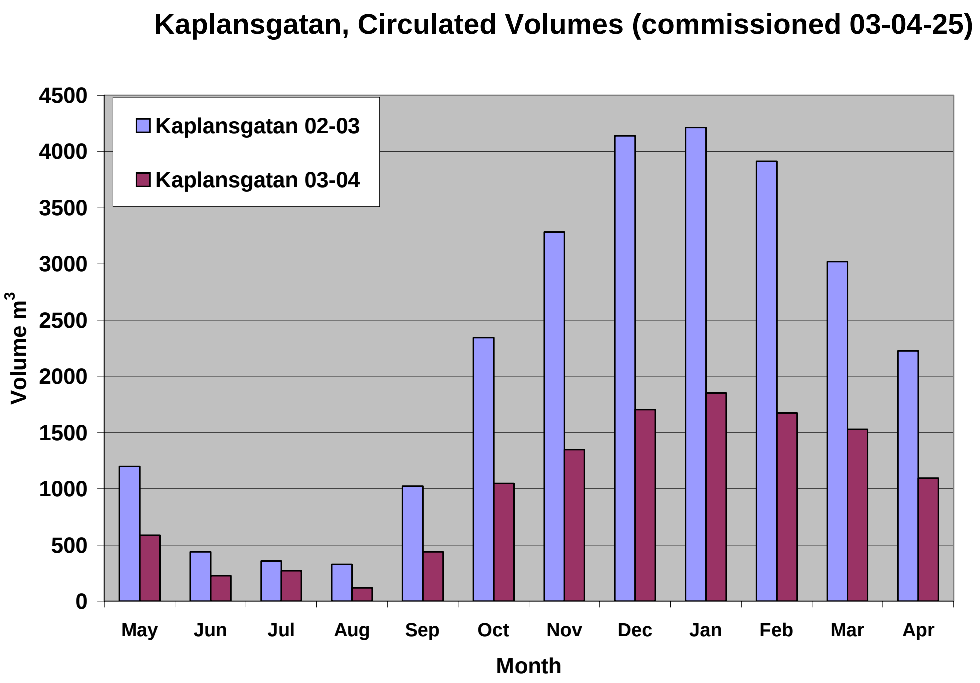

Figure 26: Circulated volumes of primary heat carrier, Kaplansgatan, Gefle

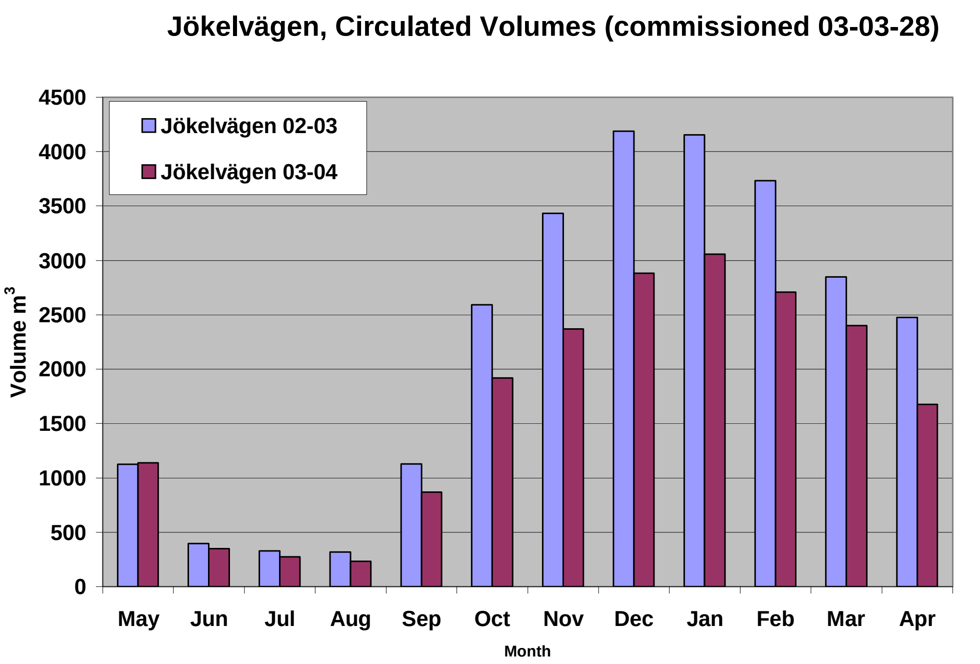

Figure 27: Circulated volumes of primary heat carrier, Jökelvägen, Gefle

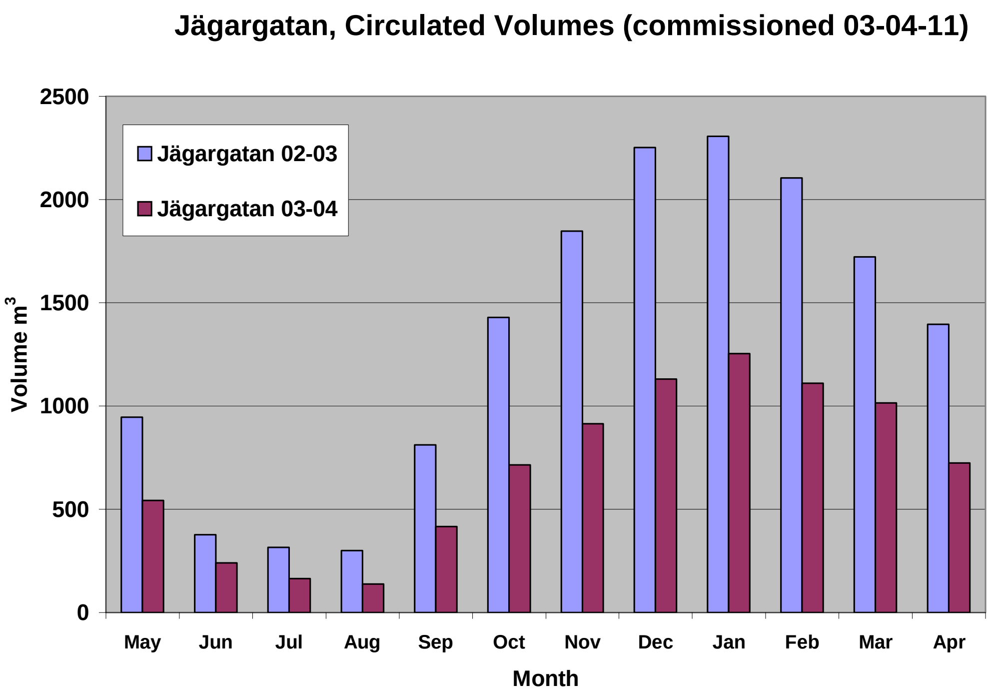

Figure 28: Circulated volumes of primary heat carrier, Jägargatan, Gefle

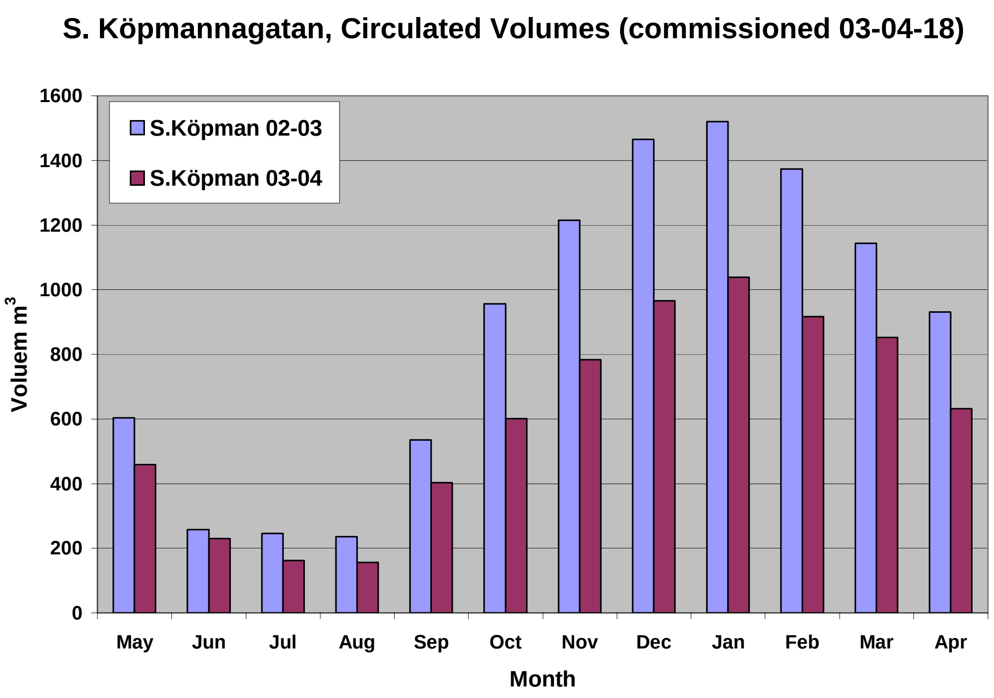

