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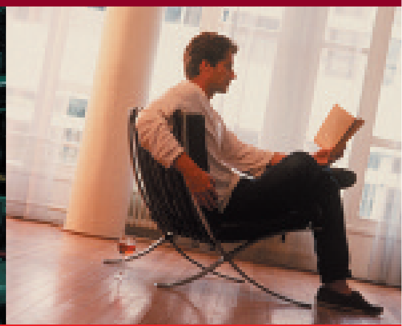

IEA DHC|CHP

International Energy Agency
IEA Implementing Agreement on District Heating and Cooling, including the integration of CHP

IMPROVEMENT OF OPERATIONAL TEMPERATURE DIFFERENCES IN DISTRICT HEATING SYSTEMS

IEA R&D Programme on

District Heating and Cooling

Improvement of Operational Temperature Differences in District Heating Systems

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Preface

Introduction

The International Energy Agency (IEA) was established in 1974 in order to strengthen the co-operation between member countries and to reduce the dependency on oil and other fossil fuels. Thirty years later, the IEA again drew attention to serious concerns about energy security, investments, the environment and energy poverty. The global situation has resulted in soaring oil and gas prices, growing vulnerability of energy supply routes and ever-increasing emissions of climate-destabilising carbon dioxide.

The IEA's *World Energy Outlook*[1] "Reference Scenario" 2004 projects that, in the absence of new government policies or accelerated deployment of new technologies, world primary energy demand will rise by 59 % by 2030, with 85 % of that coming from the use of coal, oil and natural gas. However, these trends are not inevitable. The *World Energy Outlook* "Alternative Policy Scenario" shows that more vigorous government action and accelerated deployment of new technologies could steer the world onto a markedly different energy path, where world energy demand would be 10 % lower and carbon-dioxide emissions 16 % lower.

DHC makes a difference

One of the key technologies that can make a difference is District Heating and Cooling (DHC).

DHC is an integrative technology that **can** make significant contributions to reducing emissions of carbon dioxide and air pollution and to increasing energy security.

The fundamental idea of DHC is simple but powerful: connect multiple thermal energy users through a pipe network to environmentally friendly and efficient energy sources, such as combined heat and power (CHP), industrial waste heat and renewable energy sources such as biomass, geothermal and natural sources of heating **and** cooling. The ability to assemble and connect thermal loads enables these environmentally optimized sources to be used in a cost-effective way and also offers on-going fuel flexibility. By integrating district cooling, carbon-intensive electricity-based air conditioning, rapidly growing in many countries, can be displaced.

As an element of the International Energy Agency Programme, the participating countries undertake co-operative actions in energy research, development and demonstration.

One of the programmes that has run for more than 25 years is the Implementing Agreement 'District Heating and Cooling including the integration of Combined Heat and Power'.

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[1] The annual *World Energy Outlook* presents long-term projections for supply and demand of oil, gas, coal, renewable energy sources, nuclear power and electricity. It also assesses energy-related carbon dioxide emissions and policies designed to reduce them. The annual World Energy Outlook has long been recognized as the authoritative source for global long-term energy market analysis. This flagship publication from the IEA is produced by the agency's Economic Analysis Division with input from other internal and external energy experts as required. For more information see http://www.worldenergyoutlook.org/.

Annex VII

In May 2002 Annex VII started.

Following is a list of the recent research projects (annexes) undertaken by the District Heating & Cooling Implementing Agreement. Ten countries participated from Europe, North America and Asia: Canada, Denmark, Finland, Germany, Korea, The Netherlands, Norway, Sweden, United Kingdom, United States.

Project title	**Company**	
A COMPARISON OF DISTRIBUTED CHP/DH WITH LARGE-SCALE CHP/DH	PB Power Ltd – Energy **Project leader:** **Paul Woods**	8DHC-05.01
TWO-STEP DECISION AND OPTIMISATION MODEL FOR CENTRALISED OR DECEN-TRALISED THERMAL STORAGE IN DH&C	SP Swedish National Testing and Research Institute **Project leader:** **John Rune Nielsen**	8DHC-05.02
IMPROVEMENT OF OPERATIONAL TEMPERATURE DIFFERENCES IN DISTRICT HEATING SYSTEMS	ZW Energiteknik AB **Project leader:** **Heimo Zinko**	8DHC-05.03
HOW CELLULAR GASES INFLUENCE INSULATION PROPERTIES OF DISTRICT HEATING PIPES AND THE COMPETITIVENESS OF DISTRICT ENERGY	Danish Technological Institute **Project leader:** **Henning D. Smidt**	8DHC-05.04
BIOFOULING AND MICROBIOLOGICALLY INFLUENCED CORROSION IN DISTRICT HEATING NETWORKS	Danish Technological Institute **Project leader:** **Bo Højris Olesen**	8DHC-05.05
DYNAMIC HEAT STORAGE OPTIMIZATION AND DEMAND SIDE MANAGEMENT	Fraunhofer Institut für Umwelt-, Sicherheits- und Energietechnik UMSICHT **Project leader:** **Michael Wigbels**	8DHC-05.06
STRATEGIES TO MANAGE HEAT LOSSES – TECHNIQUE AND ECONOMY	MVV Energie AG Technology and Innovationsmanagement **Project leader:** **Heinz Werner Hoffmann**	8DHC-05.07

Benefits of membership

Membership of this implementing agreement fosters sharing of knowledge and current best practices from many countries including those where:

- DHC is already a mature industry
- DHC is well established but refurbishment is a key issue
- DHC is not well established.

Membership proves invaluable in enhancing the quality of support given under national programmes. Participant countries benefit through the active participation in the programme of their own consultants and research organisations. Each of the projects is supported by a team of experts, one from each participant country. As well as the final research reports, other benefits include the cross-fertilisation of ideas which has resulted not only in shared knowledge but also opportunities for further collaboration.

New member countries are very welcome – please simply contact us (see below) to discuss collaboration opportunities.

Information

General information about the IEA Programme District Heating and Cooling, including the integration of CHP can be obtained from our website www.iea-dhc.org or from:

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Executive summary

Background

The main idea of this project is to turn attention on the question of *good cooling ability of customer substations* in district heating nets. The main reason for that is based on our experience that the optimisation of district heating very often is directed toward production, whereas questions of optimal distribution are neglected as long as the necessary load can be supplied and the customer's request for comfort is met. Our view is that *adequate operational temperature differences in district heating systems* - which more or less is congruent with *achieving low return pipe temperatures* - is an important feature for efficient net operation and gives both economic and operational benefits to the district heating supplier. Additionally, it is a prerequisite for meeting the customer's demand for reliable supply of the heat load. However, in many practical cases we have seen that district heating return temperatures are higher than necessary.

Hence, the aim of the project is to propose and verify a method to detect the most critical consumers in the net and to develop an action programme for suitable measures to be taken to increase the temperature difference in district heating networks.

This report therefore presents a *practical method* for improving the cooling ability based on field experience. The method addresses the question of how to evaluate and to improve the cooling ability of substations. The work presented in this study encompasses the following basic elements:

- Analysis of measurement data in order to determine the status of the substations in the net and to identify the reasons for resulting high return temperatures.
- Identification and repair of malfunctioning substations.
- Verification of improvements based on repeated analysis of measurement data after renovation of malfunctioning substation.
- Substantiation of the importance of this work by illustrating it with examples of the economic benefits derived from improvements.

This report is therefore mainly based on *working experience*. The work was performed by combining the skill from the involved project partners. Contributions came from ***Sweden*** in the form of field experience of long-term consultancy in DHC, from the the ***USA***, also based on the experience of their ***German*** mother institute, in analytical skill of theoretical thermal analyses and from ***Korea*** with the unique opportunity of operating district heating nets where the results of the developed method could be positively applied with the aid of development and maintenance engineers. Hence, the *main result* of this cooperation will be a methodology and the demonstration of its practical application for detecting substations that seriously affect the return temperature of the whole net. Furthermore, also smaller substations that are not working well can be identified with this method.

However, in order to successfully and sustainably affect the return temperature in a large district heating net, the work of detecting and improving substations has to continue for years on a regular basis. Of course, in practice, this means an extensive amount of work, which cannot be fulfilled within the limited scope of this project. We could therefore only initiate the work in Korea, but we were able to rely on the persistent efforts in Skogas, Sweden.

Content of the report

The report is divided in a number of main sections taking up different aspects of district heating return temperatures.

Section 2 presents a theoretical background about the *"Choice of district heating temperatures"* and earlier works done on this field. The chapter gives an introduction about the facts determining the choice of district heating (DH) distribution temperatures. Traditionally, DH emerges from the uses of fossil fired co-generation plants and temperatures were chosen to maximise the income from electricity production. Other systems however, are based on heat-only production, either fossil fired or nowadays based on biomass or municipal wastes, offering other possibilities for optimising the system temperatures. It is evident that cogeneration and heat-only production has different criteria for DH temperatures, which is one reason that low return temperatures are not always prioritised.

Section 3 " Substations with excess flows" describes the two main methods developed as diagnostic tools for the analysis of malfunctioning substations: The ***excess flow method*** and the ***target temperature method***. These methods can either be used separately or in combination. The ranking procedure according to the *Excess flow method* is an effective tool for selecting such substations that make an important contribution to high district heating return temperatures. It is explained in detail by means of examples for the Skogas net. The method uses an *arbitrary return temperature,* set some degrees lower than the actual average return pipe temperature. The excess flow evaluation can be based on data with very coarse resolution such as monthly averaged energies and flow volumes.

Another method is the *Target temperature method,* which uses analytical solutions for calculating ideal return temperatures (= *Target return temperatures*) for basic configurations of substations. By comparing a real substation with an optimal working one, the difference between the target temperature and the measured return temperatures can be calculated. This method gives time resolved return temperatures, flows and energies from which many different analyses can be performed, such as the function of the substation under certain day times or under some specific seasonal conditions. Higher resolution of the measurement data allows for more specific conclusions to be drawn about the substation. The method is also important for finding smaller malfunctioning substations, which are not strong contributors to the common return temperature of the district heating net, but nevertheless, are not working satisfyingly.

Finally, the advantage of *combining both methods* to ISA is described. ***ISA*** means: ***Individual substation analysis***. In the simplest case, the most malfunctioning substations are selected by means of the *Excess flow method* and, thereafter, further analysed by means of the R*eturn temperature method*. This limits the more cumbersome detailed analytical work to such substations, which need to be evaluated with a higher time resolution for further diagnostic work.

Section 4 *"Field applications"* describes the district heating nets in Skogas, Sweden and Cheongju, Republic of Korea, which were evaluated and improved according to the methods described in this report. The way of working was remote measurements and data collection of substations, evaluation and analysis of measurement data, improvement of substations and re-evaluation. An overview over malfunctioning substations is given as well as the results of the evaluation and of those improvements, which could be achieved during the time of the project.

In the Cheongju net, a number of substations exhibited high excess flows. About 10 of them could be improved and decreased excess flow could be validated. As to the Skogas net, much work was done in the years before this project and continued application of the Excess flow methods resulted in a steadily decreasing return temperature. Four more substations could be identified and improved during this project.

Section 5 deals with *"Malfunctions of substations",* i.e. one reason for bad cooling ability of substations. A description of typical malfunctions in substations is presented and a systematic way to diagnose them. Malfunctioning substations are the main reasons for high return temperatures, asides from inadequate control of secondary systems. Most of the diagnosis procedures have to be done on-site. The diagnostic tools and methods so far available can give some hints how and where to look on the substations, but the skill of maintenance or operating technicians is necessary in order to find the problems, which can be classified in families, totally summing up to some 50 different kinds of malfunctions. One difficult aspect of maintenance is the ownership because in most places, the substation belongs to the owner of the building and, therefore, improving a renovation or replacement of the substation presumes very good relations between district heating company and substation owner.

Section 6 covers *"General economic considerations"* about the cost-benefit of low return pipe temperatures. For optimising district heating networks, the whole system consisting of generation, distribution and consumption has to be taken into account. Network temperatures influence investment and operation costs of all components, which is why their improvement is of great importance to the overall technical and economic optimisation of the system. The influences of temperatures can be oppositional for different costs (e.g. increase of supply temperature leads to increased heat losses, but reduced pumping costs), so that each aspect has to be considered carefully for the respective district heating system. In order to illustrate the economical facts, some relevant examples for economical benefits of increased district heating cooling ability are presented. These examples are taken from Sweden and Germany. Part of the examples stems directly from the experience of district heating companies, and part of them are examples based on a simple calculation model built in Excel, called Lava and published by the Swedish District Heating Association.

Section 7 concludes the work by presenting the quintessence in *"Final discussions and conclusions"*. "*References* and "*Explanation of nomenclature"* end the main part of the report.

A large amount of information containing background information, which enables a better and detailed understanding of the substation analyses done in Cheongju and Skogas, is collected in the *Appendices.* The information however, is not necessary for understanding the main ideas of excess flow analysis developed in this project.

Final conclusions

The work for *detecting malfunctioning substations* is principally based on the evaluation of the excess flow of substations, i.e. the flow of district heating water (in m³ per time interval), which passes a substation in order to transfer the desired load to the customer. *Excessive flow means flow in comparison with a better working or ideally working substation.* For this evaluation, *two methods* have been developed: *Excess Flow Method* and *Target Temperature Method*, respectively.

By means of a consequent application of the excess flow method in Skogas, it was possible to decrease the return temperature even in a large net. Changes of the operational conditions at the production plants however temporarily increased the return temperature, but continuous work reduces it again.

The Cheongju plant was evaluated for 1,5 years with both the excess flow method and the target temperature method, and a combination of both. A number of malfunctioning substations could be identified and improved. A two month long return temperature evaluation of the improved sub-stations confirms the substantial decrease of the individual return temperatures in about ten substations (out of a total of 108). Although these few substations evaluated for two months under intermediate load conditions (September - October 2004) will only result in a slight decrease of the common return pipe temperature of the district heating net, annual savings will already be visible after some year of operation.

A critical step in the effort of decreasing the return pipe temperature is the diagnostic work and the repair of malfunctions. For that purpose, criteria for malfunctions and ways how to detect them haven been presented. In addition, a complete list of possible malfunctions and the way they affect the system or the customer has been compiled. Some principal malfunctions (hot water, space heating water circulation system) can be detected by means of time resolved analyses such as the *target temperature method.* However, for more subtle causes of malfunctions, the experience of skilled maintenance engineers is indispensable.

The economic benefit for repairing malfunctioning substations has been illustrated with a couple of examples. Theoretical cost-benefits can be calculated by means of the Lava calculus, which is published through the Swedish District Heating Association. Examples show that the benefit can be especially large if the production plant includes co-generation or heat recovery from stack gas condensing systems, for mentioning two examples. Reduced heat losses and pumping costs can be other examples. In certain cases, the operation of expensive top load plants and in special cases, construction of new plants, can be avoided. Some practical examples from a district heating company finally support these calculations.

Finally, we believe that the consequent improvement of operational temperature differences in district heating systems and resulting low return temperatures has an economic potential which is highly underestimated by many district heating operators.

Table of contents

1 Introduction

General aspects

The main idea of this project is to turn the attention to the question of *good cooling ability of customer substations* in district heating nets. The main reason for that is based on our experience that the optimisation of district heating very often is directed toward production, whereas questions of optimal distribution often are neglected if only the necessary load can be supplied and the customer's request for comfort is met. Our view is that *improvement of operational temperature differences in district heating systems* - which more or less is congruent with the question of *achieving low return pipe temperatures* - is an important aspect of efficient net operation and gives both economic and operational benefits to the district heating supplier. Furthermore, it is a prerequisite for meeting the customers demand for reliable supply of the heat load.

Hence, the aim of the project was to propose and verify a method to detect the most critical consumers of the net and to develop an action programme for suitable measures to increase the temperature difference in district heating networks.

Under this keynote, we intend to describe a *practical method* for improving the cooling ability based on field experience in this study. The method addresses the question of how to evaluate and to improve the cooling ability of substations. The study is based on the following basic elements:

- Analysis of measurement data in order to determine the status of the substations in the net and to detect the reasons for resulting high return temperatures.
- Identification and repair of malfunctions of substations.
- Verification of the improvements based on new analysis of measurement data after renovation of malfunctioning substations.
- Substantiation of the importance of this work by illustrating it with examples of economic benefits derived from improvements.

There are many reasons for chasing a *large difference between supply and return temperature*. Some are obvious operational one: Higher energy transport capacity, lower pumping power, lower heat losses, among others. Another main concern for district heating systems are *low return temperatures*, especially in the case where condensing cooling devices (such as used in cogeneration, stack gas coolers, heat pumps and so on) are parts of the heat production system. Assuming constant supply temperatures, large temperature difference means low return temperature – both are the two sides of the same coin.

Low return temperatures, however, cannot be chosen as an operational parameter; they are the result of effective operation in practice. That means that the return temperatures are generated by the working components of substations, i.e. control valves and heat exchangers. Having this in mind, it becomes evident that the key to low return temperatures is the effective operation and right dimension of those components.

This report is therefore mainly based on *working experience*. The work was performed by combining the skill from the involved project partners. Contributions came from ***Sweden*** in the form of field experience of long-term consultancy in DHC, from the partnership of ***USA*** and ***Germany*** in analytical skill of theoretical thermal analyses and from ***Korea*** with the unique opportunity of operating district heating nets where the results of the developed method could be positively applied with the aid of development and maintenance engineers. Hence, the *main result* of this cooperation will be a methodology and the proof of its practical application for detecting substations, which seriously affect the return temperature of the whole net. Furthermore, smaller substations that are not working well can be identified with this methodology.

Most of the work described in this paper deals with theoretical analysis of measurement data and improvement work which *actually* is performed as part of the routine work done at some DH companies for keeping their net in proper shape. Especially, we would like to take this opportunity to thank the district heating company ***Södertörn Fjärrvärme AB*** and its ***district heating director Hans Andersson*** for giving maximum support to this project by greatly delivering all experience and measurement data which are reported for the Skogas DH-net in this report. Without this support, it would not have been possible to carry out the project.

Content of the report

The report is divided into a couple of main sections covering different aspects of district heating return temperatures.

Section 2, after the *Introduction*, presents a short theoretical background on the *"Choice of district heating temperatures"* and earlier work done in this field.

Section 3 " Substations with excess flows" describes the two main methods developed as diagnostic tools for the analysis of malfunctioning substations: The *excess flow method* and the *target temperature method*. These methods can either be used separately or in combination. In the latter case, we call the combined use of the both methods *"ISA: Individual substation analysis"*.

Section 4 "Field applications" describes two district heating nets in Skogas, Sweden and Cheongju, Republic of Korea, which were evaluated and improved according to the methods described in this report. The way of working was remote measurements on substations, evaluation and analysis, improvement and re-evaluation. An overview over substations is given as well as the results of the evaluation and of those improvements, which could be achieved during the time of the project.

Section 5 deals with *"Malfunctions of substations",* i.e. the main reason for inadequate cooling ability of substations. A systematic discussion of malfunction is presented and a systematic way to diagnosing them. Most of the diagnosis procedures have to be done on-site. The diagnostic tools and methods so far available can give some hints about how and where to look at the substations, but the skill of maintenance or operating technicians is necessary in order to find the problems, which can be classified in families, totaling more than 50.

Section 6 treats *"General economic considerations"* about the cost-benefit of low return pipe temperatures. Both, examples from theoretical calculations and from practical experiences are presented.

Section 7 concludes the work by presenting the quintessence in *"Final discussions and conclusions"*. "*References* and "*Explanation of nomenclature"* end the main part of the report.

A large amount of information containing background information, which enables a better and detailed understanding of the substation analyses done in Cheongju and Skogas, is collected in the Appendices. The information however, is not necessary for understanding the main ideas of excess flow analysis developed in this project.

Experts group

As mentioned in the *Preface,* this project was performed as one of the projects within IEA-District Heating and Cooling Program, Annex VII. In such projects, an Experts group is supporting the project team with ideas and a wealth of experience, and forming a panel, which helps to develop the essential traits of the project. Of course, it also assists the project group in getting all the technical details understandable and right. Such a counsel is an invaluable help in this type of project; therefore, we are very grateful to the following members of the Experts group for their assistance:

Jan Elleriis, Vice President, Metropol. Copenhagen Heating Transmission Comp. CTR, Denmark

Peter Mildenstein, Onyx Sheffield, United Kingdom.

Gunnar Nilsson, Göteborg Energi, Göteborg Energi AB Sweden.

Paul Sears, Natural Resources Canada, Canmet Energy Technology Centre, Canada.

Seungkyu Ha, R&D Team, Korean District Heating Corporation, Korea.

Mirja Tiitinen, Manager DH, Finnish District Heating Association.

Rune Volla, Viken Fjernvarme AS, Norway.

The cooperation

The project is a result of the cooperation of three institutions representing four countries:

The consultant company **ZW Energiteknik AB from Nyköping, Sweden,** was the initiator of the project with Heimo Zinko as the project leader and editor of the report. The work was based on the long-term consultant experience in improvement of substations by Håkan Walletun and Håkan Lindkvist carried out at Södertörn District Heating Company in Skogas. All three are co-authors of the report.

The **Fraunhofer Center for Energy and Environment, Pittsburgh, PA, USA,** contributed significantly to the theoretical and economical analyses within the project. The center was mainly represented by Achim Loewen, the US project leader, who got substantial support from Michael Wigbels at the center's German mother institute Fraunhofer UMSICHT. This is why both are named as co-authors of the report.

The district heating company **Korea District Heating Corporation, Seoul, Republic of Korea,** which offered the complete district heating net of Cheongju as one of the basis for the validations of the theoretical analyses. The Korean project leader was Dir. Hoon, Lee. The analysis and improvement work for the Cheongju district heating net were carried out by SeungKyu, Ha, Bong-Kyun, Kim and YounHong, Kim. All four are co-authors of the report.

Acknowledgements

The authors whish to thank ***Timo Bungert*** of the Fraunhofer Center for Energy and Environment in Pittsburgh for the important work with transforming basic international English to something which comes closer to school English.

The contribution of Director Hans Andersson, Södertörn Fjärrvärme AB, is already acknowledged above in a special location.

All authors also have the pleasure to acknowledge the engagement of the national district heating associations of Sweden and Korea and of the US Department of Energy by giving both financial and idealistic support to the project.

2 The choice of temperatures in district heating systems

Summary

This chapter gives an introduction to the considerations determining the choice of district heating (DH) distribution temperatures. Traditionally, DH emerges from the use of fossil fired co-generation plants. Temperatures were then chosen to maximise the income from electricity production. Other systems, however, are based on heat-only production, either fossil fired or nowadays based on biomass or municipal wastes, offering other possibilities for optimising the system temperatures.

2.1 General optimisation aspects

2.1.1 General optimisation aspects

The question of adequate system temperatures is as old as district heating based on hot water distribution. Of course, the main reason for that is that hot water as distribution medium has a limited working range, which within the European district heating practice is 10 to 150°C. More precisely, as far as district heating temperatures are concerned, we are speaking about two different temperatures, the ***supply temperature*** and the ***return temperature***. In relation to the temperature range given above, the supply temperatures is allocated to the upper half and the return temperature to the lower half of this temperature range. However, in an economical sense, an important factor for the optimal distribution temperature is the ***difference*** between the supply and return temperature. The reason for that is that the transported power is proportional to the temperature difference of the medium. That means, for a given design load and a limitation on the mediums maximum flow velocity, the pipe dimensions and, therefore, the distribution costs are proportional to the achievable temperature difference.

On the other hand, temperature ranges are also determined by the systems connected to the distribution system: Production plant and house heating system, respectively. The production plant often determines the level of supply temperature, while the house heating system influences the level of the return temperature. Such a situation can be illustrated in a diagram, see Figure 2.1-1 (for more details see f. i.: Frederiksen, Werner, 1993).

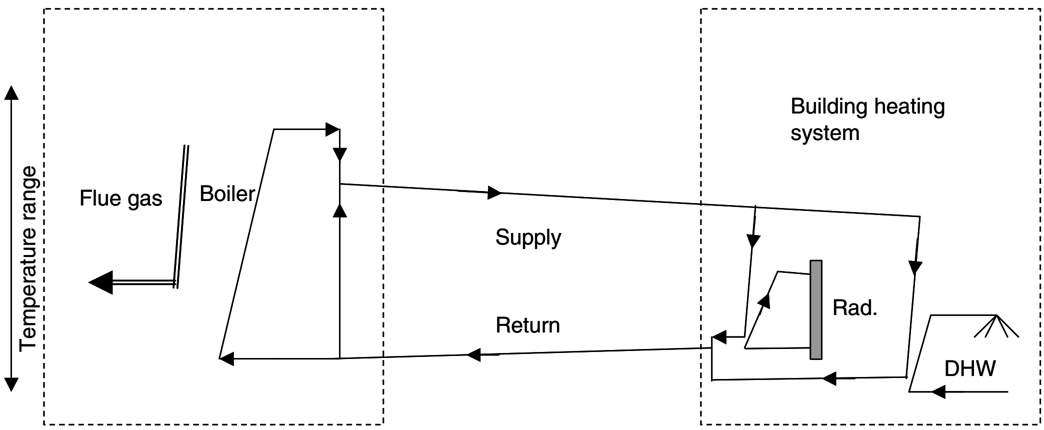

Figure 2.1-1: Schematic temperature distribution in a district heating system

Therefore, the optimisation of the working temperatures in district heating systems is an important task in many aspects:

- ***Thermodynamically,*** that means that the distribution temperatures are the result of a combined planning of production, distribution and building heating system. Especially in cogeneration heat distribution, the interaction of those three components can be very important because of the dominant role of the electricity generation in the economic optimisation. An optimised system is expected to result in the lowest total system costs.

- ***Thermally***, a distribution system working at right temperatures can make optimal use of the available energy, i. e. total energy losses might be minimised. Such a system is often associated with low mean distribution temperatures.
- ***Operationally,*** the system is a compromise between thermodynamical optimisation and practical system operation with good dynamic response. Such a system is often associated with a high temperature difference between supply and return pipes.

Regarding ***thermodynamic*** net optimisation, the system limits include all three main parts of the district heating systems: Production plant, heat distribution net and secondary building heating system. Much effort has been spent on optimisation, especially with regard to cogeneration plants, because the temperature levels are intimately connected with the efficiency of electrical power production. Models have been developed, for example, by Glück 1985, Boehm 1986 and Winkens 1987, Hansson 1990, Snoek et al., 2002.

In such an analysis, the optimisation is based on minimising the irreversible energy losses by maximising the total exergy of the regarded system. Such irreversibilities can be found when the temperature of the working medium drops without producing corresponding mechanical work. This for instance is the case with the heat contained in the stack gases of boilers, in the condensers of thermal power plants, in all heat exchangers, and in energy losses from district heating pipes. Other forms of irreversibilities occur with the energy dissipation of auxiliary equipment such as pump motors fans and so on. Thermodynamic optimisation therefore involves both the 1^{st} and the 2^{nd} Theorem of thermodynamic. The optimisation procedures are very complex and internal relationships might be highly non-linear. For example, there is a strong interdependence between net electrical power output of cogeneration plants on the one hand and supply temperature, return temperature, mass flow and DH pumping power of the district heating system on the other hand. Frederiksen and Werner (1993) show in one example of thermodynamic optimisation of a system including a cogeneration power plant with back pressure turbine district heating that the ***tempe-rature difference*** between supply and return pipe is *proportional to the square root of the heat load*. Although the analytical derivation is based on many simplifications (for instance, constant radiator temperature is equal district heating return temperature), this result should be mentioned as a basic rule of thumb for thermodynamic optimisation. The implication of this result is namely that both the temperature difference as well as the mass flow is proportional to the suare root of the heat load, which can give a first indication about how to operate a district heating system over the year, see Figure 2.1-2. However, in practice some other restrictions exist, for example that the lowest practical supply temperatures should be high enough to ensure a safe and healthy domestic hot water production at all operating conditions. Therefore, in practical applications, other control functions are chosen, as it also shown in Figure 2.1-2, in which the control curve for the Skogas plant also is depicted (see Figure 2.1-4).

Normally, total thermodynamic optimisation is often only possible for smaller systems, such as local heating systems constructed under a certain time span and limited in area. The reason is that the house systems and production plants change over time. Very often newer radiator systems have lower distribution temperatures, in some areas floor heating might be dominant, to mention a few examples. Areas with high thermal line density can call for higher distribution temperatures than areas with low densities. Production plants involving heat pumps, stack gas coolers or cogeneration plants might need lower temperatures than boiler-based heating plants, and so on.

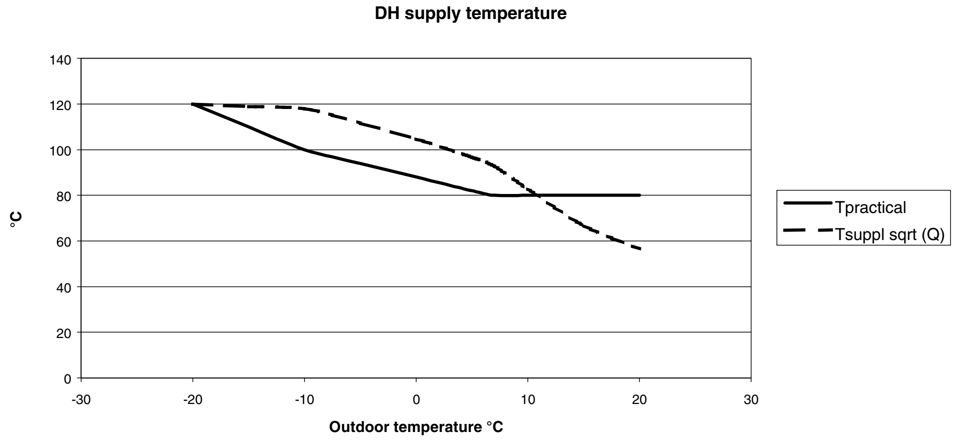

Figure 2.1-2: SQRT(load)-law according to a simplified thermodynamic optimisation systems compared with practical control curve as applied in the Skogas net

In practice, it will be difficult to find one distinct boundary condition in district heating systems that were developing over an extended period, as it is very often the case in countries with long district heating tradition. Instead, the network will supply heat to a mixture of different customers connected to it. For example, buildings connected to the district heating system in the Swedish System Skogas present a wide range, from buildings built in the 1960 with 80/60°C radiator systems to new constructed detached houses with floor heating systems (i.e. systems with 40/30°C heating systems). In addition, hospitals, prisons and industrial users with a high DHW demand are connected. That also means that even if the systems design was initially based on optimisation, it is not necessarily longer the best solution for the system as it looks like today.

Consequently, suitable operation of such a system cannot be based on design optimisation but must be achieved with experience and feedback from continuous evaluation of the system in operation.

Hence, one of the main objectives of the work in this project is devoted to the task of finding an evaluation practice for rendering the system in such dynamical and thermal shape that it is easily and effectively operated.

2.1.2 Thermal optimisation

In **thermal optimisation**, usually we want to minimize the heat losses from all system components. That means the dimensioning usually goes towards lower mean temperatures. However, the heat losses of a network are not always directly in proportion to the mean temperature of the pipes, because a lower supply temperature can mean in some cases a larger pipe dimension, which normally exhibits a higher heat loss coefficient. Since a district heating network consists of different sections with different pipe lengths and dimensions, the right choice of the supply temperature must be calculated for the whole net. Therefore, one established way for operational control is to make an optimisation of the profit by balancing the income for the marginal sale of electricity with the costs for pipes, heat losses and house installations. Such a balance often results in design load supply temperatures between 100 and 120°C and summer temperatures around 80°C. The winter control strategies often follow the outdoor temperature in a linear control function. At some intermediate outdoor temperature (often around 0°C), a break point marks the transition to a volume flow control at constant temperature (see Figure 2.1-2 and Figure 2.1-4). In the last two decades, much effort was spent on investigations dealing with the improvement of net operation by decreasing *both supply temperature and return temperature*. Important contributions on that were made by Boehm (1988), Hansson (1990), Volla (1996) and Snoek (1997). These studies result generally in recommendations for the optimal supply temperature depending on the boundary conditions for the optimisation. That means the *optimal supply temperature* depends on the choice of varied parameters. In *new systems*, all parameters including type of house heating system and radiator temperatures are variables. In an *existing environment with a new district heating* network being installed, only the district heating distribution system is free to be chosen. In an already *completely developed system*, only the temperature levels might be free to be optimised. The three mentioned cases would result in different optimal supply temperatures.

One way to achieve low return temperatures is cascading different loads in a suitable way. One of the most applied cascading devices is the two step-substation used for both hot water production and heating. Another cascading connection is the series connection of absorption chillers and hot water load summer time. Cascading has been extensively studied in an IEA-project (Snoek 2002). The reason is obvious: The lower the building systems return temperature, the lower the district heating return temperature.

The general outcome from the study mentioned above (Snoek 2002) was that cascading systems should be arranged in a way that the load ratio between different levels is balanced appropriately during the majority of time throughout the year. Usually, the magnitude of the total loads in the upper cascading level should be higher than that in the lower level in order to avoid the use of high temperature water in the lower level. Any imbalance between the two levels will reduce the achievable temperature difference because of the necessity of bypassing hot water. Therefore, different climates and load conditions require different ways of cascading. An additional basic insight was confirmed, namely that cascading design that favours flow reduction in winter time facilitates net expansion, since flow (i.e. power capacity) is limited in the winter.

2.1.3 Operational choice of district heating temperatures

Nowadays, there is a general trend towards lower ***supply temperatures***, the reason being of course reduction of heat losses. For instance, a number of Swedish cities are now working with maximum temperatures of 110°C and some even with 100°C on the coldest winter days. But in large nets, 120°C remains as the basic design temperature, and it can vary from country to country, being 130°C in Germany and even 150°C in some Eastern European countries. These latter design temperatures are based on different traditions, some emerging from earlier systems with distribution of hot steam. In Cheongju, which has a net structure built relatively recently, the system is influenced by Scandinavian technology and the design temperature is also 120°C. On the other hand, in Scandinavian countries, also a low pressure/low temperature design has been introduced with 90°C as maximum temperature. The reason for that is reduction of costs in smaller systems by allowing a more simple installation.

The ***return temperature*** is not an independent parameter, but depends on the house heating system. Older radiators have a (design) setting of 80°C supply respectively 60°C return and modern ones have 60/45°C. In the Skogas net, this can result in effective heating system temperatures of 70/50°C. Heating systems with lower temperatures, returning a lower temperature back to the district heating system, are very rare and do normally not affect the mean return temperature. A newer heating control method is also operating with “low flow” radiator systems, which typically averages of 80°C supply and 40 - 30°C return. If radiators in older buildings could be readjusted to these temperatures, the return temperature in the wintertime could be essentially reduced (Gummerus, Petersson, 1999). However, a prerequisite for this is that the radiator valves must be replaced with new fine-tuning valves.

The design temperatures are based on the coldest (design) winter days. However, the normal situation is one with much lower heating needs around –5 to +5°C outdoor temperature. In this case, the return temperatures are much lower (see Figure 2.1-3). This figure shows a well working substation in the Skogas network, in which the mean return temperature in summer time is around 27°C compared to wintertime, when the return temperature is above 40°C. The figure shows also the range of the supply temperature being 120 – 75°C.

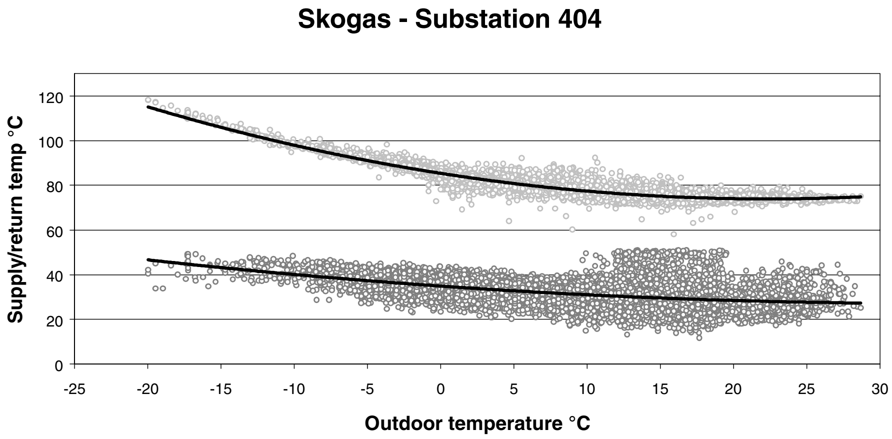

Figure 2.1-3: Operating temperatures for a well working substation (S404) in the Skogas network (full lines are trend curves)

Figure 2.1-1 also illustrates the influence of the domestic hot water production. During summer time, with negligible radiator loads, the return temperature is determined by the DHW production. During day times in summer with outdoor temperatures between 20 and 30°C and when the hot water load is high, the return temperature is rather low, cooled by the incoming city water at 12°C. At night times, however, with very low DHW load, the hot water circulation returns water at temperatures between 40 and 50°C, which can be seen for an outdoor temperature range of 10 - 20°C, which are typical Swedish summer night temperatures.

These low temperatures are achieved on good working substations. Other substations will not achieve these low temperatures. Industrial loads and operational bypasses will contribute to increase the return temperatures and, therefore, Figure 2.1-3 should be compared with the operating temperatures for the Skogas network as a whole, shown in Figure 2.1-4. The average temperatures for the whole net are about 10 to 15°C higher than for a good working substation.

Hence part of the work reported in this paper deals with the possibilities of reducing the return temperature of the district heating net as a whole.

The supply temperature in Figure 2.1-4 shows the typical operation control in many district heating systems. Starting with the highest loads on cold winter days, the supply temperature decreases linearly with increasing outdoor temperature. In the case shown in Figure 2.1-4 (Skogas), the sharp transition at the break point is reduced by using an intermediate control curve with lower slope for outdoor temperatures between –10 and +7°C.

In comparison, the operating temperatures for the Korean net in Cheongju are shown in Figure 2.1-5. In this case, the control function follows another strategy due to the climatic difference between Korea and Europe. The supply temperature varies only slightly from 105 to 100°C between winter and summer time, the reason is the use of absorption chillers which are operated more effectively in the summer time at those higher supply temperatures. The use of absorption chillers with high return temperatures at base load (low DH cooling ability) is also one reason for the relatively strong increase of the return temperature in summer time in the Cheongju net. Another is high return temperature of bath facilities, which are used all year round, yet their influence on the return temperature is most expressed in summertime.

Supply- and return temperature in Skogås 2002

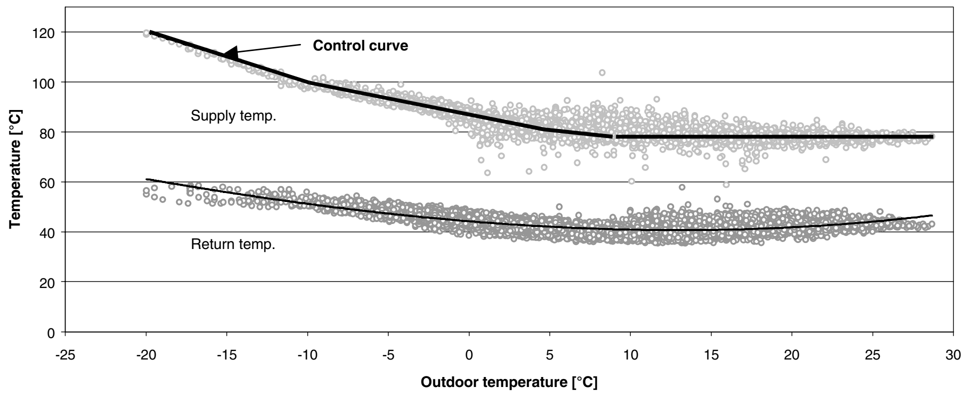

Figure 2.1-4: Operating temperatures of the district heating network in Skogas. (Thick line: DH supply control curve, thin line: trend curve return temperature)

Supply- and return temperature Cheongju 2003

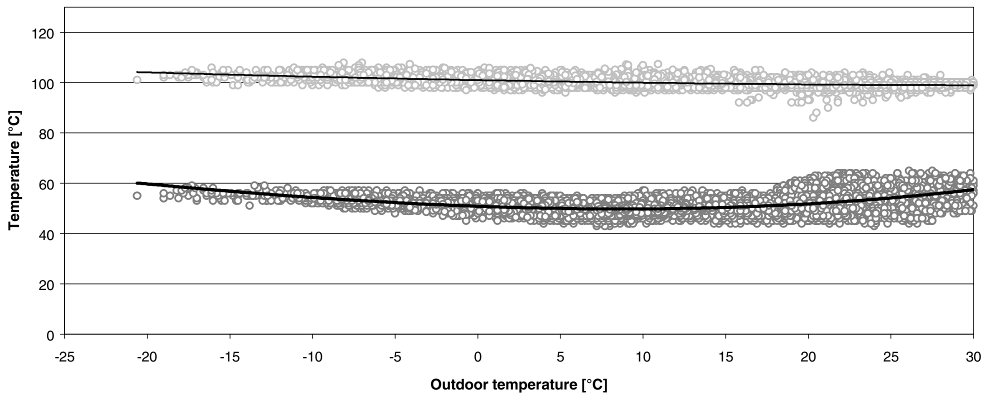

Figure 2.1-5: Operating temperatures of district heating network in Cheongju

2.1.4 The role of low return temperatures in production plants

2.1.4.1 District heating systems with boilers

Low supply and return temperatures are said to be characteristic of efficient district heating networks. However, in systems with heating-only boilers providing heat, the influence of the temperature level on energy efficiency is not very large. One important point concerns the full-load capacity of the network. With an increasing ***temperature difference***, a higher heating load can be transmitted through a pipe. This is especially important for nets under expansion, where the piping dimensions reach the design limits during winter. Any increase in temperature span can therefore be of interest for increasing available power, i.e. connection of new customers. The connection of new customers with energy needs all year round can then be very profitable. A decrease of the return temperature by 1°C in a net designed for 110/45°C increases the annual energy delivery by ca.1,5 %. Therefore, if the new customers show a “normal” energy consumption profile, the gain in heating capacity for an increase temperature span of 1°C is 1,5 % of the annual load. In section E2, some other examples are presented.

The reduction of heat losses is another reason. Even if the energy gain due to heat loss reduction is small, a reduction of the annual mean temperature by 1°C would result in a reduction of heat losses in a typical net by ca. 1,5-2,0 %, depending on system size (see section 6). In aproximate terms, one third of this loss is associated with the return pipe temperature and two-thirds with the supply pipe.

2.1.4.2 Heat production in condensing plants

A much higher impact can be achieved in production plants with condensing devices, such as stack gas coolers and condensers in cogeneration plants. Stack-gas condensing means that by means of a stack-gas cooler in the chimney one can extract some of the condensing heat from the steam in the stack-gases leaving the boiler. Return-water of the district heating system will cool the stack-gases. In order to cool the stack-gas and thus make it possible to extract the condensing energy, the return temperature in the district heating system has to be lower than the dew point of the stack-gas. This means that the lower the return temperature T_{return} is, the more energy can be extracted from the stack-gas and then delivered to the district heating system. See Figure 6.2-2 in section 6. The energy gain in such devices and thus the economical profit of the temperature decrease can be significant. The more water or hydrogen is contained in the fuel, the more energy can be recovered by stack gas condensers. For boilers fuelled with wood chips, the energy gain can be up to 30 % of the higher heating value of the fuel.

In cogeneration steam plants, the electricity production in a single step backpressure turbine is first of all related to the temperature to which the steam can be expanded. This in turn is primarily a function of the district heating supply temperature, which is to be achieved in the DH heat exchanger. The energy gain depends on the type of system, if the cogeneration is produced in a plant that is solely of the backpressure type, or in a combined hot and cold condensing power plant. If the steam turbine has several levels of condensation, both return and supply temperature might affect the electricity production gain. Some examples are given in Section 6.

2.1.4.3 Heat production with electrical heat pumps

Electrically driven compressor heat pumps working as production plants, which often are the case in Sweden, are sensitive to the DH temperatures. The efficiency of a single stage heat pump depends primarily on the supply temperature to be achieved. If the condensers of two heat pumps are connected in series, the COP will be higher than for individually or parallel coupled heat pumps; a decrease of T_{return} will increase the performance of the unit slightly. In general terms, lower temperatures increase the heat pump COP, therefore saving electricity. As a rule of thumb, between 0,5 and 1 % of working electricity can be saved by decreasing T_{supp} and/or T_{return} by 1°C (Walletun, 2002).

3 Substations with excess flow

Summary

*This chapter describes the two main methods developed as diagnostic tools for the analysis of malfunctioning substations: The **Excess flow method** and the **Target temperature method**. These methods can either be used separately or in combination. The ranking procedure according to the Excess flow method is an effective tool for selecting such substations that make an important contribution to high district heating return temperatures. It is explained in detail by means of examples for the Skogas net. The excess flow evaluation can be based on data with very coarse resolution such as monthly averaged energies and flow volumes.*

Another method is the Target temperature method, which uses analytical solutions for calculating ideal return temperatures (= Target Return Temperatures) for basic configurations of substations. By comparing a real substation with an optimally working one, the difference between the target temperature and the measured return temperatures can be calculated. This method gives time resolved return temperatures, flows and energies from which many different analyses can be performed, such as the function of the substation under certain day times or under some specific seasonal conditions.

3.1 Introduction

Generally in district heating systems, it is of interest to achieve a *large difference between supply and return temperature.* There are many reasons for that, lower pumping power, higher energy transport capacity, lower heat losses, among others. Another main concern for district heating systems is *low return temperatures*, especially in the case where condensing cooling devices (such as used in cogeneration, stack gas coolers, heat pumps and so on) are part of the heat production system. Assuming constant supply temperatures, large temperature difference means low return temperature – both are the two sides of the same coin.

Low return temperatures, however, cannot be chosen as an operational parameter; they are the result of effective operation in practice. That means that the return temperatures are generated by the working components of substations, i.e. control valves and heat exchangers. *Having this in mind, it becomes evident that the key to low return temperatures is the effective operation and right dimension of those components.*

3.1.1 District heating capacity

The energy E (or heating capacity) distributed in a district heating net follows a quite simple law:

$$E = V \cdot C \cdot (T_s - T_r) \cdot \qquad (3.1)$$

and the return temperature T_r can therefore be written as

$$T_r = T_s - \frac{E}{V \cdot C} \qquad (3.2)$$

Were V = the mass flow rate, and C = the thermal capacity of water and T_s and T_r the temperature of the supply and return pipe, respectively. Therefore, with the supply temperature given, mass flow rate and the return temperature are the indicators of the working ability of net piping. A good cooling of a substation means lower mass flow and if all substations contribute to the same goal, the return temperature would ideally be low. If the resulting new mass flow is lower than the design point, new customers can be connected to the same pipe. Hence with a given pipe system in the ground, more customers can be connected and more energy can be sold per year.

Therefore, it is profitable for net operators to put continuous efforts on lowering district heating mass flows, which according to equation (3.2) means achieving a larger cooling ability of substations and results in lower return temperatures.

