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Lower return temperatures within District heating Systems

A Comparison of Danish and German District heating Systems

Master Thesis

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HORS D'ŒUVRE

The Laws of Thermodynamics:

Zero: You must play the game.
First: You can't win.
Second: You can't break even, except on a very cold day.
Third: It doesn't get that cold.

(Eclipse now, 2009)

AALBORG UNIVERSITY

STATUTORY DECLARATION

I hereby declare that this Master Thesis has been written by me without any external unauthorised help. Any parts, words or ideas, of this thesis, however limited, and including tables, graphs, maps etc., which are quoted from or based on other sources, have been acknowledged as such without exception.

Place, Date Dipl.-Ing.(FH), Dipl.-Ing. Brandweiner Otmar

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ABSTRACT

Title: Lower return temperatures within District heating Systems- A Comparison of Danish and German District heating Systems

Theme: Lowering the return temperature within District Heating Systems

Key words: District Heating, lowering return temperature, Skagen, Badenova, Friesenheim

This Master Thesis attempts to answer the question how District heating Systems can lower the temperature within the return flow. The two District heating Systems of Friesenheim at Badenova in Germany and Skagen in Denmark were compared. As an initiating problem the return temperature in the Badenova district heating system is approx. 60° C, whereas in Skagen it is 40° C. A higher return temperature results in larger net losses, further on less energy stored in a thermal store and lower efficiency of heat production. These facts makes district heating less attractive. For each District Heating System the annual consumption was analysed and simulated. A detailed analysis about the already installed District Heating system was made to ensure that the energy can still be transported via the already existing pipes with using the lower temperatures. Further on the heat supply- as well as the substations were analysed if they can work more efficient by using the lower temperatures. Finally a plan was made how the return temperature can be lowered and a financial bonus plan was introduced to make this advantage more attractive to the consumers.

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1 INTRODUCTION

District heating is used to transport heat in urban area from a heat-producing unit to a consumer. The central sources are mostly waste incineration plants, combined heat and power plants (CHP's) or other industrial processes where heat occurs as by-product. The energy source varies different types of fuels.

The following Chapters summarizes the historical development of District Heating and some future perspectives to illustrates the need that District Heating has to be optimized and need further development to become more sustainable.

The Research Question in Chapter 2.1 describes the targets of the research of this Master Thesis.

1.1 District Heating – Historical Background and Future Perspectives

The concept of transporting heat through pipes is very old. About 3,000 years ago installed the Chinese people flue gas channels into walls and floors. (Fernwärme Forschungsinstitut, 2008) The ancient Romans used pipe systems to transport heat to dwellings and baths. (Stierhoff & Taylor, 1983) The so-called hypocaust (lat. hypocaustum) heated floors and walls of buildings and open spaces by heated gases from a fire or furnace below. (Encyclopædia Britannica Online, 2008) Figure 1.1 shows a photograph of ruins of an ancient roman villa with a hypocaust below the floor.

Figure 1.1 Ruins of the hypocaust under the floor of an ancient villa, Rome (Encyclopædia Britannica Online, 2008)

By building an iron stove-type furnace below the surface, Benjamin Franklin heated a series of row houses by running the flue below the floors, which were tiled and fireproof. (Stierhoff & Taylor, 1983) In 1770, James Watt used steam to heat his factors and living areas. In England were buildings with distances of approx. 270 m heated by a central source. (Fernwärme Forschungsinstitut, 2008) In U.S. was the first water heating systems installed by 1830. Birdsill Holly, a noted hydraulic engineer, installed the first commercial successful District Heating system in 1877. (Stierhoff & Taylor, 1983)

In the ending of the 19th century urban areas started to incinerate the accruing waste in so-called waste incineration plants. How the historical development of waste incineration and the use of the produced heat was and is still used is summarized in the following chapters.