Figure 29: Circulated volumes of primary heat carrier, S.Köpmannagatan, Gefle

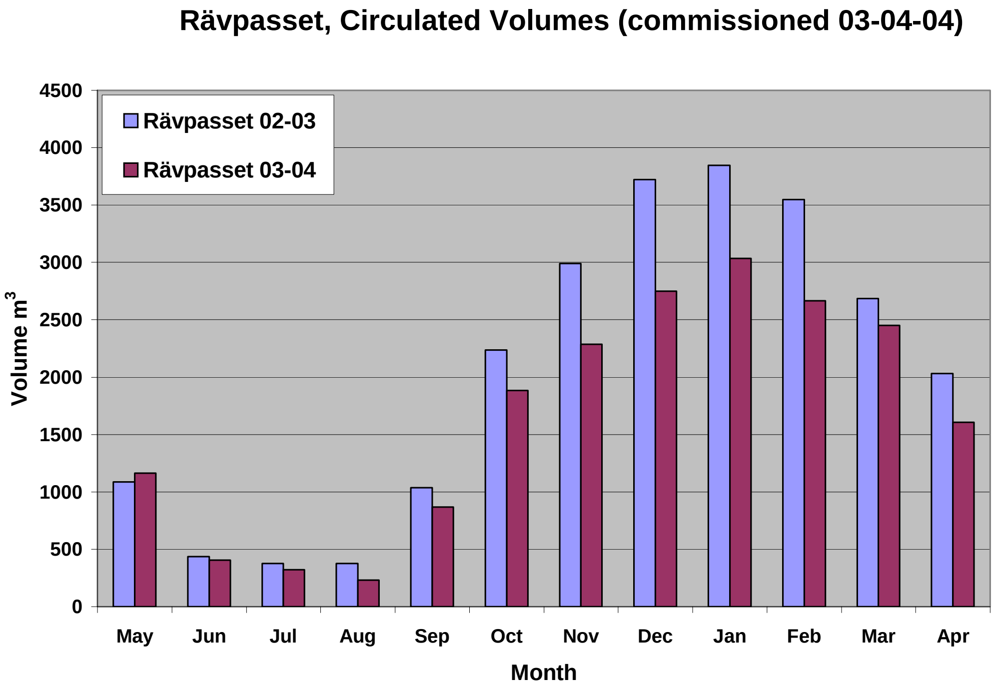

Figure 30: Circulated volumes of primary heat carrier, Rävpasset, Gefle

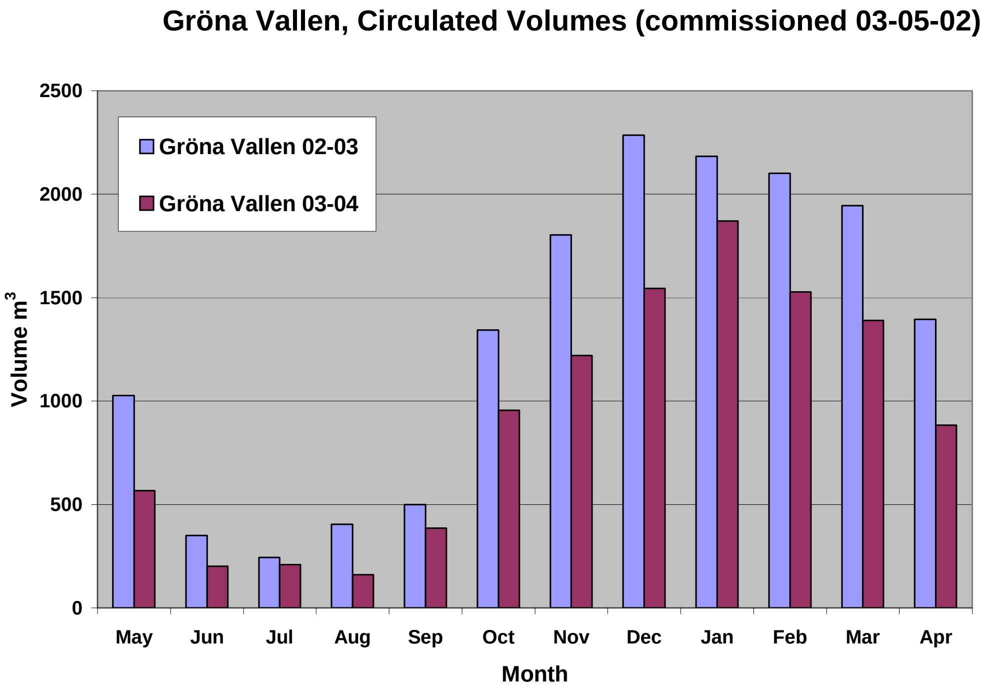

Figure 31: Circulated volumes of primary heat carrier, Gröna Vallen, Gothenburg

9 APPENDIX IV – DESCRIPTION OF FIELD OBJECTS

A selection of suitable residential building was conducted based on configuration and of historical measured data in order to be able to compare the objects before and after the replacement. The selection was decided by an independent consultant company FVB AB. A separate evaluation of the Enabler system was going to be conducted on behalf of the Swedish district heating association. The requirements on the primary side data was hourly values of supply- and return temperatures, volumes and energy.