3.1.2 Return temperature

On the other hand, it is generally not quite simple to know, what the right return temperature should be. It depends on the types of loads, which primarily are the heating and ventilation air heating systems of the buildings and the hot water production systems. Unconventional loads might be industrial and service loads, saunas or absorption chillers, any of those complicating the picture of an ideal return temperature. The heating loads can vary depending on the age of the buildings and type of heating systems used. In order to get an overall picture, the net operator might have to get an idea about all the hundreds or thousands of substations in his net, contributing to the return temperature. Ideally, he should have a simulation algorithm for the basic substation configurations in his net in order to see if they work properly. In general, this procedure is cumbersome and probably not successful because due to a lack of information about the status of substations (which very often are owned by the customer).

On the other hand, the energy delivered to the customers is very often measured, meaning that information about volume flow and temperature is available, or at least summarised over certain invoicing periods. As it is shown below, this approximated information can already be used for further analysis.

3.1.3 Excess-flow analysis - a practical way

With the mass flows and temperatures available, the net operator can investigate what would happen with the performance of each substation, when the return temperature would be below the actual average value of the return temperature; let's say by 3 or by 5°C. In this *hypothetical case,* each substation will contribute to the same lower average return temperature with its own heating capacity, which we call the ***Reference Return Temperature (RRT)***. Lower return temperature means lower mass flows. As the cooling abilities of the individual substation are fictitively increased, the mass flows *decreases* in proportion to the increased temperature differences.

Hence this hypothetical approach towards a new average temperature will result in a fictitive excess flow, telling us, how much a substation affects the return temperature of the district heating network. Ranking according to these excess flows can therefore indicates which of the substations should be investigated further for improving its cooling ability.

We call this method of arbitrarily chosen fictive reference return temperatures the ***Excess flow method***. It is described in detail in Chapter 3.2.

3.1.4 Target return temperature shows the limit

There is a practical limit for the achievable return temperature in a substation. This limit is usually given by system properties. Such limiting factors are design return temperatures of the house heating system (as a function of the outdoor air temperature), the temperature of the incoming cold city water and the requirements of the hot water circulation. In the case of industrial loads or other service loads, some other properties or processes might govern the return temperature. However, in each case, an ideal return temperature can be defined, which might depend on some other operating or climatic conditions. We define this ideal return temperature as the ***Target Return Temperature (TRT)***, i.e. that temperature which should be ideally achievable for each good working substation.

This temperature is neither a given nor a constant temperature. The Tareget return Temperature will vary over the year and it will be a function of the substations design parameters, the time dependent load and supply temperature and the type of heating system the substation is delivering heat to. The target return temperature can be used in order to analyse the function of a substation in more detail and possibly allows drawing some conclusions about the function of a substation and how to improve it. The ***Target temperature method*** is described in detail in Chapter 3.3.

3.2 The Excess-flow method

3.2.1 Excess flow evaluation

In a district heating network, the *actual temperature in the return pipe* at the entrance back to the power plant is the weighted result of the contribution of the operation of all substations, large as well as small. It is evident that larger substations with high design capacities and high mass flows will have a larger influence on the return temperature than smaller ones. Therefore, in order to evaluate the function of the district heating system with respect to a lower reference temperature, it is important to have a closer look at both the *actual return temperature and the total energy delivery* of each of the substations involved in the system.

3.2.1.1 **R**eference **R**eturn **T**emperature RRT

The idea of the Excess flow method is to analyse the volumetric flow rate of each substation with respect to a desired ***Reference Return Remperature (RRT)****.*

That means, if the objective for the DH system is to decrease the mean return temperature by for example 5°C compared to the actual temperature, each substation with an actual return temperature higher than the RRT would exhibit a lower mass flow, or lower amount of water volume passing under a given period. The difference between the actual water flow rate and the fictive water flow rate based on RRT is called *Excess flow* and is a measure for the impact each substation has on the return temperature of the system. Substations with high energy capacity might have a big influence even if their return temperature is only slightly above the reference return temperature.

Hence, the key of the evaluation procedure is to select a proper RRT with respect to which all sub-stations are to be evaluated. The RRT should be somewhat below the actual temperature, but not too much making the goal impossible to realize. In the *Excess flow method* discussed in this chapter, the RRT is assumed just some degrees under the actual mean return temperature. On the other hand, the *Target return temperature method* (TRT) described in Chapter B3 goes beyond that and describes a method that tells us, which return temperature can ideally be achieved with the actual types of substations installed in the net.

3.2.1.2 Excess flow

Mathematically, the Excess flow can be determined as follows.

The energy delivered by a substation during a certain period can be described as:

$$E = V_{act} \cdot C \cdot (T_s - T_{r,act}) \tag{3.3}$$

The same energy can be delivered at a reference return temperature $T_{r,RRT}$ by the same substation which can be written:

$$E = V_{RRT} \cdot C \cdot (T_s - T_{r,RRT}) \tag{3.4}$$

Here V_{act} and V_{RRT}, respectively, denote the DH medium flow volume in m³; the actual one and the calculated one based on the desired reference return temperature, respectively, for the investigated time period, e.g. one month; E = Energy in a given period (in kWh), C thermal capacity of water (1,16 kWh/(°C m³)), T_s = supply temperature and T_r = return temperature; both actual as well as reference return temperature are denoted.

The Excess flow V_E for the considered time period then follows from equating (3.3) and (3.4):

$$V_E = V_{act} - V_{RRT} = \frac{E}{C}\left(\frac{1}{T_s - T_{r,act}} - \frac{1}{T_s - T_{r,RRT}}\right) \tag{3.5}$$

Hence, for the normal case, that the temperature difference $ÄT_{act}$ is lower than $ÄT_{RRT,}$ the Excess flow V_E (measured in m³) becomes positive and is proportional to the design power of the substation in question. By means of this simple calculation, the influence of each substation to reach the chosen reference return temperature can be evaluated and ranks can be assigned for a complete net, as it is the case in the enclosed examples from Skogas (Sweden), see Table 3.2-1.

3.2.1.3 Ranking lists

Based on the amount of Excess flow, ranking lists can be established. For instant in Skogas, the 25 selected substations will be ranked for a given period according to their Excess flow, for instance for February. In Table 3.2-1 measured values are energy use and DH flow volume for February. The original data are the sums of hourly values, but they could also be just sum readings from meters for the whole period, i.e. February in this example. The individual temperature differences dT are thus calculated values, according to equation (3.6):

$$dT = (T_s - T_{act}) \qquad (3.6)$$

The supply temperature is also a measured value. Using this and the weighted temperature difference, an average temperature difference can be calculated as well as the average return temperature.

The excess flow is calculated according to Equation (3.5) and the substations are ranked according to this value. That means that the substations with highest excess flow will contribute most to the return temperature. The contribution can either be caused by low temperature differences, or high flows, or both. The substations will be listed on the top of the list and marked. Such substations should be checked further in order to see, if improvements are possible. The ranking in the Table 3.2-1 gives the answer. Negative excess flow values indicate that the actual return temperaures of the substations are lower than the chosen RRT.

On the contrary, the substations at the bottom end of the Table have a low contribution to the level of the return temperature. However, even their function can be checked and their ideal return temperature evaluated by means of the target return temperature method described in Chapter 3.3.

Table 3.2-1: Excess flow ranking Table for February 2002, Skogas

	Actual Supply temp		85,0°C	*SKOGAS*
	Return temp (calculated		42,1°C	**February 2002**
	Aver. actual cooling **ÄT**		42,9°C	
	RRT		48°C	
Substation Nb.	**Energy** [MWh]	**ÄT** [°C]	**Volym** [m³]	**Excess flow** [m³]
S452	416,69	32,3	11324,8	3 682
S1962	381	34,5	9697	2 708
1S960	316,08	34,8	7965,83	2 168
S2015	419,08	38,1	9660,21	1 973
S1961	254,36	36,7	6080,67	1 415
S744-1	356,14	39,4	7934,1	1 402
S451-1	436,69	42,4	9036,6	1 027
S680	329,1	41,0	7043,02	1 006
S2014	296,59	43,4	5997,03	557
S674	186,27	45,3	3606,61	190
S718	85,72	44,5	1690,53	118
S744-2	106,91	47,0	1997,38	36
S3093	112,81	47,1	2101,91	33
S820	96,67	50,5	1681,47	-92
S912	127,177	50,4	2216,81	-116
S712	87,27	52,2	1467,43	-133
S871	308,03	49,2	5501,21	-149
S898	85,814	53,7	1401,85	-172
S863	269,42	49,8	4754	-188
S778	195,936	50,6	3398,86	-195
S809	312,94	49,6	5536,28	-204
S777	199,76	51,7	3389,71	-274
S1766	246,54	52,3	4139,51	-383
S404	356,13	51,0	6130,6	-402
S913	298,68	53,4	4910,73	-568
Sum/average:	**6281,807**	**42,9**	**128664,15**	**13 439**

3.2.2 Evaluation practice

In principle, it is worthwhile to do these evaluations periodically for given periods because the influence of seasonal properties can be used to get some hints on malfunctioning systems. For instance, the return temperatures in summer time can give an indication if the domestic hot water system works properly. The return temperatures during wintertime can be significant for the radiator system. High return temperatures may indicate malfunctions in the respective system. A detailed analysis can also result in other indications for a certain type of malfunctioning of a system. In the Skogas system, the evaluation is done for the representative months February (winter), April (intermediate period) and a three-month summer period. Complete ranking lists for the nets in Skogas and in Cheongju will be presented in Appendices 3 and 4.

3.2.2.1 Comments on the enclosed excess flow lists

In this chapter, the use of the excess flow method is exemplified for the evaluation of some substations in Skogas.

February, as shown in Table 3.2-1 is usually the coldest period in Sweden with monthly mean temperatures of about -4°C, and low temperatures down to -20°C. Hence, the radiator load in this month is the principal source of heat consumption. High excess flow in February indicates problem with the radiator system: Either high radiator system return temperatures, or maybe a bad working heat exchanger (or of course other reasons such as a forgotten open bypass somewhere in the system). The substations S451 and S452 are large substations connected to a secondary network, therefore the return temperature from such systems is generally higher. Station no. S451 has been recently renovated and works relatively well. S452 on the other hand, - being on the renovation list but not renovated yet - is an old installation with fouled heat exchangers and large control valves and therefore gives high excess flows in the summer and winter. S1962 also shows large excess flow. It supplies heat to a large multifamily building built in the 1960-ies and is planned to be renovated. A contrary example is S898, a smaller well working substation with large cooling below the target point.

For Skogas, two more periods besides February are chosen for further evaluation of selected substations and shown in

Table 3.2-2 and Table 3.2-3: April and June - August, respectively, year 2002.

Table 3.2-2: Comparison of substations under different seasonal conditions in Skogas: April 2002

Supply temperature	82,0°C
RRT	48,0°C
Average calculated ÄT	42,3°C
Calculated return temperature	39,7°C

Consumer Code	ÄT [°C]	Heat [kWh]	Flow [m³]	Excess flow [m³]	Adress
S1962	21,7	203,16	8238	4 484	
S452	30,3	296,33	8595	3 120	Tornslingan 41
S744	39,0	243,26	5483	988	Stortorpsvägen 41-43
S1961	36,8	168,97	4034	912	Loftvägen 16
S2015	41,6	283,93	5993	747	Murvägen, Trångsund
S1960	39,8	207,86	4586	745	Loftvägen 9-21
S451	43,0	298,22	6083	573	Korpstigen 10
S680	42,4	240,79	4988	539	
S898	50,4	60,724	1058	-64	Beateberg

April is a period in which the heat load and the domestic hot water load are about equal. In the summer period June - August, the domestic hot water is the main part of the load. That means that in the summer period, the domestic hot water system is significant for the return temperature. The return temperature in the middle of the night gives an indication about the hot water circulation flow, whereas the temperatures achieved in the morning and in the evening indicate how well the hot water heat exchanger is cooled down by the incoming cold water flow.

Table 3.2-3: Comparison of substations under different seasonal conditions in Skogas: June – August 2002

Supply temperature	78,0°C
RRT	42,0°C
Average calculated ÄT	37,3°C
Calculated return temperature	40,7°C

Consumer Code	ÄT [°C]	Heat [kWh]	Flow [m³]	Excess flow [m³]	Adress
S452	21,4	255,04	10487	5 189	Tornslingan 41
S744	24,3	179,86	6506	2 769	Stortorpsvägen 41-43
S451	30,7	230,25	6581	1 797	Korpstigen 10
S898	20,0	37,21	1630	857	Beateberg
S1962	35,4	136,71	3395	555	Loftvägen 3-5
S680	38,4	206,29	4717	432	Rapsodivägen (garage)
S1960	38,3	138,42	3174	299	Loftvägen 9-21
S1961	45,1	99,13	1930	-129	Loftvägen 16
S2014	Missing data				

It can also be seen in the summer time that the secondary net of S452 produces high excess flow, due to the heating of hot water circulation, as does S744. It is a substation serving a hospital. A relatively large amount of hot water consumption marks the system, distributed to many places with high amount recirculation flow. The system gives especially high return temperatures in the summer time, but is difficult to improve. The substations S1960, S1961 and S1962 are serving large block buildings with high radiator temperatures 75/55°C. Both SS 1961 and S1962 show high overconsumption in the summer, probably due to oversized control valves for hot water flow. S898 provides hot water to a prison and is similarly to S744-1 delivering hot water to many system branches with distributed piping that must be kept warm in the summer time. The same holds for S680, serving a 4-pipe group house system with long distribution pipes, making it work poorly, especially due to oversized control valves.

It should be mentioned already here that the substations 451-1, 1961, 1962 and 1766 have undergone repairs during this project (see chapter 4.2.3 for discussion of the results of the repairs).

3.3 Individual evaluation of the target temperature

In this context, we use “target temperature” synonymously with the more exact expression “target return temperature.”

3.3.1 General Approach

There are several approaches to determining specific benchmarks of customer substations in order to evaluate the function of these substations. All are based on the availability of data from measurement systems placed at the equipment of the substations. In the beginning of this project, a method has been applied based on statistical cluster analysis. As this method can only lead to good results if more information is available than usually contained in the measurement data, a second approach based on thermodynamic models of individual substations has been developed.

3.3.1.1 Statistical cluster analysis

The main target of this approach was to determine specific clusters depending on measured values and to find a target temperature for each cluster. The target temperature in each cluster is determined based on the following relationship:

$$T_{R,C} = f\left(Q_C, T_{C,out}, T_{C,Supply}, f_{C,QR}, t_{C,d}\right) \tag{3.7}$$

With:

Q_C	Measured load of the customer substation in cluster kWh/h
$T_{C,out}$	Outside temperature in cluster C
$T_{C,Supply}$	Supply Temperature of the customer substation in cluster C
$f_{C,QR}$	Proportion of hot water load of the customer substation in cluster
$t_{C,d}$	Time of the day in cluster h.

Depending on the length of the cluster’s edges, more or less measured return temperatures of the observed substation fall into the cluster. The minimum or an average of the lowest return temperatures defines the target temperature (see Figure 3.3-1). However, it cannot be determined from the measured values, if a substation is working well and which one could serve as a reference substation. Therefore, the process of setting a target temperature within a cluster was somewhat arbitrary. The only way to overcome this disadvantage was to extend the information about the substation by heuristics.

This information could be received by using the excess flow method, which gives a ranking of well and badly working substations. In the end, this method was cumbersome and not working without heuristic information about the substations. Therefore, another approach has been developed to overcome these obstacles.

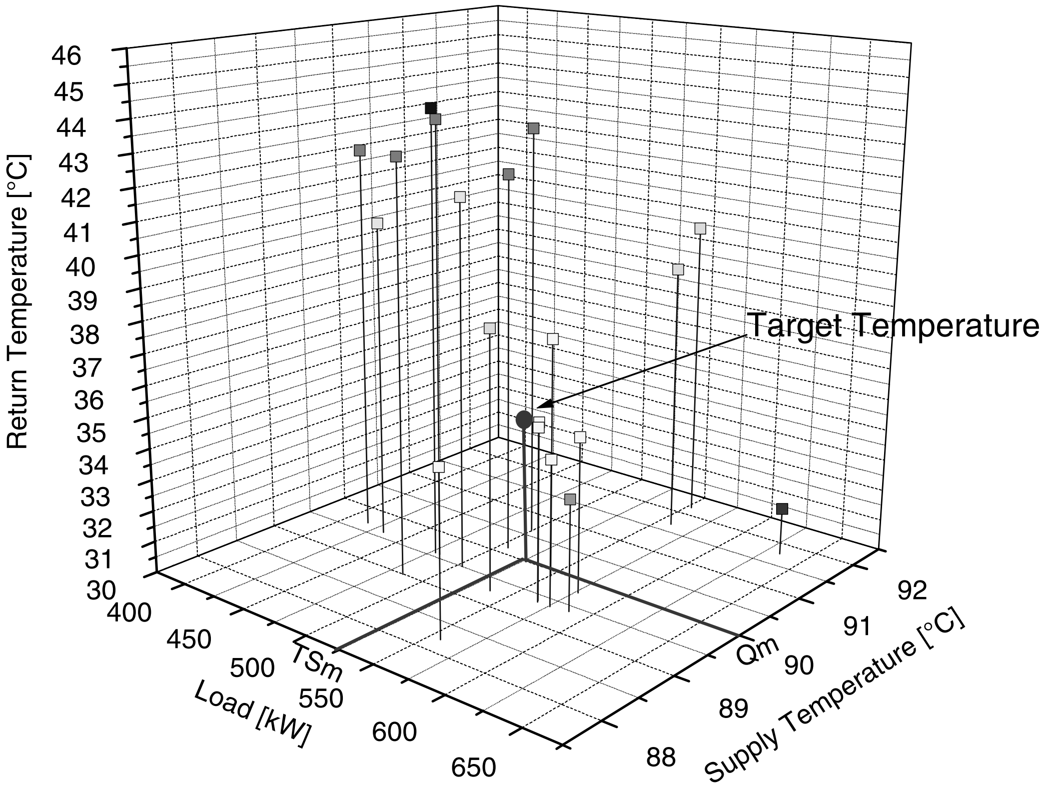

Figure 3.3-1: Cluster method to determine the target temperature

3.3.1.2 Thermodynamic models

In order to determine the target temperatures of customer substations in specific situations over the year without knowing which one could serve as reference substation, two thermodynamic models of common substations have been developed and applied. These are 1-stage and 2-stage parallel substations. Based on the measured data as input, it is possible to calculate target temperatures for a variety of customer substations. A comparison of these optimal return temperatures with the measured return temperatures in the same situation also gives the possibility to determine the excess flow and one can decide, whether the substation works well or not with respect to an ideal case.

The single-stage parallel model

Figure 3.3-2 shows a scheme of a 1-stage parallel customer substation. Compared to Figure 3.3-1, only the parts of the substation, which have a thermodynamic influence on the return temperature, have been used for the model. This results in a model that is relatively easy to handle, while still giving reasonable results. Figure 3.3-2 also shows all necessary parameters in order to calculate the target temperature from the measured data.

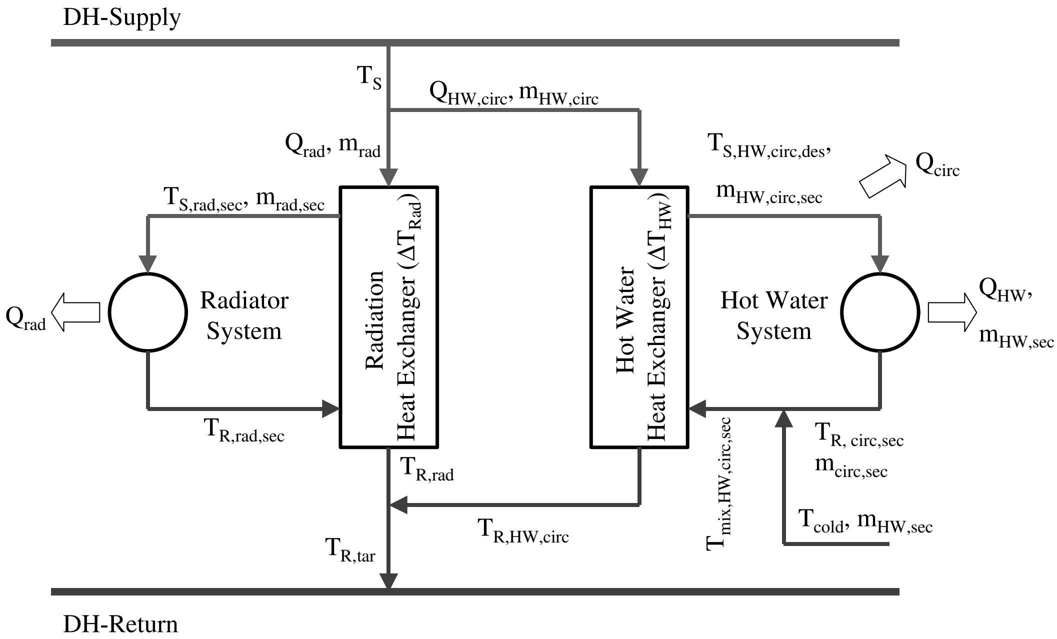

Figure 3.3-2: Model of a single stage customer substation

The substation consists mainly of the heat exchanger for space heating (or radiator) system and the heat exchanger for the hot water production. Within the radiator heat exchanger, the heat carried by the DH-water is transferred to the space heating system and thus, the DH water is cooled down. The hot water heat exchanger is used to transfer the heat to the hot water supply. A hot water recirculation flow is necessary in order to provide continuously hot water at the tap water locations.

The total heat load of a substation at a certain time can be calculated by summarising the radiator heat load Q_{rad}, the heat load for hot water production Q_{HW} and the heat losses of the piping, of the hot water circulation system Q_{Circ}. All these loads can be calculated by analysing the heat demand of a certain substation over the year. This method will be explained further in the section "Evaluation of the heat demand for space heating, hot water and circulation".

The target temperature is a mixture of the output mass flows of the radiator heat exchanger and the hot water heat exchanger. It can be calculated as a function of design parameters of an optimal single stage customer substation and measurement values of the heat load of the space heating and hot water system and the heat loss of the circulation system. Other parameters are the outside temperature and the supply temperature. The detailed model and its specific equations are explained in *Appendix 2 – "The calculation of the target return temperature for single-stage and two-stage customer substations"*.

The two-stage parallel model

Unlike the single stage substation, the two-stage substation has a preheating stage of the cold water for the tap water system in an additional heat exchanger. Figure 3.3-3 shows the simplified system with corresponding parameters. For calculating the target temperature, the overall heat load of a customer substation again has to be divided into the heat demand for space heating, hot water and circulation, respectively. This is done the same way as for the single-stage substations as described above.

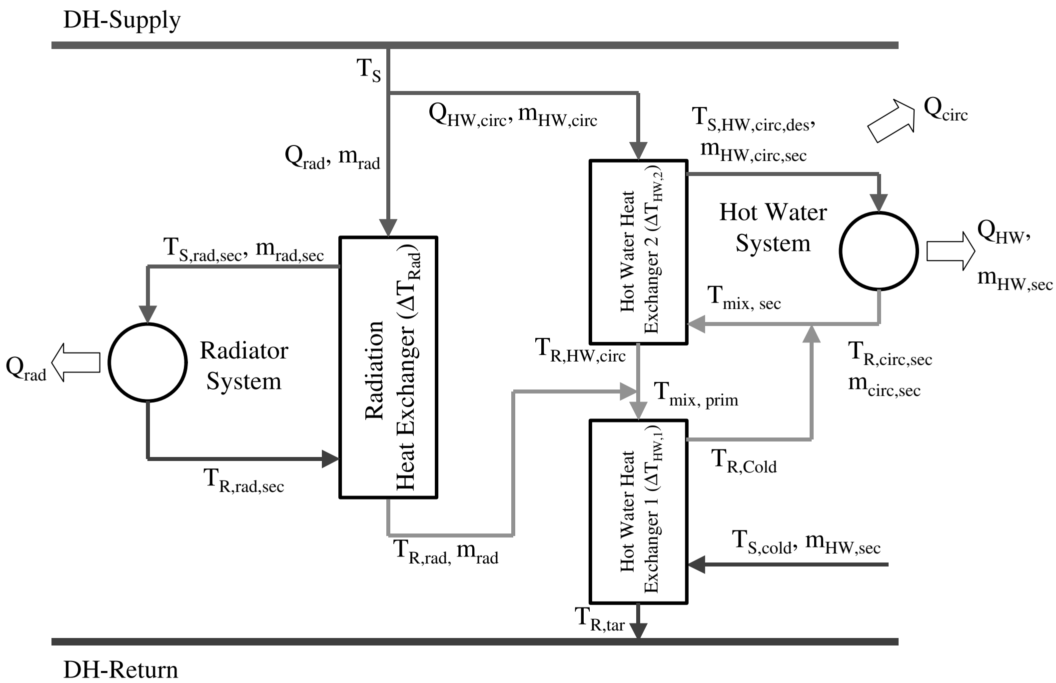

Figure 3.3-3: Model of a two-stage customer substation

Evaluation of the heat demand for space heating, hot water and circulation

Aside from design parameters, the most important input parameters for the target temperature models for single and two-stage substations are the heat demands for space heating, hot water and circulation. Therefore, a method has been developed in order to determine these parameters on the basis of the available measurement data. The measurements contain data of the total heat demand of each substation over a period of one year on an hourly basis. Using certain periods of a day and/or of the year, it is possible to distinguish between the different heat loads and to determine the respective heat demand for a special point in time.

Looking at a day in the summer period (see figure below) when no space heating is necessary, it is possible to determine the heat load for circulation. This is more or less the heat load at such times where usually no hot water is demanded. The following diagram shows a typical heat load of a substation on a very hot day in summer. It can be seen that the load at night is dominated by the circulation losses. It is obvious that not only one day of the year should be used to determine the circulation load. Therefore, several hot days are used for calculating an average circulation load.

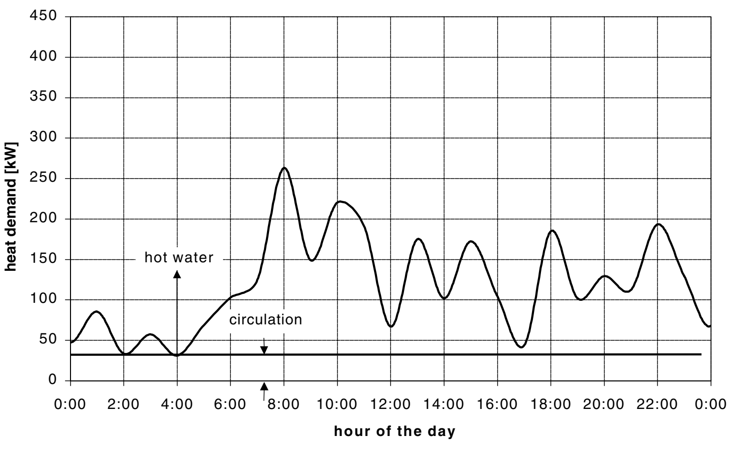

Figure 3.3-4: Determination of the circulation heat demand (= circulation heat loss)

Another way to determine the heat demand for the hot water circulation is to find an average value from a certain amount of hours with the lowest heat demands over the year. Appropriate results can be achieved by using the 25 lowest values of the year.

The diagram below shows the method to determine the heat demand for space heating. Compared to the hot water load, this heat demand is usually less dominated by the daytime. Primarily, the heat demand for space heating is a value varying slowly with the outside air temperature biased by the thermal mass of the building. The quickly varying peaks are caused by the hot water load. Therefore, the space heating load can be determined by an average daily heat demand subtracted by the circulation loss, see Figure 3.3-5. The latter can be seen as constant over the year.

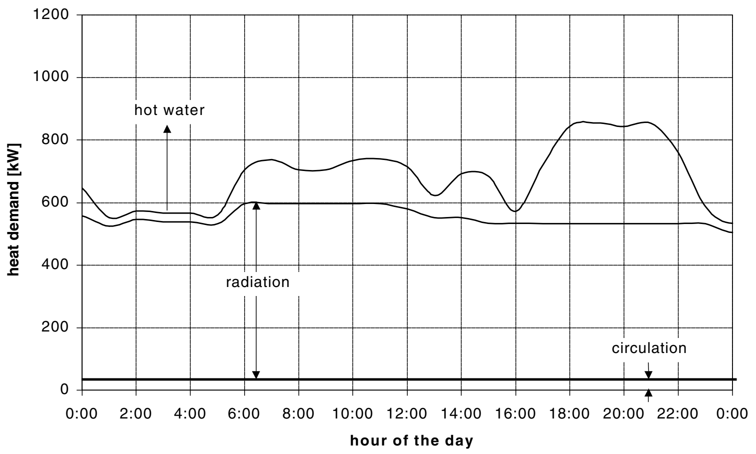

Figure 3.3-5: Determination of the space heating demand

The space heating load of a substation depends on the outdoor temperature and is of course neither constant over the year nor over the day. Usually the heat demand for space heating is high in winter times and low in the summer. Differences occur also between day and night. Therefore, it is useful to average the load over a certain time. Preliminary calculations have shown that a good way to determine the space-heating load is to calculate the total heat demands averaged over six hours. This is shown in Figure 3.3-5 above.

Finally, the hot water heat load can be calculated by subtracting the space heat and the circulation heat load from the total heat load according to equation 3.8.

$$Q_{HW} = Q_{total} - Q_{rad} - Q_{circ} \qquad (3.8)$$

All other equations not listed here are found in this Appendix 2).

Calculation of the cold water temperature

Due to the varying average outside temperature, the cold-water temperature for the tap water system varies over the year. A good way to model this effect is to use a sine function with a maximum in August and minimum values in February.

Figure 3.3-6 shows the modelling of the cold-water temperature for the example of Sweden where this temperature varies between 6°C in winter and 12°C in summer.

The corresponding equation is as follows:

$$T_{cw} = T_{cw,mean} + \sin\left(\frac{t_{year} - 3285}{8760} \cdot 2 \cdot 3.1416\right) \cdot \left(T_{cw,\max} - T_{cw,mean}\right). \qquad (3.9).$$

The parameter t_{year} describes the hour within a year and has a range between 0 to 8760. $T_{cw,mean}$ denotes the annual mean temperature of the cold water (= 9°C in our case) and $T_{cw,max}$ denotes maximum cold water supply temperature occurring in Sweden in August.

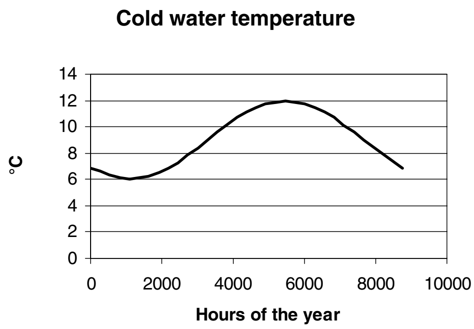

Figure 3.3-6: Cold water temperature over the year

For other countries, the temperature range and the day for the maximum temperature might be changed according to the local conditions.

3.3.2 Application of the target temperature analysis tool

In Appendix 2.2, a simple Excel-tool for the calculation of the target return temperatures of one-stage and two-stage customer substations is presented[2]. In this chapter, results of some

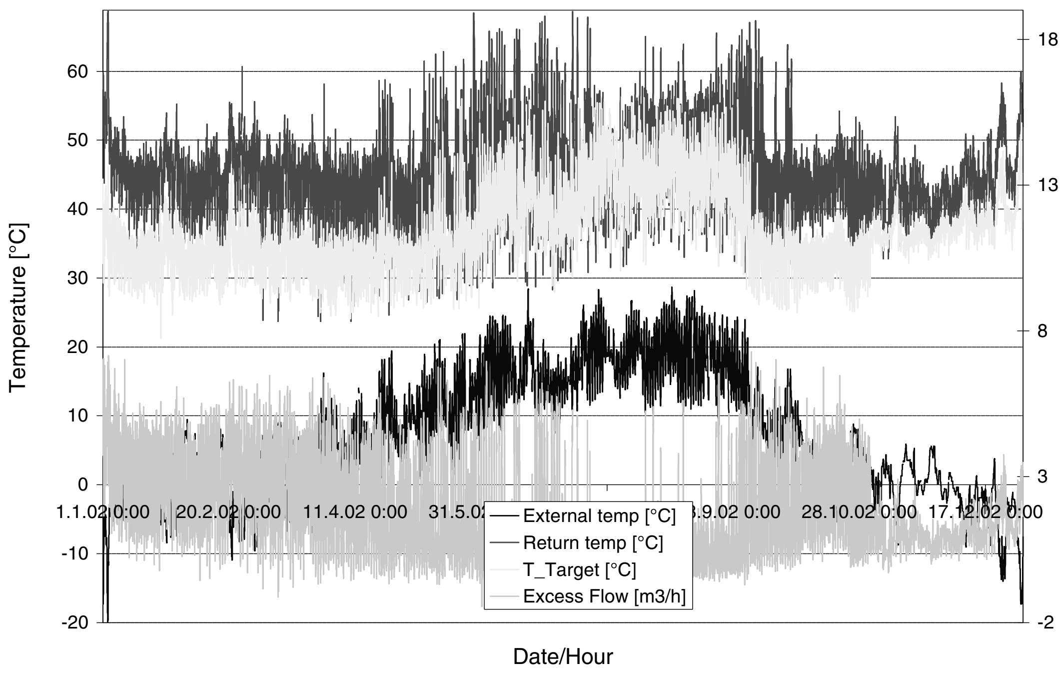

Figure 3.3-7: Calculation results for a badly working substation

calculations will be presented. Examples of well working and of poorly working substations will be shown. The diagram in Figure 3.3-7 shows the results of the TRT - analysis of a badly working

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[2] A calculus in Excel for the calculation of target temperatures according to the TRT – method can be received on request from Michael Wigbels, Umsicht, Germany. E-mail:Michael.Wigbels@Umsicht.Fraunhofer.de.

2-stage 70/50°C substation. It is the Swedish substation S744-1. Especially on winter days and in the intermediate period, this substation shows very high return temperatures.

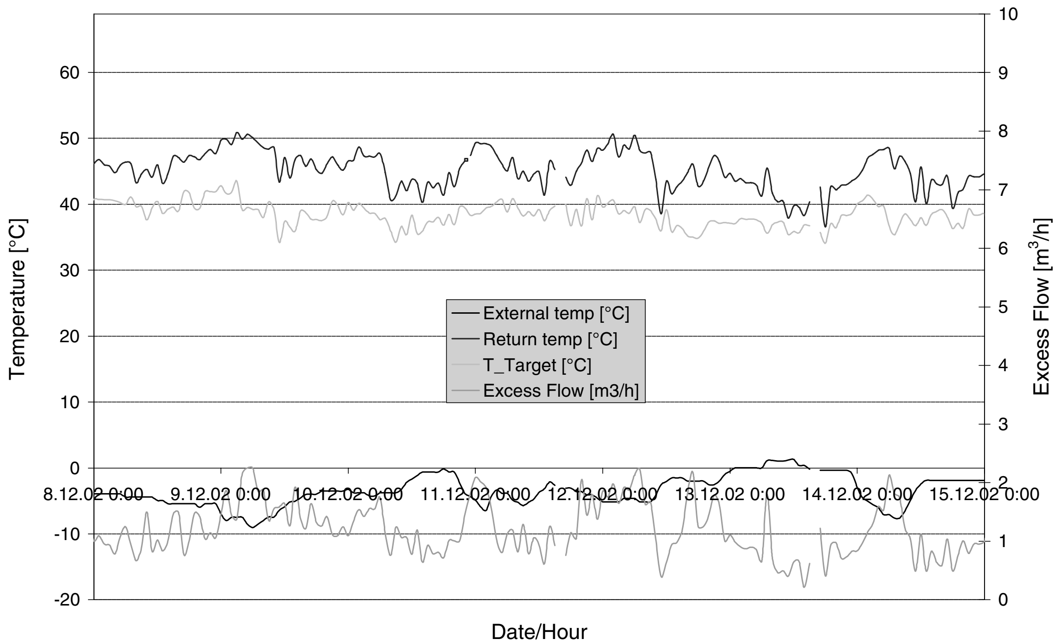

Figure 3.3-8 Poorly working substation in winter

The diagram in Figure 3.3-8 presents the results of the same substation for a week in winter starting on the 8th of December 2002. It can be seen that the excess flow is very high in the morning when the heat demand for hot water rises. Therefore, it would make sense to check the hot water system of this substation.

It can also be seen that over the whole period the return temperature is approximately 10°C higher than the target temperature. It can be assumed that not only the hot water system, but also the radiator system of this 2-stage substation has malfunctions. Actually, S744-1 is a substation for a secondary network serving a hospital with generally high return temperatures because of a large amount of hot water and hot water circulation.

The diagram in Figure 3.3-9 shows results for a well working substation. Again, a similar 2-stage substation, S898, serving a secondary network for a prison, is presented. The excess flow at most times of the year is close to zero. This means the return temperature is approximately at the target temperature level. It can be seen that until April 2002 the excess flows were higher. Therefore, it can be anticipated that afterwards a malfunction has been detected and eliminated.

Finally, the diagram in Figure 3.3-10 shows the results for one week in the winter. In this case, the return temperature is also close to the target temperature and there are no significant deviations indicating malfunctions of the system.

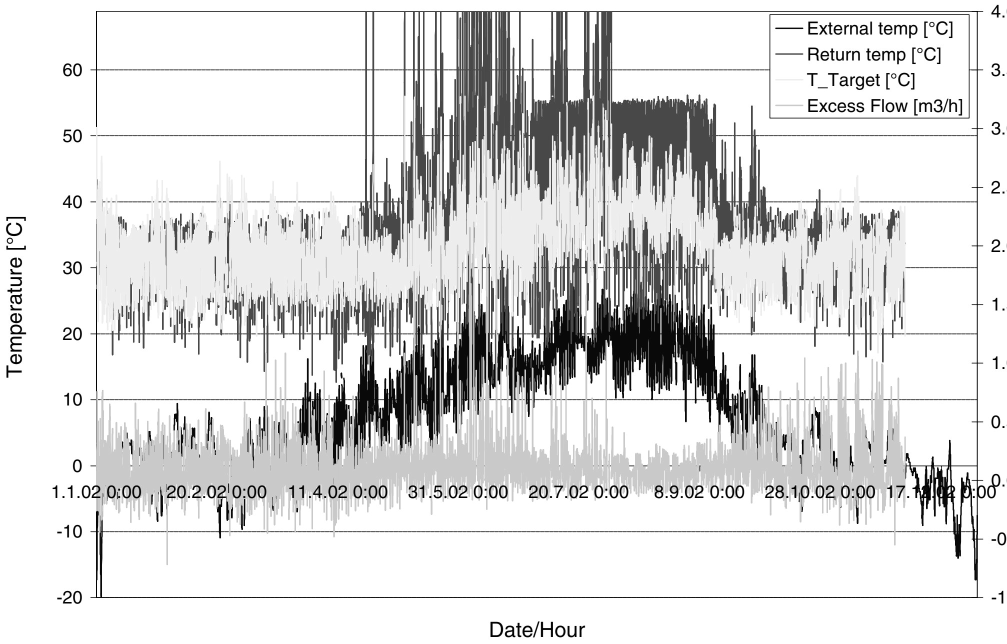

Figure 3.3-9: Calculation results for a well working substation

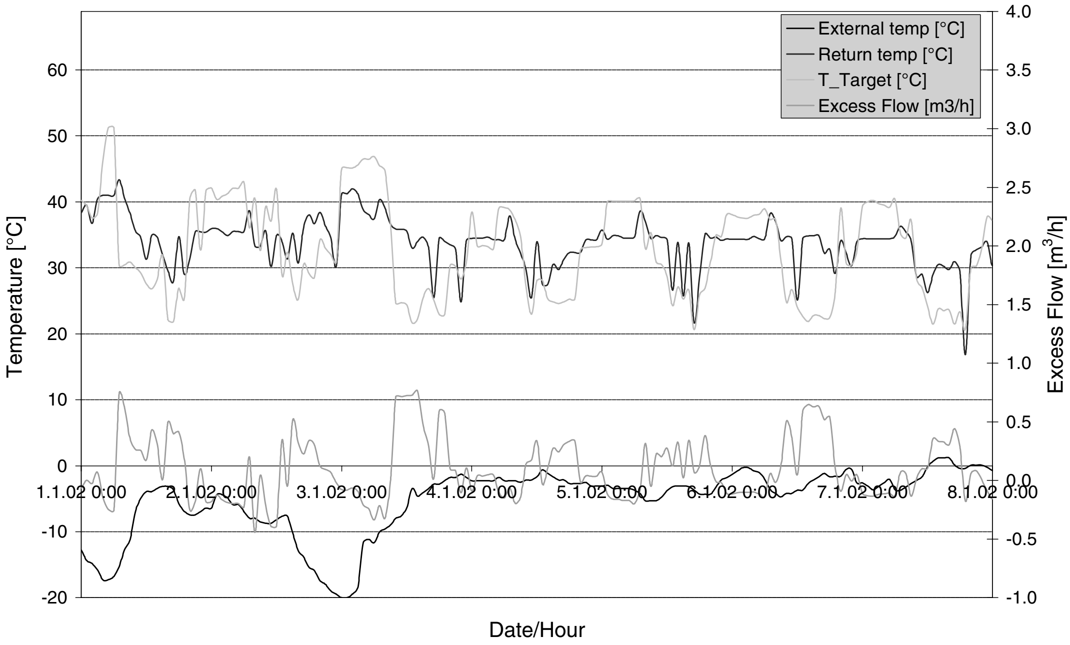

Figure 3.3-10: Well working substation in winter

*From the examples above it can be concluded that the **Target temperature method** based on an analytical simulation tool for determining the ideal target return temperature, can give a good indication of the status of a specific substation, when hourly measurement data is available.*

3.4 Combined method for evaluation of cooling effectiveness of substations

3.4.1 Introduction

In Chapters 3.2 and 3.3 above, two return temperature methods have been described, allowing the analysis of DH substations with respect to their ability to make optimal use of the district heating medium, i.e. to cool down the medium adequately in order to extract as much heat as possible with a mass flow rate as low as possible. We propose here, that *both methods can be combined* to allow the most complete analysis of the operational state of a substation, and in addition yield information about future basic malfunctions of the substation. We will call this method ***ISA: Individual substation analysis***. In the following chapters, a detailed description of the necessary inputs and the way of how to apply ISA will be given.

3.4.2 The application range of ISA

3.4.2.1 Objective with ISA

ISA will be used in order to find the reason for high return temperatures in district heating systems and to analyse the possible return temperature for the system in question. The method will result in a ranking of substations according to their cooling ability. *It is not a new method, rather a combined use of the previously described methods.*

3.4.2.2 Area of application of ISA

ISA should be used if the district heating system shows a tendency for high return temperatures, either at a certain seasonal time or daytime, or under certain operational conditions such as high return temperatures under sensible operating conditions, such as cogeneration or use of stack gas condensers.

The analysis can be done for a whole net, only for a part of a net, or even just one substation. The choice is up to the analyst with regard to the number of substations to be included and depends on the problem to be investigated. F.i. if the problem is high return temperatures at the production plant, the analysis should include all the substations of the net in question. If, on the other hand, the question is a high volume flow to a special customer, analysing just the substation in question is adequate.

3.4.2.3 Who will have interest in the results of ISA?

The generated results should be of interest to the users of both sides of a substation. On one side, the district heating operator will be interested in optimal use of the existing net, i.e. the possibility of transporting as much heating power as possible through the pipe system. That implies return temperatures as low as possible.

On the other side of the substation, there is the owner of the substations, i.e. the customer. He is interested in comfort, i.e. adequate temperature and on low district heating costs. Very often, the DH costs include a price component proportional to the volume of the DH medium passing through the substation. In this case, the customer is interested in the lowest volume as possible, i.e. low return temperature at a given supply temperature. Hence, in many cases there is a common interest on both sides for knowing the cooling ability of the substation and therefore to eventually improve the system.

3.4.3 Input data

The idea of the ISA method is to use a minimum of input data from substations, i.e. data which are very often available due to the case that the customer must be billed. However, some additional data are very helpful for increasing the accuracy and the amount of information to be generated about the substation. Hence, ISA calls for a number of necessary and additional data, as well for complementary system information. The following information is asked to be input for each substation:

Necessary data (hourly values)

- Primary mass flow
- Primary energy to substation
- Outdoor air temperature

Useful additional data (hourly values)

- T_{supp} District heating production plant
- T_{ret} District heating production plant
- T_{in} substation (primary side)
- T_{out} substation (primary side)

System design data

- Cold water temperature (annual function)
- Radiator design temperatures (supply/return)
- HW - HEX : cold end temperature difference
- RAD - HEX : cold end temperature difference
- Building balance temperature T_B
- Eventual specification of other types of load

Type of substation or connection

- Parallel connection
- Two-stage
- Secondary network
- Industrial load, Sauna, a.o.

3.4.4 The return temperature

In ISA, both types of return temperatures as defined in Chpt. 3.2 and 3.3 will be used:

- The r*eference return temperature* RRT is the choice of the operator for calculating excess flow.
- The *target return temperature* TRT is the temperature that ideally can be achieved in a given substation.

3.4.5 Description of ISA method

ISA combines the two methods *Excess flow method* and *Target temperature method,* which also can be used independently from each other. *The reason for the combination is to check how well a substation works in comparison with its design conditions*.

3.4.5.1 Excess flow analysis

The procedure for the *Excess flow analysis* is presented in Chapter 3.2. The excess flow analysis ranks substations based on gross operational data for a certain period, for example *one month*. It uses RRT, f. i. 5°C below the actual return temperature. The goal is to indicate substations, which should be considered for improvements because of strong contributions to the actual return temperature. For example, the ranking lists shown in Appendix 3 and 4 list the substations with high excess flows in the beginning and good working substations exhibiting in some cases even negative excess flow at the end of the list.

The drawback of the excess flow method is, that RRT is a desired return temperature, which is chosen without knowing, if it could be achieved in reality. However, it gives a clear indication about such substations, which one should have a closer look at, because their contribution to the excess flow is significant.