1.1.1 District Heating in Germany

The first Central Heating system of Germany was in the new Sanssouci palace in Potsdam in 1769. In 1893 the Hansestadt Hamburg built a power plant and tested the supply of steam over a distance on 300 m to their town hall. This was the first time that heat and electricity was produced at the same time. The town Dresden built the first European District heating plant in 1900. This plant was using steam to transport the heat. After World War II in fact of a shortage of fuel was in Germany District Heating promoted. In 1990, after the reunion of Germany was a very extensive program implemented to reconstruct the District Heating in East-Germany. Since 1997 is the power economy in Germany liberated. In 2000 Germany made laws for protection of the generation from combined heat and power. The whole German District Heating System is about 50.000 km long. (Fernwärme Forschungsinstitut, 2008)

1.1.2 District Heating in Denmark

In1903 Frederiksberg, an independent municipality of Copenhagen built an waste incineration plant and started the first District Heating System in Denmark. (DBDH, 2008) Several other towns followed that example in the following years. In World War II also Denmark had a shortage of coal and switched to peat and lignite as energy source. One further restatement was that the indoor temperatures were set down to 18 °C for living houses and to 10 °C in churches, museums and cinemas. By the end of the 50s the Danish Society changed to a "use and throwaway society". This made it more easily to incinerate waste because the heat value of the waste rose. In the 60s the municipality of Kolding started with experiments of today termed "pyrolysis" and succeeded with new ways of waste gas incineration. In the following years the technology of waste incineration got more developed. During the 60s also the Danish people and government became more aware of environmental protection, hence the energy crises of the 70s made the cogeneration also more attractive. Till 2000 were several energy-action plans carried out which promoted the increase of District Heating in Denmark. Since 2003 forces the IPPC Directive of the European Commission that new power plants uses the best available technology and so the combined heat and power (CHP) is nowadays most used to provide District Heating in Denmark. (ApS & Rambøll, 2004) The following diagram shows the development of combined heat and power in Denmark from 1980 to 2007.

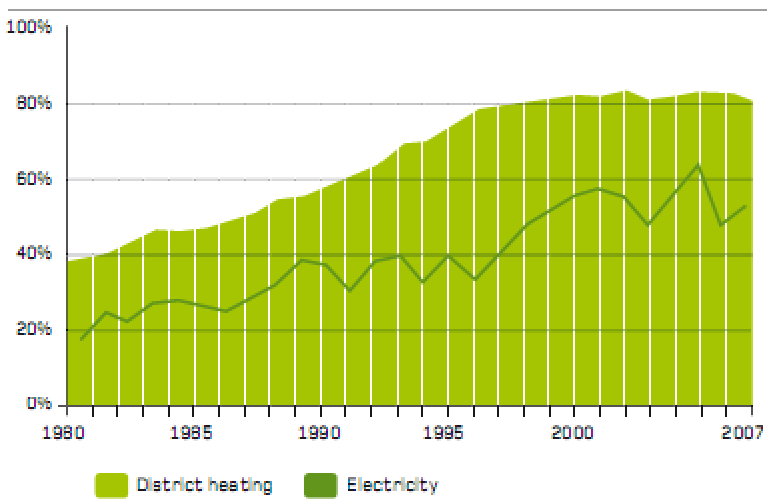

Figure 1.2 CHP Shares in Electricity and District Heating Production (DBDH - Danish Board of District Heating, 2009)

1.1.3 Future Perspectives and Developments of District Heating

The history has shown that District heating supplied by combined heat and power (CHP) is a very cheap way to supply urban areas with heat. The fact that CHP is the most efficient way to produce electrical power and heat is undisputed and most sustainable. The target of the German Federal Government is to raise the amount of produced electricity by CHP from about 12 % to 25 % till 2009. That means an annual increase of 2750 MW of installed power. (AGFW, 2009)

The Danish board of District heating tells in the annual report 2008 that till 2030 the District heating has to expand up to 70 %. Further on are the goals to make costumers save further 25 % on heating and reduce the return temperature to 35 °C. This goals will be reached by implementing further sustainable energy systems like using waste heat in CHP units with condensation, large scale solar heating, biogenic fuels and access of wind energy within district heating.