The pilot project evaluation objects consisted of district heating connected residential buildings with 2-pipe radiator systems and hot service-water heating and no forced ventilation because the Enabler for ventilation is not yet developed. All district heating stations was before the replacement equipped with conventional shell and tube heat exchangers in 2-stage configuration with conventional automatic control of the radiator- and hot service-water system.

The newly installed stations from NordIQ are parallel configured with copper brazed plate heat exchangers. The old radiator system circulation pump was also replaced by a speed-controlled pump for constant pressure operation.

9.1.1.1 Jökelvägen

The building consists of two separate buildings, 3 floors with basement, Figure 32. There are 76 apartments covering 5950 m^2 of heated surface.

Figure 32. One of the two buildings at Jökelvägen, Gefle

Gävle Energi AO Värme **Distribution**

Projektkort Ombyggnation Fjärrvärmecentraler

Fc-nummer		**Adress**	**Populär**
1222		Jökelvägen 22	
Abonnent		**Kontaktman**	**Telefon**
Teknisk effekt 595 kw	**Läst effekt** 350 kw	**Fördelningsarea** 6159 m²	**Antal lägenheter** 76
Nyckelnummer			

Projektnummer	**Planerad projektstart**

Befintlig central		**Ny central**	
RC Värme	TA 2222	RC Värme	ENABLER
RC Vatten	TA 2222	RC Vatten	ENABLER
RC Vent		RC Vent	
VVX Värme	CTC SKR126	VVX Värme	Swep B45/100/40
VVX Vatten	AJEWEX 8451-214	VVX Vatten	Swep B45/100/40
VVX Vent		VVX Vent	
SV Värme	TA M15C V298 20/6,3	SV Värme	M800 V241 20/6,3
SV Vatten	TA EM5C V241 15/1,0	SV Vatten	M800 V241 15/4,0
SV Vent		SV Vent	
Avstäng.ventil	DN65	Avstäng.ventil	DN65
Filter	DN65	Filter	DN40
Mätare	DN25	Mätare	DN25

9.1.1.2 Rävpasset

The building consists of 10 separate houses with six 2-floor apartments with basement. The ten houses are spread out on a large surface, Figure 33. There are 60 apartments covering 6570 m^2 of heated surface.

Figure 33: Three of the ten houses at Rävpasset visible, Gefle

Projektkort — Ombyggnation Fjärrvärmecentraler

Fc-nummer 1260		**Adress** Rävpasset 6A	**Populär**
Abonnent		**Kontaktman**	**Telefon**
Teknisk effekt 657 kw	**Läst effekt** 413 kw	**Fördelningsarea** 6570 m²	**Antal lägenheter**
Nyckelnummer			

Projektnummer	**Planerad projektstart**

Befintlig central		**Ny central**	
RC Värme	TA 230U	RC Värme	ENABLER
RC Vatten	TA 229W	RC Vatten	ENABLER
RC Vent		RC Vent	
VVX Värme	AJEWEX RC121	VVX Värme	Swep B45/100/40
VVX Vatten	AJEWEX VC221	VVX Vatten	Swep B45/100/40
VVX Vent		VVX Vent	
SV Värme	TA M15C STL 32/6,7	SV Värme	M800 V241 20/6,3
SV Vatten	TA EM5C V298 15/2,5	SV Vatten	M800 V241 15/4,0
SV Vent		SV Vent	
Avstäng.ventil	DN40	Avstäng.ventil	DN
Filter	DN40	Filter	DN40
Mätare	DN20	Mätare	DN25

9.1.1.3 Jägargatan

Figure 34: One of the houses at Jägargatan, Gefle

The building consists of 9 separate houses with three 2-floor apartments without basement, Figure 34. The nine houses are spread out on a large surface. There are 28 apartments covering 2300 m^2 of heated surface.