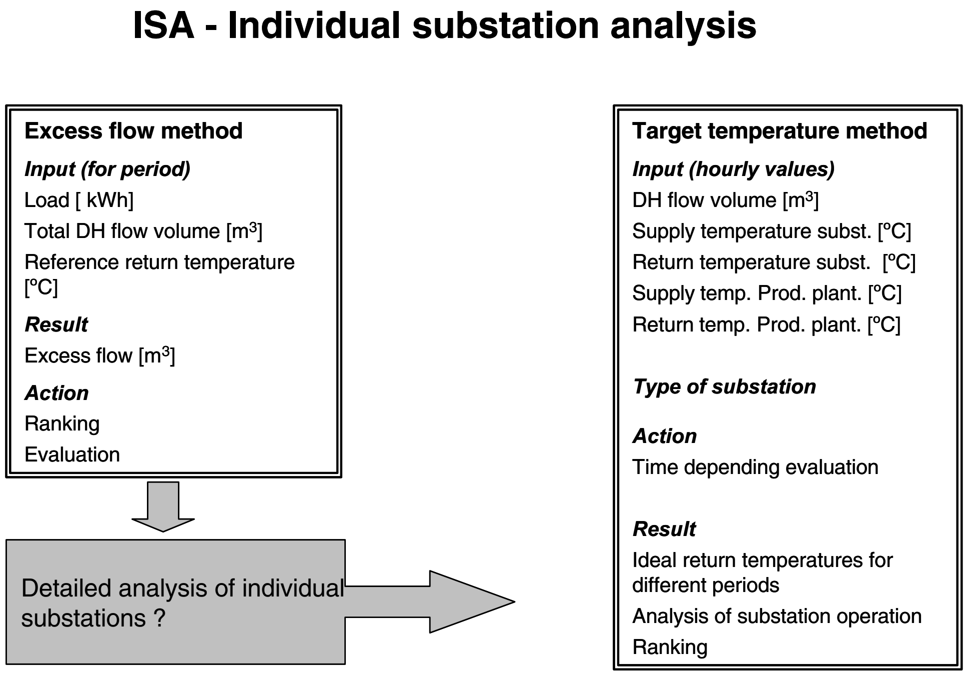

Figure 3.4-1: Flow chart for Individual Substation analysis ISA

Necessary inputs

- Primary mass flow
- Primary energy to substation
- User defined reference return temperature

Excess flow ranking

A ranking list for substation is established as shown in Appendix 3 and 4. The ranking is according to the difference of actual volume flow minus the volume flow RRT for each substation, i.e the excess flow.

Substations with high volume flows either have high heating power, low cooling ability, or in the worst case both. In any case, they contribute significantly to the actual return temperature of the system.

The ranking gives an indication about which of the substations are very important for the potential decrease of the return temperature in the network. The worst substations will be analysed further by means of the **Target temperature method**.

3.4.5.2 Individual Target return temperature evaluation of substations

This part of the analysis gives an indication about the return temperature that should (can) be reached with each of the critical substations. Each substation is compared with the result of a theoretical model of the generic type of substation in question, i.e. in our case one-stage or two-stage parallel substations.

Necessary inputs

All data inputs according to chapter 3.4.3 as described above based on a longer period, for example one year.

Target temperature analysis of individual substations

Now the method described in chpt. 3.3 is consequently applied. That means that - presumed that input data is available; a TRT analysis is made for a complete year of operation. In detail, the following analyse are performed:

- The measured return temperatures of each substation are compared with the theoretical return temperatures that are used as target temperatures.
- Return temperatures can be weighted for certain periods in order to indicate behaviour for typical periods, such as summer, winter, night or daytime. This will analyse the function of hot water and radiator unit, respectively, of the substations.
- New excess flow based on the *target temperature varying with time* is calculated for each substation.
- Recommendations for further improvements are given. The model returns possible target temperatures, which should be reached for each of the investigated substations.

3.4.6 Example of application of the ISA method

The combined ISA method is now applied on substations in the Cheongju district heating net. This chapter is therefore linked to the results partially presented in Section 4.1 and therefore only the main results are presented here.

3.4.6.1 Excess flow method

The first step in the ISA analysis is to perform the Excess flow analysis according to Chapter 3.2.

The district heating net of Cheongju is analysed during four 3-month periods in order to get a time resolved excess flow ranking. In this ranking, it was assumed that the average net temperature could be decreased by 5°C. This means in principle that the following return temperatures are envisaged:

Table 3.4-1: Return temperatures in the Cheongju net

Period	**Existing T_{ret} 2002/2003 °C**	**Target reference temperature TRT °C**
December - February	52,1	47,1
March - May	50,7	45,7
June - August	61,3	56,3

In Table 4.1-5 of chapter 4.1, a list of the most malfunctioning substations is presented based on the evaluation of different 3-month periods. This table is reproduced here for the sake of completeness. In the next to the last column of this table, the excess flow sums for a 9-months period are shown. An extended list of the excess flow for all four periods and for the complete year is shown in Appendix 3-2. Comparison of the excess flow results from different periods makes it evident that three types of malfunctioning substations exist:

Malfunctions in winter time → problem with space heating system

Malfunction in summer time → problem with domestic hot water system

Malfunctioning over a whole year → general problem with substation.

Table 3.4-2: Comparison of substations under different seasonal conditions in Cheongju: June 2003– August 2003 and total season

Supply temperature	99,1°C	Average calculated Ä T	37,8°C
Calculated return temperature	61,3°C	Reference Ä T	48,0°C

No.	Nb. of sub-units	Maximum power [kW]	ÄT [°C]	Heat [kWh]	Flow [m³]	Excess flow [m³]	Sum excess flowDec – Aug [m³]	Malfunction period
C43	1	767	10,0	366716	32149	25 440,8	74763,4	A
C67	3	1 436	17,6	172436	8603	5 448,6	19190,1	S
C63	1	532	3,5	20265	5056	4 685,6	16697,6	S
C41	1	372	15,4	111630	6356	4 314,1	25153,9	A
C104	1	902	3,6	17662	4337	4 014,2		S
C20	1	1 634	25,3	199045	6911	3 270,2	9836,2	S
C91	1	4 398	32,6	369970	9973	3 205,5	8631,7	S
C8	4	715	19,4	110503	4989	2 967,4	3607,1	S
C17	5	1 391	22,2	138506	5473	2 939,3	15789,9	A
C2	2	1 378	28,5	197302	6086	2 476,4	5682,4	S
C65	1	2 749	33,0	279685	7439	2 322,4	34017,8	A
C51	1	3 204	40,9	280498	6024	893,1	19739,7	W

Code

A	Highest total overflow all seasons
S	Bad function in summer
W	Bad function in winter

By analysing all the periods and a fourth one, i.e. that for September –November 2003, the following ranking of substations with excess flow larger than 10 000 m³/year on an all year basis was found, Table 3.4-3.

Table 3.4-3:List of substations with high excess flow

No.	Excess flow [m³]	No.	Excess flow [m³]
C43	85133,5	C21	16849,9
C63	41958,4	C30	16128,6
C41	33134,3	C67	15491,1
C20	28292,9	C51	13650,2
C8	26263,5	C60	13193,3
C65	24926,7	C49	12834,7
C31	21685,2	C89	12339,0
C17	18900,4	C91	11913,4
C32	17631,1	C7	11021,8

Because it was not possible to deal with all of those substations showing high excess flow during this project, a priority list with substations to be improved within this project was established (see Table 4.1.7 in Chapter 4.1).

By means of the Target temperature method (TRT-method), it was expected that further details about the malfunctioning substations could be revealed.

3.4.6.2 Target temperature method

In order to apply this method, the following hourly values were available for all but about 20 substations:

- *Delivered heat, volume flow and Ä T for the most interesting substations*

Furthermore, the following plant production data were available:

- *Supply temperature, return temperature, outdoor temperature, supply pressure and return pressure.*

With these inputs, a list with the following hourly values can be calculated for each of the substations with available data can be calculated:

- *Avg Load* *[kW]*
- *Total Heat* *[MWh]*
- *Avg return temp* *[°C]*
- *Avg TRT* *[°C]*
- Avg Flow [m³/h]
- *Total Flow* *[m³]*
- *Avg Excess flow* *[m³/h]*
- *Total Excess flow* *[m³]*
- *Relative Excess flow.* *[%]*

In Appendix 3-3, a complete list of TRT-method data for Cheongju is shown.

A part of it, i.e. the substation ranking and the conclusions, which can be drawn for the different periods, are shown in Table 3.4-4.

The table presents results ranked according to the annual excess flow of the substations. Note that the excess flow in this case is based on the individual performance conditions of each substation, i.e the target return temperature TRT of each type of substation, single- or two-stage.

It gets evident that about 15 substations have very large excess flow on the annual basis. As can be expected, most of them are performing badly during wintertime, the time when the load is large and therefore their contribution to the annual excess flow is high. The columns shadowed in dark-grey show the wintertime ranking of the substations and it can be seen that they agree quite well with the top-listed substations of the all-year ranking. The shadow-marking of the cells indicates such cells, which have an excess flow higher than 10 % of the maximum excess flow of worst working substation for each period. As can be seen, in both the summer and the winter case, the number of shadowed cells is smaller, indicating that “top-malperformers” exist in both periods; i.e. there are substations with problems in the radiator system and others with problems in the hot water system. In the transition seasons spring and fall, the peak excess flows are not so pronounced.

Compared with the results of the Excess flow method, we can state that the worst performing substations have been found in both methods. Hence, C 43, C65, C41, C51, C67, were highly ranked in both methods. The substations C63 and C17, which were ranked highly according to the excess flow method, are further down in the TRT-list. However, other substations are turning up in the latter. Those are C42, C49, C56, C57, C58, C66 and C68 on an all-year basis, which mostly reflects winter operation. Among the new stations not top-marked in the excess flow method for summer operation are C50, C79, C80, C81, C88, C103, C105 and C108.

Table 3.4-4: Summary of ranking of the function of the substations in Cheongju according to their ***excess flow*** *under different periods. (ID = identification number of substation)*

All year		Mal-function			December - Februray		March- April		June - August		September-November	
ID	Exc. flow [m³]	W	S/F	S	ID	[m³]	ID	[m³]	ID	[m³]	ID	[m³]
C51	186586				C51	136760	C88	8910	C43	10805	C88	3413
C65	156188				C65	120070	C43	7092	C81	4762	C43	2274
C56	134221				C56	94444	C65	5655	C105	2784	C90	2174
C58	120156				C43	77009	C90	5192	C41	2743	C100	2068
C43	111127				C58	75523	C91	3564	C50	2462	C41	1859
C68	91876				C57	67133	C41	3143	C108	2095	C51	1552
C57	87444				C68	61690	C31	2983	C63	2071	C65	1466
C67	80622				C67	57086	C32	2630	C103	1807	C63	1382
C66	68334				C66	45722	C51	2435	C79	1807	C32	1210
C41	55106				C41	39880	C67	2282	C88	1648	C31	1194
C49	49850				C64	24095	C57	2213	C67	1420	C99	1181
C42	42552				C42	20155	C84	2077	C20	1165	C20	1159
C46	41736				C63	16095	C100	2024	C91	1120	C91	1005
C64	40016				C49	15346	C89	2018	C65	1114	C107	788
C88	32754				C90	13920	C66	1991	C17	805	C89	779
C90	24700				C88	12836	C63	1663	C99	598	C44	738
C44	23537				C46	10497	C99	1642	C64	503	C21	702
C63	20532				C44	8259	C21	1634	C60	503	C49	667
C45	16487				C84	8025	C30	1633	C89	466	C17	602
C69	14246				C32	7772	C17	1543	C51	423	C60	583
C32	13377				C69	6598	C73	1531	C31	422	C30	496
C84	12591				C73	6567	C20	1435	C58	347	C52	392
C31	12570				C59	6475	C42	889	C32	338	C67	358
C91	11743				C89	5866	C56	831	C21	267	C84	204
C105	11050				C31	5598	C70	750	C84	265	C35	180
C62	10833				C91	5279	C64	644	C4	204	C42	69
C89	10241				C45	4673	C3	580	C2	189	C38	-3
C73	10092				C70	4511	C92	546	C92	139	C45	-35
C100	9786				C3	4376	C44	466	C27	124	C77	-68
C50	9774				C92	4083	C74	443	C90	88	C57	-81
C30	8572				C30	3539	C33	392	C12	79	C66	-86
C79	7172				C75	3307	C2	295	C77	64	C48	-87
C17	7135				C81	3153	81	113	C101	64	C102	-96
C59	6824				C87	2976	C5	-6	C5	-12	C56	-100
C3	6470				C62	2784	C38	-12	C30	-21	C73	-144
C20	6469				C17	2683	C77	-20	C57	-144	C81	-144
C21	6375				C83	2634	C102	-62	C8	-225	C64	-179
C70	6020				C100	2586	C62	-78	C33	-255	C62	-210
C92	5648				C21	2568	C45	-104	C56	-262	C94	-228
C81	5619				C33	2342	C52	-152	C59	-289	C46	-237
C99	5272				C20	2329	C58	-204	C6	-360	C33	-246
C33	3663				C5	1901	C98	-209	C14	-374	C106	-296
C103	3605				C86	1758	C27	-374	C66	-377	C78	-309

Malfunction: W = winter, S/F = spring/fall, S = summer

This means that each method contributes with different priorities due to the selection of the return temperatures. The excess flow method uses a return temperature lowered by a certain amount, for example 5°C. The target return temperature method calculates an ideal individual return temperature for each substation based on an optimal working substation.

However, the worst cases have been identified with both methods. *Hence, we can conclude that both methods work well for the most seriously malfunctioning systems, whereas the TRT-method can serve to identify substations, which considerably deviate from the ideal behaviour but not necessarily have to show the gravest impact on the net's return temperature.*

3.4.6.3 Excess flow as a function of return temperature and heating capacity

As a consequence of the TRT-method, some more system variables are available besides the excess flow, f. i. maximum supplied power of the substation and the actual or the average return temperature. The reason for high excess flow is either a high heating capacity (load) of the substation or substations with a malfunctioning component or with inadequate design of the secondary circuit, either space heating or domestic hot water, or both.

The connection of the excess flow on the one hand and heating capacity and return temperature on the other hand can be seen from the next two diagrams of Figure 3.4-2.

From Figure 3.4-2a, it can be seen that in general, the high excess flows are caused by the large substations with high heating capacity. In these cases, substations working on only slightly elevated return temperatures can cause high excess flows. However, the Figure 3.4-2b shows also, that in some exceptional cases high excess flows are due to unreasonably high return temperatures of substations with lower heating capacity. The numbers of some substations with the highest excess flow are indicated in the diagram. To the right of the dashed line, malfunctioning sub-stations show high return temperatures. To the left, they usually have high heating capacities. A combination of both - in the middle-range - results in the highest excess flows.

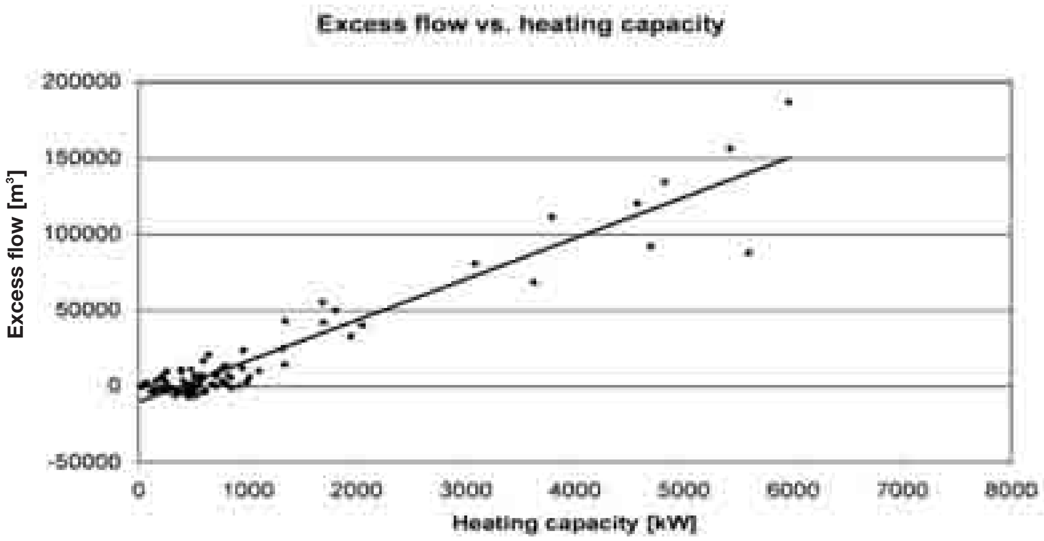

Figure 3.4-2a: Excess flow as a function of the heating load for substations in Cheongju.

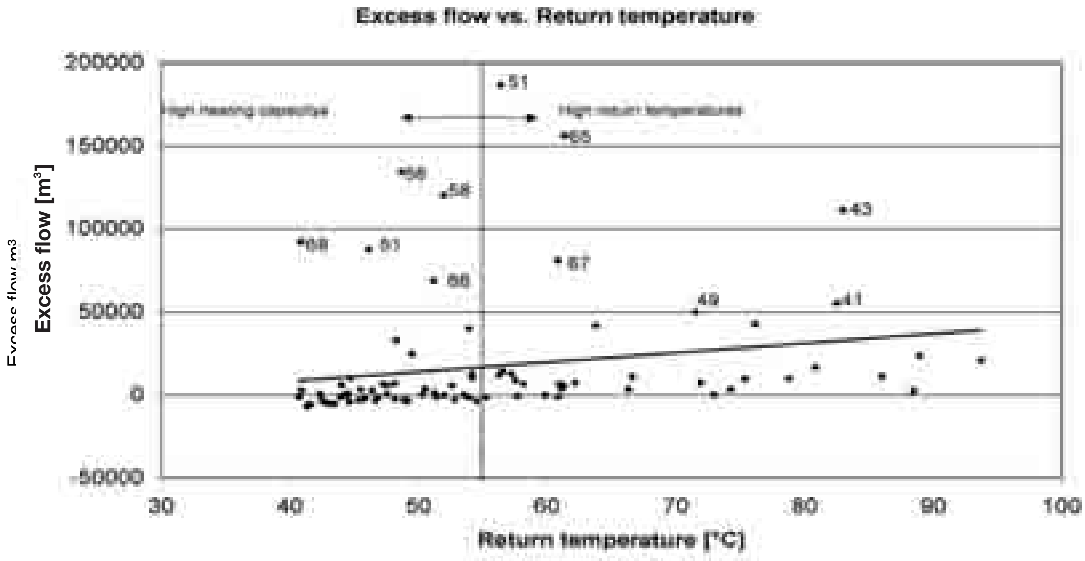

Figure 3.4.2-b: Excess flow as a function of return temperature. In the diagram, also the substations with high return temperatures are indicated.

3.4.7 Discussion of the combined individual substation analysis ISA

By supplying district heat, the energy company has a responsibility to supply the customer with heat under economic and reliable conditions. The customer pays an adequate price for both the energy supply and for the fact that the energy is supplied at his conveniance, as far as quantity and time are concerned. There are two facts, which can disturb this order.

One is that the supplier sees that he is not delivering the energy in an optimal way. Either he does not make the best use of his net, i.e. he is not using the full capacity of his net, or he does not make good use of his production plant, that means he is not producing heat in the most efficient way. In both cases, the return temperature of the net can be the reason.

A simple analysis of the *excess flow* based on summary data for a given period can soon bring an answer about which substations should be dealt with in order to bring down the return temperature some degrees. For this, the **excess flow method** is a very effective tool.

However, in order to understand, which parts of the substation, space- or hot water heating, is malfunctioning, and which return temperature the substation ideally could deliver, the **target return temperature method** is a good tool for an individual analytic approach for malfunctioning substations. The supplier gets a better understanding about what could be expected and some hints about, where to increase efforts. In particular, the supplier can get hints about how the space heating or the hot water systems are working and - in the best case - some first indications for the type of malfunction.

The **target return temperature method** is also of special importance, if a district heat customer suffers comfort problems. In this case, a detailed analysis of the hourly measurement data over the year can give a deeper insight into the function of the substation and gives a good support for further repair or new design of the substation. Analysis results will also be advantageous in the discussion between supplier and customer. This discussion will be necessary in all such cases where the supplier will take influence on the customer owned substation for securing that the substation, in combination with the secondary system, works as efficient as possible.

4 Field applications

Summary

In the first part of this Section, the selected Korean DH-net of Cheongju, including heating plant, substations and the data evaluation system are described. The relatively new Cheongju CHP plant was selected for being a smaller, but an appropriate representation of KDHC district heating, well suited for further evaluation. TRT-method evaluations and results from improvement of the cooling ability of some selected substations of the Cheongju district heating are presented.

In the second part, the district heating system of Skogas and the evaluated substations are described. The excess flow method is used for the evaluation of all the 25 selected substations, as well as for the evaluation of improved substations after repair.

4.1 Field applications: Cheongju – district heating

4.1.1 Cheongju CHP Plant

Cheongju CHP plant is located at the outskirts of the newly developed city-area and supplies heat to new areas such as Bunpyong, Yongam, Habokdae. By December 2002, district heating services are supplied to 29,875 households and the power plant delivered power to the public grid.

Figure 4.1-1: Cheongju CHP plant (First heat supply date: May, 1997)

4.1.1.1 Heat Production Facility

The production plant of Cheongju is comprised of a cogeneration boiler (CHP), a heat-only boiler (HOB) and a heat accumulator with following capacities:

CHP: Heat production: 120 MW_{th}, - Electricity output: 61.4 MW, oil-fired.

HOB: 2 x 90 MW_{th}.

HOB is used as supplementary heat source. HOB uses LSWR (Low Sulphur Waxy Residue) as main fuel and diesel oil as alternative fuel during start-up.

Heat accumulator: 20,000m^3.

The heat accumulator is designed to charge surplus heat produced from the CHP-plant at night and to discharge the heat during daytime in winter and spring/fall seasons.

4.1.1.2 Distribution net

The distribution network in Cheongju is comprised of 53 km trench length with pipe dimensions between DN 850 and DN 22 mm. Standard pipe technology with preinsulated pipes is used. The design supply temperature is 120°C and return temperatures are between 45 and 60°C. Design pressure is 16 bar. The heat is supplied to five districts as shown in Table 4.1-1.

Table 4.1-1: The different heating districts of Cheongju

Region	Region name	Number of Consumer	Maximum power (MW)	Households
	Habokdae	13	27	4,037
	Gaesin,Chungbuk University	19	38	4,919
	Bunpyong	27	74	11,665
	Yongam	15	48	6,940
	Sannam	5	14	2,314
Sum		79	200	29,875

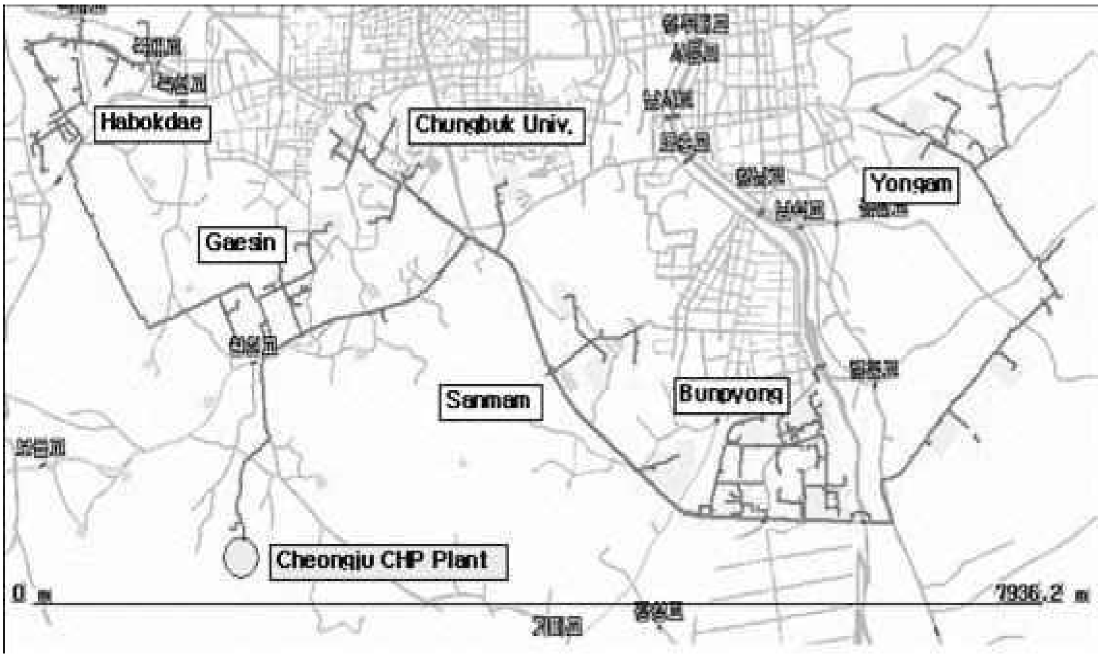

Figure 4.1-2: Cheongju branch network configuration

4.1.1.3 Customer substations

In Korea, the delivery point of district heat is the primary shut off valve located 2 m outside of the buildings ground wall closest to the consumer's heat exchanger. The heat supply equipment beyond this valve belongs to the property owner, except heat meter and leakage detection equipment.

Usually, the customers can be grouped into three categories such as apartments, public buildings and commercial buildings, see Table 4.1-2.

Table 4.1-2: Typical uses of public and commercial buildings:

- Living facility: Apartment managing office, social welfare facility, workshop.
- Public facility: Local office, fire station, police station, post office, etc.
- Churches.
- Facilities for young and old: Kindergarten, home for elderly people.
- Hospitals.
- Educational and institutional facilities: School, education institute, job training places.
- Office and service centres.
- Hotels.

- Supermarkets and shops.
- Saunas and bath facilities.
- Theatre and cinema.
- Exhibition and museum.

Customer substations are sized differently for the different applications listed above. However, most of them have the same type of substation: Single-stage parallel connected or two-stage substations (see Appendix 1) are the most common types in the Cheongju net. An exception are substations for sauna and bath facilities installed before 2000, which normally use parallel connection when combined with hot water storage (see also Appendix 3.1 for a complete list of the substations in Cheongju).

4.1.1.4 Operation of the district heating system

In the Cheongju net, a total of seven critical control devices are in place for safe operation of the net. These devices either control the temperature difference or the pressure difference in order to ensure that adequate power is available to the most distant customers at all times. The control readings are transmitted by the distribution control system (DCS) to the control room of the heating plant. Consistent real time pressures and temperatures are sustained by adequately changing speed of the circulation pumps.

4.1.2 The data evaluation system

The data measurement system consists of heat meter, remote metering device and public phone line, see Figure 4.1-3.

Figure 4.1-3: Remote metering system for heat load at customer

The heat meter equipment is specified as follows:

Flow meter:

Medium: Warm water

Type: Impeller type flow meter

Design criteria: Pressure 16 bar; temperature 120°C; resolution 6 digits.

20 - 40 Apartments: 10 litre/pulse

50 - 125 Apartments: 100 litre/pulse

150 - 200 Apartments: 1000 litre/pulse.

Temperature sensor:

Two paired sensors, RTD (PT 100, 0°C) Range of temperature measurements: 0 –150°C.

Integration unit:

Input signal: Volume flow – pulses.

Pulsed temperature sensor signal: RTD (PT 100, 0°C) for supply and return lines

Unit: Gcal, 6 Digits.

Temperature difference between supply and return: Maximum 80°C; minimum 3°C.

4.1.2.1 Installation Status in KDHC

- Remote Metering Controller: 2,556 units
- Local computerised control Systems: 11 units.

This remote metering device allows the main control room to check and record the amount of heat consumption and the current state of heat meters at the customer-site in order to prepare invoices automatically. The signals are transmitted through the public telephone network. The power source of the substation management and of the measurement system is AC 220V and connected to the customer's outlet. In case of power failure, the metering systems operates normally for 24 hours after power outage by means of an inside battery. Data on the spot is conserved semi-permanently by a lithium battery.

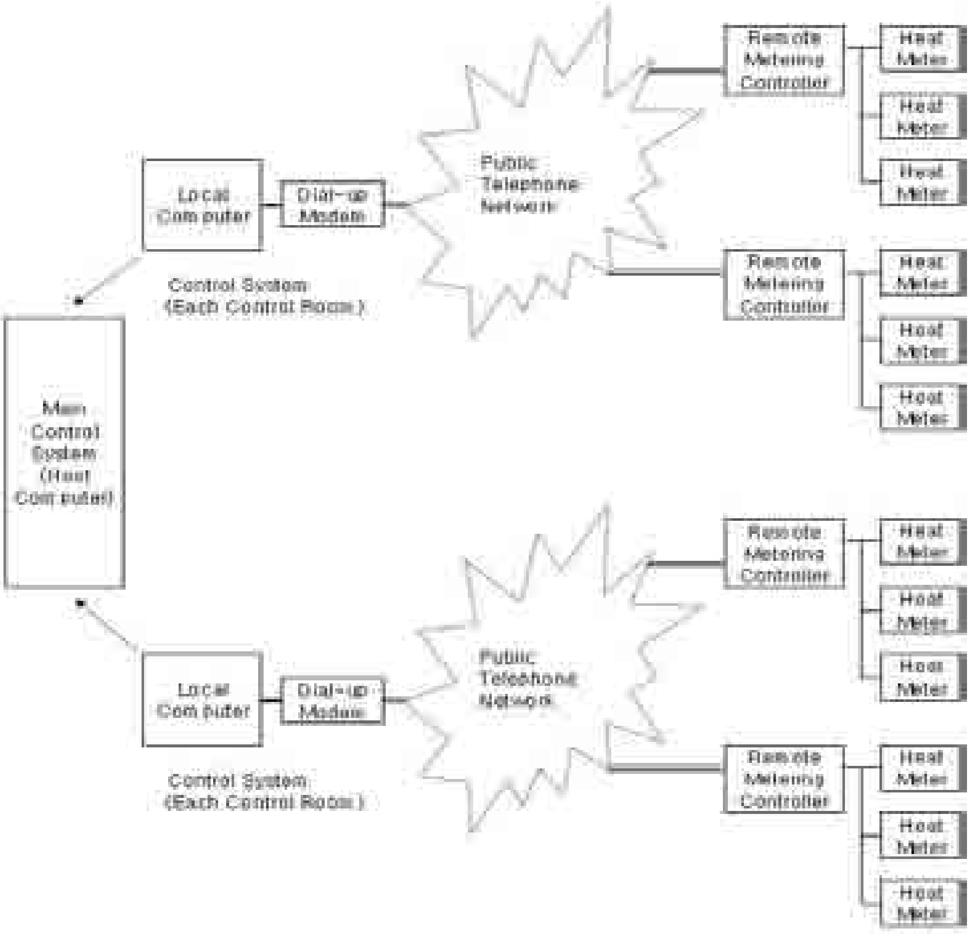

Figure 4.1-4:The remote metering system of Cheongju

4.1.3 The heat load and heat supply at the Cheongju plant

From Figure 4.1-5, the supplied energy can be seen. It becomes obvious, that the climate of Cheongju quite similar to the climate in European countries: A large amount of heat is delivered to apartment buildings, the remainder to public and commercial customers. Summers have a low heat load and winters are cold. That means that the heat load differs a lot between summertime and wintertime as can be seen from Figure 4.1-6.

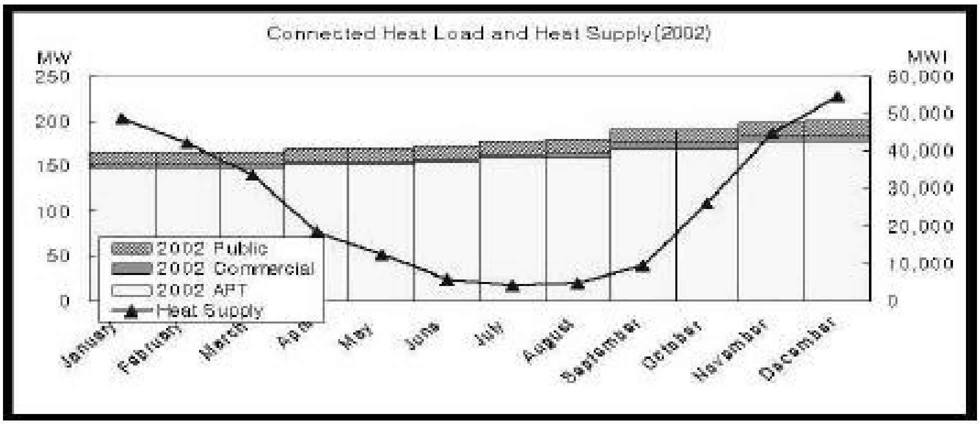

Figure 4.1-5: Heat Supply during 2002

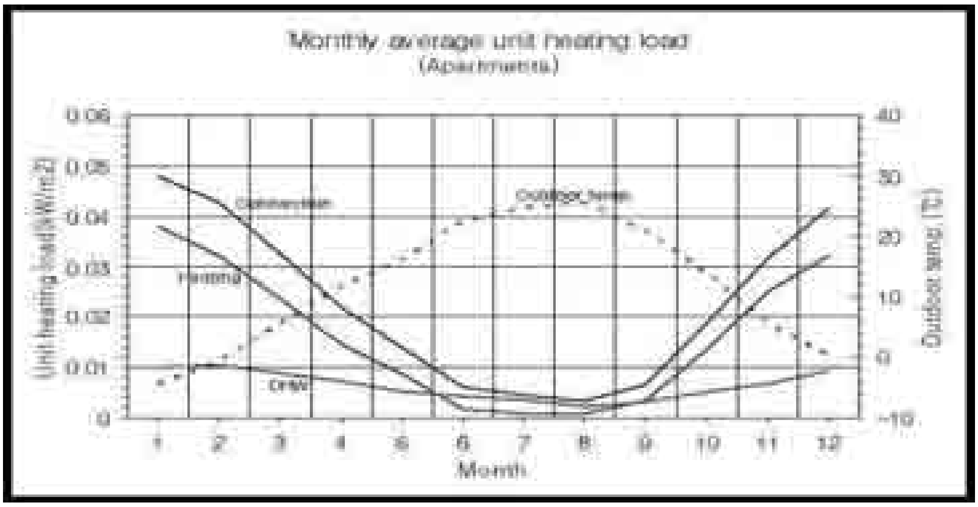

Figure 4.1-6: Specific heat load for apartments

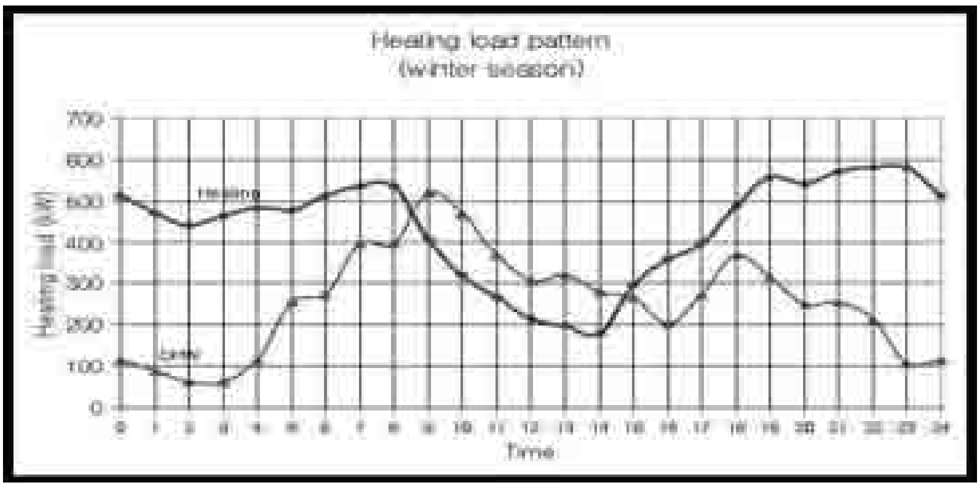

Figure 4.1-7: Heating and hot water load pattern (winter)

The load pattern is also different in summer and winter. The hot water demand peaks in the morning, while the heating demand is highest at night and at its minimum at noon (wintertime), as shown in Figure 4.1-7.

During spring and autumn, the heating needs are quite low and the hot water load dominates (Figure 4.1-8). In summertime, hot water is primarily supplied, but absorption cooling driven by district heating is supplied as well, but so far at to a limited level.

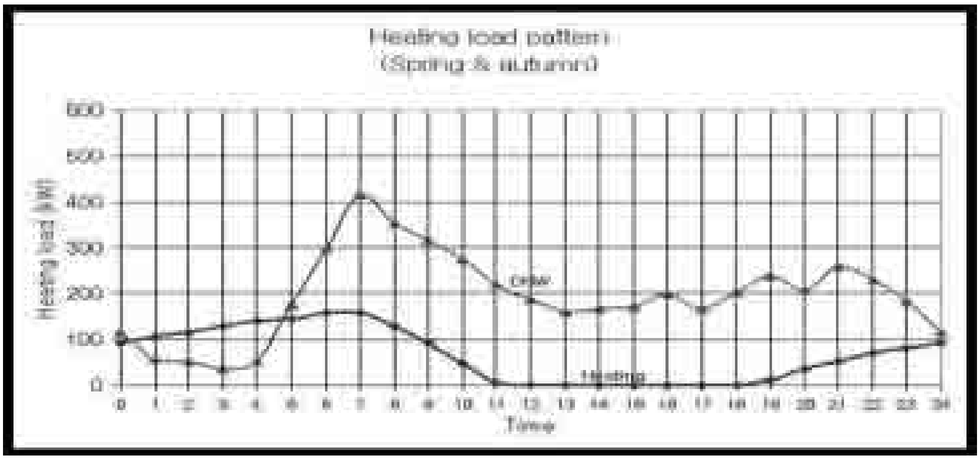

Figure 4.1-8: Heating and hot water load pattern (spring and autumn)

However, this absorption cooling requires relatively high supply temperatures in the summertime. Therefore, the supply temperature is almost constant 100°C all the year round (Figure 4.1-9), also resulting in high return temperatures.

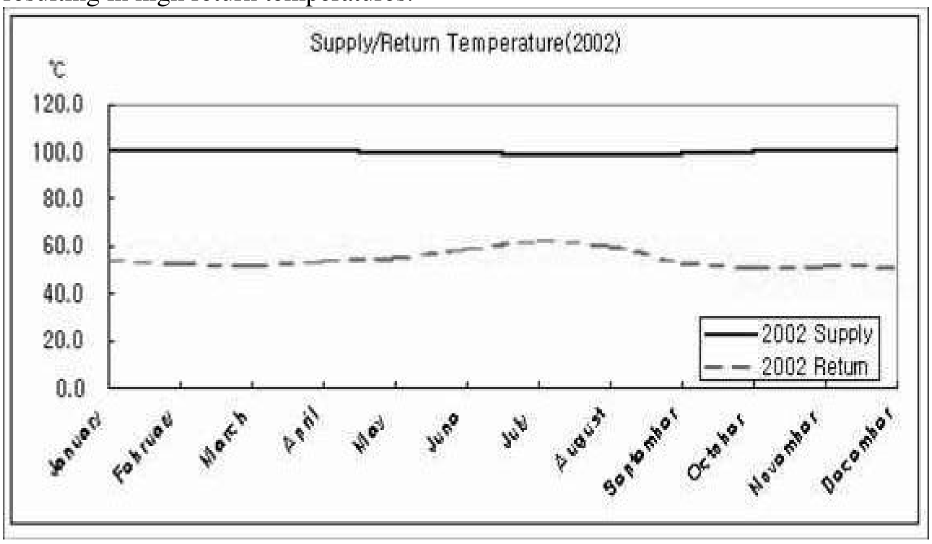

Figure 4.1-9: Supply/return temperature, Cheongju

4.1.4 Excess flow evaluation

4.1.4.1 Comments to the excess flow lists

In this chapter, the use of the excess flow method is exemplified by evaluating some substations in the Cheongju network. The evaluation was done for three periods, three months each.

Note: Substations in the Cheongju net are denoted with C, for example C43, C67 and so on.

The substations with the highest excess flow in the summer period are the numbers C43, C67, C63 and C41. It can be seen in Table 4.1-3 to Table 4.1-5 that C 43 has the highest excess flow in all three periods. It is a sauna with relatively low ÄT, especially in the summer time. Many of the other substations have a lower excess flow in summer than in winter, indicating that many problems are caused by the radiator system, which also normally has a large heating capacity. However, two substations show a high excess flow in the summertime: C63 and C104. Both of them are schools and the temperature difference is only about 3,5°C. There is probably a bypass valve installed by the customer just to circulate water. C63 is also very bad in the wintertime.

Table 4.1-3: Comparison of substations under different seasonal conditions in Cheongju: December 2002– February 2003

Supply temperature	101,0°C	Average calculated Ä T	48,9°C
Calculated return temperature	52,1°C	Reference Ä T	54,0°C

No.	Number of Substations	Maximum power [kW]	Ä T [°C]	Heat [kWh]	Flow [m³]	Excess flow [m³]	Malfunction period
C43	1	767	22,5	1 019 044	39 769	23 198,7	A
C65	1	2 749	37,4	2 543 426	59 712	18 355,3	W
C51	1	3 204	40,5	2 915 720	63 276	15 866,1	W
C41	1	372	17,0	363 149	18 789	12 884,0	W
C90	1	4 616	46,5	4 859 108	91 701	12 690,8	
C32	1	3 388	41,5	2 518 560	53 299	12 346,9	
C31	2	2 114	45,5	2 458 835	47 407	7 426,2	
C67	3	1 436	41,5	1 444 207	30 549	7 066,2	S
C63	1	532	17,4	180 546	9 118	6 182,3	S

Table 4.1-4: Comparison of substations under different seasonal conditions in Cheongju: March 2003– May 2003

Supply temperature	100.0°C	Average calculated ÄT	49.3°C
Calculated return temperature	50.7°C	Reference ÄT	54.0°C

No.	Number of Substations	Maximum power [kW]	Ä T [°C]	Heat [kWh]	Flow [m³]	Excess flow [m³]	Malfunction period
C43	1	767	13,9	551 120	34 832	25 871,0	A
C65	1	2 749	33,6	1 312 556	34 295	12 952,1	W
C41	1	372	18,5	252 112	11 981	7 881,2	W
C67	3	1 436	34,9	726 461	18 273	6 460,6	S
C63	1	532	9,1	72 123	6 981	5 808,4	S
C31	2	2 114	41,4	1 166 032	24 755	5 795,5	W
C32	1	3 388	44,2	1 224 131	24 307	4 402,2	W
C90	1	4 616	50,3	2 318 702	40 489	2 786,8	W
C51	1	3204	47,8	1 240 282	22 781	2 613,8	W

Another substation working poorly in summer and winter is C67. However, the cooling ability drops most during summer, which indicates that there is a problem with the hot water production. A similar problem might be occuring in C7. Both substations are connected to apartment buildings. Other stations that exhibit high excess flow in the wintertime are C65, C41 and C51. C65 is a substation for a large apartment building. The cooling does not seem to be too bad, around 35°C, but because of the size of the substation, any effort to increase the cooling would be worthwhile. C51 is also a large substation for an apartment building contributing with a high overflow in wintertime.

The last column in Table 4.1-3 denotes the worst operating period of the sub-stations. A denotes worst conditions of the year, and S and W denote substations working worst during wintertime (W) and summertime (S), respetively.

In Table 4.1-5, prepared for the period from June to August and the sums for all three periods (Dec 2002 – August 2003) are shown. From these results, the following ranking of the substations over all weather conditions can be established:

Substation with high excess flow: C43 – C65 – C41 – C51 – C63 – C67 – C17.

It should be mentioned that the reference return temperatures are chosen to be 5°C lower than the return temperature at the heating plant. From the excess flow lists one can see that the return temperatures at the evaluated substations are much higher during summertime than the average return temperature at the plant. It is difficult to find the reason why this is so, but evidently the remaining substations, which were not evaluated, have a better cooling performance. The calculated average of all evaluated substations is 61,3°C, whereas the mean return temperature at the plant was 56°C.

Table 4.1-5: Comparison of substations under different seasonal conditions in Cheongju: June 2003– August 2003 and total season

Supply temperature	99,1°C	Average calculated Ä T	37,8°C
Calculated return temperature	61,3°C	Reference Ä T	48,0°C

No.	Number of Substations	Maximum power [kW]	Ä T [°C]	Heat [kWh]	Flow [m³]	Excess flow [m³]	Excess flow Dec. – Aug. [m³]	Malfunction period .
C43	1	767	10,0	366716	32149	25 482,4	74552,1	A
C67	3	1 436	17,6	172436	8603	5 468,2	18995,0	S
C63	1	532	3,5	20265	5056	4 687,9	16678,6	S
C41	1	372	15,4	111630	6356	4 326,8	25092,1	A
C104	1	902	3,6	17662	4337	4 016,2		S
C20	1	1 634	25,3	199045	6911	3 292,9	9836,2	S
C91	1	4 398	32,6	369970	9973	3 247,5	8631,7	S
C8	4	715	19,4	110503	4989	2 980,0	3607,1	S
C17	5	1 391	22,2	138506	5473	2 955,1	15610,6	A
C2	2	1 378	28,5	197302	6086	2 498,8	5682,4	S
C65	1	2 749	33,0	279685	7439	2 354,2	33661,6	A
C51	1	3 204	40,9	280498	6024	925,0	19404,9	W

Code

A	Highest total overflow all seasons
S	Bad function in summer
W	Bad function in winter

The excess flow list for the period September – November 2003 is shown in Table 4.1-6. As before, the substation for the Sauna C43 exhibits the highest excess flow, but in late autumn the cooling obviously gets somewhat better than during the hot summer period because a heating load is added to the hot water load. Another poorly working substation is C63, which is a school. As before, this substation continuously has a very low cooling ability, which is around 7°C in this period.

Other substations with low cooling ability especially during the wintertime are C41, C20, C8 and C65. In addition, C31, C32, and C17 (earlier seen working bad summer time) are among the malfunctioning substations.

From this table one can also see that there are some other substations with relatively low cooling ability (< 20°C). However, their total annual loads are not that high, and therefore they are not assigned top ranking. One of these stations is C60, which serves a public building. This substation has very low cooling in the wintertime, the temperature difference is only around 12°C.

Table 4.1-6: Excess flow substation September - November 2003

No.	Number of sub-stations	Maximum power [kW]	Ä T [°C]	Heat [kWh]	Flow [m³]	Excess flow [m³]	Malfunction period
C43	1	767	25	547 402	19 180	10 581,4	A
C63	1	532	7	46 665	5 916	5 182,8	S
C41	1	372	20	170 414	7 376	4 699,1	A
C20	1	1 634	37	555 652	13 349	4 621,4	S
C8	4	715	34	374 501	9 631	3 748,0	S
C65	1	2 749	44	792 228	15 935	3 491,4	A
C31	2	2 114	45	857 182	16 868	3 403,5	W
C17	5	1 391	40	466 064	10 176	2 854,9	A
C32	1	3 388	47	941 889	17 642	2 847,6	W
C21	2	1 592	42	521 606	11 006	2 812,7	
C30	1	1 511	43	606 895	12 284	2 751,3	
C67	3	1 436	42	471 874	9 971	2 558,9	S
C51	1	3 204	48	976 400	17 881	2 544,4	W
C60	1	345	12	43 702	3 156	2 469,2	

4.1.5 Description and analysis of substations with high excess flow

In this chapter, a more detailed investigation of substations with high excess flows will be presented. These substations and their malfunctions are briefly described. Table 4.1-7 shows a list with critical substations as identified in the chapter above. Most of the earlier built substations are of the parallel type. However, since 2001, two-stage type substations have been installed in buildings with heat loads larger than 200 kW. In Saunas and bath facilities, single-stage or two-stage substations with hot water accumulators were installed. (See Appendix 1 for the different types of investigated substations).