2 RESEARCH QUESTION AND METHODOLOGY

The Master Thesis includes a literature research including social, environmental and economical aspects. Experts were be interviewed via email, phone or other possibilities to gather the necessary information.

2.1 Research Question

For the transport of energy in a District Heating system water is used which is heated up in the supply station and are pumped through the supply pipe to the consumer, where the energy is "consumed" by the heating system. The cooled water is transported through the return pipe and again heated in the supply station. The energy that is transported within this pipe system can be calculated by the caloric equation:

$$\dot{Q} = \dot{m} * c * \Delta T \quad c = 4.18 \frac{J}{kg * K} \tag{2.1}$$

So the higher the difference between the supply and return temperature is the higher is the transported energy. Figure 2.1 illustrates this with a transport capacity of 5 and 20 MW. Further On the higher the temperature in the pipes is the higher are also the losses.

Table 2.1**Fehler! Verweisquelle konnte nicht gefunden werden.** summarizes some supply and return temperatures of some countries. Germany has higher supply and return temperatures than Denmark; even the domestic hot water has in Denmark a higher temperature.

Table 2.1 Examples of temperatures used for the design of central heating systems (Mildenstein & Skagestad, unknown)

Country	Supply Temperature	Return Temperature	Hot Water
Denmark	70	40	<60
Finland	70	40	55
Korea	70	50	55
Romania	95	75	
Russia	95	75	50
United Kingdom	82	70	65
Poland	85	71	55
Germany	80	60	55