Gävle Energi AO Värme **Distribution**

Projektkort Ombyggnation Fjärrvärmecentraler

Fc-nummer		**Adress**	**Populär**
631		Jägargatan 14-16	
Abonnent		**Kontaktman**	**Telefon**
Teknisk effekt 200 kw	**Läst effekt** 135 kw	**Fördelningsarea** 2300 m²	**Antal lägenheter** 24+4
Nyckelnummer			

Projektnummer	**Planerad projektstart**

Befintlig central		**Ny central**	
RC Värme	TA 230U	RC Värme	ENABLER
RC Vatten	TA 239W	RC Vatten	ENABLER
RC Vent		RC Vent	
VVX Värme	CTC SKR42	VVX Värme	Swep B45/44/30
VVX Vatten	CTC SKR84	VVX Vatten	Swep B45/44/30
VVX Vent		VVX Vent	
SV Värme	TA M15C V298 15/2,5	SV Värme	M800 V241 15/4,0
SV Vatten	TA EM5C V298 15/1,0	SV Vatten	M800 V241 15/4,0
SV Vent		SV Vent	
Avstäng.ventil	DN40	Avstäng.ventil	DN
Filter	DN40	Filter	DN
Mätare	DN25	Mätare	DN25

9.1.1.4 Kaplansgatan

The building consists of one building, three floors with basement, Figure 35. There are 47 apartments covering 3936 m^2 of heated surface.

Figure 35: Kaplansgatan, Gefle

Gävle Energi AO Värme **Distribution**

Projektkort Ombyggnation Fjärrvärmecentraler

Fc-nummer 270		**Adress** Kaplansgatan 11	**Populär**
Abonnent		**Kontaktman**	**Telefon**
Teknisk effekt 525 kw	**Läst effekt** 230 kw	**Fördelningsarea** 3936 m²	**Antal lägenheter** 43+4
Nyckelnummer			

Projektnummer	**Planerad projektstart**

Befintlig central		**Ny central**	
RC Värme	TA 230U	RC Värme	ENABLER
RC Vatten	TA 229W	RC Vatten	ENABLER
RC Vent		RC Vent	
VVX Värme	AGA R151	VVX Värme	Swep B45/44/30
VVX Vatten	AGA S233	VVX Vatten	Swep B45/44/30
VVX Vent		VVX Vent	
SV Värme	TA M15 STL 20/2,3	SV Värme	M800 V241 15/4,0
SV Vatten	TA M310 V241/1,0	SV Vatten	M800 V241 15/4,0
SV Vent		SV Vent	
Avstäng.ventil	DN50	Avstäng.ventil	DN40
Filter	DN50	Filter	DN40
Mätare	DN25	Mätare	DN25

9.1.1.5 S. Köpmannagatan

Figure 36: S. Köpmannagatan, Gefle

The building consists of one building, 3 floors with basement, Figure 36. There are 39 apartments covering 3125 m^2 of heated surface.

Gävle Energi AO Värme **Distribution**

Projektkort Ombyggnation Fjärrvärmecentraler

Fc-nummer 57		**Adress** S.Köpmangatan 13	**Populär**
Abonnent		**Kontaktman**	**Telefon**
Teknisk effekt 280 kw	**Läst effekt** 123 kw	**Fördelningsarea** 3125 m²	**Antal lägenheter** 39
Nyckelnummer			

Projektnummer	**Planerad projektstart**

Befintlig central		**Ny central**	
RC Värme	TA 2222	RC Värme	ENABLER
RC Vatten	TA 2222	RC Vatten	ENABLER
RC Vent		RC Vent	
VVX Värme	CTC SKR84	VVX Värme	Swep B45/44/30
VVX Vatten	CTC SKR168	VVX Vatten	Swep B45/44/30
VVX Vent		VVX Vent	
SV Värme	M750 V298 20/4,0	SV Värme	M800 V241 15/4,0
SV Vatten	M300 V241 15/1,0	SV Vatten	M800 V241 15/4,0
SV Vent		SV Vent	
Avstäng.ventil	DN50	Avstäng.ventil	DN50
Filter	DN50	Filter	DN32
Mätare	DN25	Mätare	DN25

9.1.1.6 Gröna Vallen

Figure 37: Gröna Vallen, Gothenburg

The demand regarding historic information in the form of hourly average values was fulfilled on all buildings except the one in Gothenburg. The building consists of 120 apartments covering 5981 m2 heated surface with basement, Figure 37. A 60% share of the building is administrated by a building company, Familjebostäder and the other share is managed by three privately owned associations (BF1, BF2, BF3) that are connected to the radiator system of Familjebostäder according to Figure 38. The radiator system in share of Familjebostäder are equipped with old thermostatic valves and there are balancing valves on the separate riser pipes. In the privately owned share manually operated valves are installed on the radiators and only one balancing valve mounted on the return pipe each of these three buildings.