With the excess flow list such as Table 4.1-5 as guidance, a team of technicians was checking the substations with high excess flow and found the operational problems listed below.

Table 4.1-7: List of malfunctioning substations

No.	Number of Substations	Maximum power [kW]	Ä T [°C]	Heat [kWh]	Load	Type	Malfunction period
C43	1	767	10,0	366 716	Sauna	2-stage	A
C67	3	1 436	17,6	172 436	Apartment	Parallel	S
C63	1	532	3,5	20 265	School	Parallel	S
C41	1	372	15,4	111 630	Sauna	Parallel	A
C20	1	1 634	25,3	199 045	Apartment	Parallel	W
C8	4	715	19,4	110 503	Apartment	Parallel	W
C17	5	1 391	22,2	138 506	Apartment	Parallel	A
C65	1	2 749	33,0	279 685	Apartment	Parallel	A
C51	1	3 204	40,9	280 498	Apartment	Parallel	W
C60	1	345	12	43 702	Public facility	Parallel	A

As a general problem, it turned out that in many cases control valves after some time are not functioning properly. Indeed, the fact that valves do not move or close properly is a significant mechanical failure. Either a leakage in the valve occurs or a bypass is opened in order to diverge the district heating water through the heat exchanger. The scheme in Figure 4.1-10 illustrates, how this bypass is used in Korean substations.

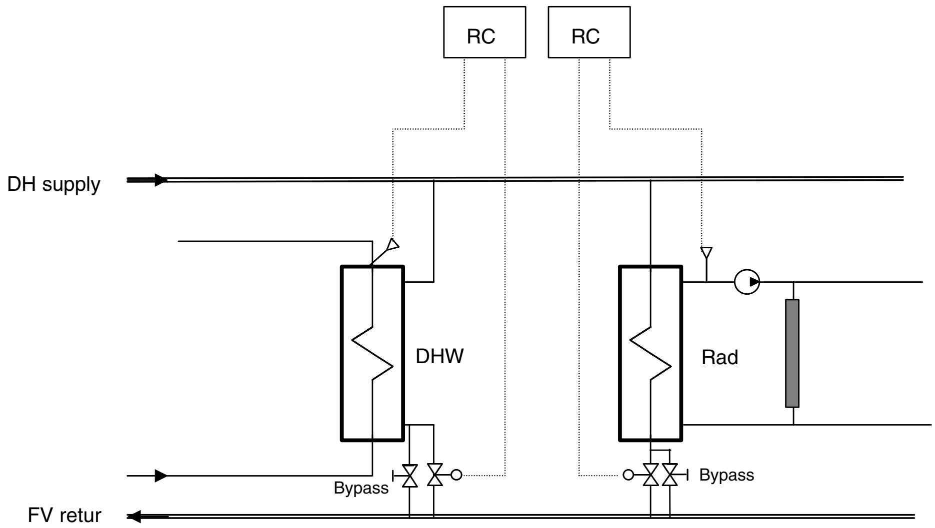

Figure 4.1-10: Use of bypass valves in Korean substations, both in radiator and DHW circuit

4.1.5.1 C43 - Eun Sauna

Type: Two-stage with hot water accumulator (Figure H1-10).

Load: Heating 200 kW, hot water 2 x 400 kW (70°C).

DHW-storage: 20 m³, supply temperature 70°C (sauna).

Malfunctions: Thermal control valves (TCV) (type Siemens).

Investigation and analysis

This substation is serving a public sauna building with high temperature water. Therefore, relatively large amounts of hot water loads can be drawn into the system and temperatures at the primary side can reach 70-80°C. During the on-site inspection, it was observed that the TCV did not close completely and therefore small leakage flows were prevailing under no-load conditions. The main problem was a loose connection between valve stem and actuator, which allowed a leakage flow through the valve resulting in high return temperatures.

Figure 4.1-11: The connection between valve stem and actuator

4.1.5.2 C67 : Gaesin Jugong 1 Apartment Substations-2, 3

Type: Three parallel connected substations for apartment buildings (Figure 1.1-1, Appendix1).

Load: Total design load 1400 kW.

Investigation and analysis

Sub – 3

Malfunction: Heating control valve

This substation is working badly in summer and winter.

Sub – 2

Malfunction: Heating and DHW TCVs.

The technical problems in both substations 2 and 3 are similar to the problems found in C43.

4.1.5.3 C63: JeungAhn Elementary school

Type: Parallel connected substation for school.

Load: Heating 500 kW; Hot water 150 kW.

Malfunction**:** By-pass valve (DHW-TCV) and electronic circuit board of actuator.

Investigation and analysis

This substation showed a cooling ability of less than 15°C. During on-site inspections, it turned out that a bypass valve (connected in parallel to the TCV for DHW) was manually opened. Valves bypassing the control valves have previously been common in Korea. The reason for this bypass was delivery assurance. However, they are not longer used in standard design since August 2001. In this case, the open bypass was initiated because of a failure in the electronic circuit of the actuator. However, the customer opened the bypass without notifying the DH-operator.

4.1.5.4 C41: OK Sauna

Type: Parallel connected substation with heat storage for sauna (Figure 1.1-9, Appendix1).

Load: Heating 50 kW; Hot water 400 kW.

DHW-storage: 15 m³; supply temperature 70 - 75°C (sauna).

Malfunction**:** Control valves.

Investigation and analysis

Hot water

This substation serves a sauna and exhibits a low cooling ability all year round. Similar to the Eun sauna, hot water storage was installed on the secondary DHW side to supply hot water to warm bath and showers. The set temperature of DHW is about 70 - 75°C. The main problem with these types of system is that the water in the hot water storages is continuously circulated and therefore delivers hot water back to the heat exchanger. A temperature controlled circulation system would assure stratification in the storage tank and hence a lower return temperature. With respect to risks for growth of Legionella germs, the bottom temperature in the hot water storage could be decreased at least to 55°C. It is planned to rebuild the system.

Heating

As in the case of Eun sauna, the reason for imperfect closing was a misfit of the connection between the valve stem and actuator. If the connection is not installed properly, the TCV actuator cannot guide the valve correctly, which results in excess flow and a high return temperature.

4.1.5.5 C20: Bunpyong 4-2 Apartment S-1

Type: Parallel connected substation for apartment building.

Load: Total design load: 1600 kW.

Malfunction**:** Hot water circuit.

Investigation and analysis

Figure 4.1-12 shows the DHW temperature status of this substation, which is serving a residential building. The secondary DHW supply temperature is about 90°C and the district heating medium leaves the heat exchanger also with 90°C.

As a result of the investigation, it turned out that the TCV for the DHW preparation was bypassed, i.e. the substation was operated abnormally in order to ensure delivery to the highest floors of the building (20-stores). The DHW control valve will be exchanged.

Figure 4.1-12: The temperature status of DHW (the secondary DHW supply temperature is 90°C)

4.1.5.6 C8: Bunpyong 3-1 Apartment S-4

Type: Parallel connected substation for apartment building.

Load: Total design load: 715 kW.

Malfunction**:** Hot water TCV.

Investigation and analysis

In this case, the mechanical malfunction of the TCV was also the main problem. The valve was not closing properly and therefore using too much DH water during lower loads.

4.1.5.7 C17: Bunpyong 5 Apartment S-5.

Type: Parallel connected substation for apartment building.

Load: Total design load: 1 400 kW.

Malfunction**:** Bypass valve in heating circuit.

Investigation and analysis

In case of this substation, DH water flow never stops completely throughout all seasons. By means of the function tests, it turned out that there is always a small flow through the heat exchanger, even when all TCVs and the by-pass valve for DHW are closed. The reason is a flow leaking through the bypass valve in the heating circuit (see Figure 4.1-13).

Figure 4.1-13: Bypass valve as part of the installation in C17 (large valve with steering wheel)

4.1.5.8 C51; Habokdae Samil Apartment S-1

Type: Parallel connected substation for apartment building.

Load: Total design load: 3 200kW.

***Malfunction*:** Radiator heat exchanger.

Investigation and analysis

This substation has high excess flows in the wintertime. The temperature difference is not so bad, around 40°C, but the total heating load is very high. Hence, even minor malfunctions can contribute significantly to the average return temperature. We suppose that there is a problem with scaling in the heat exchanger, resulting in high return temperature on the primary side.

4.1.5.9 C60; Workers Welfare Center S-1

Type: Parallel connected substation for service centre.

Load: Heating: 230 kW. Hot water: 150 kW.

***Malfunction*:** Control valves.

Investigation and analysis

This substation serves a public building. As shown in Table 4.1-6, it can be seen that this substation has a relatively low temperature difference from September 2003 to November 2003. The field inspection revealed that the control equipment, i. e. control valves for both heating and DHW circuits, are out of order and bypasses are activated manually. A repair is planned for this equipment.

4.1.6 Improvements

The examples of chapters 4.1.5.1 to 4.1.5.9 show that the excess flow list is very helpful in selecting important malfunctions of substations. Of course, after this simple way to identify malfunctioning substations, the main inspection work for identifying the type of malfunction has to be done on-site. After having identified the problems, they can be solved and the results should be noticeable in new excess flow lists established after the repairs.

4.1.6.1 Sauna (with parallel type heat exchanger)

In the following Table 4.1-8, improvement work on the above listed malfunction is presented. As we have seen, many substations have problems with the control valves. Another kind of problem refers to the design of substations for saunas, which includes hot water storage with high circulation flows.

Table 4.1-8. Improvements on malfunction

No.	Nb. of Sub-units	ÄT [°C]	Type	Malfunction types	Improvements
C43	1	10,0	Sauna	TCV failure Improper set points (DHW)	Repair Adjust set point
C67	3	17,6	Apartment	TCV failure	Repair
C63	1	3,5	School	TCV failure (DHW) Opening by-pass valve (DHW)	Change (Circuit board)
C41	1	15,4	Sauna	TCV failure Improper set points Wrong design (DHW)	Repair Adjust set point
C20	1	25,3	Apartment	Opening bypass valve (DHW) TCV	Adjust bypass valve
C8	4	19,4	Apartment	TCV actuator (DHW)	Repair
C17	5	22,2	Apartment	TCV bypass valve (Heating)	Change
C65	1	33,0	Apartment	Not found	Reset (all TCV)
C51	1	40,9	Apartment	Heat exchanger (H DHW)	Cleaning
C60	1	12	Public facility	TCV actuators (H DHW)	Change (all TCV)

For the substations with hot water storage, a new type of control strategy for the circulating flow can be applied. It is generally not so easy to solve all these problems in substations, because the substations belong to the owner of the property. Very often - for practical reasons - it takes time to get repairs to be done, which are not emergencies or instantaneous maintenance. As part of this project, however, KDHC has taken over the responsibility (and costs) of the renovation work.

4.1.6.2 Comparison of Excess flow before and after improvement

In order to include results for the improvement in this report, the excess flow for a period of two months for 2003 and 2004 is compared for those substations, which are identified in . Because of erroneous measurements, substation C18 is omitted. The results of the improvements can be seen in Table 4.1-9.

Table 4.1-9: Comparison of excess flows in September/October 2003 and 2004, respectively

September 2003 - October 2003					
Supply temperature		99,3°C			
Average calculated Ä T		31,2°C	Reference Ä T		47,7°C
Actual return temperature		68,1°C	Reference return temperature		51,6°C
Consumer code	**Max power [kW]**	**Ä T [°C]**	**Heat [kWh]**	**Flow [m³]**	**Excess flow [m³]**
C43	767,0	24,5	391 964,0	13 790,0	7 120,2
C63	532,0	3,5	17 028,8	4 203,5	3 913,8
C41	372,0	17,6	109 318,4	5 350,0	3 489,7
C20	1 634,0	33,8	324 684,0	8 269,8	2 744,8
C67	1 436,0	36,8	268 540,0	6 297,5	1 727,9
C17	1 391,0	36,8	258 912,0	6 061,0	1 655,2
C65	2 749,0	42,3	443 932,0	9 043,3	1 489,2
C60	345,0	8,7	15 161,2	1 629,9	1 371,9
C51	3 204,0	45,5	462 000,0	8 757,0	895,4
		31,2	**2 291 540,4**	**63 402,0**	**24 408,1**

September 2004 - October 2004					
Supply temperature		99,4°C			
Average calculated Ä T		37,4°C	Reference Ä T		47,7°C
Actual return temperature		62,0°C	Reference return temperature		51,7°C
Consumer code	**Max power [kW]**	**Ä T [°C]**	**Heat [kWh]**	**Flow [m³]**	**Excess flow [m³]**
C43	767,0	24,9	104 168,0	3 608,9	1 836,3
C63	532,0	7,2	45 298,0	5 409,6	4 638,8
C41	372,0	26,7	93 287,2	3 009,1	1 421,7
C20	1 634,0	44,6	297 540,0	5 748,2	685,1
C67	1 436,0	43,2	238 728,0	4 759,3	697,0
C17	1 391,0	42,1	237 684,0	4 868,7	824,2
C65	2 749,0	45,8	353 000,0	6 662,7	655,9
C60	345,0	16,0	10 045,6	541,1	370,2
C51	3 204,0	49,0	508 196,0	8 932,9	285,2
		37,4	**1 887 946,8**	**43 540,5**	**11 414,4**

In Table 4.1-9, the supply and the reference return temperatures as well as the average ÄT (referred to as "Reference ÄT") are measured at the power plant. Furthermore, individual ÄT belonging to the substations are measured at the substations as well as individual flows and delivered energy. As it can be seen, C43 and C63 are still delivering high excess flows. Indeed the reason for the low excess flow of C43 was that the sauna was shut down under 2004. The work on C63 improved slightly the cooling ability (from ÄT = 3,5 to 7°C), but is generally still awful and the heat load three-doubled during 2004 compared to 2003 because of new loads. Hence, the development of the cooling ability of this substation has to be followed up under a longer time.

The nine evaluated substations combined deliver an average return temperature (because of malfunction) of about 21°C higher in 2003 and 14°C in 2004 than the average return temperature at the power plant. For this reason, the return temperature at the power plant was chosen as the reference temperature.

The comparison makes it obvious that the improvement procedures were successful. The total flow through the substations decreased and so did the remaining excess flow. However, it should be noted that the total heat delivery was lower during the 2004-period. Anyway***, the average cooling ability of the nine substations increased from 31°C to 38°C.***

It is obvious that this first use of the excess flow evaluation was successful by pin-pointing the worst cases and try to work on them. There are 107 substations belonging to the net, many more have to be adjusted. However, this type of improving the cooling ability in a large net is a continuous process, which must be treated with endurance and long sight.

4.2 Skogas district heating system

4.2.1 The district heating system

Skogas/Lannae is located in the south part of Stockholm in the Huddinge community. The tenements in Skogas generally consist of multifamily houses from the 1960-ies and 1970-ies and semi-detached houses from the 1980-ies. There are also two shopping centres in the area. Lannae is an industrial estate.

In Skogas/Lannae, about 121 GWh heat is delivered annually to the customers and the rated heat load is 49 MW. The total number of substations is 227 of which approximately 100 are serving semi-detached houses.

The heat delivered in Skogas is mostly produced in the Skogas heating plant, predominately with biogas and pine oil as fuel. Högdalen's combined heat and power plant, located in the neighbourhood where the most common fuels are waste and waste products, is also connected to the network. The capacity of the Skogas heating plant is sufficient for Skogas and Lannae, although it is possible to deliver heat to and from Skogas from the outside by means of a transport heating pipe.

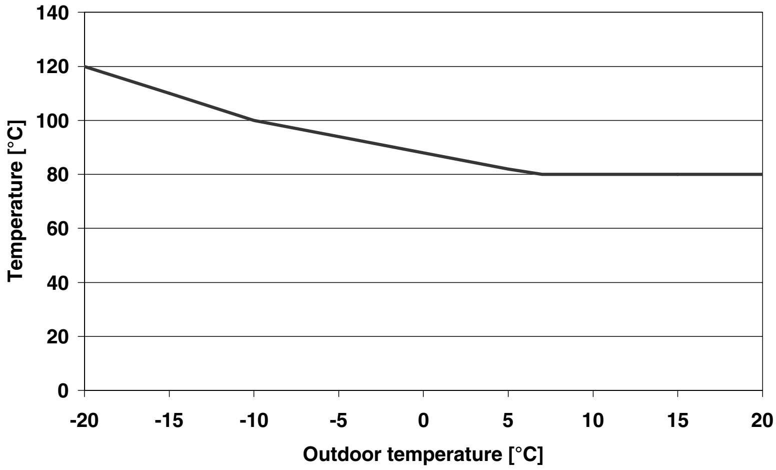

Figure 4.2-1: Supply temperature in Skogas heat plant

The supply temperature varies, as one can see in Figure 4.2-1 between 80°C and 120°C. The lower limit is given by some substations serving secondary networks (2-pipe systems), which must receive the lowest supply temperature of 78°C.

The customers in Skogas are a mixture of multifamily houses, offices and commercial buildings and semi-detached houses. In Lannae, which was connected with Skogas in October 2001, there are only offices and commercial buildings.

The 25 substations selected for this project are all located in Skogas, see Figure 4.2-3. They all serve multifamily houses of different sizes with the exception of two public buildings. The design load differs from 280 kW up to 2000 kW. The substations are mostly 2-stage connected, but a few have a 1-stage connection, and some substations serve a secondary network, i.e. a 2-pipe hot water system. For more information, see the enclosed Appendix 1.1.

The heat load requirement of multifamily houses during a 24-hour period is fairly equally distributed among different buildings and is usually just slightly larger during the day than during the night. Sometimes one can identify two heat load peaks, one in the evening and one in the morning, as shown in Figure 4.2-2.

In offices and in commercial buildings, the activities going on there determine the heat load. Typically, the heat load is larger during the day than during the night and if night setback is in use, one can identify a peak in the morning and a decrease in the evening. For some industrial loads, the heat load can even be larger during the night than during the day.

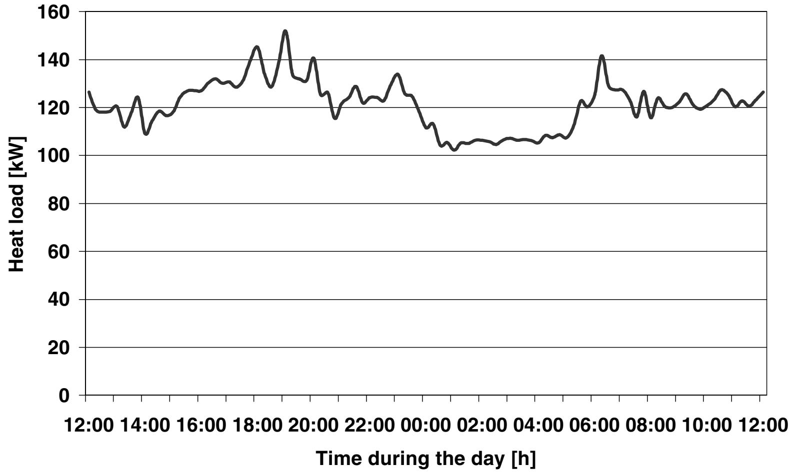

Figure 4.2-2: Examples of daily variation of heat load during a 24-hour period (T_{air} = +5°C) in multifamily houses (from 12 pm until12 pm next day)

4.2.2 The data evaluation system (Measurement system)

Södertörns Fjärrvärme AB, the owner of the district-heating network in Skogas/Lannae, collects data continuously from almost every substation by means of distant reading system, except for semi-detached houses. The data are saved in a central database, and it is possible to follow each substation directly on the PC. One can also find historical data for all connected and activated substations back to the installation of the distant reading system (approx. 2000).

For further analysis of the 25 selected substations, we have exported data to Microsoft Excel with one-hour resolution for year 2001 and 2002. For each substation, supply and return temperatures are available, volume flows and energies together with outdoors temperatures and production data (temperatures, pressure). As seen in Figure 4.2-3, pressure differences and supply temperature in the district heating network are given for two more points, in addition to those of the Skogas heat plant. For additional evaluations such as improvements in various substations, data for year 2003/2004 have been collected as well.

4.2.2.1 Control system (Measurement system)

The Fix/iFix[3] product family installed in Södertörns Fjarrvarme AB is an integrated PC-based software for supervisory control in for example power plants and district heating networks.

The resolution and quality of the available data depends on several of the factors described below. The resolution of the integrator (heat meter) can be one source of failure. There are various kinds of integrators installed in the substations, such as ABB-Metering (SVM), Enermet, Kamstrup. The type of integrator is also dependent on the resolution of the flow meter. Various kinds of makes are installed representing different types of flow meters, for example inductive, mechanical and ultrasound meters. If the flow meter is oversized (low resolution), the pulse signal to the integrator can be incorrect, especially in the summertime when the flow is low. This can result in low quality of the collected data.

Another source of error can be the fact that some integrators just update temperature values when there is a pulse signal from the flow meter. Otherwise the latest temperature value is kept.

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[3] More information can be found on the manufacturer GE Fanuc Automation international website http://www.gefanucautomation.com/default.asp, go to products.

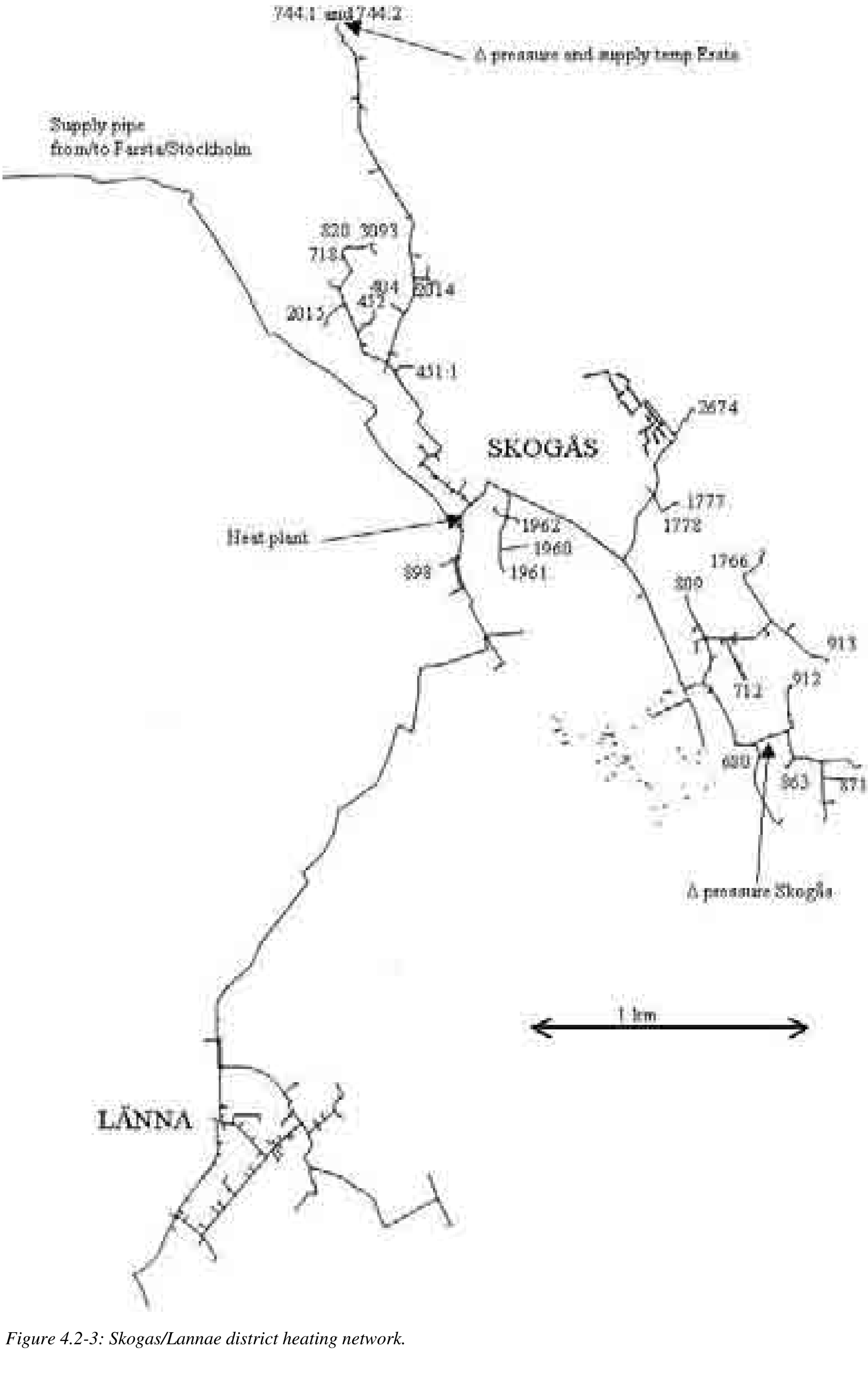

Figure 4.2-3: Skogas/Lannae district heating network.

4.2.2.2 Collected parameters and database

In each substation, supply- and return temperatures and flows are measured. From the temperature difference and flow, the heat withdrawal is calculated. These parameters are presented continuously in Fix/iFix (see Figure 4.2-4), and it is also possible to have a closer look at each substation.

The time between two samples depends mainly on two parameters. The substations are organized in groups that form a loop. Each substation is connected one at a time in the loop. When the last substation has been connected, the loop starts all over again. If the substation does not respond, another nine attempts will follow. If still no answer is available, the latest value will be kept. Depending on the number of substations in the loop and the connection ability, the time resolution of the data will differ between a few seconds and up to several minutes.

Supply and return temperature, flow, heat load and accumulated flow and heat load are saved on a central hard drive/server for every loop. Only changes are registered to save space on the hard drive, which also has a consequence on the resolution. The changes must be larger than a certain set value (see below) to be registered, otherwise the latest value will be kept. The set values are:

- Temperatures 0,5°C
- Flow 0,1 m³
- Heat load 0,5 kW.

It is possible to follow each substation on-line on a PC, as shown in Figure 4.2-4, but one can also find historical data for all connected and activated substations back to year 2000.

2003-11-24 **Energimätare Skogås 1, AB 263 - 835** 10:34:02

ABONNENT	EFFEKT (kW)	FLÖDE (m³/h)	R.TEMP (°C)	F.TEMP (°C)	STÄLL.ENERGI (MWh)	STÄLL.VOLYM (m³)	PLATS
263	14,20	0,25	32,30	82,20	189,54	3830,28	Brf Aida, Edbov.
404	644,00	10,09	30,60	88,00	6197,77	106560,41	Brf Trångsund, Tornslingan 33
451.1	728,00	13,25	37,90	86,20	6772,86	189242,42	Kv Kungen, Korpstigen 10
451.2	381,00	6,58	35,80	86,00	3833,40	74164,01	Kv Prinsen, Trångsunds Torg
452	670,00	16,17	50,60	88,70	6527,04	242486,11	Kv Springaren, Torslingan 39
680	542,00	13,51	51,31	88,19	6714,52	39707,91	Kv Sviten, Rapsodiv. 156
689	2571,00	53,80	45,98	87,22	63733,04	393114,78	Kv Porten, Storvretsv. 17
691	27,50	0,60	43,76	83,37	341,88	8452,69	Bst. Norströmsv.
712	102,80	1,50	27,76	88,66	1662,94	27817,36	Kv Mästersångaren, Barytonv.91
713	100,00	2,25	46,20	84,64	1556,15	31474,79	Samf Toppen, Rapsodiv.
714	152,40	3,00	40,63	84,45	2315,22	41839,06	Kv Mässan, Rapsodiv. 73
716	39,40	0,75	39,63	84,64	613,14	13586,46	Kv Mästersångaren, Barytonv.95
718	104,30	2,30	45,60	85,10	4084,81	79376,03	Brf. Löparen 2, Springarv.8
744.1	633,00	12,91	42,30	84,80	12371,96	280963,53	Stortorpskliniken
744.2	????	????	????	????	????	????	Stortorpskliniken (bostäder)
765	22,20	0,45	39,89	82,73	443,64	11140,59	Förskola, Fjäderstigen 14
766	10,40	0,30	51,22	81,41	129,89	5952,77	Fritidshem, Tjäderstigen 16
774	4003,00	95,60	50,17	86,34	50751,56	1241101,75	Kv. Pelaren, Fäbodav. 1
805	12,80	0,21	40,09	93,60	399,45	26103,72	PC (SFAB)
809	506,00	9,00	36,77	85,29	6354,37	14460,40	Kv. Visan, Duettv.77
812	5,47	0,15	50,34	82,10	113,28	3679,25	Barnstugan, Barytonv.14
816	????	????	????	????	????	????	Trångsundskolan
817	27,50	0,60	45,46	85,06	515,17	12017,39	Daghem, Norströmsv.1A
820	140,00	2,24	30,79	84,56	3564,49	63508,84	Brf Löparen 1, Springarv.7
834	248,10	4,50	38,01	85,35	1849,61	38251,77	Kv. Balladen, Melodiv.6
835	242,80	4,50	39,25	85,98	3156,32	57975,21	Kv Balladen, Melodiv.16

Skogås 2 | Skogås 3 | Historik | MENY

Figure 4.2-4: Overview over substations in Skogas in Fix/iFix. Data from from the left denote substation number, heat load, mass flow, return temperature, supply temperature, energy, volume and location address

The historical data are presented in diagrams, such as Figure 4.2-5, for each substation. This is a fast way to have a closer look at a special substation, but for further analysis, the data are exported to Excel.

One can export historical data in two ways. The easiest way is to use a function in Fix/iFix. With this, one can export data for up to 21 days with one-hour resolution (500 values). The format is .dat, which is possible to import in Excel. With this method, either instantaneous values or average values can be sampled. Another way is to use Novotek Report, which is a macro in Microsoft Excel, which allows exporting data directly to Excel. Here, it isn't possible to choose which kind of data one wants to look at, but one can export complete data sets with instantaneous values for up to three months, which is less time consuming.

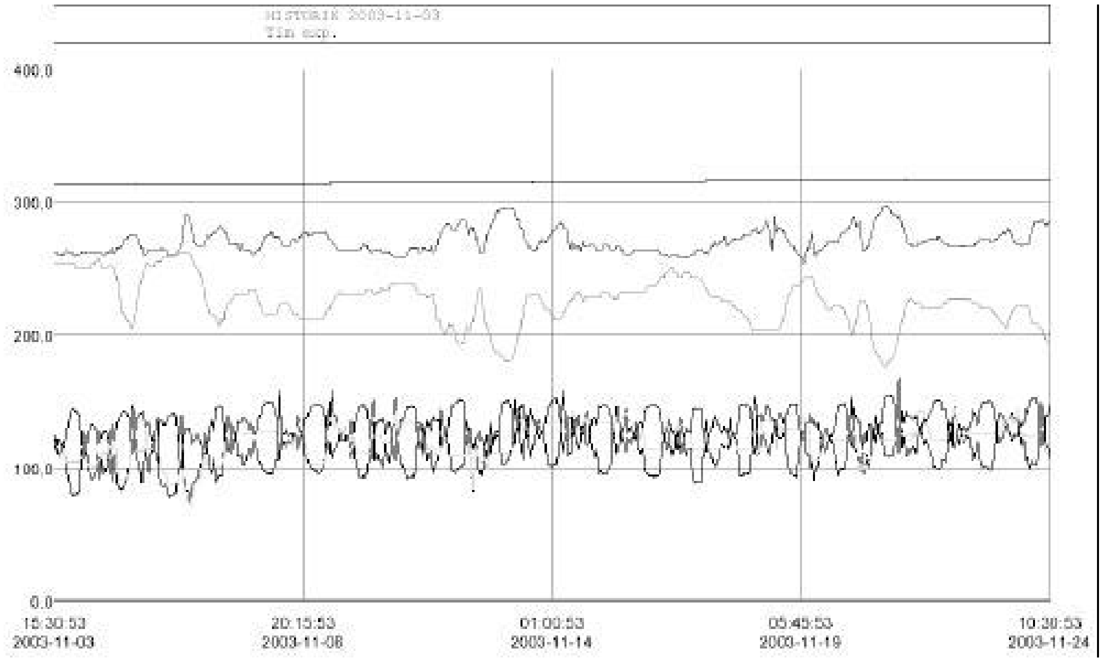

Figure 4.2-5: Historical data for one substation during a 21-day period. Note that the scale at the left is for heat load. From top to bottom in the beginning of the curves: Accumulated flow and energy, T_{supply}, flow rate, T_{return}, $T_{outdoor}$, heat load

The collected data for the evaluations in this project are exported with Novotek Report. This means that the data values are instantaneous values with one-hour resolution.

4.2.2.3 Excess flow evaluations

Since the middle of 1990-ies, SFAB and ZW Energiteknik have collaborated to improve the cooling ability in Skogas district heating network. One of the tools has been the Excess flow method described in Chapter 3.2, which is carried out every month. As one can see in Figure 4.2-6, the cooling ability (green line) has improved during the first part of the period.

In the year 2001, as mentioned above, Lannae was connected to the Skogas district heating network. That, combined with changes in the operation of the district-heating network, has affected the total network temperature negatively. Due to these changes, much work done earlier is not noticeable in the statistics, see Figure 4.2-6 and Figure 4.2-7. In spite of that, the work is not wasted, but it clearly shows that network improvement is a continuous process. One reason for the deteriation is that, in general, the substations in Lannae have a lower cooling ability due to a different customer structure.

4.2.2.4 Excess flow

For Skogas, three periods are chosen for further evaluation of selected substations: February, April and the period June – August, respectively, for the year 2002. February is usually the coldest period in Sweden with monthly mean temperatures of about -4°C, and low temperatures down to -20°C. Hence, the radiator load is the principal source of heat consumption in this month. April is a period in which the heat load and the domestic hot water load are about equal. In the summer period of June - August, the domestic hot water is the main part of the load. That means that for each period, the excess flow can be significant for the (mal-) function of portions of the customer system, radiator or domestic hot water circuit.

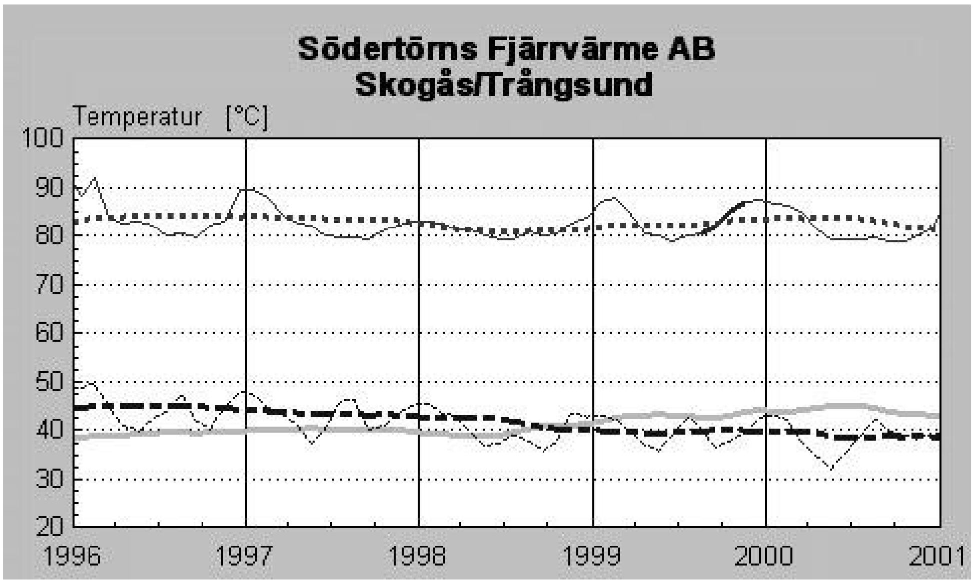

Figure 4.2-6: District heating network temperatures in Skogas 1996 until 2001. Lines from top to bottom: Monthly average supply temp. (thin line), annual mean temp. supply (dotted). Lower curves: Monthly average return temp. (thin dashed line). Annual average return temp. (dashed thick line), cooling ability (grey line)

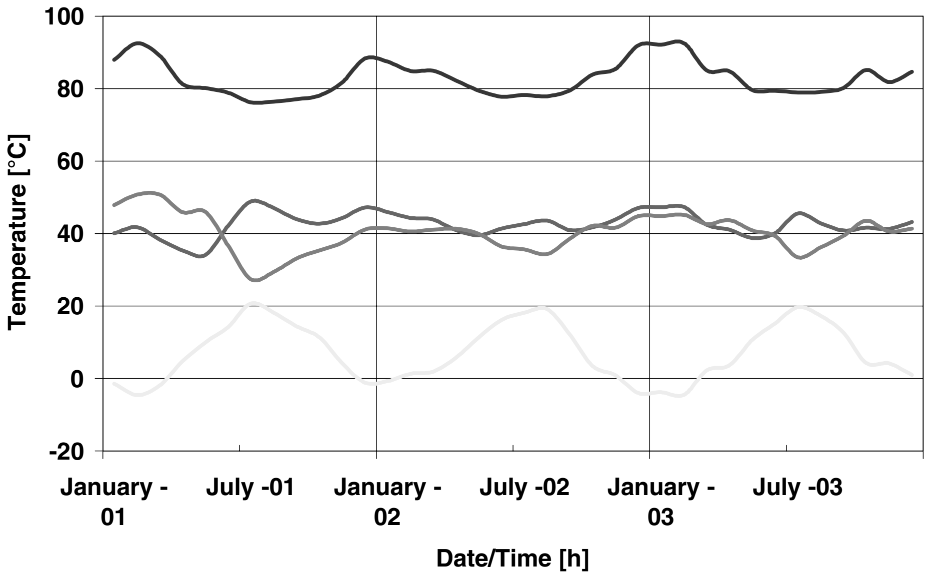

Figure 4.2-7: Monthly supply and return temperatures and cooling ability in Skogas district heating network 2001, 2002 and 2003. Lines from the top to bottom at the start of the curves: Supply temp., cooling ability, return temp., outdoor temperature

The nine worst cases of excess flow for each period are shown in Table 4.2-1 to Table 4.2-3. The complete ranking list can be found in Appendix 4.2.

From the tables, it can be seen that substation number S452 exhibits high excess flow during the whole year. S452 is an old installation, with fouled heat exchangers and large control valves, and therefore has a god improvement potential. This substation, as well as S451:1 and S2015, are substations delivering heat to secondary nets (2-pipe system), and therefore have generally high temperatures, especially in the summer period. Considering the circumstances, S451:1 works relatively well due to a recent renovation. However, the return temperature will be high in the summer period with only domestic hot water loads due to recirculation in the 2-pipe system which keeps the pipes warm (to guarantee high enough domestic hot water temperature).

The substations S1960, S1961 and S1962 all serve multifamily houses, large block flat houses with more than seven floors. They were built during the sixties and use high radiator temperatures of 75/55°C. Due to these high radiator temperatures (old installations), they all have low cooling during the winter period. During the summer, S1960 and especially S1962 show high excess flow mostly because they use older fouled heat exchangers and oversized control valves for domestic hot water.

S744:1 serves a hospital, with relatively high consumption of domestic hot water. Due to this large domestic hot water system, with a high degree of recirculation, this substation gives high return temperature, especially in summer. This is not a result of bad equipment in the substation but of the domestic hot water system, and is therefore difficult to improve. S898, serving a prison, is in pricipal similar to S744-1, providing domestic hot water to many units in a large system, and therefore has low cooling in the summer period.

S680 provides heat to a 4-pipe distribution system. It is very old and especially the domestic hot water heat exchanger works poorly. For this reason, the cooling ability is lowered during the summer and the intermediate period. The heat exchanger for heating is only slightly better, and the substation is on the renovation list.

Table 4.2-1: Extreme cases of excess flow in Skogas during February 2002

	Current T_{supply}	85,0 °C	Calculated T_{return}	42,1 °C		**SKOGAS/LANNA**
	Target cooling	47,9 °C				**February 2002**
	Cooling	42,9 °C				
Substation	**Energy [MWh]**	**dT [°C]**	**Volume [m³]**	**Excess flow**	**T_{return} [°C]**	**Name**
S452	417	32,3	11325	3 682 m³	52,7	Kv Springaren1-3,Kungen3, 7-10
S1962	381	34,5	9697	2 708 m³	50,5	Brf Skogås 1
S1960	316	34,8	7966	2 168 m³	50,2	Brf Skogås 2
S2015	419	38,1	9660	1 973 m³	46,9	Kv Brickan, Tärningen
S1961	254	36,7	6081	1 415 m³	48,3	Brf Skogås 3
S744	356	39,4	7934	1 402 m³	45,6	Stortorpskliniken
S451	437	42,4	9037	1 027 m³	42,6	Kv Prinsen 1-6
S680	329	41,0	7043	1 006 m³	44,0	Samf Skogåsen
S2014	297	43,4	5997	557 m³	41,6	Brf Prinsessan 2

Table 4.2-2: Extreme cases of excess flow in Skogas during April 2002

	Current T_{supply}	82,2 °C	Calculated T_{return}	39,7 °C		**SKOGAS/LANNA**
	Target cooling	47,5 °C				**April 2002**
	Cooling	42,5 °C				
Substation	**Energy [MWh]**	**dT [°C]**	**Volume [m³]**	**Excess flow**	**T_{return} [°C]**	**Name**
S1962	203	21,7	8238	4 484 m³	60,5	Brf Skogås 1
S452	296	30,3	8596	3 120 m³	51,9	Kv Springaren1-3,Kungen3, 7-10
S744	243	39,0	5483	988 m³	43,2	Stortorpskliniken
S1961	169	36,8	4034	912 m³	45,4	Brf Skogås 3
S2015	284	41,6	5994	747 m³	40,6	Kv Brickan, Tärningen
S1960	208	39,8	4586	745 m³	42,4	Brf Skogås 2
S451	298	43,0	6083	573 m³	39,2	Kv Prinsen 1-6
S680	241	42,4	4989	539 m³	39,8	Samf Skogåsen
S2674	142	44,0	2823	208 m³	38,2	Brf Baletten

Table 4.2-3: Extreme cases of excess flow in Skogas during the summer (June - August) 2002

	Current T_{supply}	78,0 °C	Calculated T_{return}	40,7 °C		SKOGAS/LANNA
	Target cooling	42,3 °C				June-August 2002
	Cooling	37,3 °C				
Substation	**Energy [MWh]**	**dT [°C]**	**Volume [m³]**	**Excess flow**	**T_{return} [°C]**	**Name**
S452	255,04	21,4	10487,9	5 189 m³	56,6	Kv Springaren1-3,Kungen3, 7-10
S744	179,86	24,3	6506,1	2 769 m³	53,7	Stortorpskliniken
S451	230,25	30,7	6581,2	1 797 m³	47,3	Kv Prinsen 1-6
S898	37,21	20,0	1630,53	857 m³	58,0	Beateberg Kriminalvårdsanstalt
S1962	136,71	35,4	3395,07	555 m³	42,6	Brf Skogås 1
S680	206,29	38,4	4717,57	432 m³	39,6	Samf Skogåsen
S2674	142,61	37,7	3318,85	356 m³	40,3	Brf Baletten
S1960	138,42	38,3	3174,94	299 m³	39,7	Brf Skogås 2
S3093	53,77	33,6	1405,13	288 m³	44,4	Brf Löparen 3

4.2.3 Results from replacement of substations

During the last years, several substations in Skogas have been improved in different ways, either by totally rebuilding substations or by replacing components such as heat exchanger, control valves and/or optimizing settings of heating and domestic hot water parameters. This could be achieved due to the consequent application of the excess flow method.

The focus in this evaluation is on new substations (including *new heat exchangers*). (Substations with *new control valves* must not necessarily exhibit better cooling, but replacing large valves with smaller ones improves the dynamic of the valve regulation, which sometimes also can improve the return temperature).

The evaluation period refers to three different periods of the year before and after the changes. The periods are similar to the ones described above: One winter month, one intermediate month and a three-months summer period. This makes it easier to see, whether or not the improvement contributes to better cooling of the DH water over the year.

The excess flow method is used for both, the evaluation of substations and of the achievable return temperature. To make sure that the *return temperature* really is lowered, the return temperatures of the different periods are also compared, rather than only the cooling ability, since the cooling ability also depends on the supply temperature.

Four substations of the 25 included in this project have been completely renovated during the last years, including one substation for which only the heat exchangers have been replaced. In S1962, just the heat exchanger for the heating system has been replaced, but this still gives a good result for a large part of the year.

The result of the above-mentioned exchanges of substations and heat exchangers is shown in the following Tables. In Appendix 4.2, one can find the complete excess flow ranking lists.

All four substations have increased their cooling ability, and therefore reduced the excess flow during wintertime. The evaluated period in 2004 was colder than the corresponding period of 2000. This fact contributes somewhat to higher return temperatures in the wintertime 2004. This should be kept in mind when comparing return temperatures for the two periods.

Especially substation S451 has been improved a lot, although it still is not achieving the target temperature during wintertime[4]. This substation is serving a secondary net (2-pipe system), and regarding that, the substation now works fairly well. S1961 has also improved and is one of the best working substations after the renovation. S1766 and S1961 have improved slightly during the winter, although S1776 was working relatively well before the replacement as well, as far as the cooling ability is concerned.

[4] Note that the target temperature was arbitrarily chosen to be 5°C lower than the actual return temperature. See also Chapter 3.2.

Table 4.2-4 a: Excess flow and return temperature of the four substations during the winter period, before renovation.

			Current T_{supply}	86,0 °C	Calculated T_{return}	46,0 °C	**SKOGAS**
			Target cooling	45,0 °C			**February 2000**
			Cooling	40,0 °C			
Substation	**dT [°C]**	**Energy[MWh]**	**Volume [m³]**	**Excess flow**	**T_{return} [°C]**	**Name**	
S451	34	478	12 344 m³	3 020 m³	52,0	Korpstigen 10, Trångsund	
S1961	40	291	6 388 m³	712 m³	46,0	Loftvägen 12, Skogås	
S1962	45	337	6 576 m³	2 m³	41,0	Loftvägen 3-5, Skogås	
S1766	49	258	4 623 m³	-409 m³	37,0	Musikalv (vid nr 72) Skogås	

Table 4.2-4 b: Excess flow and return temperature of the four substations during the winter period after renovation.

	Current T_{supply}	95,0 °C	Calculated T_{return}	47,8 °C			**SKOGAS/LANNA**
	Target cooling	52,2 °C					**January 2004**
	Cooling	47,2 °C					
Substation	**Energy[MWh]**	**dT [°C]**	**Volume [m³]**	**Excess flow**	**T_{return} [°C]**	**Name**	
S451	570	50,3	9948	364 m³	44,7	Kv Prinsen 1-6	
S1962	238	50,7	4121	121 m³	44,3	Brf Skogås 1	
S1961	208	52,3	3498	-6 m³	42,7	Brf Skogås 3	
S1766	158	53,1	2608	-43 m³	41,9	Musikalen Samfällighetsförenin	

The intermediate period also shows good results after the renovations. Substations S1766 and S1961 have slightly improved compared to the other substations. Again, S451 has improved a lot and works fairly well.

Table 4.2-5 a: Excess flow and return temperature of the four substations during the intermediate period before renovation.

			Current T_{supply}	81,2 °C	Calculated T_{return}	40,6 °C	**SKOGAS**
			Target cooling	45,6 °C			**April 2000**
			Cooling	40,6 °C			
Substation	**dT [°C]**	**Energy[MWh]**	**Volume [m³]**	**Excess flow**	**T_{return} [°C]**	**Name**	
S451	29	353	10 688 m³	3 891 m³	52,2	Korpstigen 10, Trångsund	
S1962*	32	333	8 844 m³	2 432 m³	49,2	Loftvägen 3-5, Skogås	
S1961	45	191	3 727 m³	49 m³	36,2	Loftvägen 12, Skogås	
S1766	50	198	3 477 m³	-336 m³	31,2	Musikalv (vid nr 72) Skogås	

* Mars 2000

Table 4.2-5 b: Excess flow and return temperature of the four substations during the intermediate period after renovation.

	Current T_{supply}	85,0 °C	Calculated T_{return}	42,0 °C			**SKOGAS/LANNA**
	Target cooling	48,0 °C					**Mars 2004**
	Cooling	43,0 °C					
Substation	**Energy [MWh]**	**dT [°C]**	**Volume [m³]**	**Excess flow**	**T_{return} [°C]**	**Name**	
S451	458	45,8	8791	410 m³	39,2	Kv Prinsen 1-6	
S1962	336	45,1	6535	398 m³	39,9	Brf Skogås 1	
S1961	283	46,9	5300	123 m³	38,1	Brf Skogås 3	
S1766	239	50,1	4185	-180 m³	34,9	Musikalen Samfällighetsförenin	

After the renovation, all substations except S451 meet the target temperature in the summer period. S451 has improved about ten degrees on the return temperature, which has resulted in an acceptable excess flow for this kind of substation, i.e. 2-pipe system.

Table 4.2-6 a: Excess flow and return temperature of the four substations during the summer period before renovation

			Current T_{supply}	76,7 °C	Calculated T_{return}	46,7 °C **SKOGAS**
			Target cooling	35,0 °C		**June-August 2000**
			Cooling	30,0 °C		
Substation	**Energy [MWh]**	**dT [°C]**	**Volume [m³]**	**Excess flow**	**T_{return} [°C]**	**Name**
S451	339	26,2	11369	2 864 m³	50,5	Korpstigen 10, Trångsund
S1962	51	33,8	1316	45 m³	42,9	Loftvägen 3-5, Skogås
S1961	161	49,2	2871	-1 168 m³	27,5	Loftvägen 12, Skogås
S1766	205	49,3	3652	-1 491 m³	27,4	Musikalv (vid nr 72) Skogås

Table 4.2-6 b: Excess flow and return temperature of the four substations during the summer period after renovation.

	Current T_{supply}	80,0 °C	Calculated T_{return}	39,1 °C		**SKOGAS/LANNA**
	Target cooling	45,9 °C				**June-August 2003**
	Cooling	40,9 °C				
Substation	**Energy [MWh]**	**dT [°C]**	**Volume [m³]**	**Excess flow**	**T_{return} [°C]**	**Name**
S451	276	40,7	5956	680 m³	39,3	Kv Prinsen 1-6
S1961	125	47,4	2321	-75 m³	32,6	Brf Skogås 3
S1962	127	47,5	2343	-83 m³	32,5	Brf Skogås 1
S1766	147	49,7	2603	-214 m³	30,3	Musikalen Samfällighetsförenin

4.2.4 Conclusions

After the evaluation, one can see that substations, which have been totally reconstructed, show improved cooling ability and therefore decreased excess flow. They have all "moved down" in the excess flow list as a result of their improvement. Of course, the possibility of improvement depends on how good the substation was working before the renovation took place. For example, S451 had a very low cooling ability initially, and therefore the improvement was high.

Of course, the replacement of substations is a slow process. In our cases, 4 substations of 25 evaluated ones and of about 100 total installed in the Skogas network have been processed. In many other substations, only control valves have been replaced for the sake of improved control dynamic not reported here. But also, the process of establishing monthly excess flow lists continues and new substations will show up at the top of the list after the repairs. At a given time, some new decisions about improvements will be made, and so on. Gradually, we are sure the return temperature of the whole net will be brought down.

5 Malfunctions of substations

Summary

In this chapter, typical malfunction of substations are listed according to their occurrence in practice. The severity of impairment the malfunction imposes on the customer and/or the district heating operator is also indicated. Diagnostic tools and methods available so far can give some indications on how and where to look at the substations, but the skill of maintenance or operating technicians is necessary in order to find the problems. Therefore, practical advice about how to detect malfunctions is also given.

5.1 Type of malfunctions in district heating substations

5.1.1 Introduction

District heating substations that on an annual average exhibit a temperature difference lower than 30°C can be suspected to suffer from some kind of malfunction. This malfunction can be found either in the substation itself or in the system connected to it, f. i. the radiator or hot tap water system. Some of these malfunctions can have an impact on the delivered heat capacity or domestic hot water temperature, or else ***impair the comfort to the customers***. For instance, substations with low cooling ability and high flow rates can prevent the malfunctioning substation and the substations of the costumers downstream to get enough power when it is cold. In such cases, the customers will claim to get malfunctions identified and repaired as soon as possible and therefore the district heating company normally soon becomes aware of the problem.

Other malfunctions ***concern only the net operator***. These malfunctions result in low temperature difference or high mass flow rates and impair the net dynamic and controllability of the net operation. The costumer still gets his heat and is not affected elsewhere by the malfunction. However, in most cases, malfunctions cannot be properly identified by the cooling properties of a substation. In this case, additional diagnostic methods must be applied.

We can conclude that two main classes of malfunctions exist; one, which only impairs the cooling (temperature difference) of substations and another, which impairs both cooling of substations and the comfort of the customer.

5.1.2 Type of malfunctions

There are many reasons for the malfunction of a DH substation. Defects can be built in during installation or repair of a substation, due to wrong design or choice of components. Defects can also occur due to aging or wear of components. Additionally, malfunctions can occur due to choice of unsuitable control parameters in the control equipment. Finally, the heat application environment can be designed in a way that the intended system function cannot be achieved.

In the subsequent discussion, the following categories of malfunctions are used:

R malfunctions associated with components, design features or operating conditions in the radiator heating system.

W malfunctions associated with components, design features or operating conditions in the domestic hot water circuit.

C malfunction caused by defective substation components (such as filter, heat meter, electrical break-down, defect heat exchangers or defect regulators).

E malfunction caused by external circumstances (such as too low supply temperatures, low pressure differences, secondary use of heat pumps or heat exchangers causing high secondary return temperatures).

The malfunctions can thus have influence on comfort as well as cooling of the district heating net. Some malfunctions also lead to increased consumption of electricity. The Tables A.5.1 to A.5.4 of Appendix 5 lists malfunctions experienced in the practice presented for each of the categories listed above. A differentiation is made between malfunctions impairing the substation cooling only and the customer comfort, respectively. For component abbreviations, see Figure 5.1-1 and explanations below.

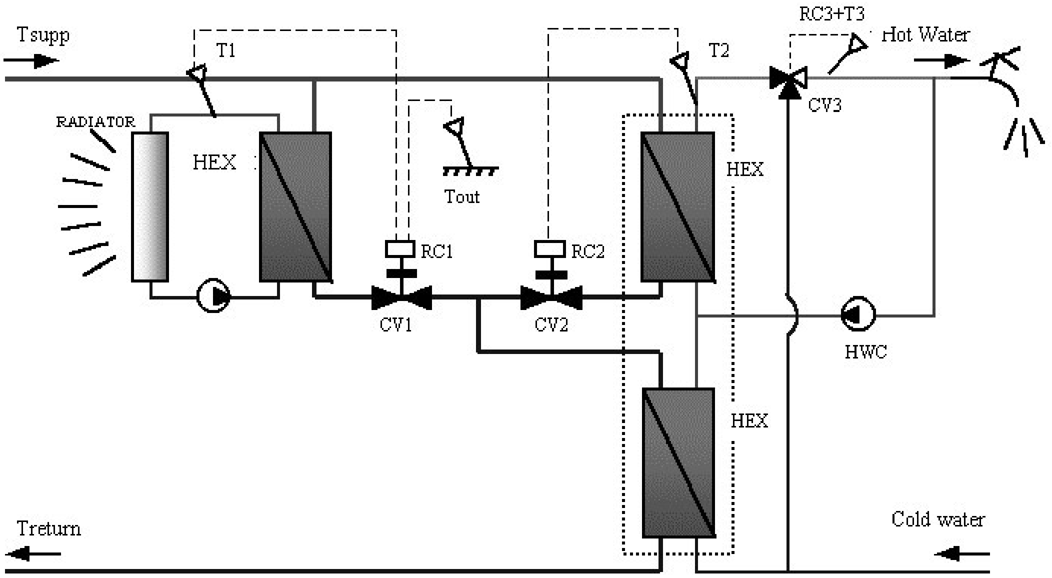

Figure 5.1-1: Typical 2-stage substation for which malfunctions are described

Explanation:

HEX	*Heat exchangers*
CV1	*Control valve radiator system*
CV2	*Control valve hot water preparation*
CV3	*Control valve hot water limitation*
T1	*Radiator temperature sensor*
T2	*Hot water temperature sensor*
T3	*Hot water temperature safety limiter*
Tout	*Outdoor temperature sensor*
HWC	*Hot water recirculation*

In an earlier investigation carried out at Södertörn District Heating in Sweden (Walletun, 1986), we have found that about 60 % of the malfunctions discovered in district heating substations can be ascribed to the heating system (radiator heating or ventilation systems). About 30 % can be assigned to deficiencies in the domestic hot water system and the remaining 10 % are associated with faults in components such as a damaged heat exchanger, circulation pump or control valve.

The same investigation also showed that roughly one third of the malfunctions found could be assigned to comfort problems and 2/3 to problems that impair the substation cooling with the result of increased return temperature out of the substation into the district heating net.

One should keep in mind, however, that the above result is depending on how quickly the customers report comfort problems to the energy-company. Another influencing fact is the number of persons working with efficiency problems. Thus, the more service-personal is involved, the more faults are detected.

5.1.3 Common malfunctions

In Swedish district heating systems[5], the following ***faults*** dominate (the notation belongs to the lists presented in Appendix 5, Tables A.5.1 – A.5.4).

- Damaged valve controller or leaking valves (fault R1, R2, W1, W2 or C4). This fault was also very common in Korean systems.
- Incorrect/unsuitable reference values in control stations (fault R7, R8, W7 or W9).
- Secondary systems not optimally designed for connection to district heating systems or they are not adjusted in the correct way (Fault R15, R16, R17 or W20).

Malfunctions leading to considerably increased return temperatures Tret in the district heating system can also be assigned to following main causes:

- Customers with high heat demand in secondary systems with bad or insufficient cooling. For instance old and not adjusted space heating systems or ventilation circuits with poorly working air heating batteries (aero-temp).
- Damaged or manually adjusted valve controllers, which might cause short circuiting in the district heating substation[6].
- District heating substations with domestic hot water systems including accumulation have without exception bad cooling. In the last years, it has also been observed that there are increased health risks in the form of Legionella germs in domestic hot water accumulators. For this reason, an extra increase of the set temperature has been undertaken very often, which has raised the return temperature T_{ret} even more. This malfunction is also quite common in the investigated Korean substations supplying heat to saunas and other bath facilities.

5.1.4 Identification of faults in district heating substations

Above, we have assorted existing types of malfunctions according to their influence on *comfort or cooling*. The types of faults *with impairment on comfort* are often easy to be found, as the energy customers who occupy a building without heating or which have problems with the quality of domestic hot water usually contact the energy company very quickly. Faults of this kind are therefore rarely of long duration and thus do not influence the cooling capacity for a long time.

Faults with *no influence on the comfort* to the customer must, however, be detected and followed up upon by other means, for instance by analysis of lists showing excess flow or reports from control visits within regular service intervals. Database supported systems for survey of the operation can also be used.

In several Swedish investigations, experiments with *operational system survey* have been used for detailed surveys and analysis. Used in a correct way, these systems have often made it possible to detect malfunctions more quickly and exceptional load charge can be detected, etc. An essential common conclusion from these works annotates the difficulty of the task to identify the type of malfunctions in a district heating substation only by means of an operational survey system. The reason is, of course, to find in the large amount of possible malfunctions as listed in the tables of Appendix 5. Especially, it might be sometimes difficult to distinguish between different types of faults. If, for instance, only the parameters T_{sup}, T_{ret} and flows are registered, it will be very difficult to discern in detail the internal systems for heat and domestic hot water, respectively.

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[5] The results presented here are mostly based on earlier Swedish experience collected during the 1980ies and 1990ies in Sweden. Experience from other countries was not consciously searched for. For further information see f. i. Gunnar Nilsson, 2000.

[6] In Korea, very often a bypass valve is placed in parallel to the temperature control valve. In some examples of malfunction of the control valve, the bypass was opened by hand by the owner of the substation in order to assure district heating supply. As a result, high flow rates lead to high return temperatures.

In order to be able to make a detailed analysis and to identify the type of malfunction, it is necessary that almost all process parameters, temperatures, flows and pressure differences in the district heating substation are included into the operation survey system. This means three different flows, one to two differential pressures and eight to ten temperatures should be measured in each substation. Usually, this is too expensive, demands too many measurenment resources and will therefore not be put in use in larger systems.

The best and most comprehensive control is therefore still the traditional visit on-site, carrying out a so-called *function or status control.* Compared to the operational survey system, a visit on-site enables for instance to control valves, listen to working sounds of pumps and valve regulators, observe changed reference temperatures and so on, and act based on the results.

5.1.4.1 Working routines

Before one makes an on site visit, one should go through previous notes from visits done in order to get information about the substation.

The first item when one arrives at the substation.is to check if an alarm is connected to the equipment in the substation.

On the primary side, one should go through the readings from the flow meter/integrator and check the temperature on the supply- and return pipe. If the temperature difference were low, the next step would be to find out the reason for that, which most often occurs on the secondary side.

To find the malfunction, one should check the temperature on the secondary side, while considering the outdoor temperature. It is good to know the outdoor temperature and thus the relative heating load, when one looks back at the notes from the visit. Furthermore, one should look for leakage on the heat exchangers and find out the temperature difference of each heat exchanger.

Check the control equipment, and if the settings differ from the readings, one has to follow up on the reason. Is the transmitter broken, or is the connection out of order etc. By changing the settings, one can control the status of the control values.

In the same way, one should check the pumps for the space heating system and domestic hot water circulation, and other equipment in the substation as well.

After having checked the substation, one should know the reason for its eventual bad cooling ability.

5.1.5 Description of methods for detection of common faults

The indicated numbers refer to the items in the malfunction lists in the Appendix Tables A.5.1 to A.5.4.

R1: A locked or manually adjusted control valve is often found by some kind of indication on the controller. However, this kind of indication will vary between different manufactures. The most reliable way is, thus, to try to change the position of the valve by hand or via a change of the reference temperature at the regulator. If the control device does not work and does not try to correct for the alteration made, the controller is either locked or manually adjusted or even defective (mechanically or electrically).

R2: The easiest way to find a leaking pilot valve is to detect a small flow via the flow meter although there has been no load charge. Preferably, the control is made during summer time when there is no need for heat. Furthermore, manual shut-off valves can often separate the systems for heat and domestic hot water and thus it will be possible to find the leaking valve.

R3: To be able to see if a heat exchanger is fouled, it has to be exposed to at least a load charge of 50 %. The higher the load, the better the fouling can be seen. The parameters studied are, other than the amount of heat load, also the four temperatures of the heat exchanger. If the two warm temperatures (incoming district heating temperature and outgoing secondary heat, respectively) are normal, the temperatures are measured at the cold end of the heat exchanger. The difference between these two cold-end temperatures should not deviate significantly from the design data. In the systems for space heating or ventilation, the design data for the difference is often less than 5°C.

R4: In order to find out if a heat exchanger has been connected by mistake in parallel flow instead of counter flow, it might be sufficient to study the marking of the tube connections in question. If one is uncertain, one should document how the connections to the heat exchanger are made in the substation and later compare them with the product sheet from the manufacturer.

R5: A running circulation pump often produces some noise. If there is no sign of circulation, it might be enough to touch the pump, which also at normal operation often is considerably warmer than the surrounding temperature.

R6 and R16: The easiest way of detecting an incorrect circulation flow is to watch input and return temperatures. If the flow is unnecessarily in the radiator circuit, the return temperature from the radiators will be high. This in turn means an increased return temperature in the district heating pipes. A circulation flow that is too low leads to comfort problems, as the heat is not transported to all risers. If it is found out that the heating system has several branches and that the return temperature among them is varying drastically, an adjustment has to be made.

R7: It is not possible to clearly determine the correct heat characteristic (defining the radiator supply temperature as a function of the outdoor-air temperature) for a building as it depends on the desired in-door temperature as well as on the construction of the building. A characteristically high heat will, however, lead to increased return temperatures, insufficient comfort (too warm) and increased consumption of energy. A characteristically low heat will of course result in the contrary.

R9 and R10: Defective or misplaced sensors may cause a very strange operation of a district heating substation. However, the most common fault is that the sensor breaks, which in most cases leads to a drastic change of the reference temperature in the controller. This often results in the valve going to an extreme position, either open or closed. In modern controllers, one can read the control value given by the sensor and from that decide if it is reasonable or not.

W1: See R1

W2: See R2

W3: To make it possible to see if a heat exchanger is fouled, it has to be exposed to at least a load charge of 50 %. The higher the load, the better the fouling can be identified. The parameters studied are, other than the amount of load, also the four temperatures of the heat exchanger. If the two warm temperatures are normal (incoming district heating temperature and outgoing temperature of the domestic hot water, respectively) the temperatures are measured at the cold end of the heat exchanger. The difference between these two cold-end temperatures (Grädigkeit) should not deviate drastically from the design data. For hot water systems, this temperature difference is normally 10 – 15°C .

W4: See R4

W6: See R5

W7: It is easy to control if the correct reference temperature is set for the domestic hot water circuit. The task is to have the reference temperature at the customer in accordance with national regulations. This often requires a reference temperature of about 50-60°C. A reference temperature that is too high might represent a risk of scalding. A reference temperature that is too low might lead to comfort problems as well as risks for Legionella germs.

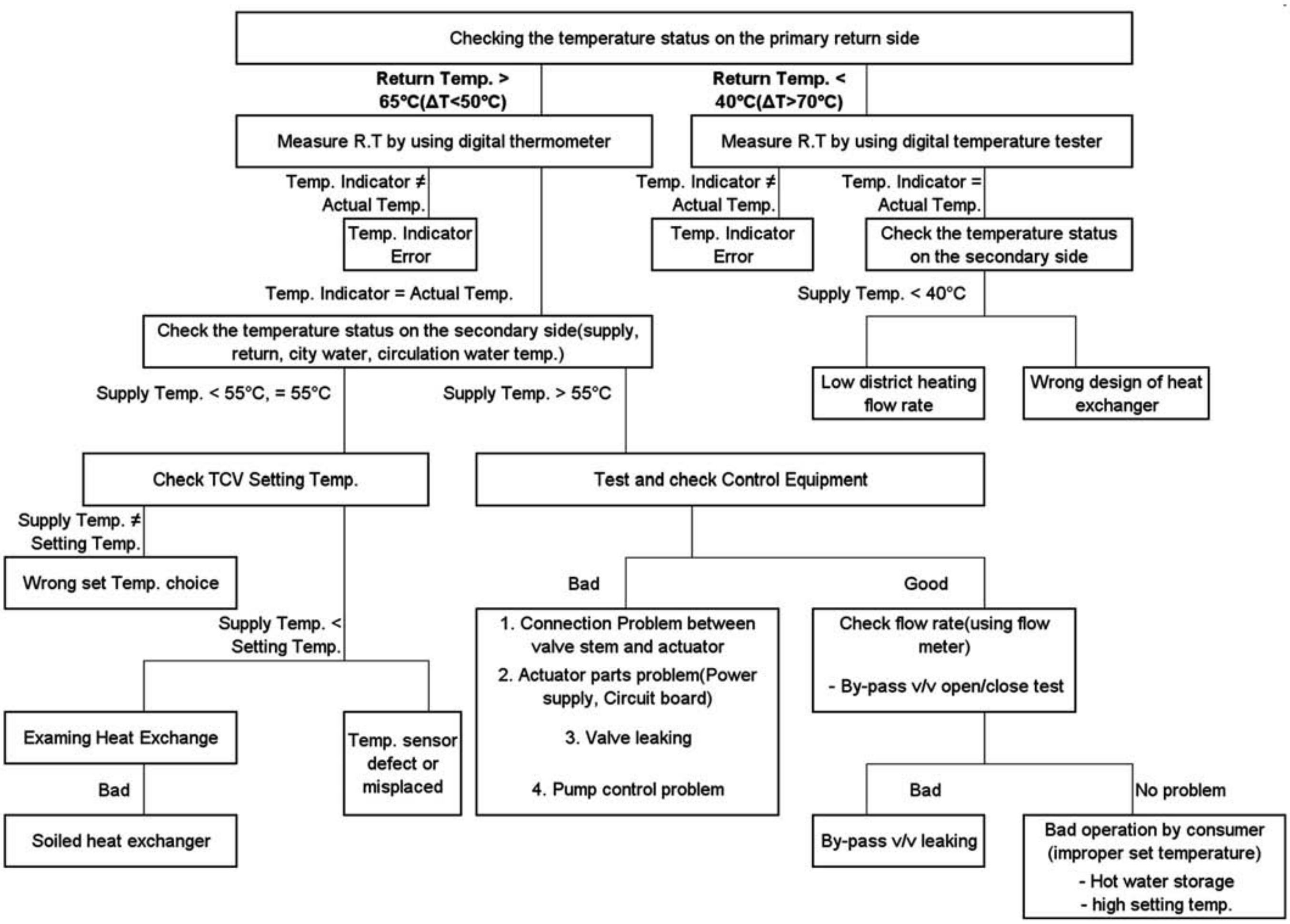
W11: Defective or misplaced sensors may cause a very strange operation of a district heating substation. However, the most common is that the sensor breaks which in most cases leads to a drastic shifting of the reference temperature in the regulator. This often results in the valve going to an extreme position, either open or closed. In modern controllers, one can read the control value given by the sensor and from that decide if it is reasonable or not. If the sensor is misplaced in relation to the heat exchanger, the control function is often deranged. If the sensor is placed more than 1 meter from the outlet of the heat exchanger, there will be inadequate response times in the control system, which often results in oscillations. If the sensor is placed directly at the outlet of the heat exchanger, there is a risk that it will be subject to uneven temperatures which often occurs during low loads.

C4: At the control of the functions it is relatively easy to discover a defect valve controller or a broken valve. By opening and closing the valves from the control station one can easily find out, if they work normally. If the process is surveyed by a DUC, one can instead open and close the valve manually and then observe if the controller resets the valve to correct position.

5.1.5.1 Error search flow chart

Another way of describing the work during an on-site visit is shown in

Figure 5.1-2. This flow-chart shows the method used by the Korean team during the work for this project. It contains more or less the quintessence of the description of the procedure in the chapter above. The import way is to check temperatures and to draw the right conclusions by knowing the load. Of course, one prerequisite is to be very dilligent during the checking procedure.



5.2 The improvement procedure

5.2.1 Introduction

As soon as the district heating company has decided to start a substation cooling project with the aim of lowering the return pipe temperature, the *working procedure* described in this chapter can be a useful tool.

The related work can be divided into two phases; first a start-up phase, with some initial elements, and thereafter a continuous working phase, comprised of work to be carried out continuously during the project.

The start-up phase

- The first step to do in a new cooling project is an *initial status survey* of the district heating network. This initial status survey will be used as a starting point for further evaluation.
- *Analyse which of the economical benefits* can be achieved, if changes in the district heating network or in the substations are made, which result in lower return pipe temperature. The Lava Calculus is in many applications a suitable analysis tool.
- *Define the objective for the cooling project*. For example, the average return pipe temperature shall be lowered by 5°C within 3 years, or the temperature differences shall increase with 10°C during the summer period. The objective should be established from the basis of the economical benefits.
- *Create a project group* with a project leader and qualified co-workers from different departments such as production, distribution, substations and market (customer connection). Very often, it is enough for the project group to meet in intervals of a couple of months in order to discuss items of common interest and the progress. The project group should follow up progress in relation to the initial status survey in order to recognise achievements, changes and deviations from the plan, etc., as far as the district heating network is concerned.

Continuous work

- *Analyse measurement data*, for example with the *Excess flow method* or the *Target temperature method* with the aim of sorting out the substations that most severely contribute to high return pipe temperatures.
- *Decide witch substations that shall be checked*, and make an on-site visit in these substations. All components and their performance shall be documented. After the on-site visit, the reason for low cooling in the substation shall be evident.
- *Analyse what can or should be done* with the poorly working substations and the involved costs to achieve that. At this stage, the first customer contacts should be made, for example through the marketing department. The discussion with the customer shall focus on which improvements of efficiency and comfort that can be achieved and at what cost.
- *Systematically document all malfunctions* in the substations and all changes/improvements. This information is very useful for future evaluations of the project.

5.2.2 Start-up phase

Experiences from different district heating companies show that it is better to deal with the cooling project as a project separated from the daily work. The experience shows that if this is the case, the project has moves faster towards the project objectives. No matter how the project is handled, a few steps must be taken before it can start:

- ***Do an initial status survey together with an economical validation***
- ***Set a project objective***
- ***Establish suitable routines for the continuous work (see next phase).***

5.2.2.1 Initial status survey

To establish a starting point, one should do the status survey. The extent of this survey should be an investigation of how the district heating network has functioned the last years, but of course the survey can be less extensive, f. i. just listing the key problems and the temperature situation over the year. In any case, one should try to answer the question why things are as they are, if the return temperatures are adequately low, if there are bottle-necks during wintertime, if the net dynamic is satisfying, if hot water is reaching all customers in summertime, and so on?

One way to do this is by preparing a simple status survey for the last 12-month period regarding:

- Supply pipe temperature in the district heating network
- Return pipe temperature in the district heating network
- Outdoor temperature.

If possible, one should use a resolution of the measurement data of one hour, but monthly averages would also work. From these measurement data, one can create different key values, for example continuous annual mean values, etc. These key-values are necessary for the upcoming evaluation.

The status survey should also concern an economical evaluation, in order to enable the calculation of the economical benefits of a lower return pipe temperature. This element is very important for motivating the upcoming work, and of course, one of the obvious reasons of starting a cooling project. The economical benefits can be found in both the production and distribution of the heat, as it is described in Section 6 of this report.

5.2.2.2 Project objective

Make a decision about the project objective. The objective can for example be to lower the return pipe temperature in the district heating network over the year by 5°C; or the return pipe temperature in the summer shall be lowered by 3°C, to mentioning another example. Alternatively, one wants to reach a special return pipe temperature in every month during the year, for example 40°C in the summer and 43°C during the rest of the year.

The objective should be established from the basis of the economical benefits, together with distribution and production factors. Sometimes it is more beneficial to improve a certain part of the district heating network, or get high temperature differences during a certain time in the year when the production is based on a specific fuel.

No matter what objective is set, it is very important that all people involved in the project are aware of it. For that reason, it is important to *formulate the objective on paper*, and make sure that everybody knows about it.

5.2.3 Continuous work

The continuous work consists of a few elements, constantly reoccurring, for example every month or every third month with the aim to detect malfunctioning substations during the varying operating conditions over the year.

5.2.3.1 Routines for the continuous work

When the continuous work starts, collection of measurements data and analyses of those are the main tasks of the work. It is very important to find routines for collecting and analysing data from the production and from the readings in each substation.

The composition of the “cooling ability” project group with members from the different departments such as distribution, production and market is very important. The risk is large that otherwise the work can lead to suboptimising one aspect of district heating and neglecting the others with the result that other departments will counteract the process. It must become obvious that the project is a project of the energy company and not of a certain enthusiast.

Depending on what method one uses for the analyses, different measurement data will be needed. The *Excess flow method* and *Target return temperature method* described in the Section 3 of this report can of course be used.

5.2.3.2 Analysis of measurement data and substations

Both methods described in this report can be used to sort the substations in a way that points out substations with poor cooling. It is very important to use a method that does not just sort according to cooling, but also takes energy consumption into consideration. For example, if one uses the Excess flow method, one will receive a list that describes how much more water flow is needed in each substation, compared to whether the objective was reached.

After one has sorted the substations according to their contribution to the return temperature, one has to investigate the function of the substations with the highest contributions. Start with the decision of which substations that shall be checked, and make an on-site visit in these substations. All components and their performance shall be documented. After the on-site visit, the reason for low cooling in the substation shall become evident. If not, maybe one must do another on-site visit (for example at a time with a different heat load), to find out, what kind of malfunctions exists.

After the analyses of these worst-case substations, one should have a list of what can be or what should be done with the badly working substations and what costs this will result in.

5.2.3.3 Deal with malfunctions

This is the most important element of the project. Without any improvements to the substations, one cannot reach the objective, and the work with the objectives, status report and analyses is useless.

Overall, patience, persistence and understanding of the customer’s view of the malfunctions are important in order to achieve progress.

During this stage, the first customer contacts are made, preferably by the enegineering department. The discussion with the customer shall focus on which improvements of efficiency and comfort can be achieved and at which costs. For example, one can write a letter with an overall view of the substation, energy consumption, comfort and efficiency, which makes the customer more interested. If an exchange of components is necessary etc, it is very useful if the company can offer some help and assistance for the new design.

5.2.3.4 Document, follow up and analysis

The reward for the analyses carried out, on-site visits and improved substations comes, when the follow-up reports are made. Hopefully, one can conclude that the return pipe temperature is decreasing and the temperature difference is increasing.

It is also enjoyable when the production costs are lowered because of the lower return pipe temperature. All achieved objectives and results shall be distributed within the project group among all co-workers regularly.

For the above reason, it is very important to document all changes, and analyse measurement data regularly, to note trends etc. This makes it possible to put a finger on what has been done, and what the action has resulted in. This will, at the end, lead to a better knowledge of the district heating network.

5.3 Identifying malfunctions by means of the contour mapping method

5.3.1 Contour mapping

Contour mapping can be used to create an overall view of how the substation's different parts are working. This method is based on three-dimensional diagrams consisting of large sets of measurement data, see Figure 5.3-1. Contour maps are created with daytime hours on the X-axis (0-23 hour), and the outdoor temperature on the Y-axis. The variation in the outdoor temperature sets the scale of the Y-axis, for example is -15° to +15° suitable in Sweden. The Z-axis, the third dimension, consists of isolines and corresponding colour marking. Suitable diagrams can for example be generated for the return pipe temperature or the flow in the substation.

For creating these contour maps, measurement data with a resolution of one hour are adequate. In the diagram of Figure 5.3-1b, the isolines are generated by tree-dimensional interpolation amoung all return temperature values of a whole year and plotted after a smoothing procedure vs daytime and outdoors temperature.

The variation in colour is, for example, from 15 to 65°C (blue to red) for the return pipe temperature. In this method, the colour scale should always be the same for a given application f. i. the return pipe temperature, and thus allow comparisons between different substations. The run of the curves and the colur distribution of the resulting pictures can be use for analysis of the function of the substation.

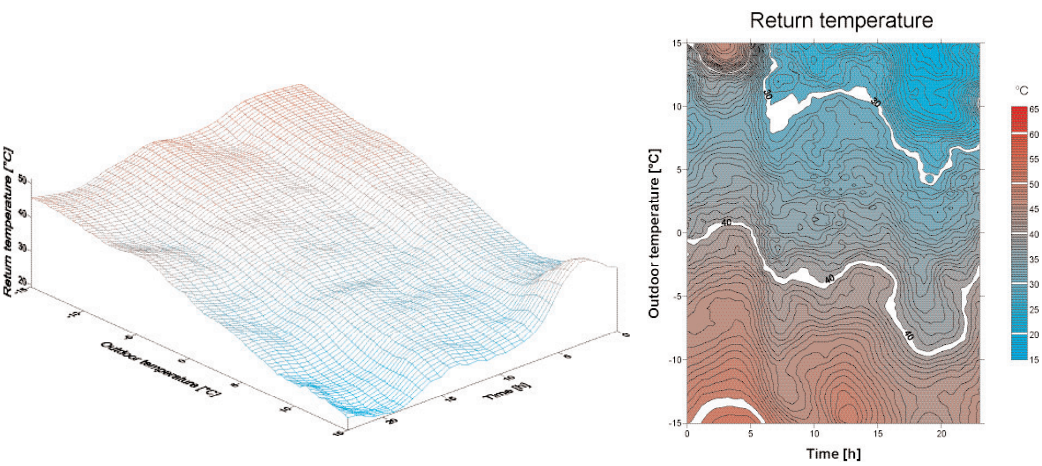


Figure 5.3-1 a, b: Example of contour maps, describing the return pipe temperature in a god working substation

It is possible to detect some malfunctions in substations with these contour maps, such as fouled heat exchangers, leaking control valves, faults in domestic hot water circulation etc. Initially, one can sort malfunctions concerning the domestic hot water system, or the space heating system by just looking briefly at the contour maps. The next step is to do a closer analysis of specific regions of the map; for example, one can find the domestic hot water circulation in the left upper corner of the Figure 5.3-1b above. During summer, when only domestic hot water loads exist, the temperature of the incoming cold water dominates the return pipe temperature. At night, when no domestic hot water is used, the load is only caused by the heat losses in the circulation and therefore the return pipe temperature is high.

The method can also be used for documenting changes over the time in the district heating network and substations. For example, one can document a substation before and after an improvement and thereafter analyse the differences.

5.3.2 *Example from Skogas*

One example of how this 3-D visualisation can be used is shown in the example of Figure 5.3-2. It shows the contour map of the return temperature for Substation 451 in Skogas, serving a 2-pipe secondary network, which had large problems with fouled heat exchangers a few years ago. This becomes obvious, when looking at a contour map for the return pipe temperature in the substation (se Figure 5.3-2a). The contour map is almost completely red, witch means that the return pipe temperature is very high all year. This is a typical behaviour of a substation with fouled heat exchangers.

In this special case, after cooperation with the customer, the substation was rebuilt and in Figure 5.3-2b one can see the results. After rebuilding, one clearly can see the domestic hot water circulation, upper left corner in Figure 5.3-2b, which results in high return temperatures during summer night hours.

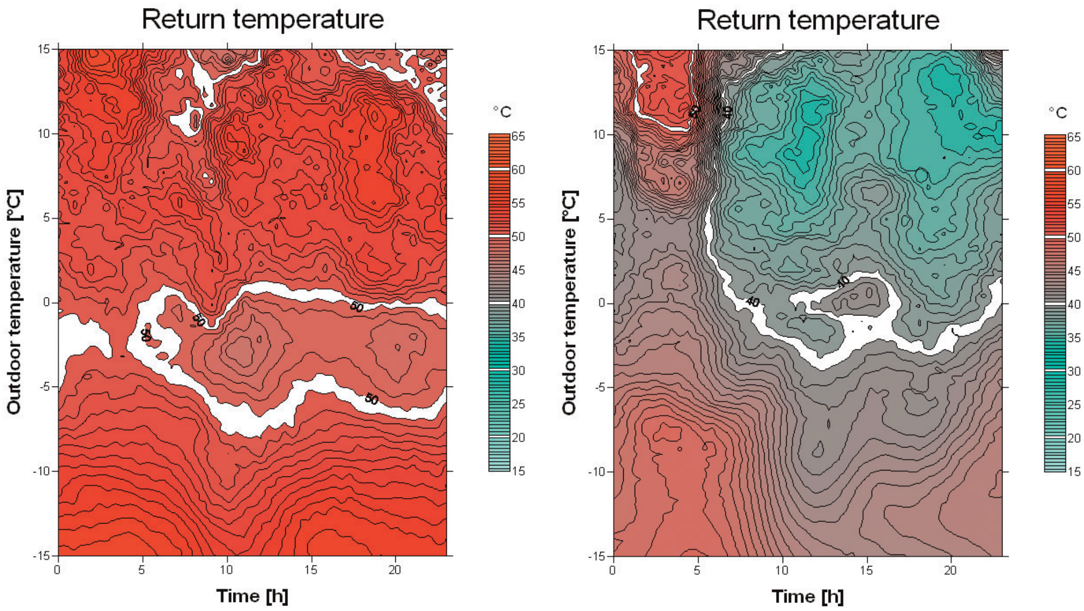


Figure 5.3-2 a, b: Contour maps from substation 451 in Skogas before and after rebuilding

With falling outdoor temperatures, the return pipe temperature increases due to increased load of the space heating system. During the night, without domestic hot water load the return pipe temperature is higher than during the day. One can clearly follow the use of domestic hot water (more blue or less red regions in the map), with a peak in the morning, and one in the evening.

By working with this type of contour map analysis, the location of the red and blue tips on the map can give the experienced analyst a very strong and fast tool for the detection of malfunctions. Other parametes suitable for this type of analysis is the flow rate and the cooling ability of the substation. A more detailed presentation of this technique is given in Lindkvist, Walletun, Selinder, 2004, however, so far only in Swedish.

6 General economic considerations

Summary

For optimising district heating networks, the whole systems consisting of generation, distribution and consumption have to be taken into account. Network temperatures influence investment and operation costs of all components, which is why their optimisation is of great importance to the overall technical and economic optimisation of the system. The influences of temperatures can be oppositional for different costs (e.g. increase of supply temperature leads to increased heat losses, but reduced pumping costs), so that each aspect has to be considered carefully for the respective district heating system.

However, in many cases, lowering the temperatures leads to reduced operation costs and, thus, also to improved overall economics, if the investment costs necessary for achieving these lower temperatures are not too high. Especially reduced return temperatures have a positive effect, so that special emphasis should be put on their optimisation.

6.1 General economic considerations

6.1.1 Investigation of complete systems

District heating systems consist of one or more generation plants, the distribution network, and the customer substations. Supply and return temperatures are the most important parameters at the interfaces between these three components of the overall system. In order to optimise the system, the qualitative and the quantitative influence of network temperatures on all components and their operation has to be determined.

Usually, lowering the temperatures leads to improved overall economics of the district heating system. However, lower temperatures can also have a negative influence on some costs. Pumping costs for example will be higher if the temperature difference between supply and return pipe will be reduced due to lowered supply temperatures. In the following chapters, several aspects and their influences on the operational costs are being discussed.

6.1.2 Influence of network temperatures on heat generation costs

The influence of the supply temperature on the generation plant (or vice versa) depends very much on the type of the heat producer. In co-generation plants with extraction condensing turbines for instance, lower supply temperatures in the district heating network lead to increased electricity generation and, thus, increased earnings. The efficiency of heat only boilers, e.g. fuelled by gas or biomass, is independent from the supply temperature. The temperature of hot water produced in gas engines and fuel cells is fixed due to the temperatures of the internal cooling circuits. On the other hand, the efficiency of heat pumps depends very much on the supply temperature because it is determined by the temperature difference between heat source (ground) and supply temperature.

However, the influence of the return temperature on costs of heat generation is usually much higher. Systems such as geothermal and solar thermal systems or waste heat utilisation, where the heat of the return is “lost”, benefit very much from efficient cooling in the customer substations. Increasing the cooling by 100 % cuts the heating costs in half. Heat generation plants that “incinerate” primary energy carriers (boilers, gas engines and fuel cells) can more efficiently use heat from flue gases or latent heat of steam if the return temperatures are lower. Reducing the return temperature to approximately 50°C with conventional technology or to about 30°C with condensing boiler technology can increase the energy yield by 5 – 10 %, for relatively humid fuels such as biomass even by up to 30 %, see examples in chapter 6.2.

6.1.3 Influence of network temperatures on distribution costs

Costs of heat distribution also strongly depend on the temperatures in the district heating system. With lower supply temperatures, no measures for compensation of heat expansion of metal pipes (e.g. plastic jacket/metal inner pipe) are necessary. Temperatures below 90°C enable the use of plastic medium pipe systems, which in smaller dimensions are less expensive than conventional systems based on metal pipes, (Klöpsch, Zinko, 1999).

Assuming, that the same amount of heat shall be supplied, a lower difference between supply and return temperature requires either wider pipes or increased velocity, which leads to increased pumping costs. Pumping costs strongly depend on the size of the distribution system, the flow velocities and the pipe diameters. Examples have shown that increasing the temperature difference by 10 % can reduce pumping costs by 20 - 30 %.

Lower temperatures in both, supply and return pipes, also lead to reduced heat losses. Savings due to reduced losses are equivalent to the generation costs of the lost heat plus increased pumping costs due to increased mass flows.

The usable cost advantage of lower temperatures and increased temperature differences in heat distribution networks depends significantly on individual circumstances such as pipe parameters, network pressures, heat load curves etc. and, thus, has to be calculated for each specific district heating network to be optimised.

6.1.4 Interrelation between network temperatures and customer substations

As long as supply temperatures are at least as high as the temperature necessary to provide sufficient heat for the respective demand (depending e.g. on the outside temperature), changes in the supply temperature have no negative impact on the operation of the consumer substations and their in-house installations.

On the other hand, the customer substations have the main influence on return temperatures and temperature differences of the district heating network. Often their return temperature is higher than the design return temperature due to malfunctions. Improved settings and operation of the substations can lead to significant savings due to reduction of heat losses, pumping costs and more efficiency at the generation plants. However, if the substation is already working well, the temperature difference can only be improved by optimising the installations for heating and hot water supply at the customers. This can be done by well-adjusted and optimised operation of the heating equipment (although replacing radiators by bigger ones usually is not economic). Necessary investment costs have to be evaluated for each specific customer system to be optimised and compared to achievable return temperature reductions and respective savings.

In Chapter 6.2, influences of changes in supply and return temperature on different costs are exemplified. In Appendix 5, a list of substation malfunction is presented which shows the type of adjustments or repairs on the customer systems might be necessary.

6.1.5 System optimisation

Depending on the specific combination of generation plants, distribution network and customer substations, supply and return temperatures should be adjusted in such a way that the overall optimum can be achieved. In order to determine the optimal overall concept and operational parameters, first the technical boundaries given by the different components have to be evaluated. These could be the maximum heat transfer capacity of heat exchangers, minimal achievable return temperatures in customer substations, minimum and maximum pressures, etc. Then it has to be evaluated, which possibilities exist to extend these boundaries and what will be the respective costs (e.g. exchange of heat exchangers, reconstruction of installations in houses, installations of heat storage tanks, implementation of modern control equipment). Finally, the optimal operational parameters within the original and the extended boundaries and the respective operational costs have to be determined. Calculations have to include pumping costs, costs due to heat losses, savings in the generation plants (e.g. through increased electricity generation), laying costs etc. Savings achieved by different measures have to be compared with the respective investment costs or depreciation. Thereafter, the most economic alternative can be chosen.

In general, it can be said that lower temperatures and a bigger difference between supply and return temperature are advantageous. As supply temperatures nowadays are low enough to enable the use of plastic jacket or even plastic medium pipes, special emphasis should be put on lowering the return temperatures.

6.2 Examples of cost benefits through improved temperature differences in district heating

6.2.1 Example: Possible savings in a cogeneration system

The significant influence of the return temperatures in district heating networks has been described by Martin Rüetschi in his article “The return temperature in DH networks - a key factor for the economical operation of DH” (Rütschi, 1997). He investigated the influence of reducing the return temperature by 10 K on different components and parameters and achieved the following results:

Due to a decreased difference between DH return and ambient temperature, heat losses will be reduced by approximately 6 % (0,6 % per 1 K reduction of return temperature). This leads to savings of about 1 % of the total heat fed into the system.

The 10 K reduction of return temperatures leads to an increase of the temperature difference between supply and return, which in turn leads to reduced mass flows and, thus, a reduction of the necessary pumping energy of approximately 40 %.

For a 2-stage heat extraction in a CHP plant, a 10 K reduction of return temperatures leads to an increase in electricity generation of 5 kWh_{el}/MWh_{th}.

As an example, possible annual savings were calculated for a plant with 40 MW thermal capacity and 12 MW electrical capacity. The overall efficiency was supposed to be 0,9, the time of full usage 4.500 h/a. Prices were assumed to be 23 €/MWh for fuel, 110 €/MWh for electricity and 40 €/MWh for heat. Based on

-	Fuel expenditures of	5.982.115 €/a,
-	Pumping costs of	64.790 €/a,
-	Electricity sales of	6.074.148 €/a,
-	Heat sales of	6.317.113 €/a,

a reduction of the return temperature by 10 K leads to the following cost reductions:

-	Heat losses:	71.785 €/a
-	Pumping costs:	27.446 €/a
-	Additional power generation:	101.236 €/a
	Total	**200.467 €/a**

These savings make up 3,3 % of the fuel and pumping costs or about 1 % of the total annual costs of the CHP plant.

6.2.2 LAVA – calculus for the calculation of cost savings

This description belongs to the Excel calculus LAVA developed for the Swedish District Heating Association (see also Walletun, 2003).[7]

The objective of the model is to give an approximate indication of possible cost saving measures in a district heating system if the temperature levels are changed. This is done by either decreasing the temperature in the return pipe or by changing the supply temperature.

[7] The Lava calculus is a simple Excel based program for calculating cost variations when changing distribution temperatures. The calculus can be loaded down from the home page of the Swedish District Heating Association in a Swedish version. http://www.svenskfjarrvarme.se/download/347/Vaerderingsmetod.xls An English Version is available on request from ZW Energiteknik AB.

6.2.2.1 Typical costs possible to influence by temperature choice

In the LAVA model, the influence of temperature levels of the district heating systems, by either decreased return temperature (T_{return}) and/or by changed supply temperatures (T_{supp}) can be investigated.

The shape of the supply temperature control curve consists usually of two branches. A temperature depending branch starting at DOT (Dimensioning outdoor temperature) and a constant branch at a lowest possible supply temperature at partial load (see for instance Figure 2.1-4). The last one is usually called basic temperature ($T_{supp\ bas}$). The final return temperature T_{return} is a function of a number of parameters such as supply temperature, flow, cooling in district heating substations, by-passes in the distribution system and heat losses from distribution pipes.

Changing the supply and return temperatures in the district heating system will affect the following costs:

- An increase of T_{supp} or a decrease of T_{return} enables a higher maximum delivery of heating power in the existing distribution system thus increased delivery capacity.
- The variable production costs are influenced as T_{return} and T_{supp} will influence the highest heating power possible to be delivered by heat pumps if any and on the COP of the heat pump.
- A decrease of T_{supp} will increase the heat possible to recover in the condensing stack gas cooler.
- It is also conceivable that the quantity of waste heat possible to recover from the industry can be increased if T_{return} is decreased.
- A reduction of T_{supp} and/or T_{return} often enables a higher production capacity of electricity at a cogeneration plant. However, depending on type of cogeneration plant the importance of the temperature levels varies.
- An increase of T_{supp} and/or a reduction of T_{return} will reduce the flow in the distribution system and therefore the pumping costs.
- A reduction of T_{return} and/or T_{supp} reduces the heat loss from the supply pipes.
- At many production plants for district cooling, condenser heat is recovered in the district heating system. Heat recovery in the return pipe is then often more favourable than input of heat into the supply pipe. This means that it is possible to use cheaper cooling machines and also that less operating electricity is consumed. The economic importance of these benefits will increase if T_{return} can be reduced.