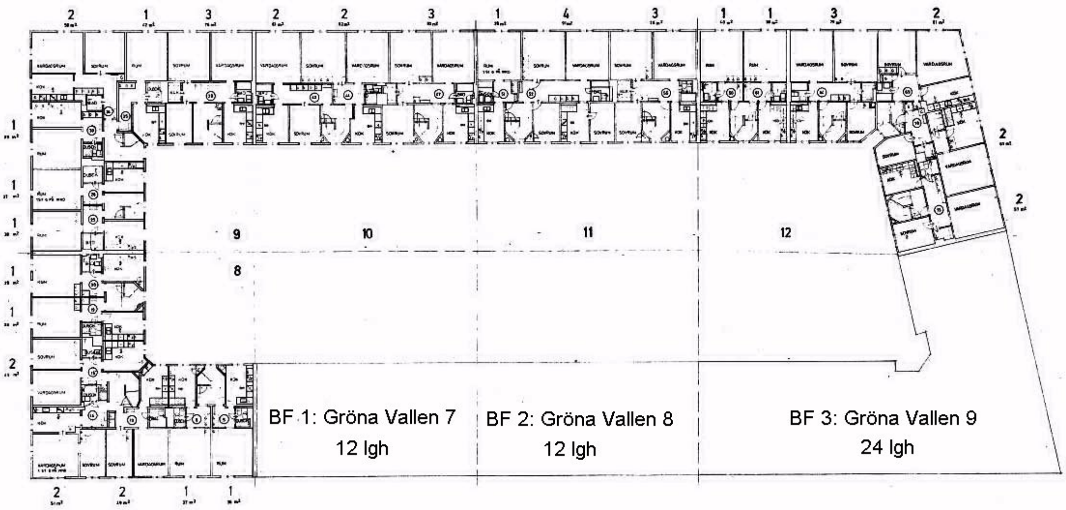

Figure 38 Plan drawing of Gröna Vallen

9.1.1.7 Operating observations Rävpasset

The hydraulic condition at Rävpasset was in such shape that the apartment owners had commonly decided to perform an overhaul of the system before the replacement was performed. In Gefle as in Gothenburg, the district heating station is owned by the energy distributing company and therefore a little is know concerning the secondary installations in the buildings connected to the district heating system. In January '04, most of the radiators not in operation before the heating period '03-'04 had been taken care of and a coarse balancing of the distributed system had been conducted. The radiator pipes entered each apartment in the roof of the basement and was branched to the radiators at the second and first floor as well as the basement. Due to the fact that the radiators in the basement was located in a lower level than the circulation pipes, a heat lock was established preventing an even distribution of heat in the apartment. The circulation flow was very low due to an unwanted restriction in the flow meter (1,0 litre/h m^2) so that the radiator supply temperature had to be increased significantly. The flow meter was replaced in the end of February and the total circulation flow was increased by 13,5%. This was sufficient in order to start circulation in the basement radiators. By measuring the flow rate in the radiator system using a, for the purpose installed balancing valve, a flow rate 13,5% higher than compared with the reading from, on the secondary side installed flow meter was obtained. By using the remote control for the circulation pump, a reading of the flow rate could be performed. The flow rate from the balancing valve and the remote control was the same. The PLC software was updated 1:st of April and the flow rate from the flow meter and the balancing valve was now the same. A programming fault in the pulse conversion routine made that the new flow meter together with the old PLC software version generated a reading that was to small compared to the actual flow. This resulted in a 13 % increased heat supply during March, see Figure 18.

9.1.1.8 Operating observations Jökelvägen

At the building Jökelvägen a similar unbalance as Rävpasset occurred due to the same flow restriction in the flow meter so that a low flow rate was circulated. When the new DHS was installed, the reference temperature sensor was installed in an empty apartment. When the level of consumption was unknown and the apartment did not have any inhabitants the room temperature could be adjusted lower compared if the apartment not had been empty (lack of internally generated heat). In the end of September '03 it came to our knowledge that the apartment now was occupied, so the room set point was increased. The room temperature in the reference temperature apartment did not increase independent of how much heat that was supplied to the building. After a conversation with the apartment owner where the reference sensor was installed on the 15:th of December, it came to our knowledge that the radiator valves was almost closed and that the tenants of this apartment appreciated a low room temperature compared to the set point value. We asked the tenant to open up the radiator valves in order to get an idea what the room temperature would become. The room temperature increased rapidly, Figure 39.

Apparently the valves was closed a couple of days later. In order to get an idea concerning the level of energy consumption that was representative for the building, we asked the permission to remove the valves to the radiators in the middle of January. The following month until April, the room temperature was stable on a high level when it became low and not affected by the energy supplied to the building. After talking to the tenant if came to our knowledge that the valve had been mounted again without our knowledge. The tenant explained that the valves had been remounted due to too high room temperature.