However, the changes suggested will not cause many disadvantages. A problem that might occur in summertime (or at other moments with low load) is too low flows in the fringe areas of the district heating system. This can result in too low domestic hot water temperatures in areas with detached buildings.

6.2.2.2 Basic inputs to LAVA

The determination of temperatures starts with a description of the present situation. For instance, it might be suitable to compile general basic information about the system describing the distribution system and the required load. The basic parameters always needed for the calculations are T_{return} and T_{supp} as well as the outdoor temperature T_{out}. Furthermore, the mass flow Q and/or the heating power P are needed. Hourly mean values, if available, are a suitable time-base. The data should preferably comprise complete years, but not necessarily calendar years.

6.2.3 Examples of cost savings derived by LAVA calculus

In the following, some examples for improved heat distribution strategies for district heating are given. The examples illustrate how production and distribution are closely related and that a system must be optimised in combination of both aspects in order to achieve highest possible benefit. The presented examples are based on a typical Swedish district heating net of a smaller city. However, for practical reasons some simplifications of and corrections to the input data have been made, therefore we call the place X-City.

Note that the costs and economic examples are valid at first hand for Sweden. The prices are given in US$ based on the cost situation in Sweden year 2000.

6.2.3.1 Description of the energy supply to the X-City district heating system

In 1996, the district heating system in X-City consisted of about 135 km of distribution pipes. About 410 larger district heating substations and about 1 650 detached houses were then connected to the system. The load requirements of the customers were about 327 GWh in 1996. The production demand for the same year was about 379 GWh, the difference (52 GWh) is assigned to heat losses. From the duration diagram in Figure 6.2-1 can be seen that X-city is principally using the following production sources for heat production:

- Three heat pumps with slightly more than 10 MW heating power each, recovering low cost waste heat from industries. The return pipe of the district heating system makes the heat sink. Today heat pumps stand for the production of the basic load.
- A solid fuel furnace heated with a mixture of waste and wooden products. The boiler is equipped with a condensing stack-gas cooler with air humidifier. The total heat effect *of it is* about 22 MW.
- Purchase of industrial *wood-based process* heat used as top load heat.
- A small quantity of waste heat is recovered from other industries during the warm part of the year.
- Top load is produced in oil boiler units under about 200 top - hours a year. However, this makes a relatively small contribution of about 3-4% of the annual energy supply.

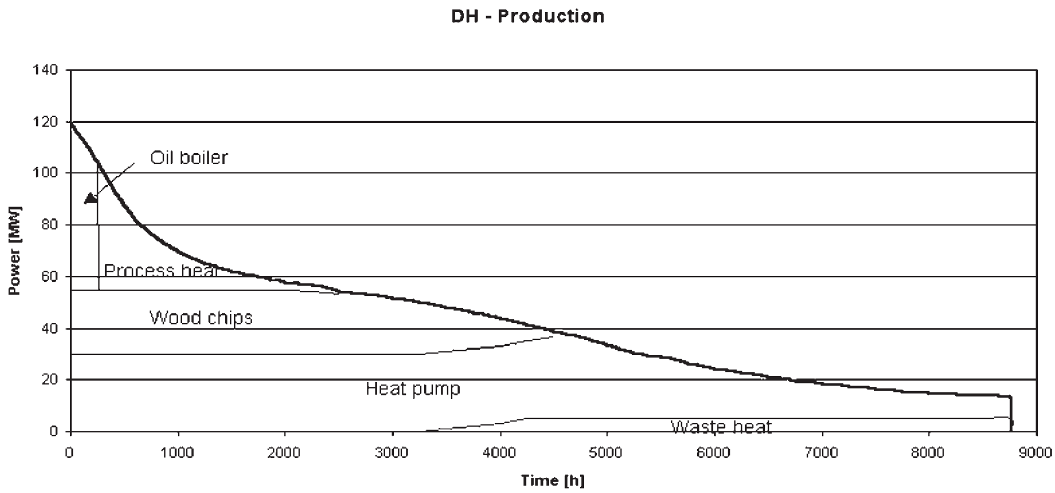


Figure 6.2-1:Load duration diagram at X-City, as it was 1996

From the load duration diagram shown above one can get an idea of the duration of different possible production cases. This information will form the basis for the changes of system temperatures.

Figure 6.2-1 shows that in that example the year could be divided into four periods as far as heat production is concerned:

a) During the coldest 2 500 hours (about 0°C>Tamb> -25°C) all three main production sources are used, meaning that the variable marginal production cost is established by the energy price from the industry for their top load heat.

b) Only the heat pumps and the solid fuel boilers are in operation during the intermediate period between 2 000 and 4 500 hours according to the load duration curve (about +10°C > T_{amb} > 0°C) (as well as a small quantity of waste heat are purchased).

c) Only the heat pumps are in operation during the warmest period between 4,500 and 8,760 hours (about +30°C>T_{amb}>+10°C) - as well as a small quantity of waste heat. The variable marginal production cost is here settled by the heat pumps.

d) The top load is shown separately at the absolutely highest load consumption. In our example, this period is about 200 hours.

The production costs can vary quite significantly between different energy companies and plants. Therefore, the cost levels have to be determined locally for each individual operating case. The marginal cost of heat production is of special interest, i.e. the cost for the last produced MWh.

The following guidance values can be used as an example of cost at heat production:

- During spring, summer and autumn the marginal cost might vary between about 10 and 20 US$/MWh. In our case costs of 16 US$/MWh are chosen.
- During winter time the marginal cost might vary between about 11 and 40 US$/MWh, and in our example it is 24 US$/MWh.
- The costs of the top load oil is 70 US$/MWh.

Another cost necessary for estimating the value is the price for electricity paid for the distribution pumps. This cost usually varies between 50 and 70 US$/MWh including distribution costs and taxes. However, owing to the flexibility of the price for electricity there might be large variations in this case also. Co-generation plants are not considered in our examples. However, these plants can essentially affect the economical results from the calculations.

The operating temperatures of the system can be described as follows:

Temperature at DOT, $T_{supp\ DOT}$ = *110°C*

Breakpoint at about = *+5°C*

Basic temperature, T_{supp_bas} = *about 75°C (lowest temperature, summer time).*

The calculated mean values for a period of 12 months are:

T_{supp} = *84.9°C*

T_{return} = *48.9°C*

T_{out} = *6.1°C*

Average cooling ΔT = *36.0°C.*

As another measure of the temperature value in a district heating system serves the **number of distribution degree-hours G**. This value can be calculated as being the number of hours in a year multiplied by the temperature difference between the water of the district heating pipes and the surroundings:

$$G = ((T_{supp} + T_{return})/2 - T_{out})*8\ 760 \text{ degree-hours.}$$

For the period in question in X-City, G is calculated to *532 500 degree-hours.*

The heat losses from the distribution system are also included into the description of the present situation. The annual distribution loss in a district heating system is directly proportional to the number of annual degree-hours, assuming that the average ground temperature reflects the average annual ambient temperature. Multiplying G by the average heat transfer coefficient and the total surface of the pipe jacket will result in the heat losses. Therefore, the amount of degree-hours is an indicator used for describing the network changes over a longer period. F.i., it can be assumed that if G has decreased by about 4 % from one period of 12 months to another, the distribution losses have decreased roughly the same amount during the period.

6.2.3.2 Examples for the impact of temperature changes on the production costs

The following premises hold for the cost examples:

- *Reduction of the mean value of the return temperature by 5°C*
- *Reduction/increase of the mean value of the supply temperature by 5°C.*

A) Influence of T_{return} on the heat recovered in a condensing stack-gas cooler

By means of a stack-gas cooler in the chimney one can extract some of the condensing heat from the humid air in the stack-gases leaving the boiler. Return-water of the district heating system cools the stack-gases. In order to extract a large amount of the condensing energy, the return temperature in the district heating system has to be lower than the dew point of the stack-gas at a reference temperature. This means that the lower the return temperature T_{return}, the more energy can be extracted from the stack-gas and delivered to the district heating system.

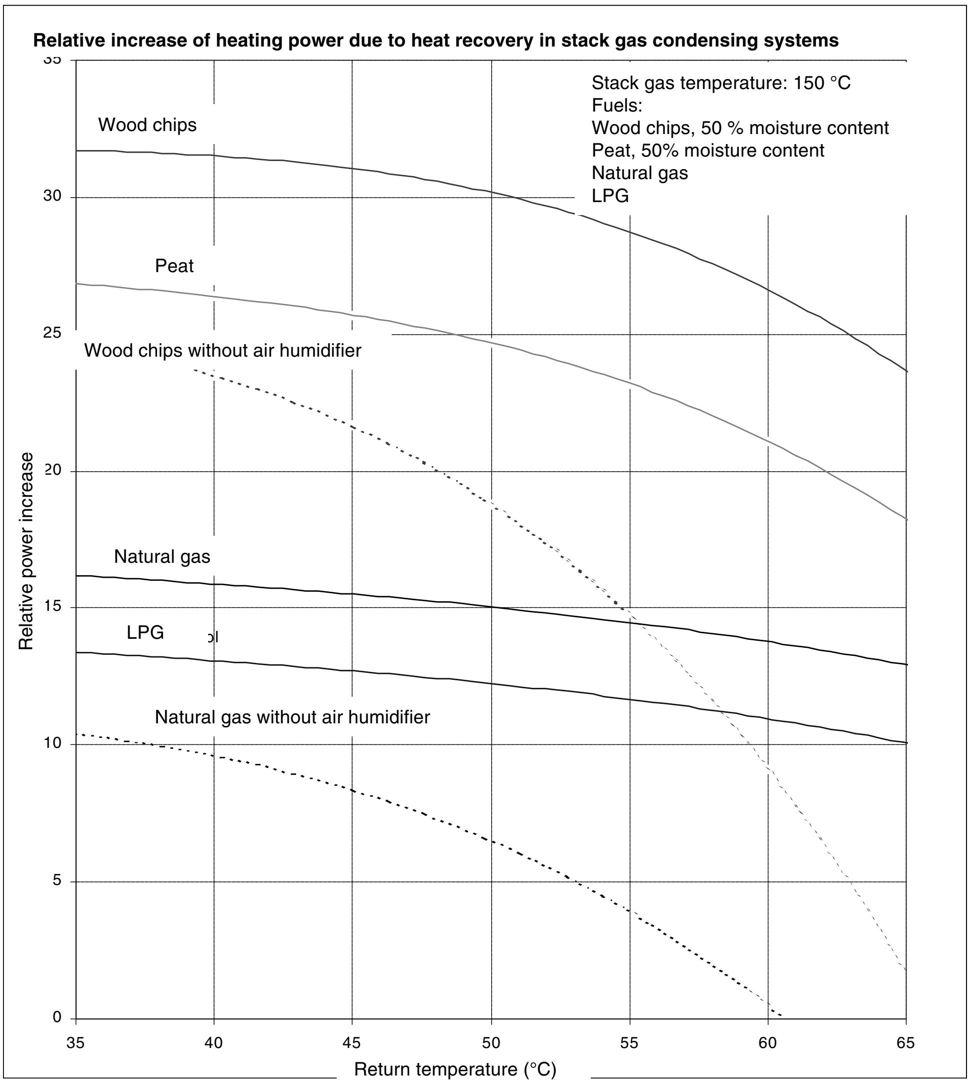


Figure 6.2-2: The relative increase of the produced power in percent of the boiler heating power as a function of the return temperature $T_{ret.}$ (The example in the Figure is compiled by Fagersta Energetics AB on existing plants (Fagersta, 2000)

Other parameters influencing the load of the stack-gas cooler is the type of fuel used, its content of hydrogen and steam, temperature of the stack-gas as well the fact if the equipment is provided with a so called air humidifier which will make it possible to cool the stack-gases even more.

Figure 6.2-2 shows some examples of the possible increase of heating power in a stack-gas cooler.

For instance, we can see that it is possible to recover a considerably higher heating power from wet wood chips than from natural gas. We also see that a reduction of the return temperature by 5°C implies a more drastic power increase in plants missing humidifiers (sometimes more than 5 %), compared to plants furnished with this equipment.

An example is a solid fuel furnace fuelled by wood chips with a stack-gas condenser. In most cases, we will then end up in the range of the upper curves in Figure 6.2-2. We suppose that it is possible to reduce the return temperature by 5°C from 50°C to 45°C. For wood chips, this might mean an increase of the recovered heat by about 2 % of the boiler capacity. Now suppose that we can do this for 4500 hours a year. The boiler heat capacity is 20 MW and the marginal cost 16US$/MWh.

*The annual cost will then be: 2 % * 4 500 * 16 * 20 = 28 800 US$.*

B) Influence of T_{return} and T_{supp} on the performance of single stage heat pumps

When a connected heat pump increases the temperature of the district heating water to the supply temperature T_{supp} (so called "premium heat") with only one compression level, the heat pump COP will be primarily influenced by T_{supp} rather than by T_{return}.

The heat pump COP can be calculated by means of the following equation:

$COP = \eta_i * (T_{cond}/(T_{cond}-T_{evap}))$, where

- T_{cond} = the condenser temperature expressed in K (usually the condensing temperature is about 4K higher than T_{supp}).
- T_{evap} = the evaporator temperature stated in K (the evaporator temperature is often about 4K below the final temperature of the source of the heat pump).
- η_i = correction factor for internal heat-pump losses etc. (Often a value of about 0,7 for larger heat pumps).

In our example, we will assume that the heat pump heats the district heating water up to 80°C, which is equal to T_{supp} during a great part of the year. The source of heat has on average a temperature of 7°C (for example waste water). We also assume that the heat pump is used for about 6000 hours/year and that the price of electricity is on the average 60 US$/MWh (tax for electricity included).

T_{cond} will then be approx. T_{supp} + 4°C = 84°C or 357K. The evaporation temperature will be 3°C or 276K. The heat pump COP is then: COP = 0.7 * 357 (357-276) = 3 085. This results in operating cost for electricity of 60/3.085 = 19,4 US$ per MWh delivered heat.

A decrease of T_{supp} by 5°C means that the heat pump COP is increased to 3.242, corresponding to 3.242/3.085 = 1.051, thus an output increase of 5.1 %. This in turn makes it possible to reduce the cost of electricity by about 4.9 %, corresponding to 0.95 US$/MWh of heat. In our example for X-City, the heat pump is used about 6 000 full-load hours at 30 MW.

The annual cost saving is: 285 900 US$ per year.

A decrease of T_{supp} will also often cause an increase of the highest heating power possible to be delivered by the pump. This means that further savings can usually be reached when the heat pump can be used to replace expensive heat production in units (for instance top load boilers) with a higher variable cost for heat production. This potential power increase is not included into the calculations as it is specific for each plant, but in many cases, it might involve considerable additional savings.

C) *Influence of T_{return} on waste heat possible to recover*

In Sweden, industrial waste heat is used in more than 40 district heating systems. At these plants, a process medium is cooled by water from the return pipe of the district heating system.

If it is possible to decrease the return temperature T_{return}, the quantity of waste heat possible to recover will increase. The relative amount of heat possible to recover when T_{return} is lowered by 5°C will of course vary from plant to plant but is often up to 10-15%. The saving might in certain cases be considerable as the price per MWh recovered waste heat usually is essentially lower than the cost for the replaced heat production. Furthermore, the operation time for recovering of waste heat is often very high.

In our example we assume that the purchase price for recovered waste heat on average during the year amounts to 5 US$/MWh and that the marginal cost for heat production to be replaced during this period amounts to 16 US$/MWh. The operation time is about 5 000 hours per year. The quantity of waste heat possible to recover when T_{return} is decreased by 5°C is assumed to increase by 10 %. The annual saving then amounts to: 10 % * 5 000 * (16-5) = 5 500 US$/year per purchased MW of heat.

The annual saving will therefore be: 55 000 US$.

6.2.3.3 Example for the impact of temperature changes on the distribution costs for district heating

A) *Influence of T_{return} and T_{supp} on the cost of heat losses*

The total temperature level in the district heating system is determining the value of the heat losses. In the description of the plant in Chapter 6.2.3.1, the network temperature and the degree-hour number are calculated for the plant in question and the annual heat loss was estimated to 52 GWh. A decrease of the average value for a year by 5°C on T_{supp} or T_{return} will reduce the amount of the heat losses by ca. 4 % or 2080 MWh. The average marginal heat costs are assumed to be 16 US$/MWh.

The annual saving will therefore be: 33 280 US$.

B) *Influence of T_{return} and T_{supp} on the costs for pumping power.*

An improvement by 5°C in total cooling (thus a decrease of T_{return} or and increase of T_{supp}) will reduce the requirements for flow in the district heating system at an unchanged heating power. This will involve a lower cost for electricity for the distribution pumps owing to lower pumping requirements. In the calculations, we have assumed that the requirement of power for the pumps is roughly proportional to the third power of the flow rate. Furthermore, we have assumed that about 75 % of the electric power added can be utilised as heat.

In the description of the plant presumptions (Chpt. 6.2.3.1), the average ΔT of the net was 36°C. If we succeed in improving the ΔT value to 41°C, this will also mean that the requirement of flow is reduced, i.e. the flow is reduced by about 14 %. With the third-power-dependence between pumping power and flow as given above, a flow reduction by 14 % will result in a power reduction by 36 %.

The consumption of electricity for the district heating pumps in our example has been about 2,1 GWh. That means the improved cooling ΔT will signify a reduction of the consumption of electricity to about 1.4 GWh. With an average cost for electricity of 60 US$/MWh (including tax for electricity) the saving of electricity will be about 42 000 US$ a year. From this the share of pump-energy used as heat shall be subtracted. As we assumed, this share is 75 %, the cost of heat being on average 16 US$/MWh. Hence, additional heat worth 8 400 US$ per year must be purchased.

The annual cost saving will therefore be 33 600 US$/year.

C) Influence of increased temperature difference on the net capacity

If the DH temperature differences T_{supply} minus T_{return} increases, in some nets hydraulic bottle-necks can be avoided. That means f. i. that more customers can be connected for a given design flow rate. The value of an increased net capacity differs locally and must be analysed from case to case. However, in new production it is easily to be calculated, having the choice between two alternative pipe dimensions and the costs associated with those.

A temperature difference ÄT increase by 10 % means a decrease of flow by 10 % .If the pipe dimension can be decreased in this case from DN800 to DN700, the investment will be reduced by 550 US$/m. However the flow will actually be reduced by 30 % in this example, hence only one third of the reduction is on the account of the increased temperature difference. If the section is 5 km long, the cast saving will be 550 US$* 0,33 * 5 000 =900 000 US$.

If this amortized in 20 years with a 6 % interest rate, the annuity is 8,7 %, that means that the annual value of the cost saving will be 78 000 US$. If instead a new pipe system has to be built, the investment will be much higher and hence the significance of the increased temperature difference (improved cooling capacity) of the net will be much more dramatic.

This example illustrates the fact that the value of temperature changes, i. e. increased cooling ability, can vary a lot, depending on the local condition of the district heating system.

6.2.4 Example of cost saving at Göteborg Energy

This chapter is based on a lecture by Gunnar Nilsson, Göteborg Energy, as presented at the 2nd meeting of the Expert Group in Cheongju, Korea, September 2004. The examples are the results of operational measures in the distribution network of Göteborg Energy with the aim of reducing the distribution temperature. It should be noted the Göteborg Energy has a very large net, distributing 3 500 GWh heat a year. The maximum heat capacity is about 2 000 MW.

It should be noted, that cases presented below by no means are exceptional situations, but that these types of malfunctions are quite common. However, it is not until recent, that attention paid to the issue of cooling ability of substations and costs related with high return temperatures.

6.2.4.1 Hot water production for apartments

In an older housing area, a group of 16 multifamily houses were converted from an oil heating block central to district heating. A secondary net provides water to local substations, which included 16 local water storage tanks. The way of control of these storages was such that under most conditions relatively high return temperatures were fed back to the net. Year 2002, the substations were replaced by ordinary direct acting heat exchangers for hot water preparation. As can be seen from Figure 6.2-3, the substation cooling increased by about 20C after renovation.

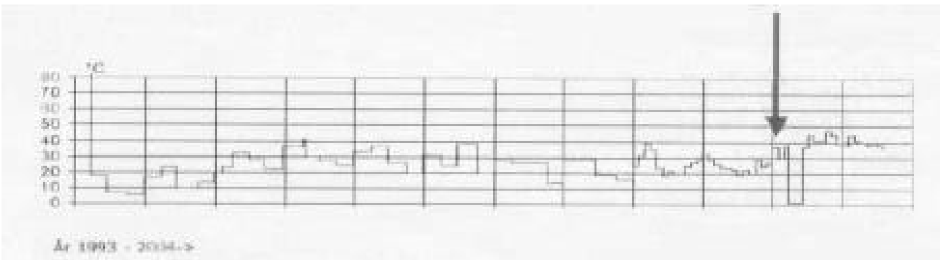


Figure 6.2-3: Cooling of primary substation to a secondary distribution system in a housing area in Göteborg: The cooling ability increases when hot water storage tanks are replaced by direct acting heat exchangers.

The total investment cost was 91 200 US$ and the annual cost saving due to lower return temperatures was estimated to 11 400 US$. Hence, the simple payback time for the investment is 8 years.

6.2.4.2 Hot water production in a sports arena

Similar to the first example, also here the heat was distributed in a secondary net connected to a primary substation. The hot water is prepared in a secondary substation including hot water storage.

During the renovation, the storage was removed and hot water was prepared at the primary sub-station and is directly delivered to the user. The investment was 11 880 US$, which was shared between the customer and the supplier because of the improved water capacity to customer in the new system.

Similar to the case before, the cooling ability of the new hot water system increased by 25C. The annual cost reduction was estimated to be 7 500 US$, which means that the simple payback time was about 1,6 year.

6.2.4.3 Shortcut in a large shopping mall

The shopping centre was connected to district heating in 1972. During construction, a bypass valve was installed in order to secure an undisturbed supply of district heating to other customers. The valve was thereafter forgotten and continuously kept open until 2002, when the low cooling ability was detected and the reason for it identified. A simple closing of the valve improved the cooling ability by 30C (Figure 6.2-4). The annual cost saving for this measure was estimated to 14 300 US$ with an investment of 0 SEK.

Figure 6.2-4: Substation cooling record at a shopping mall in Göteborg, Sweden.

7 Final discussion and conclusions

Final discussion

The main intention of this report is to describe a *practical method* for improving the cooling ability based on field experience. The method addresses the question of how to evaluate and improve the cooling ability of substations. The study is based on the following basic elements:

- Analysis of measurement data in order to find out the status of the substations in the net and to detect the reasons for resulting high return temperatures.
- Identification of malfunctions of substations and repair of them.
- Verification of the improvement based on new analysis of measurement data after renovation of the malfunctioning substation.
- Substantiation of the importance of this work by illustrating it with examples of the economical benefits connected with improvements.

The work was performed by combining the skill of the involved project partners. Sweden contributed with the field experience of long-term consultancy in this area, USA with the analytical skill of theoretical thermal analyses and Korea with the unique opportunity of operating district heating nets where the results of the developed method could be positively applied with the aid of enthusiastic development engineers.

Hence, the *main result* of this cooperation is a methodology and the proof of its practical application for detecting substations, which seriously affect the return temperature of the whole net. Furthermore, smaller substations, which are not working well, can also be identified with this methodology.

When evaluating substations by means of time-resolved measurements, some discrimination can also be achieved for classifying, if the malfunction belongs to the hot water or the space heating system (a diagnosis tool based on long-term evaluation of hourly data is under development).

However, normally, the type of malfunction of substations cannot be found solely on the basis of analysis of measurement data. Considerable effort has to be spent on detecting these malfunctions on-site. Therefore, the experience from the operational engineers is in this case an irreplaceable instrument. Some *guidelines* from these experts are also presented in this report.

In order to successfully and sustainably affect the return temperature in a large district heating net, the work for detecting and improving substations has to go on for years on a regular basis. Of course, in practice, this means a large amount of work, which cannot be fulfilled within a limited project as such reported here. We could therefore only initiate the work in Korea, but we were able to rely on a persistent work in Skogas, Sweden.

Extended work over longer periods means, of course, costs. But it is also shown in this report, that the work for decreasing return temperatures has *a positive pay-off.* For example, it is estimated for Sweden that the decrease of the return temperature by *one degree has an economical value of the order of 100 million US$* (see f. i., Werner, 1999). Examples for the economical benefits of low return temperatures are also presented in this report, both based on theoretical calculations and on practical experience from some district heating companies.

Main achievements

The work for *detecting malfunctioning substations* is principally based on the evaluation of the excess flow of substations, i.e. the flow of district heating water (in m³ per time interval), which passes a substation in order to transfer the desired load to the customer. *Excessive flow means flow in comparison with a better working or ideally working substation.* For this evaluation, *two methods* have been developed:

- The E***xcess flow method*** compares the actual flow through a substation with that of a substation working on a *desired return temperature,* called the ***Reference return temperature RRT.*** Excess flow is the actual flow minus flow at RRT. Large positive values of the excess flow point out substations, which are contributing most to the elevated return temperature and therefore should be improved. Measurements can be based on data with very coarse resolution such as monthly averaged energies and flow volumes.

- The ***Target temperature method*** compares the actual flow through a substation with that of an *ideally working substation.* A ***Target return temperature TRT*** is calculated by means of an quasi-analytical method for one- and two-stage substations delivering an ideal return temperature calculated by standard methods and known parameters for the substations in question. The evaluation is based on hourly values of the most common data used for energy measurements. This method gives time resolved return temperatures, flows and energies from which many different analyses can be performed, such as the function of the substation under certain day times or under certain seasonal conditions. The high resolution of the measurement data allows more specific conclusion about the substation to be drawn. The method is also important for identifying smaller malfunctioning substations that are not heavily contributing to the common return temperature of the district heating net, but nevertheless not working satisfyingly.
- The *combination of both methods* mentioned above to ***ISA: Individual substation analysis***. In the simplest case, both methods are combined: The most malfunctioning substations are selected by means of the excess flow method and thereafter analysed further by means of the return temperature method. This limits the more cumbersome detailed analytical work to such substations, which need to be evaluated with higher time resolution for further diagnostic work.

Final conclusions

By means of a consequent application of the excess flow method in Skogas, it was possible to decrease the return temperature even in a large net. Changes of the operational conditions at the production plants however temporarily increased the return temperature, but continued work lowers it again.

The Cheongju plant was evaluated for 1,5 years with both the excess flow method and the target temperature method, and a combination of both. A number of malfunctioning substations could be identified and improved.

A two month long return temperature evaluation of the improved substations confirms the substantial decrease of the individual return temperatures in about ten substations (out of a total of 108). Although these few substations evaluated for two months under intermediate load conditions (September -October 2004) will only result in a slight decrease of the common return pipe temperature of the district heating net, annual savings will already be visible after one year of operation.

A critical step in the total methodology of efforts for decreasing the return pipe temperature is the diagnostic work and the repair of malfunctions. For that purpose, criteria for malfunctions and ways how to detect them haven been presented. In addition, a complete list of possible malfunctions and the way in which they affect the system or the customer has been compiled. Some principal malfunctions (hot water, space heating water circulation system) can be detected by means of time depending analyses such as the *target temperature method.* However, for more subtle causes of malfunctions, the experience of skilled maintenance engineers is indispensable.

The economic benefit of repairing malfunctioning substations has been illustrated with examples. Theoretical cost-benefits can be calculated by means of the Lava calculus, which is published through the Swedish District Heating Association. The benefit can be especially large if the production plant includes co-generation or heat recovery from stack gas condensing systems, as two examples. Reduced heat losses and pumping costs can be other examples. In certain cases, the operation of expensive top load plants and in special cases, construction of new plants, can be avoided. Some examples from district heating practice finally support these calculations.

All in all, we believe that the consequent improvement of operational temperature differences in district heating systems and resulting low return temperatures has an economic potential which is highly underestimated by many district heating operators.

Nomenclature

The following list of nomenclature belongs to the main parameters, indices and expressions used in the report. In some chapters slight deviations might appear.

Parameter

C	Volumetric thermal capacity	[kWh/(m³·°C)]
E	Energy per time unit, power or heating capacity	[KW]
f( )	Function	
Q	Heat load per time unit, power or heating capacity	[KW]
T	Temperature	[°C]
t	Time of the day	[h]
V	Volume flow	[m³/h]

Indices

act	Actual
B	Balance (in building balance temperature)
C	Cluster
cir	HW Circulation
cond	Condenser
cw	Cold water
d	Day
evap	Evaporator
in	In
out	Outside or outlet
r , ret	Return
R	hot water return temperature
rad	Radiator
RRT	Reference return temperature
s, supp	Supply

Expressions and abbreviations

C	C-type malfunction (components)
CHP	Cogeneration heating plant
CV	Control valve
DCS	Distribution control system
DH	District heating
DHW	Domestic hot water
DN	Nominal diameter
DOT	Dimensioning outdoor temperature

E	Excess
E	E-type malfunction (external influences)
HEX	Heat exchanger
HOB	heat-only boiler
HW	Hot water
HWC	Hot water circulation
ISA	Individual substation analysis
KDHC	Korea District Heating Corporation
LAVA	A name for a numerical calculus of cost changes when DH temperatures are changed
LSFR	Low sulphur waxy residue
R	R-type malfunction (radiator system)
RC	Control equipment
RTD	Resistance thermometer device
RRT	Reference return temperature: Return temperature of the DH net, arbitrally reduced by some degrees for calculating the excess flow of substations
SFAB	Södertörn Fjärrvärme AB (Södertörn District heating Corporation)
TCV	Temperature control valve
TRT	Target return temperature: Primary side (DH) ideal return temperature of individual substations as calculated by an analytical model
W	W-type malfunction (hot water system)

References

Abel, E. and Aronsson, S., et al., Ekonomiskt utrymme för alternativ inom ny energiteknik. (Economical space for alternatives within new energy technique). Report G25:1986, BFR, Stockholm 1986.

Boehm, B., On the Optimal Temperature Level in New District Heating Networks. Fernwärme International 15 (1986):5, 301-306.

Boehm, B., Energy Economy of Danish District Heating Systems – a Technical and Economic Analysis. Technical University of Danmark, 1998.

District Heating Statistics 1998 FVF 1999:10, Swedish District Heating Association, Stockholm, 1999.

Fagersta Energetics AB. Heat recovery and flue gas cleaning with condensing flue gas cooler. Internal communication, 2000.

Frederiksen, S. and Werner, S., Fjärrvärme – Teknik, teori och funktion (District Heating - Technique, theory and function). ISBN 91-44-38011-9, Studentlitteratur, Stockholm 1993

Glück, B., Heizwassernetze für Wohn- und Industriegebiete. Verlags- und Wirtschaftsgesellschaft der Elektrizitätswerke mbH, Frankfurt am Main, 1985.

Gummerus, P., Petersson, S. Robust fjärrvärmecentral (Strong substations). Chalmers, Inst. för Energiteknik. Report A99-223 (1999).

Hansson, T., Operational Optimisation of District Heating Systems. M. sc. Thesis, Technical University of Denmark, 1990.

Klöpsch, M. and Zinko, H.. Plastic Pipe Systems for DH, Handbook for Economic Application. IEA-District Heating and Cooling Report 1999:T6. Novem, Sittard, The Netherlands. ISBN 90-5748-005-0.

Lindkvist, H., Selinder, P. and Walletun, H. Felidentifiering i fjärrvärme-centraler med Flygfotobilder. Identification of malfunctions in substations by means of the contour mapping procedure. On Swedish. Report ZW-04/12, Sweden 2004.

Margen, P. I vilka fall lönar sig rökgaskondensering även hos kraftvärmeverk? (In which cases is stack-gas condensing profitable also in cogeneration plants?). Swedish District Heating Association Conference, ”Rökgaskondensering – Stack gas condensing”. Göteborg, 1999.

Margen, P., Mindre lokala produktionscentraler för kyla med optimal värmeåtervinningsgrad i fjärrvärmesystem. (Small local production plants for chill with optimal degree of heat recycling in district heating plants). Swedish District Heating Association. Margen-Consult AB, Nyköping 1999.

Nilsson, G. Internal communication. Working paper for handbook of substation cooling, 2000.

Nilsson, G: Cost savings by means of adjusting malfunctions of substations. Lecture hold at the 2nd meeting of the Project Expert Group in Cheongju, Korea, September 2004.

Rüetschi, M. The return temperature in DH networks - a key factor for the economical operation of DH. Euroheat & Power 10/1997.

Snoek, C., Yang, L., (1999): Optimum Connection of Multiple Thermal Loads in Buildings Connected to District Heating. 7th Int. Symp. on District Heating and Cooling, 1999 Lund, Sweden.

Snoek, C., et al. IEA District Heating and Cooling: Optimisation of District Heating Systems by Maximizing Building Heating System Temperature Differences. Novem 2002:S2 (ISBN-90-5748-022-0).

Volla, R., et al. (1999): Efficient Substations and Installations. IEA-District Heating and Cooling Report, Annex IV. Novem, Sittard, The Netherlands, 1996.

Walletun, H., Södertörn district heating parameters, Private communication, Nyköping 1986.

Walletun, H.,Effektivisering av fjärrvärmecentraler, Metodik, nyckeltal och användning av driftövervakningssystem. (Rationalizing of consumer sub-stations; Methodology, key numbers and use of plant supervision systems.) FOU 199:27. Swedish District Heating Association, Stockholm 1999. (Report ZW-98/02, ZW Energiteknik AB, 1998).

Walletun, H., Description of Lava calculus for calculation of district heating network temperature economy. ZW working document, Nyköping 2002.

Werner, S., internal communication, Fjärrvärmebyrån, 1999.

Winkens, H.P., Renski, A., Trotszkiewicz, J., wirtschaftlich optimale Vorlauftemperaturen in Wärmetransportsystemen bei gleitender und konstanter Fahrweise. Fernwärme International 16 (1987):4, 189-197.

Appendices

Appendix 1: Type of substations investigated in this project

Summary

In this chapter the generic type of substations occurring in the Swedish and Korean nets are presented. The chapter gives a schematic view and short description of each substation. The intention is to let the reader better understand the physical facts behind the cooling mechanism in each type of substation.

1.1 Generic type of substations

A very comprehensive description of substations is given in a report of another IEA project of IEA DH&C Task VI "Optimization of District Heating Systems by Maximizing Building Heating System Temperature Difference", see Snoek (2002). For this reason, in this section only the substation types used in Skogas and Cheungju are presented.

1.1.1 Parallel connected substation

Parallel-connected means in this case separate heat exchangers for the DHW system and the radiator system, respectively. A principal scheme is seen in Figure A.1.1.

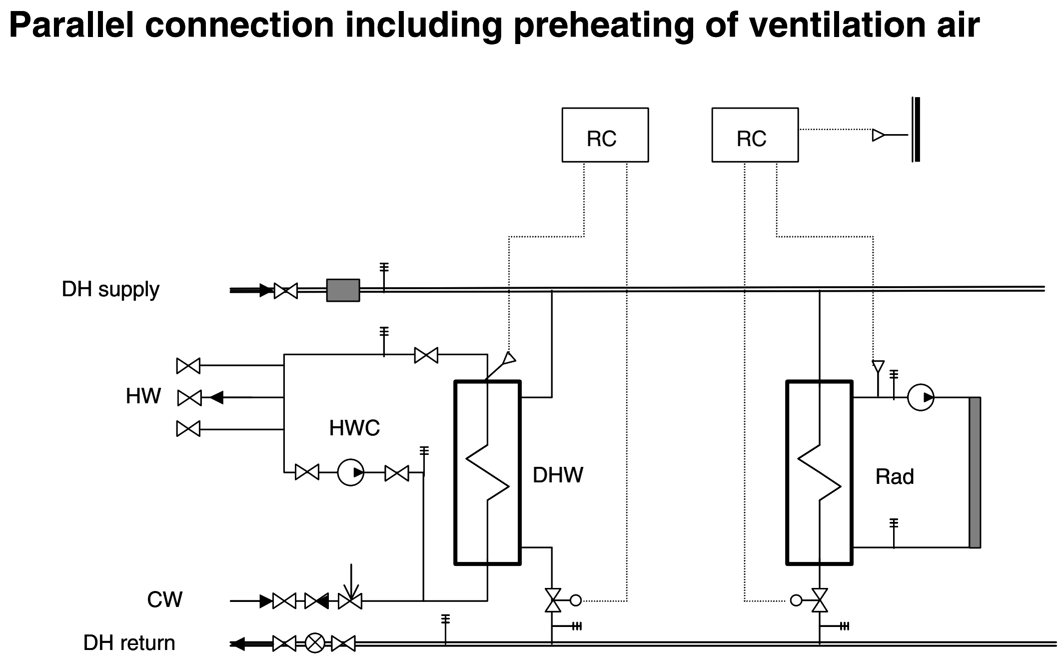


Figure A.1.1: Parallel connected substation for multi-family buildings

In this connection, DHW and radiator circuits are completely independently connected to the district heating system. The radiator temperature in the houses is usually controlled by the outdoor air temperature, and the design temperatures are often 80/60 or 70/50°C in the case of Skogas, which principally only includes houses build in the 1960 or 1970-ies. Furthermore, the primary flow is controlled by the control valve, which in turn is regulated by the radiator circuit sensor. A typical presentation for the supply and return temperatures of a 80/60°C radiator system based on a theoretical model developed by Gummérus, (1989), is shown in Figure A.1.2. It should be mentioned that in reality, the return temperature at given outdoor temperature is not one point, but a multiple of point scatters, depending on other climatic conditions, such as wind and sunshine conditions. The DHW flow is also controlled by a control valve activated by the temperature sensor for the supply of domestic hot water. This valve should normally be able to react very fast on the varying hot water loads.

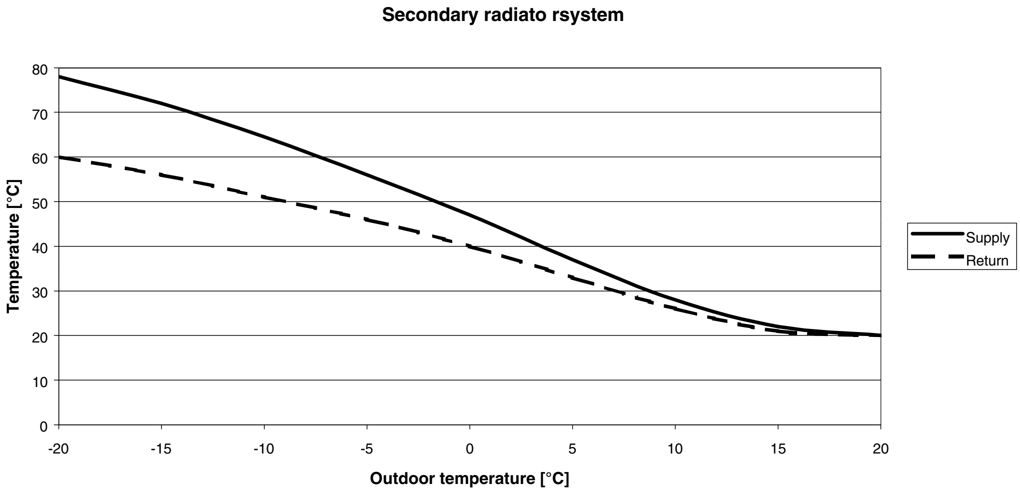


Figure A.1.2: Radiator supply- and return temperatures for outdoor air temperature controlled 80/60°C system according to Gummérus, 1989

The heat exchangers for radiators are normally dimensioned with very low difference between radiator return and DH return temperature of 1 - 2°C. That means that in wintertime, the district heating return temperature follows the radiator return temperature but is reduced by the temperature difference, which can be achieved at the cold end of the DHW heat exchanger. This heat exchanger in turn has normally a higher ÄT of 10 - 12°C (at design flow) and can therefore return the DH medium with temperatures around 15 - 20°C in Sweden and 25 - 30°C in Korea at a minimum. The DHW return temperature, on the other hand, is also affected by the hot water circulation flow (HWC) which in many country is regulated by law for the case of Legionella risks. Usually this HWC flow is a constant flow at a rate of about 20 % of the hot water design flow and its temperature back to the DHW heat exchanger should be not lower than 50°C. This will therefore increase the DH return temperature out of the DHW heat exchanger. In practice, the return temperature can be anything between 25 and 50°C, depending on the hot water load. The combined temperatures of both the DHW and radiator heat exchanger will finally give the resultant DH return temperature.

Based on this general description, we can discern three basic functions at which a substation can be checked:

Cold winter nights:

The substation is close to the temperature of the radiator system because of the fact that the influence of DHW and HWC flow is small.

Hot summer late afternoon/evening:

There is no contribution of the radiator system. The substation will work with high DHW flows biased by the contribution of the HWC flow. The DH return temperature will be at its minimum.

Hot summer night:

There is no contribution from the radiator system. The DHW flow is at its minimum, HWC is dominating and therefore the return temperature around 50°C – 55°C.

In other times - which is most of the operational time - the return temperature will be somewhere in between these extremes. This is illustrated in Figure A.1.3, which shows a contour-map diagram of the return temperature for substation 809 in Skogas. Time of the day is on the horizontal axis and outdoor temperature on the vertical axis, the total area presenting a complete operational year. (More about these diagrams and it use, especially of coloured mapping is described in section 5.3 of the main report).

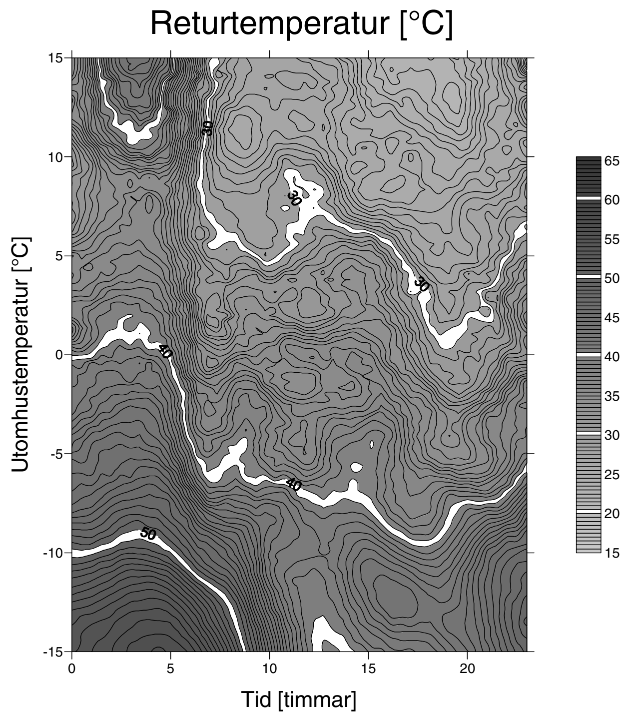


Figure A.1.3: Two-dimensional distribution of the return temperature over the year

In the description and in Figure A.1.1, there is no air ventilation heating system included. The reason for that is, that in the area of Skogas, which is investigated in this project, there are no such systems. In many other places, however, such systems are common and very often the parallel system including heating of ventilation air can look like it is shown in Figure A.1.4.

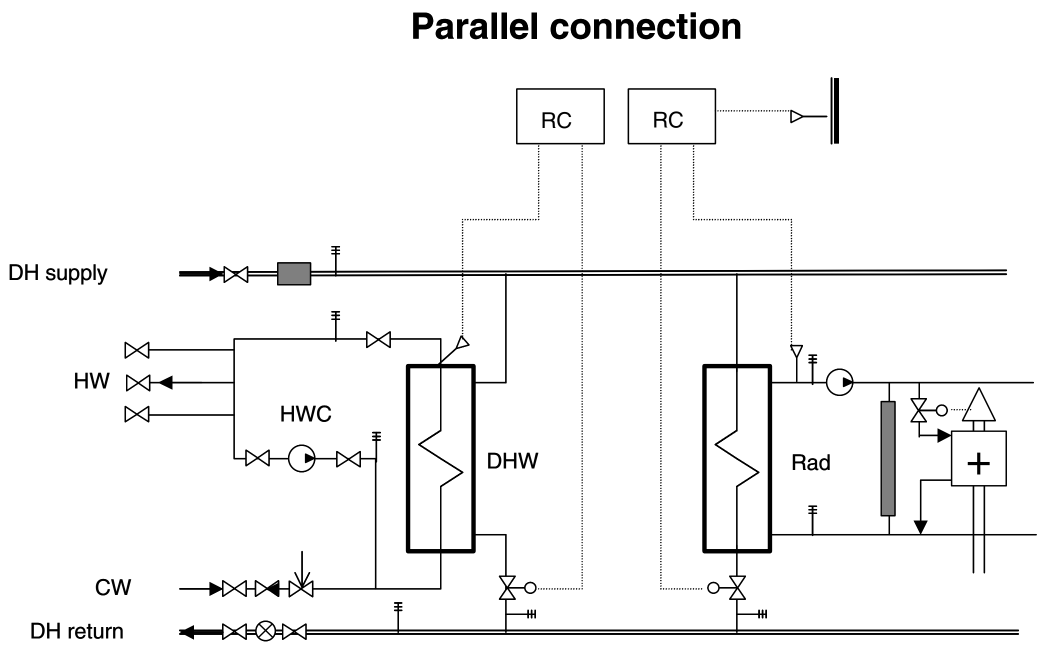


Figure A.1.4: Parallel connected substation for multi-family buildings including ventilation preheating system

The incoming air from the ventilation system is heated in a water heated aero-temp battery connected to the radiator circuit. In this case, the air heating system includes not a separate DH heat exchanger but is connected to the radiator circuit. Typical temperatures might be 80/40°C or even 80/30°C. The ventilation return temperature system is blended with the return temperature of the radiator system and contributes to slightly lower the radiator return temperature.

The ventilation system is often also connected with an air preheating system using heat exchange with the warm exhaust air.

In other cases, however, the ventilation air heat exchanger can also be connected in parallel to the radiator and DHW heat exchanger and therefore function as a completely uncoupled device.

1.1.2 Two-stage connection

This connection is very common in Sweden, but is also predominantly used in Cheongju. The basic idea is that the DHW is divided into a preheating and an afterheating stage. The radiator system is connected in parallel with the afterheating stage and the precooled DH return from the radiator heat exchangers merges with the return from the DH water through the afterheater stage. The basic idea is that the DH medium leaving the radiator heat exchanger in wintertime with higher temperature, can be further cooled down, see Figure A.1.5. Again, both flows are controlled by temperature sensors acting on the DH flow control valves.

The amount of the reduction of the return temperature depends on the dimensioning of the preheating and afterheating DHW heat exchangers. A theoretical calculation with large heat exchanger areas results in the return temperatures shown in Figure A.1.6. There is a clear difference between the both cases, single stage and two-stage substation.