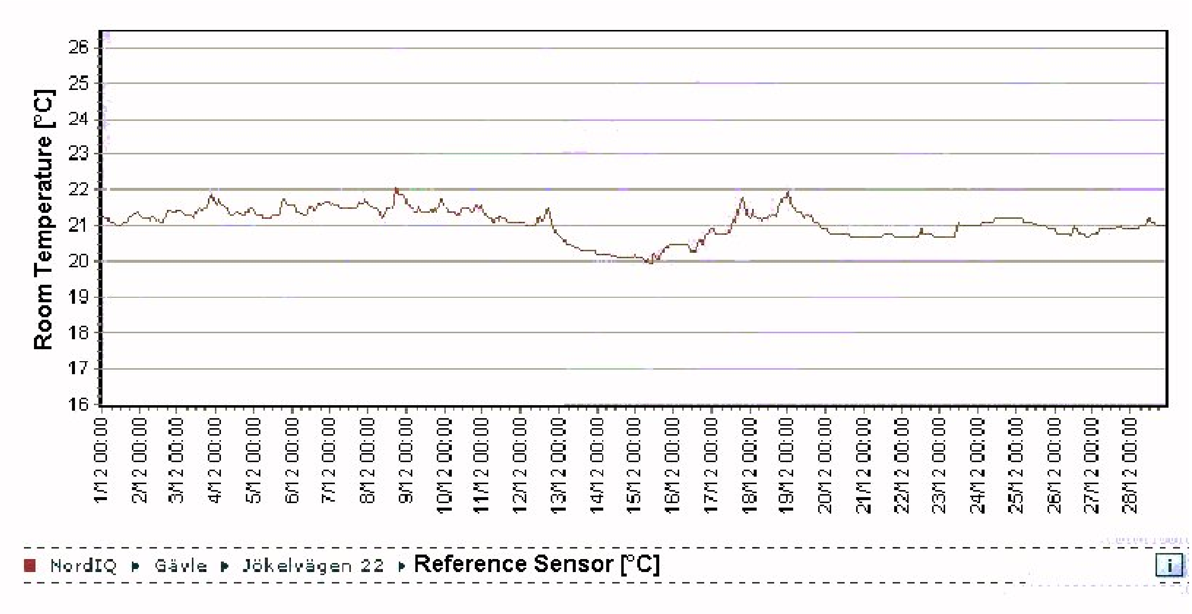

Figure 39: Room temperature, Jökelvägen, December

9.1.1.9 Operating observations Kaplansgatan

Complaints due to low room temperature was reported in November. During inspection a wide opening between the balcony door and the frame was discovered. A radiator valve was stuck in closed positioning and one radiator was too small. The unintended air-intake in the balcony door and the radiator valve was corrected whereby the room temperature became normal. The radiator system at Kaplansgatan is also unbalanced. The room temperature in the reference apartment was 23,1°C and measurements made by the technician at the building company showed that the room temperature in the other end of the building was 21°C. The reference apartment was located close to the district heating station.

9.1.1.10 Operating observations S.Köpmannagatan

The bathroom in the apartments are provided with a towel heating radiator, heated by the hot service-water circulation circuited. This configuration will result in a reduced cooling of the primary heat carrier. From measurements it can be concluded that this building even before the replacement of DHS had a small specific energy consumption (112 kWh/m^2). When the energy consumption in the radiator system is low, the return temperature from the hot service-water circulation circuit will have a high impact on the total primary return temperature, Figure 40. The hot service-water flow rate was adjusted March 10, ’04 as it can be noticed form the figure.

Figure 40: Return temperatures from radiator-, HS-W-circuit and total primary return pipe

9.1.1.11 Operating observations Jägargatan

No remarks during the operating period. In November one tenant reported that the temperature in his apartment was low. The problem was solved after we asked the tenant to open up his radiator valves. During this time, the total circulation flow rate was increased.

9.1.1.12 Operating observations Gröna Vallen

The heating system of this building was more complicated than what we thought from the beginning. The building was reported to have 73 apartments with 3589 m^2 of heated surface. That this was not the case was revealed a couple of month after the installation. It came to our knowledge that also three privately owned buildings was connected to the secondary system so that the total number of apartments was 120 with a heated surface of 5981 m^2.

In the basic concept of NordIQ, there are 3 sizes of DHS in the range of 5-30, 30-70 and 70-140 apartments. When we selected the size for Gröna Vallen it fell naturally to select the middle size. The hot service-water system managed to provide hot water without problem during the most difficult summer period but regarding the complex heating system we believed that the risk was to high due to big differences in radiator system design.

The radiator system of Familjebostäder could be manually adjusted thanks to balancing valves on the risers. The flow distribution in this part of the building was not too bad, but in the privately owned buildings there was no possibility to allocate the flow due to lack of valves. The distribution system was designed for self circulation with immense pipe diameters in some branches. During the years some radiator pipes had been replaced with new ones according to the new pipe standard. After some time, the radiator system in the privately owned buildings consisted of all different pipe diameters ranging from DN15 to DN150 with no adjustment possibilities. Ten or fifteen years ago when it was time to replace the boiler in the privately owned buildings, the system was interconnected with the radiator system belonging to Familjebostäder.