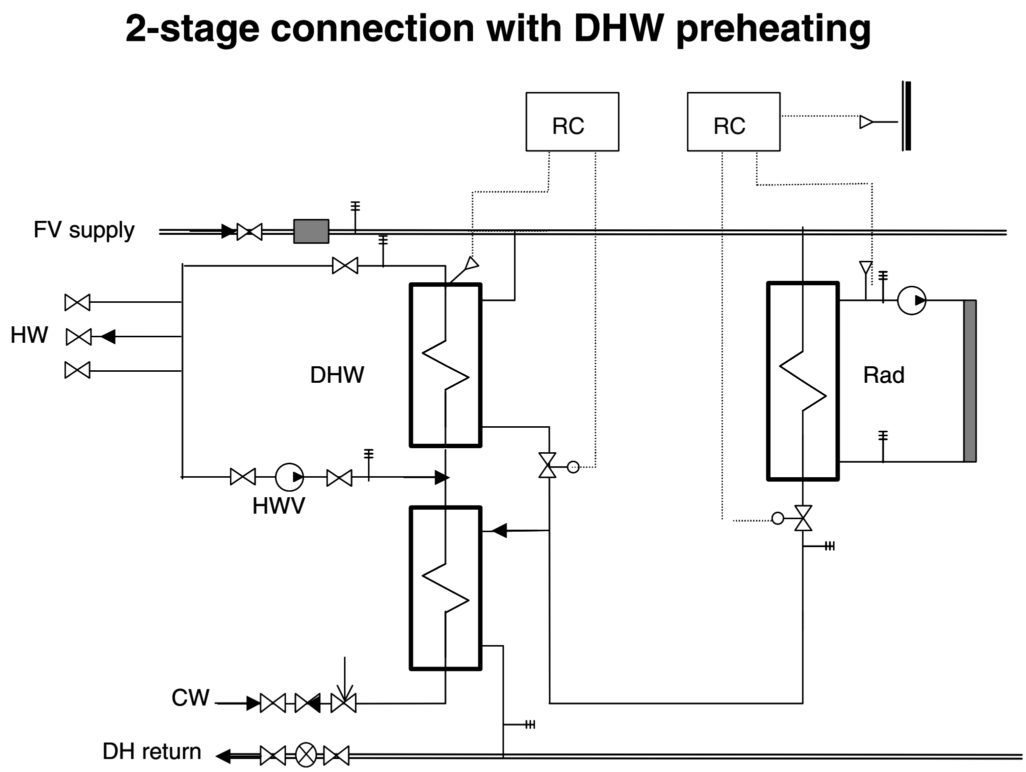


Figure A.1.5: Two-stage connection substation

However, in practice the size of the DHW heat exchangers is relatively limited because the design flow is reached only a few minutes a day and the cold-end temperature difference for this case is allowed to be high. That means that the return temperature at high flow situation is much higher than ideally could be achieved and therefore the difference between single stage and two-stage is relatively small, seen over a whole year. In a study (Walletun, 2002) it was found for a sample of substations in a large DH net that the difference in average over a year between these two types is only 1 - 1,5°C in favour of the two-stage substation.

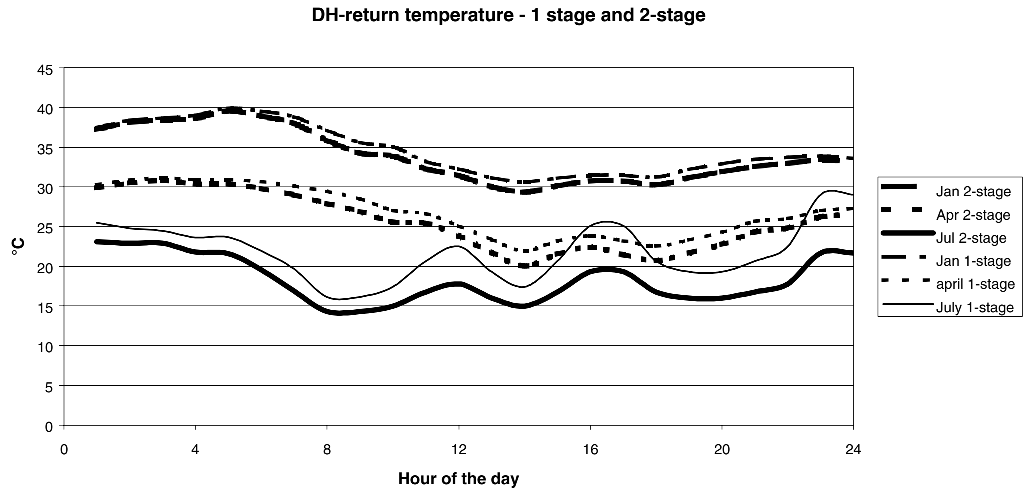


Figure A 1.6: *Return temperatures of a single stage parallel and two-stage connected substation for three different days under the year: winter, spring and summer case for a given DWH profile based on the climate condition for Stockholm.*

This is an import point to remember when we discuss the recommended method for the evaluation of substations in Section C1.

1.1.3 Secondary net

An area with a group of multifamily houses in cities is often developed by the same real estate developer. In such areas, built in the 1960-ies, very often an oil-fired block central was supplying heat to the houses. Later on, due to oil saving measures, such an area could be connected to the meanwhile expanding DH network of the city. The local distribution net thus acts as the load to the primary heat exchanger. On the other end, secondary heat exchangers are connecting the different buildings. A scheme for such a system is shown in Figure A.1.7.

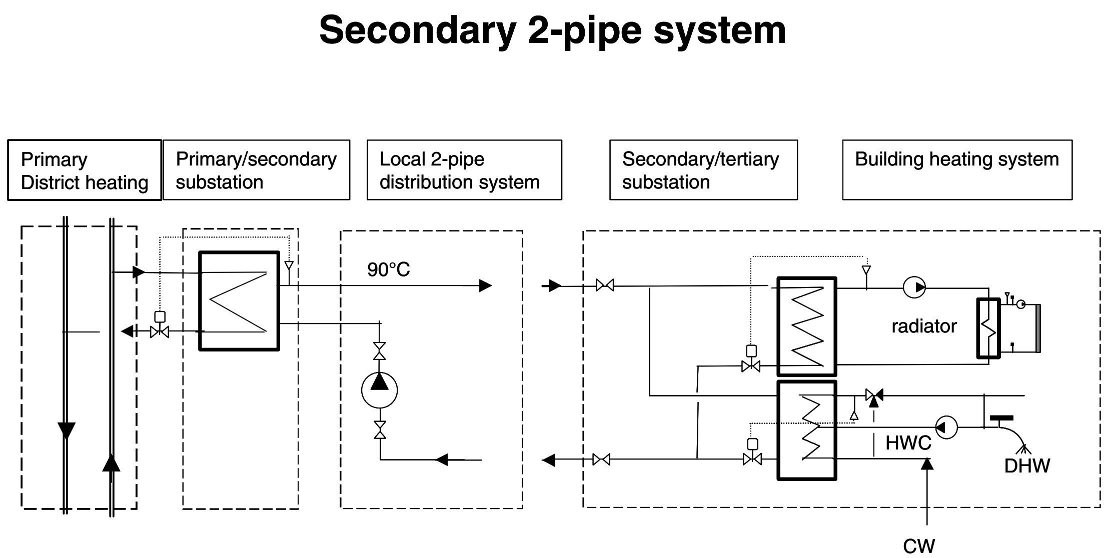


Figure A 1.7: *Secondary net connected to district heating*

In such a system heat losses and the secondary heat exchangers need higher distribution temperatures than otherwise would be the case. The design distribution temperatures in the system existing in Skogas are 90°C in winter, gradually decreasing until 65°C at outdoor temperatures larger than 10°C. Hence the control valve at the primary heat exchanger will adjust these temperatures guided by an outdoor air sensor. The control functions at the secondary heat exchangers are the same as it is described for the parallel connection substations.

1.1.4 Secondary four-pipe system

As an alternative to the secondary network with secondary heat exchangers described above, the energy from a local substation can be distributed in a four-pipe network, thus avoiding secondary heat exchangers Figure A.1.8. The radiator heat and hot water are distributed in two separated circuits. Nowadays, pipe systems exist, which include all four pipes within a single casing.

In such four-pipe systems, one primary two-stage substation as described above is often used. The control functions for the radiator circuit and the hot water distribution are similar to those in the described above for the two-stage substation. The only difference is that there will be larger distances between different houses and heat losses from the piping might be larger than it is the cases in house internal systems. Therefore, the supply temperature can be slightly higher in such systems and also the HWC flow might be somewhat larger in order to fulfil the Legionella safety rules. But it is still lower than the temperature in the system with secondary heat exchangers. In Skogas, the radiator system is designed for a temperature of 65 - 70°C in winter. On the other hand, because of heat losses, the radiator circuit return temperature can even be somewhat lower in good working systems, thus heat losses can erroneously be taken for “good cooling”. Very often, due to heat capacity effects connected with the piping system, such a four-pipe system is also characterised by less transient temperature fluctuations compared with substations serving just one building.

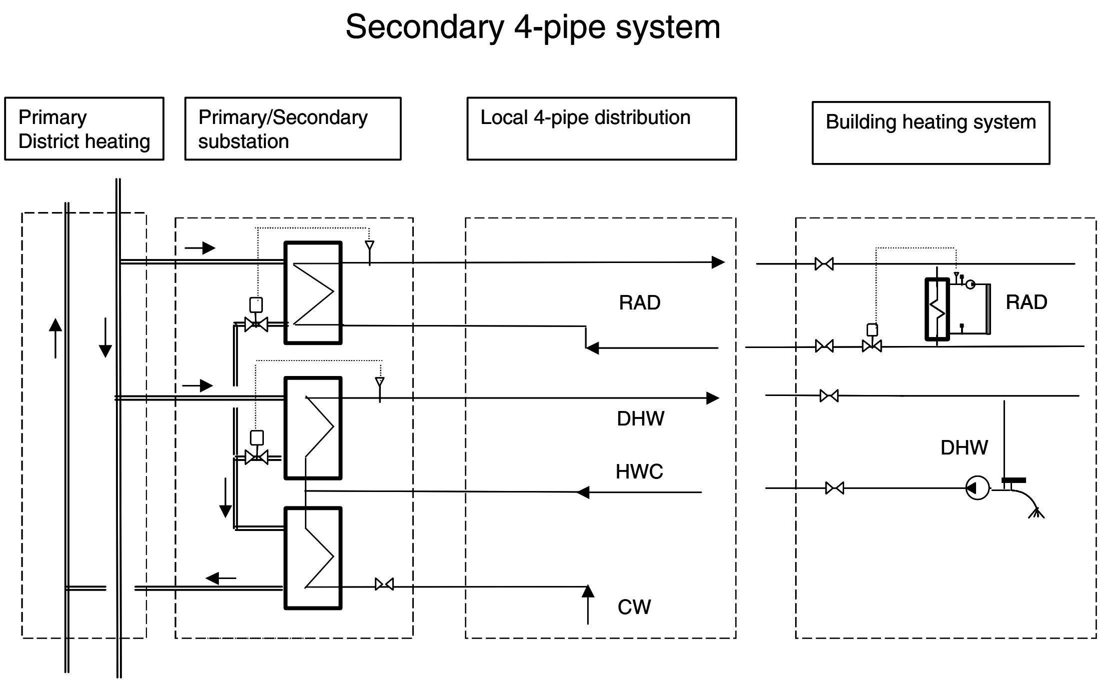


Figure A 1.8: Substation with secondary four-pipe distribution

1.1.5 Single-stage and two-stage substations with hot water storage

In Korea, the use of spas and saunas is part of the relaxing activities and bath facilities are very common. In order to clear very high instantaneous hot water loads, substations can be equipped wit hot water storages. The conventional part of the substation can either be according to single-stage or a 2-stage connection. In the Cheongju network, three sauna substations are connected, usually giving higher return temperatures. The reason for that is the storage filled with hot water

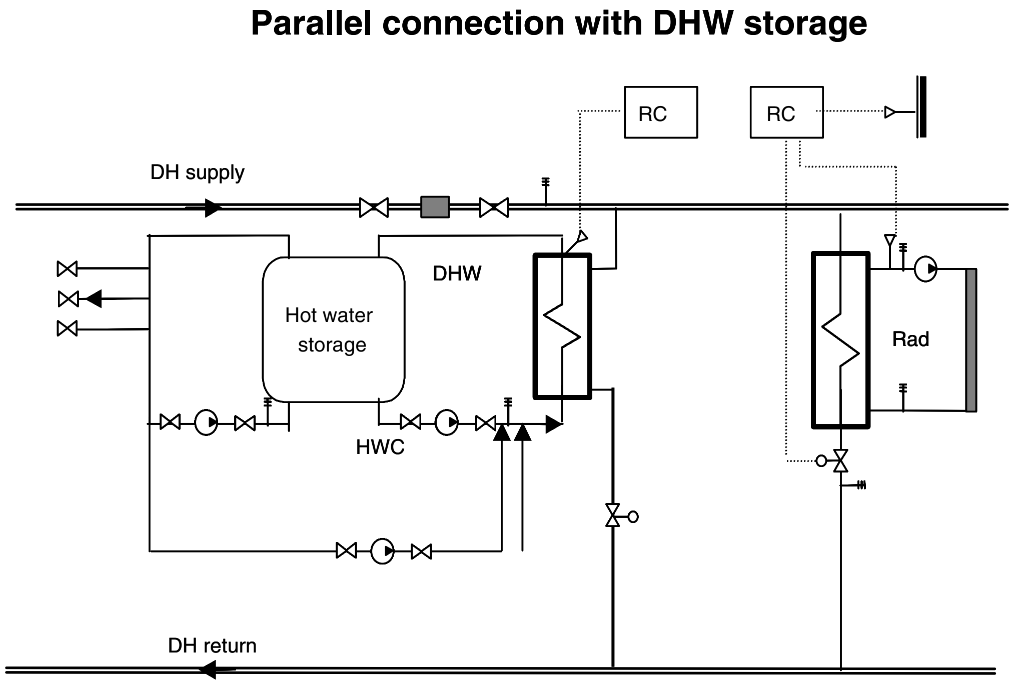


Figure A.1.9: Single-stage substation with hot water storage

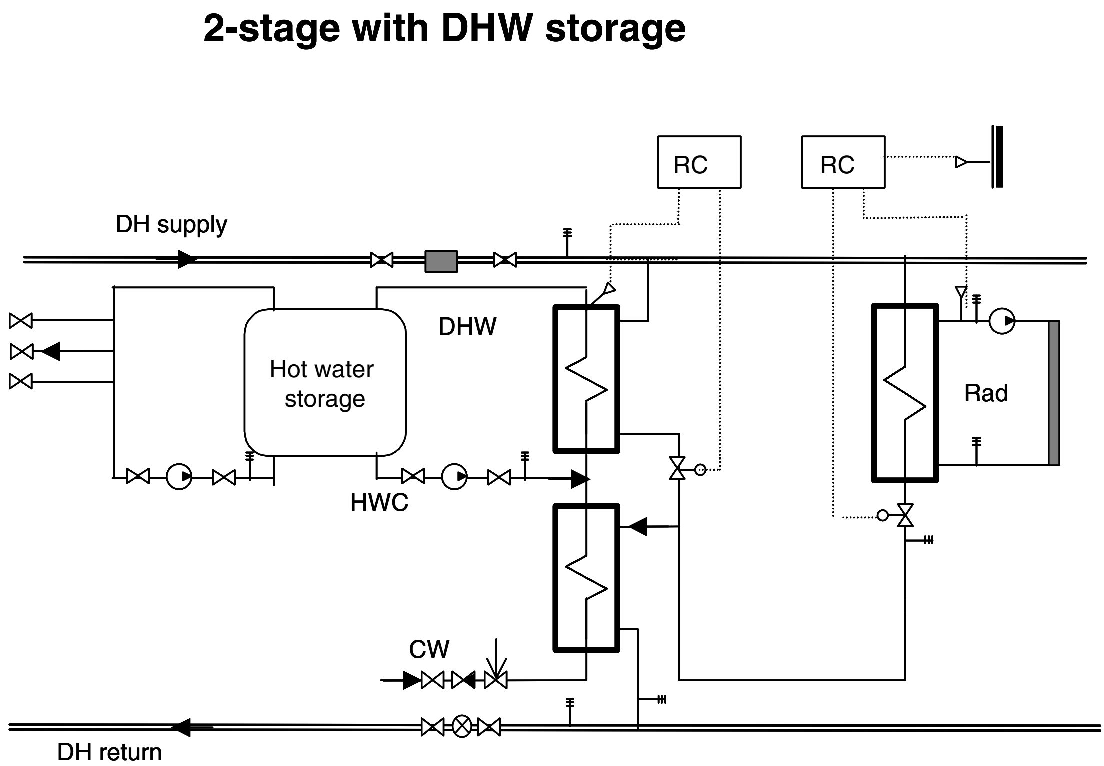


Figure A.1.10: Two-stage substation with hot water storage all the way down to the bottom, continuously recirculating hot water back to the heat exchanger, see Figure A.1.9 and Figure A.1.10 for more details. For better return temperature control, a temperature sensor should be installed in the bottom of the storage tank acting on the recirculation pump, which only starts if the water in the bottom gets too cold.

1.1.6 Substation for supply of heating and cooling

In Cheongju, seven substations are supplying both heating and cooling to offices and public buildings. These substations are of principal interest for district heating applications, enabling the district heating supplier of delivering cooling summer times when the heat load is low Figure A.1.11. However, as it is the case in Cheongju (and in many other locations with absorption chillers (ABC) as well), the price paid for that is high return temperatures[1]. In warm climates, the ABCs are working at full load at supply/return temperatures of typically 95/80°C. These high return temperatures are mixing with the lower temperatures of the conventional substations, but are responsible for the high total level of the return temperature. Hence, the use of ABC needs a careful total optimisation of the entire energy supply system including the distribution network and the production costs (and price levels) of electrical power, heat and chill. For more details on this problem, see for instance Kivistö (1999).

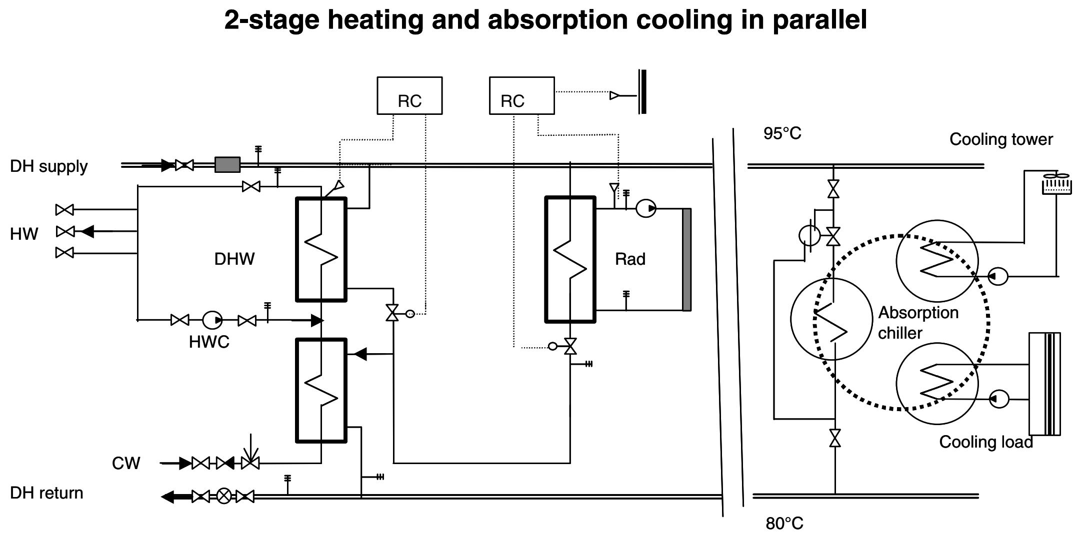


Figure A.1.11: Two-stage Rad/DHW substation combined with absorption chiller

[1] It should be noted that the company Weir Entropie nowadays offers absorption chillers special designed for district heating applications suitable for operation with both lower supply and lower return temperatures.

Appendix 2: Target return temperature method - equations and working tool

Summary

This Appendix 2 describes the details of the calculations used for determining the target return temperatures in single stage parallel and two stage substations. Furthermore, an Excel calculus for the TRT method is described.

2.1 The calculation of the target return temperature for single-stage and two-stage customer substations

2.1.1 The parallel (single-stage) substation

In order to determine the target return temperature, the mixed temperature $T_{R,tar}$ at the outlet of the two heat exchangers has to be calculated. This can be done by using the following equation:

Eq. A2-1 $$T_{R,tar} = \frac{T_{R,rad} \cdot m_{rad} + T_{R,HW,circ} \cdot (m_{HW} + m_{circ})}{m_{rad} + m_{HW} + m_{circ}} .$$

This equation can only be solved if the primary return temperature of the radiation heat exchanger $T_{R,rad}$ is known. $T_{R,rad}$ can be calculated on basis of the temperature difference of the radiation heat exchanger ΔT_{rad}:

Eq. A2-2 $$T_{R,rad} = T_{R,rad,sec} + \Delta T_{rad} .$$

The secondary return temperature of the radiation system $T_{R,rad,sec}$ can only be determined using a function of the outside temperature T_{out} and some design parameters of the heating system:

Eq. A2-3 $$T_{R,rad,sec} = T_{R,rad,min} + \left(T_{eq} - MIN\left(T_{eq}, T_{out}\right)\right) \cdot \frac{T_{R,rad,des} - T_{R,rad,min}}{T_{eq} - T_{out,des}}$$

Within this equation the minimum return temperature of the radiator system is represented by $T_{R,rad,min}$. This is the optimal temperature if all radiators of the space heating system work properly. The design return temperature of the heating system is $T_{R,rad,des}$ and the equilibrium temperature at which usually no space heating takes place is represented by T_{eq}. Finally, the minimum outside temperature for which the space heating system has been developed is $T_{out,des}$.

For solving equation A2-1, additionally the primary hot water and circulation temperature $T_{HW,circ}$ has to be calculated. This can be done by using the temperature difference of the hot water heat exchanger $\Delta T_{HW,circ}$:

Eq. A2-4 $$T_{R,HW,circ} = T_{mix,HW,circ} + \Delta T_{HW}$$

Now the mixed temperature of the cold water for the tap water supply and the circulation system has to be calculated:

Eq. A2-5 $$T_{mix,HW,circ} = \frac{T_{R,circ,sec} \cdot m_{circ,sec} + T_{Cold} \cdot m_{HW,sec}}{m_{circ,sec} + m_{HW,sec}} .$$

The return temperature of the circulation system can be calculated with the knowledge of the design circulation temperature difference ΔT_{circ} and the design supply temperature of the circulation system:

Eq. A2-6 $$T_{R,circ,sec} = T_{S,HW,circ,des} - \Delta T_{circ}$$

Furthermore, it is necessary to determine the mass flow for hot water in the secondary hot water system. This can be calculated based on the hot water demand and the temperature difference between design temperature for hot water and the cold water supply:

Eq. A2.7 $$m_{HW,sec} = \frac{Q_{HW}}{cp \cdot \left(T_{S,HW,circ,des} - T_{cold}\right)}.$$

The mass flow of the circulation system itself $m_{circ,sec}$ can be determined by the heat losses of the circulation system Q_{circ} and the design temperature difference of the circulation system ΔT_{circ}:

Eq. A2-8 $$m_{circ,sec} = \frac{Q_{circ}}{cp \cdot \Delta T_{S,HW,circ,des}}.$$

The solving of Equation A2-1 requires also the knowledge of the primary mass flow through the radiation heat exchanger. For this purpose it is necessary to calculate the supply temperature of the radiation system $T_{S,rad\ sec}$. This parameter can only be calculated on basis of design parameter of the customer substation:

Eq. A2-9

$$T_{S,rad,sec} = MAX\left(T_{R,rad,min}, \left(\Delta T_{rad} + T_{R,rad,min}\right)\right) + \frac{\left(T_{S,rad,des} + \left(\Delta T_{rad} + T_{R,rad,min}\right)\right)}{T_{out,des} - T_{R,rad,min}} \cdot \left(T_{out} - T_{R,rad,min}\right)$$

The primary mass flow through the radiator heat exchanger can then be calculated by:

Eq. A2-10 $$m_{rad} = m_{rad,sec} \cdot \frac{T_{S,rad,sec} - T_{R,rad,sec}}{T_S - T_{R,rad}}.$$

Finally the secondary mass flow through the heat exchanger system has to be evaluated which can be based on the heating load Q_{rad} which is known from an analysis of the measurement data:

Eq. A2-11 $$m_{rad,sec} = \frac{Q_{rad}}{cp \cdot \left(T_{S,rad,sec} - T_{R,rad,sec}\right)}.$$

Using the equations A2-1 – A2-11, it is possible to determine a target return temperature for an optimally working single stage customer substation. The heat capacity of the water flowing through the substation can be approximated by using the supply temperature of the specific customer known from the measurement data.

2.1.2 The two-stage substation model

In order to calculate the target return temperature in the two-stage model, some equations of the one-stage model are still valid. The equations B3, B4, B10, B11 and B12 describing the characteristics of the space heating system can still be used. Additionally, the functions necessary to calculate the hot water and the circulation mass flows B7, B8 and B9 are still valid.

For calculating the target return temperature, it is necessary to calculate the heat transfer within the hot water heat exchanger 1. Solving the balance equation leads to the following dependency:

Eq. A2-12 $$T_{R,tar} = T_{mix,prim} - \frac{m_{HW,sec}}{m_{rad} + m_{HW,circ}} \cdot \left(T_{R,Cold} - T_{S,Cold}\right).$$

There are several unknown parameters in this function. First of all, the mixture $T_{mix,prim}$ of the return temperatures at the radiation heat exchanger $T_{R,HW,circ}$ and the hot water heat exchanger 1 $T_{R,rad}$ has to be calculated:

Eq. A2-13 $$T_{mix,prim} = \frac{T_{R,rad} \cdot m_{rad} + T_{R,HW,circ} \cdot m_{HW.circ}}{m_{rad} + m_{HW.circ}}.$$

Analogues to the primary return temperatures in single stage substations $T_{R,HW,circ}$ will be calculated by the corresponding secondary return temperature $T_{mix,sec}$ and the temperature differences $\Delta T_{HW,2}$. $T_{R,rad}$ can be determined using the same dependency as for single stage substations (eq. A2-2).

Eq. A2-14 $$T_{R,HW,circ} = T_{mix,sec} + \Delta T_{HW,2} .$$

$T_{mix,sec}$ is the mixture temperature of the preheated cold water supply and the circulation mass flow. It is determined by the following equation:

Eq. A2-15 $$T_{mix,sec} = \frac{m_{circ,sec} \cdot T_{R,circ,sec} + m_{HW,sec} \cdot T_{R,cold}}{m_{HW,sec} + m_{circ,sec}} .$$

The return temperature of the circulation system $T_{R,circ,sec}$ is calculated using equ. A2-6.

Finally, the sum of the primary hot water mass flow and the primary circulation mass flow has to be calculated with the next equation:

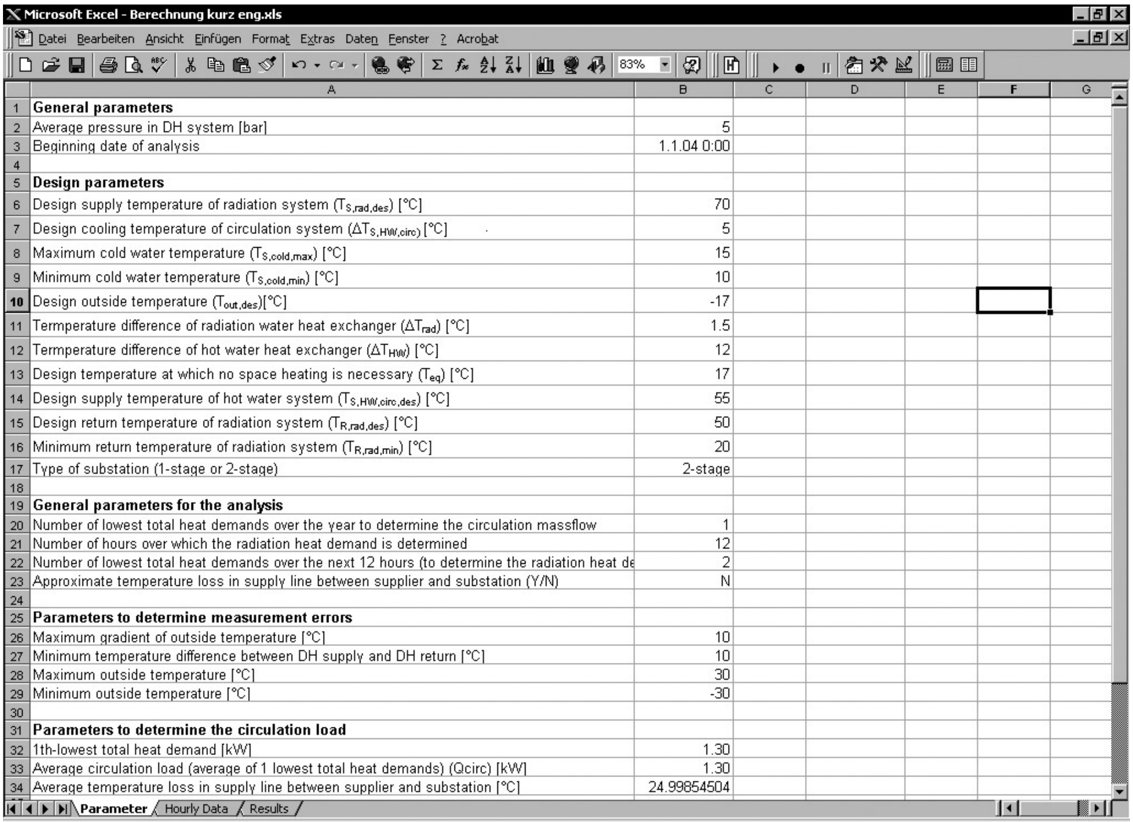
Eq. A2-16 $$m_{HW,circ} = \left(m_{circ,sec} + m_{HW,sec}\right) \cdot \frac{T_{HW,circ,des} - T_{mix,sec}}{T_S - T_{R,HW,circ}} .$$

2.2 The software tool for the determination of the target return temperature [2]

In order to analyse the different customer substations with respect to the target temperature and the corresponding excess flow, the models for single-stage and two-stage systems described in Chapter 3.3 have been implemented in an Excel environment. The equations have been integrated into Visual Basic functions in order to simplify the calculation.

In this Appendix 2.2, the TRT-tool will be explained in terms of structure and handling. It is assumed that the general operation and functions of Excel are known.

The tool delivers three worksheets. One is for the input of design parameters and other parameters that control the analysing process. In the second sheet, the measurement data and the calculated target return temperature with corresponding excess flow is stored over the measured period. The third sheet shows a visualisation of the different measured and calculated temperatures over the measured period. Figure A.2.1 shows the appearance of the calculation tool after opening it in Excel.



	A	B
1	**General parameters**	
2	Average pressure in DH system [bar]	5
3	Beginning date of analysis	1.1.04 0:00
4		
5	**Design parameters**	
6	Design supply temperature of radiation system ($T_{S,rad,des}$) [°C]	70
7	Design cooling temperature of circulation system ($\Delta T_{S,HW,circ}$) [°C]	5
8	Maximum cold water temperature ($T_{S,cold,max}$) [°C]	15
9	Minimum cold water temperature ($T_{S,cold,min}$) [°C]	10
10	Design outside temperature ($T_{out,des}$)[°C]	-17
11	Termperature difference of radiation water heat exchanger (ΔT_{rad}) [°C]	1.5
12	Termperature difference of hot water heat exchanger (ΔT_{HW}) [°C]	12
13	Design temperature at which no space heating is necessary (T_{eq}) [°C]	17
14	Design supply temperature of hot water system ($T_{S,HW,circ,des}$) [°C]	55
15	Design return temperature of radiation system ($T_{R,rad,des}$) [°C]	50
16	Minimum return temperature of radiation system ($T_{R,rad,min}$) [°C]	20
17	Type of substation (1-stage or 2-stage)	2-stage
18		
19	**General parameters for the analysis**	
20	Number of lowest total heat demands over the year to determine the circulation massflow	1
21	Number of hours over which the radiation heat demand is determined	12
22	Number of lowest total heat demands over the next 12 hours (to determine the radiation heat de	2
23	Approximate temperature loss in supply line between supplier and substation (Y/N)	N
24		
25	**Parameters to determine measurement errors**	
26	Maximum gradient of outside temperature [°C]	10
27	Minimum temperature difference between DH supply and DH return [°C]	10
28	Maximum outside temperature [°C]	30
29	Minimum outside temperature [°C]	-30
30		
31	**Parameters to determine the circulation load**	
32	1th-lowest total heat demand [kW]	1.30
33	Average circulation load (average of 1 lowest total heat demands) (Qcirc) [kW]	1.30
34	Average temperature loss in supply line between supplier and substation [°C]	24.99854504

Figure A.2.1: Parameter section of the target temperature analysis tool

This sheet contains the input data for the target temperature analysis. The design parameter input sheet is divided into different sections for the input of specific data for the calculation.

At the top, general parameters information has to be given for the pressure in the pipeline system, which should be analysed. This data is needed to calculate the heat capacity coefficient of the DH-water. The start date of the analysis has to be given for calculating the cold water temperature over the year. The next section asks for input of design parameters These are necessary for solving the model equations. In order to explain the different values, the corresponding model parameter is

[2] A calculus in Excel for the calculation of target temperatures according to the TRT – method can be received on request from Michael Wigbels, Umsicht, Germany. E-mail: Michael.Wigbels@Umsicht.Fraunhofer.de.

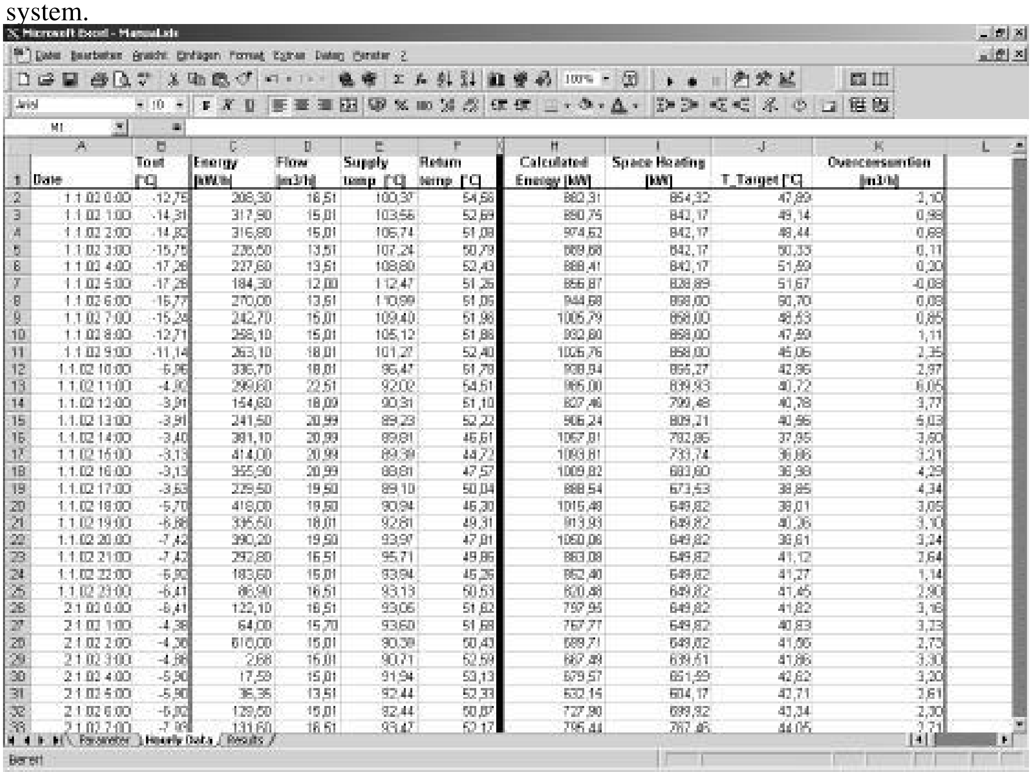
presented in parenthesis. For further information, please observe the description of the single-stage model and the two-stage model in Chapter 3.3 and Appendix A1.

The next section contains information necessary to determine the circulation load and the space-heating load. The circulation load, which is assumed constant over the year, is calculated as an average of a certain number of lowest heat demands over the year. Therefore, it is necessary to specify the number of how many low values should be included in the average. The space heating load is calculated using the method described in the chapter "Evaluation of the heat demand for radiator, hot water and circulation" of Chapter 3.3.1. For adjusting the calculation of the radiator heat demand to local characteristics, it is possible to decide over how many hours the heat load should be averaged and how many of the lowest values in this period should be taken into account.

Usually measurement data contain values that cannot be physically justified. Therefore, in the third section of input data, ranges are given within which the measurement data is accepted or otherwise stated as erroneous data.

Finally, two parameters are represented which are calculated based on the preliminarily provided input data. These parameters cannot be influenced by the user of the analysis tool. The parameters give only some information about the circulation load.

Figure A.2.2 shows an example of the tool's calculation part for target temperatures and excess flows over the year. This sheet is protected and cannot be changed by the user of the software system.



1	Date	Tout [°C]	Energy [kW/h]	Flow [m3/h]	Supply temp [°C]	Return temp [°C]	Calculated Energy [kW]	Space Heating [kW]	T_Target [°C]	Overconsumption [m3/h]
2	1.1.02 0:00	-12,75	208,30	16,51	100,37	54,58	882,31	854,32	47,89	2,10
3	1.1.02 1:00	-14,31	317,90	15,01	103,56	52,69	890,75	842,17	49,14	0,98
4	1.1.02 2:00	-14,83	316,80	15,01	106,74	51,08	974,62	842,17	48,44	0,68
5	1.1.02 3:00	-15,75	226,50	13,51	107,24	50,79	869,68	842,17	50,33	0,11
6	1.1.02 4:00	-17,28	227,60	13,51	108,80	52,43	888,41	842,17	51,59	0,30
7	1.1.02 5:00	-17,28	184,30	12,00	112,47	51,26	856,87	828,89	51,67	-0,08
8	1.1.02 6:00	-16,77	270,00	13,61	110,99	51,05	944,68	858,00	50,70	0,08
9	1.1.02 7:00	-15,29	242,70	15,01	109,40	51,98	1005,79	858,00	48,53	0,85
10	1.1.02 8:00	-12,71	258,10	15,01	105,12	51,88	932,80	858,00	47,59	1,11
11	1.1.02 9:00	-11,14	263,10	18,01	101,27	52,40	1026,76	858,00	45,06	2,35
12	1.1.02 10:00	-6,96	336,70	18,01	95,47	51,78	938,94	856,27	42,96	2,97
13	1.1.02 11:00	-4,90	299,60	22,51	92,02	54,51	985,00	839,93	40,72	6,05
14	1.1.02 12:00	-3,91	154,60	18,09	90,31	51,10	827,46	799,48	40,78	3,77
15	1.1.02 13:00	-3,91	241,50	20,99	89,23	52,22	906,24	809,21	40,96	5,03
16	1.1.02 14:00	-3,40	381,10	20,99	89,81	46,61	1067,81	782,86	37,95	3,60
17	1.1.02 15:00	-3,13	414,00	20,99	89,39	44,72	1093,81	733,74	36,86	3,21
18	1.1.02 16:00	-3,13	355,90	20,99	88,81	47,57	1009,82	683,60	36,98	4,29
19	1.1.02 17:00	-3,63	229,50	19,50	89,10	50,04	888,54	673,53	38,85	4,34
20	1.1.02 18:00	-5,70	418,00	19,50	90,94	46,30	1015,48	649,82	38,01	3,05
21	1.1.02 19:00	-6,88	395,60	18,01	92,81	49,31	913,93	649,82	40,36	3,10
22	1.1.02 20:00	-7,42	390,20	19,50	93,97	47,81	1060,06	649,82	38,61	3,24
23	1.1.02 21:00	-7,42	292,80	16,51	95,71	49,86	883,08	649,82	41,12	2,64
24	1.1.02 22:00	-6,90	183,60	15,01	93,94	45,26	862,40	649,82	41,27	1,14
25	1.1.02 23:00	-6,41	86,90	16,51	93,13	50,53	820,48	649,82	41,45	2,90
26	2.1.02 0:00	-6,41	122,10	16,51	93,06	51,82	797,96	649,82	41,82	3,18
27	2.1.02 1:00	-4,38	64,00	15,70	93,60	51,68	767,77	649,82	40,83	3,23
28	2.1.02 2:00	-4,36	616,00	15,01	90,39	50,43	689,71	649,82	41,56	2,73
29	2.1.02 3:00	-4,88	2,68	15,01	90,71	52,59	687,49	639,61	41,86	3,30
30	2.1.02 4:00	-5,90	17,59	15,01	91,94	53,13	679,57	651,59	42,62	3,20
31	2.1.02 5:00	-5,90	36,36	13,51	92,44	52,33	632,15	604,17	42,71	2,61
32	2.1.02 6:00	-6,90	129,50	15,01	92,44	50,87	727,90	699,32	43,34	2,30
33	2.1.02 7:00	[illegible]	131,60	16,51	93,47	52,17	795,44	767,46	44,05	2,71

Figure A.2.2: Measurement and calculation data sheet in the target temperature analysis tool

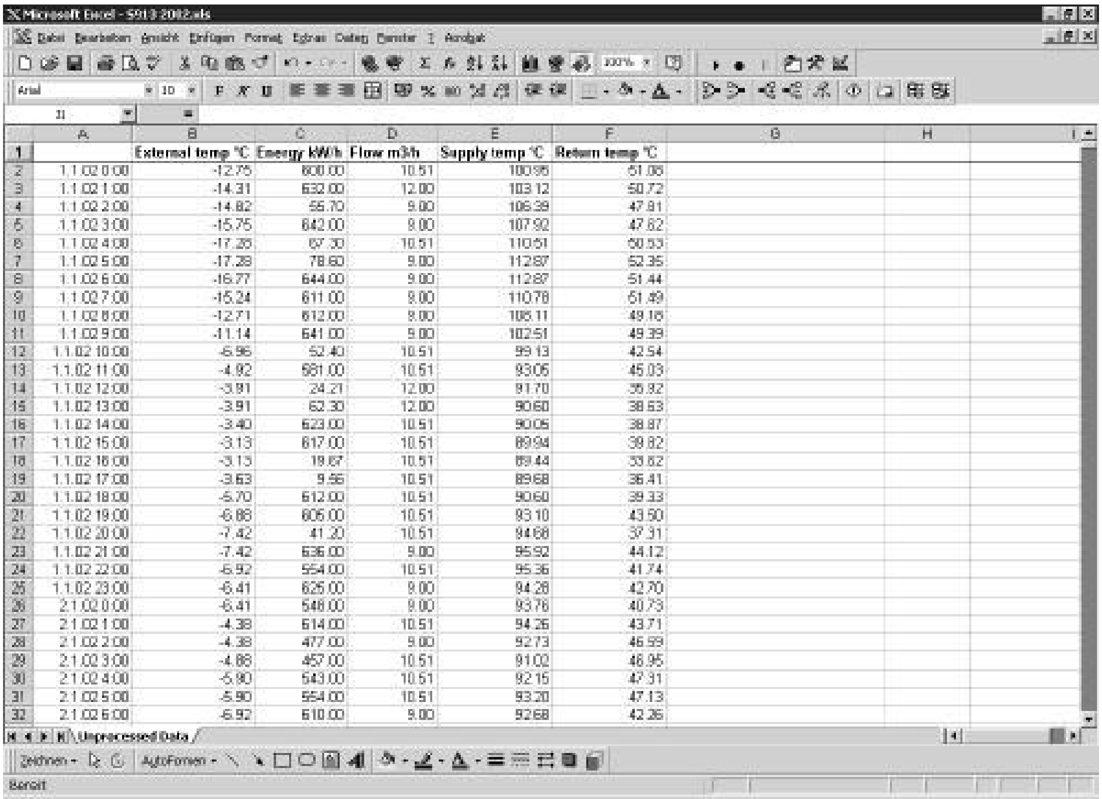
The sheet contains measurement data on an hourly basis, which has to be given as input for the analysis (left of the black line). This part of the sheet contains the date and time of the measurement and the outside temperature. There is also information that is specific for the customer substation. This includes the total heat demand and the corresponding mass flow, supply temperature and return temperature.

In order to read the input data, a button has been placed in the control panel of the software tool. By pressing this button, a dialog window appears asking for input data. Within this window, one or more Excel files containing the measurement data can be opened. Each of these files should contain the measurement data of one substation. It is necessary that the file has the format shown in Figure A.2.3.

The file should have one worksheet with data columns containing date with time, outside temperature, total heat demand, mass flow, supply temperature and return temperature. For the calculation process, it is essential that each row only has the prescribed order. Otherwise, the calculation process will cause errors.

After the file containing the measurement data is opened, the data is automatically stored in the data section of the worksheet “hourly data” and the calculation process starts. The calculation process can also be initiated by pressing the corresponding button in the control panel. The calculation takes usually some minutes and the process of the calculation can be followed looking at the status line. After the calculation is finished, the results are stored within the same directory where the measurement data is located. The name of this file is composed of the name of the measurement file end the ending “_analysed”. If more then one substation should be calculated, the next file must be opened and the described process starts again until each selected substation has been calculated.

When the calculation procedure is finished, the results can also be seen on the third sheet of the target temperature calculation tool (Figure A.2.4). There, a diagram is shown which contains the measured and calculated values.



	A	B	C	D	E	F
1		External temp °C	Energy kWh	Flow m3/h	Supply temp °C	Return temp °C
2	1.1.02 0:00	-12.75	600.00	10.51	100.95	51.06
3	1.1.02 1:00	-14.31	632.00	12.00	103.12	50.72
4	1.1.02 2:00	-14.82	55.70	9.00	106.39	47.81
5	1.1.02 3:00	-15.75	642.00	9.00	107.92	47.62
6	1.1.02 4:00	-17.28	67.30	10.51	110.51	50.53
7	1.1.02 5:00	-17.28	78.60	9.00	112.87	52.35
8	1.1.02 6:00	-16.77	644.00	9.00	112.87	51.44
9	1.1.02 7:00	-15.24	611.00	9.00	110.78	51.49
10	1.1.02 8:00	-12.71	612.00	9.00	105.11	49.16
11	1.1.02 9:00	-11.14	641.00	9.00	102.51	49.39
12	1.1.02 10:00	-6.96	52.40	10.51	99.13	42.54
13	1.1.02 11:00	-4.92	581.00	10.51	93.06	45.03
14	1.1.02 12:00	-3.91	24.21	12.00	91.70	35.92
15	1.1.02 13:00	-3.91	62.30	12.00	90.60	38.53
16	1.1.02 14:00	-3.40	623.00	10.51	90.06	38.87
17	1.1.02 15:00	-3.13	617.00	10.51	89.94	39.82
18	1.1.02 16:00	-3.13	19.67	10.51	89.44	33.62
19	1.1.02 17:00	-3.63	9.56	10.51	89.68	36.41
20	1.1.02 18:00	-5.70	612.00	10.51	90.60	39.33
21	1.1.02 19:00	-6.88	606.00	10.51	93.10	43.50
22	1.1.02 20:00	-7.42	41.20	10.51	94.68	37.31
23	1.1.02 21:00	-7.42	636.00	9.00	95.92	44.12
24	1.1.02 22:00	-6.92	554.00	10.51	95.36	41.74
25	1.1.02 23:00	-6.41	625.00	9.00	94.28	42.70
26	2.1.02 0:00	-6.41	548.00	9.00	93.76	40.73
27	2.1.02 1:00	-4.38	614.00	10.51	94.26	43.71
28	2.1.02 2:00	-4.38	477.00	9.00	92.73	46.59
29	2.1.02 3:00	-4.88	457.00	10.51	91.02	46.95
30	2.1.02 4:00	-5.90	543.00	10.51	92.15	47.31
31	2.1.02 5:00	-5.90	554.00	10.51	93.20	47.13
32	2.1.02 6:00	-6.92	610.00	9.00	92.68	42.26

Figure A.2.3: Input data sheet for the target temperature analysis tool

This diagram shows the target temperature, the measured return temperature and the outside temperature. Additionally, the excess flow is presented. Excess flows that are larger then zero represent times where the substation works badly in comparison to an optimal substation. Negative values indicate a period where the substation works well.

In order to look at specific days it is possible to use the scaling dialog of Excel by clicking on the x-axis (Figure A.2.5).

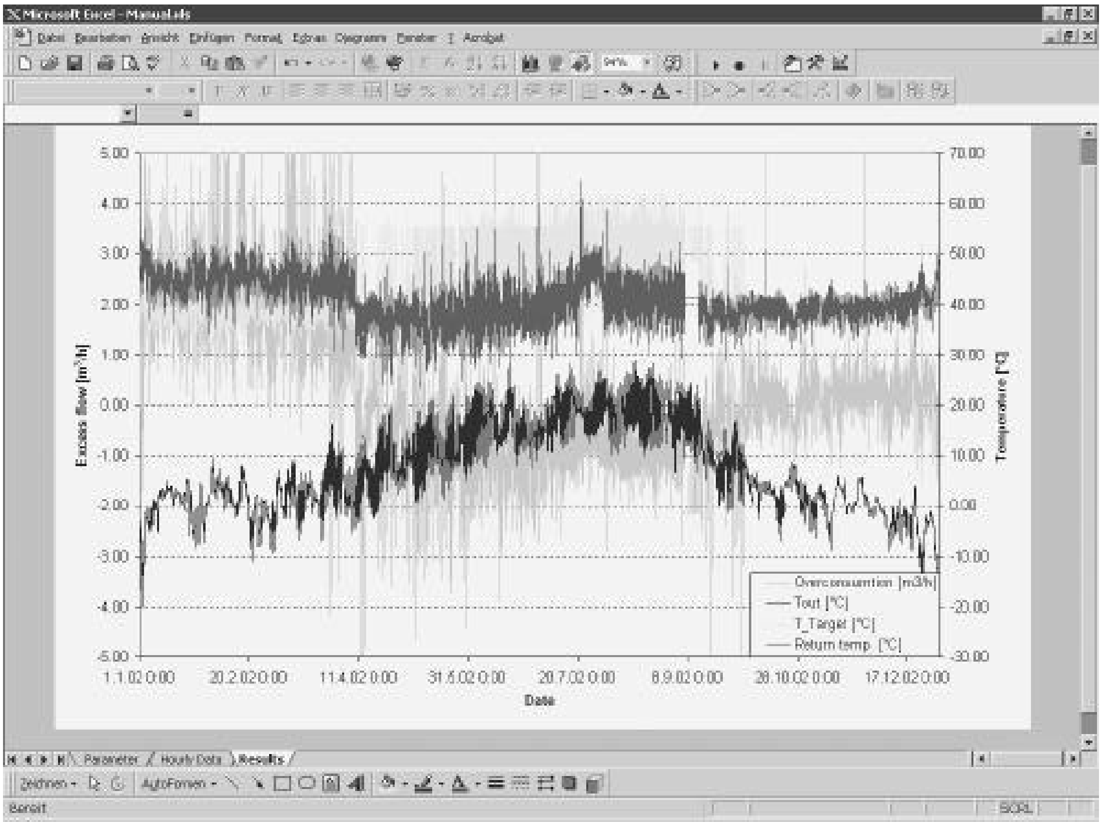


Figure A.2.4: Diagram showing results of the target temperature analysis tool

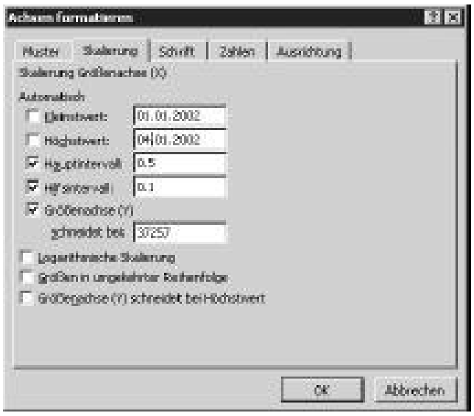


Figure A.2.5: Dialog box to change the scaling of the x-axis

Appendix 3: Substations in Cheongju

3.1 List of substations in Cheongju

No.	Customer code	Nb.	Connected Heat Load (kW)	H/E Capacity (kW)		Appli-cation	Use	First Heat supply date	Type
				Heating	DHW				
C1	501110011	1	1477	1164	1054	A	APT	97. 05. 30	
C2	501110011	2	1379	1086	1348	A	APT	97. 05. 30	
C3	501110011	3	2266	1784	1706	A	APT	97. 05. 30	
C4	501110011	4	1086	863	842	A	APT	97. 05. 30	
C5	501110021	1	2609	2057	1764	A	APT	97. 05. 30	
C6	501110021	2	1619	1275	1013	A	APT	97. 05. 30	
C7	501110022	3	1279	1008	1013	A	APT	97. 05. 30	
C8	501110022	4	715	506	715	A	APT	97. 05. 30	
C9	501110031	1	1410	983	828	A	APT	97. 12. 04	
C10	501110031	2	1208	942	773	A	APT	97. 12. 04	
C11	501110031	3	1612	1256	878	A	APT	97. 12. 04	
C12	501110031	4	2057	1610	977	A	APT	97. 12. 04	
C13	501110041	1	1154	908	926	A	APT	98. 02. 04	
C14	501110041	2	1377	1085	1013	A	APT	98. 02. 04	
C15	501110041	3	1177	927	878	A	APT	98. 02. 04	
C16	501110041	4	883	695	775	A	APT	98. 02. 04	
C17	501110041	5	1392	1106	1023	A	APT	98. 02. 04	
C18	501110051	1	1513	1198	1062	A	APT	98. 11. 02	
C19	501110051	2	980	772	926	A	APT	98. 11. 02	
C20	501110052	1	1635	1293	1484	A	APT	99. 05. 19	
C21	501110052	2	1593	1255	1468	A	APT	99. 05. 19	
C22	501110061	1	4957	3863	2841	A	APT	99. 05. 18	
C23	501110062	2	4844	3784	2817	A	APT	99. 05. 18	
C24	501110071	1	2725	2132	1582	A	APT	99. 07. 19	
C25	501110071	2	2402	1872	1054	A	APT	99. 07. 19	
C26	501110071	3	2402	1872	1054	A	APT	99. 07. 19	
C27	501110081	1	1671	1317	1561	A	APT	00. 08. 29	
C28	501110081	2	1587	1260	1454	A	APT	00. 08. 29	
C29	501110081	3	1424	1122	1406	A	APT	00. 08. 29	
C30	501110091	1	1512	1187	1444	A	APT	00. 09. 29	
C31	501110091	2	2116	1671	1660	A	APT	00. 09. 29	
C32	501110101	1	3391	2648	1926	A	APT	01. 11. 13	
C33	501110101	2	1963	1531	1365	A	APT	01. 11. 13	
C34	501120021	1	62	62	0	P	YO	97. 07. 12	
C35	501120031	1	250	233	17	C	BF	97. 12. 03	
C36	501120031	2	Cooling	0	0	C	BF	97. 12. 03	
C37	501120041	1	181	171	12	C	SF	97. 12. 05	
C38	501120051	1	95	95	0	C	SF	97. 12. 01	
C39	501120071	1	2194	2093	202	C	BF	00. 06. 10	
C40	501120071	2	Cooling	0	0	C	BF	00. 06. 10	
C41	501120081	1	372	49	372	C	SA	00. 09. 27	
C42	501120091	1	244	233	12	C	BF	02. 05. 21	
C43	501120101	1	768	198	768	C	SA	02. 09. 11	2-stage
C44	501130011	1	129	122	17	P	LF	97. 11. 19	
C45	501130021	1	165	99	81	P	YO	98. 02. 25	
C46	501130031	1	187	1163	262	P	EF	99. 02. 18	
C47	501130031	2	Cooling	0	0	P	EF	99. 02. 18	

C48	501130041	1	52	47	12	P	YO	99. 06. 11	
C49	501130051	1	490	459	70	P	LF	01. 11. 16	
C50	501130051	2	Cooling	0	0	P	LF	01. 11. 16	
C51	501210011	1	3206	2496	2199	A	APT	98. 11. 25	
C52	501210021	1	3354	2618	1584	A	APT	99. 03. 16	2-stage
C53	501210031	1	3672	2901	2122	A	APT	99. 04. 06	
C54	501210041	1	2690	2100	1379	A	APT	99. 05. 19	
C55	501210051	1	2627	2074	2299	A	APT	99. 09. 16	
C56	501210061	1	2636	2082	2300	A	APT	99. 09. 16	
C57	501210071	1	3606	2840	2112	A	APT	99. 04. 06	
C58	501210081	1	2411	1884	1286	A	APT	01. 12. 4	
C59	501220011	1	465	38	465	C	SA	01. 08. 25	
C60	501230011	1	345	233	151	P	LF	98. 12. 21	
C61	501230011	2	Cooling	0	0	P	LF	98. 12. 21	
C62	501230021	1	55	47	12	P	YO	99. 04. 19	
C63	501230031	1	533	448	151	P	EF	00. 04. 17	
C64	501310011	3	1335	3813	4421	A	APT	00. 11. 02	
C65	501310021	1	2752	2182	2336	A	APT	01. 11. 16	
C66	501310021	2	2213	1745	1750	A	APT	01. 11. 16	
C67	501310021	3	1437	1133	1392	A	APT	01. 11. 16	
C68	501310031	1	2576	2038	1527	A	APT	02. 06. 11	2-stage
C69	501330011	1	706	675	93	P	EF	01. 12. 3	
C70	501410011	1	4235	3303	2320	A	APT	01. 08. 31	2-stage
C71	501410021	1	3282	2593	2112	A	APT	01. 11. 07	2-stage
C72	501410031	1	3801	2971	1879	A	APT	01. 11. 07	2-stage
C73	501410041	1	4155	3244	1592	A	APT	02. 04. 19	2-stage
C74	501410051	1	2190	1729	1379	A	APT	02. 07. 10	2-stage
C75	501410061	1	2251	3536	2035	A	APT	02. 11. 22	2-stage
C76	501420011	1	1698	1628	198	C	SF	02. 08. 16	
C77	501430011	1	295	70	295	P	EF	02. 08. 23	2-stage
C78	501910011	1	1385	1097	1057	A	APT	99. 09. 20	
C79	501910011	2	715	559	715	A	APT	99. 09. 20	
C80	501910021	1	2183	1701	1254	A	APT	99. 09. 20	
C81	501910031	1	2750	2143	1305	A	APT	00. 09. 01	2-stage
C82	501910041	1	2151	1678	1009	A	APT	00. 09. 01	2-stage
C83	501910051	1	3616	2823	1444	A	APT	00. 09. 01	
C84	501910061	1	3149	2459	1612	A	APT	00. 09. 05	2-stage
C85	501910071	1	2393	1869	1185	A	APT	00. 09. 06	2-stage
C86	501910071	2	2824	2202	1644	A	APT	00. 09. 06	2-stage
C87	501910081	1	4125	3258	1834	A	APT	01. 09. 01	
C88	501910091	1	6855	5354	2478	A	APT	01. 09. 12	
C89	501910101	1	3185	2484	1770	A	APT	01. 09. 13	2-stage
C90	501910111	1	4621	3645	2371	A	APT	01. 09. 14	2-stage
C91	501910121	1	4402	3433	2211	A	APT	02. 09. 14	2-stage
C92	501910131	1	2392	1870	1194	A	APT	02. 09. 13	2-stage
C93	501910141	1	2704	2111	1321	A	APT	02. 09. 18	2-stage
C94	501920011	1	1043	984	113	C	BF	02. 09. 02	
C95	501930011	2	891	837	105	P	EF	99. 10. 30	
C96	501930011	3	0	-	0	P	EF	-	
C97	501930021	1	1500	1465	35	P	EF	00. 01. 12	
C98	501930031	1	505	484	21	P	EF	00. 01. 12	
C99	501930041	1	581	447	279	P	EF	00. 01. 12	
C100	501930051	1	442	442	0	P	EF	00. 01. 12	
C101	501930061	1	757	297	51	P	EF	00. 09. 20	
C102	501930071	1	676	248	17	P	EF	01. 03. 12	
C103	501930081	1	2619	1628	30	P	EF	01. 03. 13	

C104	501930091	1	902	878	24	P	EF	01. 08. 16	
C105	501930091	2	Cooling	0	0	P	EF	01. 08. 16	
C106	501930101	1	731	333	91	P	EF	02. 01. 30	
C107	501930101	2	Cooling	0	0	P	EF	02. 01. 30	

Application

C Commercial building
P Public Building
A Apartment

Use

APT Apartments
LF Other living facilities
PF Public buildings
YO Social facilities for young and old peoples
EF Educational and institutional buildings
BF Offices(general, public)
SF Services and commerce
SA Bath and sauna

Type of substation

Single-stage parallel in general
Two-stage indicated

3.2 Excess flow method - Excess flow ranking

December 2002 - November 2003				Ranking according to EXCESS FLOW analysis					
Dec. -February		March - May		June - August		Sept. - November		All Year	
No.	Excess flow	No.	Excess flow	No.	Excess flow	No.	Excess flow	No.	Excess flow
C43	23 198,7	C43	25 871,0	C43	25 482,4	C43	10 581,4	C43	85 133,5
C65	18 355,3	C65	12 952,1	C67	5 468,2	C63	5 182,8	C63	41 958,4
C51	15 866,1	C41	7 881,2	C63	4 687,9	C41	4 699,1	C41	33 134,3
C41	12 884,0	C67	6 460,6	C41	4 326,8	C20	4 621,4	C20	28 292,9
C90	12 690,8	C63	5 808,4	C104	4 016,2	C08	3 748,0	C08	26 263,5
C32	12 346,9	C31	5 795,5	C20	3 292,9	C65	3 491,4	C65	24 926,7
C84	9 647,9	C17	5 386,3	C91	3 247,5	C31	3 403,5	C31	21 685,2
C100	7 920,1	C30	5 145,5	C08	2 980,0	C17	2 854,9	C17	18 900,4
C31	7 426,2	C32	4 402,2	C17	2 955,1	C32	2 847,6	C32	17 631,1
C17	7 269,2	C91	4 269,2	C02	2 498,8	C21	2 812,7	C21	16 849,9
C67	7 066,2	C84	3 957,0	C65	2 354,2	C30	2 751,3	C30	16 128,6
C30	7 023,5	C21	3 587,1	C07	2 321,6	C67	2 558,9	C67	15 491,1
C42	6 385,3	C66	3 172,7	C58	1 547,7	C51	2 544,4	C51	13 650,2
C63	6 182,3	C20	3 029,1	C60	1 512,7	C60	2 469,2	C60	13 193,3
C75	6 085,1	C100	2 947,5	C31	1 422,6	C49	2 379,5	C49	12 834,7
C103	6 079,0	C02	2 800,2	C89	1 141,3	C89	2 318,6	C89	12 339,0
C92	5 738,0	C90	2 786,8	C21	1 123,4	C91	2 265,3	C91	11 913,4
C58	5 583,6	C51	2 613,8	C92	1 047,9	C07	1 776,5	C07	11 021,8
C89	4 836,6	C89	2 580,4	C51	925,0	C78	1 403,2	C78	9 745,2
C88	4 611,1	C42	2 077,0	C84	833,2	C02	1 395,7	C02	8 917,0
C49	4 193,0	C88	2 022,2	C32	696,9	C99	1 247,8	C99	8 159,9
C94	4 107,0	C99	1 921,3	C59	630,6	C100	1 098,1	C100	7 757,0
C44	4 076,5	C44	1 845,7	C33	549,6	C44	1 060,0	C44	7 531,7
C21	3 939,1	C92	1 755,0	C30	491,2	C84	1 049,9	C84	7 235,3
C03	3 590,9	C64	1 662,1	C99	461,4	C59	1 013,9	C59	6 728,2
C56	3 583,5	C08	1 523,5	C04	388,1	C33	857,2	C33	6 352,3
C20	3 514,3	C33	1 110,7	C64	328,2	C58	799,4	C58	5 752,6
C15	2 959,9	C56	943,1	C10	277,9	C94	688,8	C94	4 869,6
C73	2 949,3	C59	663,6	C12	256,0	C64	651,1	C64	4 519,9
C33	2 505,9	C94	637,5	C27	240,1	C108	596,3	C108	3 979,9
C104	1 901,4	C58	622,9	C05	186,5	C92	548,0	C92	3 258,8
C66	1 852,4	C15	619,0	C06	185,5	C90	468,4	C90	3 125,3
C68	1 635,7	C03	522,0	C09	132,0	C66	377,2	C66	2 666,9
C01	1 446,1	C07	404,4	C88	114,9	C56	344,6	C56	2 310,0
C81	1 201,6	C108	273,5	C19	43,4	C46	292,0	C46	1 810,4
C99	1 180,2	C103	252,7	C56	5,2	C104	266,6	C104	1 704,6
C91	1 115,0	C04	82,2	C11	-21,7	C42	234,7	C42	1 410,2
C39	1 040,5	C16	53,7	C18	-65,1	C81	222,5	C81	1 251,6
C46	1 014,8	C45	34,4	C29	-69,6	C95	213,8	C95	1 193,3
C59	974,8	C01	-121,0	C13	-92,7	C103	134,2	C103	895,3
C108	847,4	C81	-200,1	C01	-103,8	C19	134,0	C19	677,6
C95	734,0	C13	-267,6	C16	-105,9	C69	134,0	C69	494,5
C16	691,4	C14	-284,6	C52	-166,6	C101	126,8	C101	367,0
C106	569,0	C27	-390,5	C15	-188,4	C106	97,9	C39	88,1
C14	508,1	C10	-391,0	C14	-209,6	C28	95,1	C28	2,7
C35	393,2	C09	-507,0	C66	-262,7	C102	55,3	C102	-321,2
C45	385,6	C05	-585,4	C28	-324,1	C76	31,7	C76	-492,2
C02	383,4	C19	-611,3	C03	-486,3	C04	23,1	C04	-691,2
C07	312,4	C57	-618,5	C86	-525,3	C77	16,5	C77	-814,9

C62	280,8	C06	-934,9	C57	-597,0	C16	-37,1	C45	-1 288,2
C102	267,9	C12	-973,1	C90	-715,8	C10	-40,9	C35	-1 461,8
C97	223,9	C29	-1 008,4	C71	-807,7	C09	-54,9	C09	-1 647,2
C05	210,0	C86	-1 036,6	C85	-894,3	C03	-57,8	C03	-1 778,7
C101	164,5	C73	-1 101,1	C93	-1 046,3	C01	-111,7	C62	-2 094,7
C77	162,9	C18	-1 117,2	C83	-1 049,0	C14	-176,5	C97	-2 179,8
C38	155,3	C11	-1 121,1	C73	-1 102,8	C15	-178,8	C15	-2 247,4
C04	131,9	C70	-1 460,0	C70	-1 322,4	C29	-250,5	C38	-2 901,1
C74	104,3	C28	-1 551,1	C68	-1 329,0	C13	-270,6	C13	-3 046,4
C98	92,1	C82	-1 560,0	C72	-1 444,5	C12	-271,8	C98	-3 184,2
C86	14,4	C68	-2 253,6	C87	-1 472,4	C27	-293,3	C27	-4 004,9
C12	-85,3	C83	-2 597,7	C75	-1 508,4	C86	-322,0	C86	-4 513,4
C09	-135,5	C71	-2 649,8			C06	-360,8	C06	-3 146,1
C10	-157,6	C87	-2 751,0			C52	-379,0	C52	-3 287,6
C82	-178,2	C75	-2 853,2			C18	-493,3	C18	-3 524,6
C13	-547,0	C72	-3 084,9			C85	-575,5	C85	-4 207,4
C57	-689,0	C74	-3 762,7			C11	-576,3	C11	-5 028,0
C87	-698,4	C93	-4 189,7			C05	-853,4	C05	-5 741,5
C76	-747,6					C70	-947,6	C70	-1 695,2
C70	-782,0					C57	-960,5	C57	-1 742,5
C08	-896,3					C75	-977,2	C75	-1 873,5
C19	-1 080,6					C73	-1 012,4	C73	-2 093,1
C11	-1 200,9					C71	-1 025,2	C71	-2 226,0
C83	-1 348,0					C82	-1 121,3	C82	-2 469,4
C27	-1 633,5					C83	-1 305,4	C83	-2 938,9
C71	-1 713,3					C87	-1 354,4	C87	-3 067,8
C85	-1 778,0					C72	-1 586,9	C72	-3 364,9
C29	-2 105,7					C88	-1 686,8	C88	-3 792,5
C18	-2 108,3					C68	-1 875,8	C68	-3 984,1
C06	-2 134,4					C74	-1 879,3	C74	-4 013,7
C72	-2 142,5					C93	-1 937,3	C93	-4 079,8
C28	-2 486,2							C00	-2 486,2
C93	-7 649,6							C00	-7 649,6

3.3 Target return temperature method – flow ranking

Dec 2002 - Nov 2003		Ranking according to Target Return Temperature analysis							
Dec. - February		**March - April**		**June - August**		**Sept. - November**		**Year**	
ID	Ex. fl. m³	ID	Ex. fl. m³	ID	Ex. fl. m³	ID	Ex. fl. m³	ID	Ex. fl. m³
C51	136 760,8	C88	8 910,4	C43	10 805,4	C88	3 413,0	C51	186 586,1
C65	120 070,4	C43	7 092,7	C81	4 762,9	C43	2 275,0	C65	156 188,2
C56	94 444,6	C65	5 655,5	C105	2 784,0	C90	2 174,5	C56	134 221,6
C43	77 009,3	C90	5 192,6	C41	2 743,1	C100	2 069,0	C58	120 156,1
C58	75 523,3	C91	3 564,0	C50	2 462,6	C41	1 859,9	C43	111 127,4
C57	67 133,3	C41	3 143,1	C108	2 096,0	C51	1 552,6	C68	91 876,3
C68	61 690,7	C31	2 983,4	C63	2 071,0	C65	1 466,2	C57	87 444,4
C67	57 086,2	C32	2 630,2	C103	1 807,1	C63	1 382,4	C67	80 622,2
C66	45 722,7	C51	2 435,9	C79	1 807,1	C32	1 210,6	C66	68 334,1
C41	39 880,8	C67	2 282,4	C88	1 648,6	C31	1 194,2	C41	55 106,7
C64	24 095,5	C57	2 213,8	C67	1 420,4	C99	1 181,0	C49	49 850,5
C42	20 155,8	C84	2 077,2	C20	1 165,6	C20	1 159,9	C42	42 552,5
C63	16 095,7	C100	2 024,4	C91	1 120,3	C91	1 005,4	C46	41 736,3
C49	15 346,1	C89	2 018,1	C65	1 114,0	C107	788,0	C64	40 016,3
C90	13 921,0	C66	1 991,8	C17	805,8	C89	779,1	C88	32 754,8
C88	12 836,3	C63	1 663,9	C99	598,0	C44	738,7	C90	24 700,4
C46	10 497,9	C99	1 642,4	C64	503,6	C21	702,4	C44	23 537,1
C44	8 259,0	C21	1 634,1	C60	503,1	C49	667,5	C63	20 532,3
C84	8 025,1	C30	1 634,0	C89	466,1	C17	602,4	C45	16 488,0
C32	7 772,7	C17	1 543,8	C51	423,1	C60	583,6	C69	14 246,8
C69	6 598,8	C73	1 531,0	C31	422,9	C30	496,7	C32	13 377,6
C73	6 567,1	C20	1 435,3	C58	347,2	C52	392,6	C84	12 591,5
C59	6 475,7	C42	889,4	C32	338,1	C67	358,2	C31	12 570,8
C89	5 867,0	C56	831,9	C21	267,6	C84	204,9	C91	11 743,2
C31	5 598,7	C70	750,1	C84	265,3	C35	180,6	C105	11 050,3
C91	5 279,1	C64	644,1	C04	204,6	C42	69,0	C62	10 833,9
C45	4 673,3	C03	580,8	C02	189,5	C38	-3,5	C89	10 241,7
C70	4 511,4	C92	546,6	C92	139,5	C45	-35,1	C73	10 092,3
C03	4 376,2	C44	466,1	C27	124,5	C77	-68,4	C100	9 786,1
C92	4 083,9	C74	443,8	C90	88,8	C57	-81,7	C50	9 774,4
C30	3 539,7	C33	392,0	C12	79,6	C66	-86,3	C30	8 572,9
C75	3 307,6	C02	295,2	C77	64,5	C48	-87,6	C79	7 172,8
C81	3 153,8	C81	113,8	C101	64,5	C102	-96,6	C17	7 135,7
C87	2 976,9	C05	-6,7	C05	-12,4	C56	-100,4	C59	6 824,8
C62	2 784,8	C38	-12,0	C30	-21,5	C73	-144,2	C3	6 470,3
C17	2 684,0	C77	-20,5	C57	-144,7	C81	-144,8	C20	6 469,1
C83	2 634,9	C102	-62,0	C08	-225,7	C64	-179,7	C21	6 375,4
C100	2 586,1	C62	-78,3	C33	-255,0	C62	-210,4	C70	6 020,0
C21	2 568,0	C45	-105,0	C56	-262,8	C94	-228,3	C92	5 648,2
C33	2 342,8	C52	-152,7	C59	-289,9	C46	-237,1	C81	5 619,5
C20	2 329,5	C58	-204,2	C06	-360,3	C33	-246,1	C99	5 272,9
C05	1 901,9	C98	-209,6	C14	-374,5	C106	-296,1	C33	3 663,6
C86	1 758,9	C27	-374,2	C66	-377,7	C78	-309,5	C103	3 605,4

C74	1 703,1	C75	-383,3	C52	-379,6	C70	-311,4	C101	3 209,9
C99	1 594,9	C103	-456,0	C13	-434,9	C104	-380,5	C107	3 162,3
C103	1 371,1	C94	-467,7	C09	-465,7	C58	-403,1	C75	3 009,9
C71	1 232,8	C86	-484,5	C01	-515,5	C75	-429,1	C87	2 420,6
C72	1 222,7	C15	-559,2	C86	-539,8	C03	-431,3	C05	2 381,4
C01	914,6	C69	-627,7	C71	-555,0	C71	-466,8	C60	2 186,3
C101	880,5	C108	-654,7	C03	-570,9	C02	-493,9	C35	1 071,3
C15	831,2	C87	-681,2	C15	-617,5	C08	-506,8	C86	1 012,1
C12	609,1	C14	-702,7	C83	-678,1	C92	-524,8	C83	601,8
C35	292,5	C01	-705,4	C73	-681,5	C59	-577,1	C01	234,0
C94	104,6	C07	-759,9	C18	-683,8	C103	-588,9	C52	185,3
C102	42,4	C59	-775,3	C28	-710,0	C95	-607,9	C102	70,5
C14	1,3	C08	-783,1	C29	-728,3	C07	-651,8	C15	44,6
C38	-5,4	C12	-862,9	C10	-749,9	C108	-654,9	C71	5,8
C82	-53,0	C16	-870,1	C85	-803,7	C09	-658,8	C38	-23,4
C02	-172,9	C04	-919,4	C70	-818,8	C74	-784,5	C94	-60,8
C108	-185,3	C71	-959,0	C75	-821,4	C69	-852,7	C12	-183,1
C104	-229,9	C10	-959,0	C74	-846,6	C87	-854,4	C02	-207,7
C77	-230,7	C13	-968,6	C72	-895,9	C86	-869,7	C77	-535,1
C39	-305,9	C09	-970,1	C87	-951,9	C10	-879,3	C104	-942,1
C16	-407,2	C83	-1 039,1	C36	-952,5	C27	-893,9	C39	-1 241,1
C106	-429,6	C11	-1 173,8	C11	-994,1	C28	-903,0	C78	-1 242,2
C09	-533,7	C19	-1 206,3	C93	-1 017,7	C97	-924,1	C74	-1 342,1
C04	-544,8	C06	-1 218,6	C68	-1 053,7	C12	-996,9	C72	-1 375,6
C85	-611,4	C72	-1 258,4	C16	-1 172,7	C05	-1 020,7	C14	-1 701,7
C10	-759,8	C76	-1 280,4			C14	-1 027,3	C106	-1 731,5
C95	-762,5	C29	-1 345,4			C29	-1 055,9	C108	-1 883,8
C97	-802,2	C18	-1 488,3			C16	-1 058,0	C27	-2 416,9
C07	-814,0	C82	-1 609,0			C04	-1 102,0	C16	-2 673,2
C98	-888,6	C97	-1 618,9			C85	-1 120,7	C09	-2 718,3
C27	-898,7	C68	-1 628,6			C01	-1 134,0	C04	-2 899,2
C11	-995,8	C28	-1 649,9			C11	-1 186,0	C95	-3 029,2
C13	-1 008,5	C93	-3 647,2			C72	-1 243,2	C07	-3 122,3
C08	-1 068,1					C15	-1 286,4	C85	-3 214,4
C19	-1 421,3					C83	-1 311,9	C10	-3 357,8
C76	-1 591,5					C06	-1 333,7	C97	-3 364,7
C06	-1 709,2					C13	-1 365,0	C98	-3 441,0
C29	-1 955,5					C19	-1 403,7	C08	-3 506,0
C28	-1 986,2					C18	-1 543,5	C82	-3 539,2
C18	-2 062,7					C82	-1 844,4	C36	-3 780,6
C93	-5 544,0					C68	-2 303,9	C13	-4 246,4
						C93	-2 366,5	C11	-4 312,8
								C06	-5 301,4
								C19	-5 439,0
								C29	-5 948,3
								C76	-6 335,6
								C28	-6 379,2
								C18	-7 118,5
								C93	-15 739,2

Appendix 4: Substations in Skogas

4.1 List of substations in Skogås

Stn. no.	Name	Design load [kW]	Flats [number]	Area [m²]	Energy [MWh]	Domestic hot water [%]	Control values RAD [m³/h]	Control values DHW [m³/h]	Connection	Observation
S404	Brf Trålsund	1214	*	20000	3323	27	50	10,3	2-s type	
S451:1	Ab Prinsen	1563	313	34619	4023	32	63/20	1,6	2-s type/1-s type	Hot water syst., control value 20
S452	Ab Gjutingaren 1-3,	1286	312	26914	3918	34	20/25	25	2-s type/1-s type	Hot water syst., control value 25
S530	Samf Skogåsen	560	183	21567	3056	38	25	25	2-s type	
S712	Mästersångarens s	280	46	4771	818	34	2,5	5	*	
S718	Brf Löparen 2	276	75	5371	772	32	10	4	2-s type	
S744:1	Stortorps kyrkan	1300	*	29434	3162	34	*	*	2-s type	
S744:2	Stortorps kyrkan	410	~70	*	*	*	7,3	2,5	1-s type	
S809	Ab Husar 1, [illegible]	1049	179	18511	3004	35	19	19	2-s type	
S820	Brf Löparen	321	*	6800	500	29	6,3	2,5	2-s type	
S863	Ab Gjuterian, del av	896	163	17106	2701	36	16	31	2-s type	
S871	Samf Ronnarsen	597	155	15977	2844	32	14	14	2-s type	
S898	[illegible]	519	*	4490	879	22	4	2	2-s type	
S912	Allen Samf	383	61	7451	1207	35	6,3	3,2	2-s type	
S913	[illegible]	516	154	17280	2834	33	19	5	2-s type	
S1765	Musikalen Samf	609	126	13376	2222	39	12,5	5	2-s type	
S1777	Brf Drevviken Sta	653	119	11609	1850	33	6,3	2,5	2-s type	
S1778	Brf Stenladen	631	124	11472	1820	34	6,3	2,5	2-s type	
S1960	Brf Skogås 2	777	226	10689	2851	28	14	9,2	2-s type	
S1961	Brf Skogås 3	859	203	16362	2360	23	10	2,5	2-s type	
S1962	Brf Skogås 1	1105	220	17709	2953	25	16	2,5	2-s type	
S2014	Brf Prinsessan 2	852	201	12900	2701	29	25	14	2-s type	
S2015	Ab Brickan, [illegible]	1224	324	23400	3834	35	16/25	2,5	2-s type/1-s type	Hot water system, control value 25
S2674	Brf Balellen	626	130	12831	1758	34	6,3	2,5	2-s type	
S3093	Brf Löparen 3	350	*	6390	1041	28	6,3	2,5	1-s type	

* Missing

Good

Improved

Bad

Substation no. S451-1, S452, S2015

Heat exchanger for secondary net, larger substations. Buildings from the 1960s, all three quite close together within 1 km. Secondary temperatures (supply, return) 80/60°C.

Substation no. S718, S820

Multi family buildings, 3-5 floors, normal size with ca. 80 – 100 flats, built round 1965. Swedish 2-stage parallel connection. Radiator system 70/50°C.

Substation no. S404, S2014

Multi family buildings, >5 floors, large size with ca. 200 – 300 flats, built round 1965. Swedish 2-stage parallel connection. Radiator system 70/50°C.

Substation no. S744-2, S3093

Multi family buildings, 3-5 floors, normal size with ca. 70 – 100 flats, built round 1970. 1-stage parallel connection. Radiator system 70/50°C.

Substation no. S1960, S1961, S1962

Multi family buildings, >7 floors, type insulated block of flats. Ca. 200 flats each building. Built round 1965. All three quite close together within 1 km. Swedish 2-stage parallel connection. Radiator system 75/55°C.

Substation no. S898, S744-1

Special buildings: prison and hospital, respectively. Possible higher hot water consumption than normal. Swedish 2-stage parallel connection. Radiator system 70/50°C.

Substation no. S809, S871, S913, S680

Ca. 150 – 200 low group dwellings connected to a common substation. Built around 1970.

Distribution in 4-pipe system. Radiator system 70/50°C. Swedish 2-stage parallel connection.

Substation no. S1766, S1777, S1778

Ca. 120 – 130 low group dwellings connected to a common substation. Built around 1980-1985. Distribution in 4-pipe system. Radiator system 65/45°C. Swedish 2-stage parallel connection.

4.2 Excess flow ranking

	Current T_{supply}	85,0 °C	Calculated T_{return}	42,1 °C		SKOGAS/LANNA
	Target cooling	47,9 °C				February 2002
	Cooling	42,9 °C				
Substation	**Energy [MWh]**	**dT [°C]**	**Volume [m³]**	**Excess flow**	**T_{return} [°C]**	**Name**
S452	417	32,3	11325	3 682 m³	52,7	Kv Springaren1-3,Kungen3, 7-10
S1962	381	34,5	9697	2 708 m³	50,5	Brf Skogås 1
S1960	316	34,8	7966	2 168 m³	50,2	Brf Skogås 2
S2015	419	38,1	9660	1 973 m³	46,9	Kv Brickan, Tärningen
S1961	254	36,7	6081	1 415 m³	48,3	Brf Skogås 3
S744	356	39,4	7934	1 402 m³	45,6	Stortorpskliniken
S451	437	42,4	9037	1 027 m³	42,6	Kv Prinsen 1-6
S680	329	41,0	7043	1 006 m³	44,0	Samf Skogåsen
S2014	297	43,4	5997	557 m³	41,6	Brf Prinsessan 2
S2674	186	45,3	3607	190 m³	39,7	Brf Baletten
S718	86	44,5	1691	118 m³	40,5	Brf Löparen 2
S744	107	47,0	1997	36 m³	38,0	Stortorpskliniken(bostäder)
S3093	113	47,1	2102	33 m³	37,9	Brf Löparen 3
S820	97	50,5	1681	-92 m³	34,5	Brf Löparen 1
S912	127	50,4	2217	-116 m³	34,6	Alten Samfällighetsförening
S712	87	52,2	1467	-133 m³	32,8	Kv Mästersångaren 1
S871	308	49,2	5501	-149 m³	35,8	Samf Romansen
S898	86	53,7	1402	-172 m³	31,3	Beateberg Kriminalvårdsanstalt
S863	269	49,8	4754	-188 m³	35,2	Kv Symfonin, del av kv Overtyr
S1778	196	50,6	3399	-195 m³	34,4	Brf Silfversdalen
S809	313	49,6	5536	-204 m³	35,4	Kv Visan1, Serenaden3, Sången2
S1777	200	51,7	3390	-274 m³	33,3	Brf Drevvikens Strand
1766	247	52,3	4140	-383 m³	32,7	Kv Musikalen
S404	356	51,0	6131	-402 m³	34,0	Brf Trångsund
S913	299	53,4	4911	-568 m³	31,6	Sopranen & Trubaduren samf.
	6282	42,9	128664			

	Current T_{supply}	82,2 °C	Calculated T_{return}	39,7 °C		SKOGAS/LANNA
	Target cooling	47,5 °C				April 2002
	Cooling	42,5 °C				
Substation	**Energy [MWh]**	**dT [°C]**	**Volume [m³]**	**Excess flow**	**T_{return} [°C]**	**Name**
S1962	203	21,7	8238	4 484 m³	60,5	Brf Skogås 1
S452	296	30,3	8596	3 120 m³	51,9	Kv Springaren1-3,Kungen3, 7-10
S744	243	39,0	5483	988 m³	43,2	Stortorpskliniken
S1961	169	36,8	4034	912 m³	45,4	Brf Skogås 3
S2015	284	41,6	5994	747 m³	40,6	Kv Brickan, Tärningen
S1960	208	39,8	4586	745 m³	42,4	Brf Skogås 2
S451	298	43,0	6083	573 m³	39,2	Kv Prinsen 1-6
S680	241	42,4	4989	539 m³	39,8	Samf Skogåsen
S2674	142	44,0	2823	208 m³	38,2	Brf Baletten
S718	62	44,1	1224	88 m³	38,1	Brf Löparen 2
S3093	74	45,6	1432	58 m³	36,6	Brf Löparen 3
S2014	205	47,1	3819	30 m³	35,1	Brf Prinsessan 2
S744	77	48,2	1398	-21 m³	34,0	Stortorpskliniken(bostäder)
S898	61	50,4	1058	-64 m³	31,8	Beateberg Kriminalvårdsanstalt
S820	68	51,4	1157	-94 m³	30,8	Brf Löparen 1
S712	66	52,6	1096	-117 m³	29,6	Kv Mästersångaren 1
S912	90	52,0	1522	-144 m³	30,2	Alten Samfällighetsförening
S1778	143	51,5	2441	-205 m³	30,7	Brf Silfversdalen
S1777	145	51,9	2447	-225 m³	30,3	Brf Drevvikens Strand
S404	248	50,1	4341	-239 m³	32,1	Brf Trångsund
S863	201	51,2	3437	-269 m³	31,0	Kv Symfonin, del av kv Overtyr
S871	210	52,3	3520	-354 m³	29,9	Samf Romansen
S809	220	52,2	3707	-366 m³	30,0	Kv Visan1, Serenaden3, Sången2
S1766	181	53,4	2982	-371 m³	28,8	Kv Musikalen
S913	218	55,3	3462	-567 m³	26,9	Sopranen & Trubaduren samf.
	4352	42,5	89872			

	Current T_{supply}	78,0 °C	Calculated T_{return}	40,7 °C		SKOGAS/LANNA
	Target cooling	42,3 °C				June-August 2002
	Cooling	37,3 °C				
Substation	**Energy [MWh]**	**dT [°C]**	**Volume [m³]**	**Excess flow**	**T_{return} [°C]**	**Name**
S452	255,04	21,4	10487,9	5 189 m³	56,6	Kv Springaren1-3,Kungen3, 7-10
S744	179,86	24,3	6506,1	2 769 m³	53,7	Stortorpskliniken
S451	230,25	30,7	6581,2	1 797 m³	47,3	Kv Prinsen 1-6
S898	37,21	20,0	1630,53	857 m³	58,0	Beateberg Kriminalvårdsanstalt
S1962	136,71	35,4	3395,07	555 m³	42,6	Brf Skogås 1
S680	206,29	38,4	4717,57	432 m³	39,6	Samf Skogåsen
S2674	142,61	37,7	3318,85	356 m³	40,3	Brf Baletten
S1960	138,42	38,3	3174,94	299 m³	39,7	Brf Skogås 2
S3093	53,77	33,6	1405,13	288 m³	44,4	Brf Löparen 3
S820	47,17	45,9	902,61	-77 m³	32,1	Brf Löparen 1
S744	55,78	45,3	1080,03	-79 m³	32,7	Stortorpskliniken(bostäder)
S712	48,461	46,0	925,68	-81 m³	32,0	Kv Mästersångaren 1
S718	42,49	46,7	798,61	-84 m³	31,3	Brf Löparen 2
S912	75,99	45,5	1465,14	-114 m³	32,5	Alten Samfällighetsförening
S1961	99,13	45,1	1930,81	-129 m³	32,9	Brf Skogås 3
S871	152,78	45,7	2933,87	-240 m³	32,3	Samf Romansen
S2014	114,81	47,7	2114,59	-271 m³	30,3	Brf Prinsessan 2
S404	152,66	46,8	2866,1	-306 m³	31,2	Brf Trångsund
S1777	122,56	48,8	2206,06	-340 m³	29,2	Brf Drevvikens Strand
S1766	163,82	47,2	3046,84	-357 m³	30,8	Kv Musikalen
S809	210,83	46,3	3995,48	-385 m³	31,7	Kv Visan1, Serenaden3, Sången2
S863	184	47,0	3437,6	-385 m³	31,0	Kv Symfonin, del av kv Overtyr
S1778	111,25	50,9	1919,1	-392 m³	27,1	Brf Silfversdalen
S913	159,76	51,6	2718,95	-600 m³	26,4	Sopranen & Trubaduren samf.
	3122	37,3	73559			

Appendix 5: List of malfunctions in DH substations

Table A.5.1: Possible malfunctions in the **radiator heating system** – *R - type*

Ident.	**Type of malfunction**	**Impairing comfort**	**Impairing substation cooling**
R1	Control valve CV1 manually positioned or closed	yes, in most cases	yes, in most cases
R2	Control valve CV1 leaking	no	no
R3	Soiled heat exchanger	normally not	yes
R4	Heat exchanger HEX connected in parallel flow (instead of counter flow)	normally not	yes
R5	Hot water circulation HWC pump not working	yes	no, if CV1 works correctly
R6	Wrong flow rate (malfunctioning pump or frequency control)	depending on flow rate	depending on flow rate
R7	Wrong control curve applied	yes	yes, if curve is too high
R8	Control curve of shunt group less than curve of primary system	no	yes
R9	Outdoor temperature sensor Tout defect or misplaced	yes	yes, in most cases
R10	Temp sensor T1 defect or misplaced	yes	yes, in most cases
R11	Expansion vase empty or leaking heating system	yes	normally not
R12	Uneven flow distribution among two parallel HEX	no	yes, in most cases
R13	Short thermal length of radiator or ventilation battery	yes, in most cases	yes
R14	No radiator thermostat valves available or defect thermostat valves	yes	yes, often
R15	Uncontrolled radiator flow and/or bypasses	yes, often	yes
R16	Unsatisfying adjusted radiator system	yes	yes
R17	Shunted mixing valves in radiator circuit	no	yes

*Table A.5.2: Possible malfunctions in the **tap water system** – W – type*

Ident.	**Type of malfunction**	**Impairing comfort**	**Impairing substation cooling**
W1	Control valve CV2 manually positioned or closed	yes, often	yes, often
W2	Control valve CV2 leaking	no	yes
W3	Soiled DHW heat exchanger	normally not	yes
W4	Heat exchanger HEX connected in parallel flow (instead of counter flow)	normally not	yes
W5	Quick HEX combined with slow control valve	yes, often	yes, often
W6	Hot water circulation pump not working	yes	not, if CV2 works correctly
W7	Wrong choice of set temperature	yes, often	yes, if chosen too high
W8	Wrong control parameter choice	yes, often	normally not
W9	Set value RC2 > set value RC3	no	yes
W10	CV2 connected in sequence with CV3	normally not	yes, often
W11	Temp sensor T2 defect or misplaced (long distance to HEX)	yes	yes
W12	Short thermal length of hot water HEX	yes, often	yes
W13	HWC inadequately shunted	no	yes
W14	Back-flow through HWC pipe	yes, often	yes
W15	Control valve CV3 locked in a given position	depends on control of CV2	depends on control of CV2
W16	Control valve CV3 leaking	yes, often	yes
W17	Temp sensor T3 defect or misplaced	yes, often	yes, often
W18	HWC is missing, resulting in bad temperature control at low taps	yes	yes
W19	Wrong HWC flow	yes, if too low	yes, if too high
W20	Secondary HW make-up with secondary HWC	no	yes

Table A.5.3: Possible malfunctions because of **defect components** *– C – type*

Ident.	**Type of malfunction**	**Impairing comfort**	**Impairing substation cooling cooling**
C1	Wrong or defect HEX	normally not	yes, often
C2	Wrong or defect control system RC	yes	yes, often
C3	RC not in operation or electrical malfunction	yes	yes, often
C4	Wrong or defect valve/motor	yes	yes, often
C5	Wrong valve size	yes, often	yes, often
C6	Blocked filter, primary side	yes	no
C7	Blocked filter, secondary side	yes	not normally
C8	Wrong seized flow meter	yes, if valve authority is affected	not normally
C9	Malfunction of heat meter	no	no
C10	Malfunction of valves connected in sequence	yes, often	yes

Table A.5.4: Possible malfunctions due to the **external circumstances** *– type E*

Nb.	**Type of malfunction**	**Impairing comfort**	**Impairing substation cooling**
E1	Low district heating supply temperature	yes, if too low	yes
E2	Secondary use of heat pump or heat recovery system (can cause high return temperatures)	no	yes

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