On the radiator supply pipe of Familjebostäder, a T-pipe was installed and the supply pipe to the privately owned buildings was connected . A pump was installed on the supply pipe to the privately owned buildings in order for them to obtain a flow large enough to get some degree of distribution. The radiator return pipe from the privately owned buildings was connected to the radiator return pipe of Familjebostäder through a T-pipe.

The pump that was installed could operate with 3 different states (rpm). If the fastest speed was used, then the pressure on the suction side of the pump (radiator supply pipe of the Familjebostäder building) becomes lower than the pressure in the return pipe of Familjebostäder, so that a reversed circulation in the radiator branches in the apartments of Familjebostäder, located after the connection of the privately owned buildings. If the main circulation flow is reduced, then the circulation in some apartments belonging to Familjebostäder will stop due to Heat-Locks[3] and so on….

In the end , there are several conditions that prevent an optimisation of performance in order to reduce the energy consumption and improve the heating comfort in the buildings due to built-in errors in the basic design.

[3] Heat lock – the radiator is supplied by pipes that are coming from above an upper location. If the differential pressure between the forward and supply pipe, the flow will stop due to forces caused by convection that will occur due to differences in density between hot and cold water.

10 APPENDIX V – LCC CALCULATION

We make some simple assumptions

Energy price	341 SEK / MWh
Flow tariff	2kr/m^3
Heat tariff	310 SEK /kW year

ALT 1 – no replacement:

Energy consumption	1100 MWh/Year	
Temperatures	88°C Supply	47°C Return
Category number	2300h	
Investment	150 KSEK (installed DHS)	
Maintenance/operation	10 KSEK/Year	

ALT 2 – after replacement:

Energy consumption	10% lower	
Temperatures	88°C Supply	33°C Return
Heat	20 % lower spec. demand	
Investment	400 KSEK (our price including incentives and installation)	
Maintenance/operation	10 KSEK/Year	

	ALT 1 (KSEK/Year)	ALT 2 (KSEK/Year)
Energy cost	1100 * 341=375	1100 * 0,9 * 341=338
Flow cost	1100*3600/(4,18*(88-47))*2=46	1100*0,9*3600/(88-35))*2=32
Heat cost	11000/23*310=148	11000*0,9/23*(1-0,2)*310=107
Total cost	569	477
	Replacement is 92 KSEK lower per year	
	ALT 1 (KSEK/25 Year)	ALT 2 (KSEK/25 Year)
LCC	(569+10)*25 + 150=**14625**	(477+10)*25 + 400=**12575**
Result	***Earning of 2050 KSEK to Replace old system***	

11 REFERENCES

Ref. 1 :Werner S., Winberg A., Cooling of primary heat carrier in existing substations, Stiftelsen för Värmeteknisk forskning,Swedish, Rapport 272, 1987

Ref. 2: Narfgren Å., Temperature conditions in the heat exchanger of the radiator system when the secondary flow rate is varied. Swedish, Department of Heat and Power Engineering, Lunds tekniska högskola, ISSN 0280-9931, 1990

Ref. 3: Fredrikssen S., Wollerstrand J., Operating characteristics of parallel- and two-stage configured district heating stations. Swedish, Byggforskningsrådet, Rapport R68:1987

Ref. 4: Wollerstrand J., Fredrikssen S., Performance of District Heating House Station in Altered Operational Modes. 23rd UNICHAL-Congress, Berlin, 1987

Ref. 5: Gummérus P., Analysis of conventional substations in district heating systems, Doctoral thesis, Swedish, Dept. of Energy Conversion, Chalmers University of Technology, Gothenburg, ISBN-91-7032-67-. 1989

Ref. 6: Råberger L., Effectivity of substations in district heating systems, Licentiate report, Swedish, , Dept. of Energy Conversion, Chalmers University of Technology, Gothenburg, 1995

Ref. 7: Gummérus, P., The Performance of Consumer Substations, Fernwärme International, FWI 20(1991):7/8, 398-410, 1991

Ref. 8: Gummérus P., Petersson S., Robust district heating station, , Dept. of Energy Conversion, Chalmers University of Technology, Gothenburg, CTH A99-223, 1999

Ref. 9 : Rydberg,J., Calculation of the maximal heat demand in hot service-water preparation systems , Swedish, VVS 5, 1945

Ref. 10: Jonsson, E., Contribution to the calculation of the maximum load in hot service-water conduits , Swedish, VVS 5