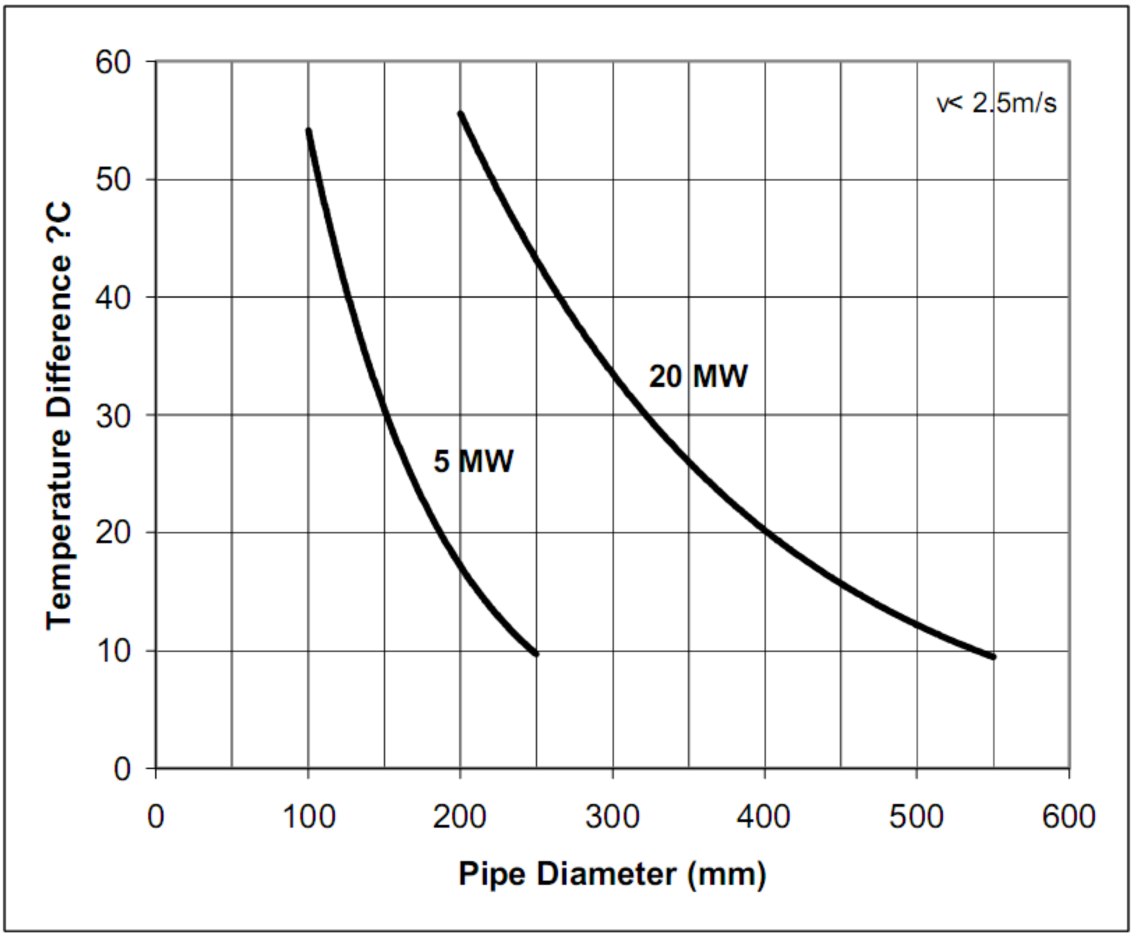

Figure 2.1 Comparative pipe diameters in relation to temperature difference (Mildenstein & Skagestad, unknown)

As an initiating problem the return temperature in the Badenova district heating system is approx. 60° C, whereas in Skagen it is 40° C. A higher return temperature results in larger net losses, further on less energy stored in a thermal store and lower efficiency of heat production. These facts makes district heating less attractive.

Within this Master Thesis, the advantage of having a colder return temperature in the district heating systems of Badenova in Germany and Skagen in Denmark will be analyzed. Two case studies will analyze why heat consumers in Badenova and Skagen do not have the same ability to cool down the received district heating water. A plan will be made to make heat consumers in Badenova and Skagen further cool down the received district heating water.

Research Question:

- What is the difference between the District Heating system of Friesenheim at Badenova and Skagen?

Sub-questions:

- Why has the District Heating System of Skagen lower return temperature than Friesenheim at Badenova?
- What are advantages and disadvantages of using lower return temperatures in district heating system?
- How can consumers be motivated to lower the return temperature of District Heating systems?

The following chapter summarizes the targets and non-targets of the research.

2.2 Target and Non-Target

Targets:

- Analysing the advantages and disadvantages of using lower return temperatures in District Heating systems
- Annual simulations of the District Heating and transmission system with different temperatures
- Analysing the differences of both District Heating systems

Non-Targets:

- Analyses of the financial costs for the consumers
- Analyses of possibilities of changing the primary energy source
- Analyses of the control technology
- Changing infrastructure of the District Heating Systems
- Cash Flow scenarios of future developments

For each District Heating System the annual consumption was analysed and simulated. A detailed analysis about the already installed District Heating system was made to ensure that the energy can still be transported via the already existing pipes with using the lower temperatures. Further on the heat supply- as well as the substations were analysed if they can work more efficient by using the lower temperatures.

2.3 Research Concept

Within that Master Thesis the background of District heating and the benefits as well as the future trends were investigated in Chapter 1. The research question with the sub-questions were specified in Chapter 2. The analysis in Chapter 3 gives an technical overview of District heating. Within that Chapter are also the two District heating systems of Friesenheim and Skagen analysed and some models and simulations are made to make the two District heating Systems comparable. Chapter 4 compares than the two District heating systems. In the Conclusion in Chapter 5 are finally all main differences summarized and the research question with all sub-questions answered. A Plan to make the lower return temperatures more attractive is described in Chapter 4.4 and summarized in Chapter 5.4

Figure 2.2 shows the steps of the research concept.

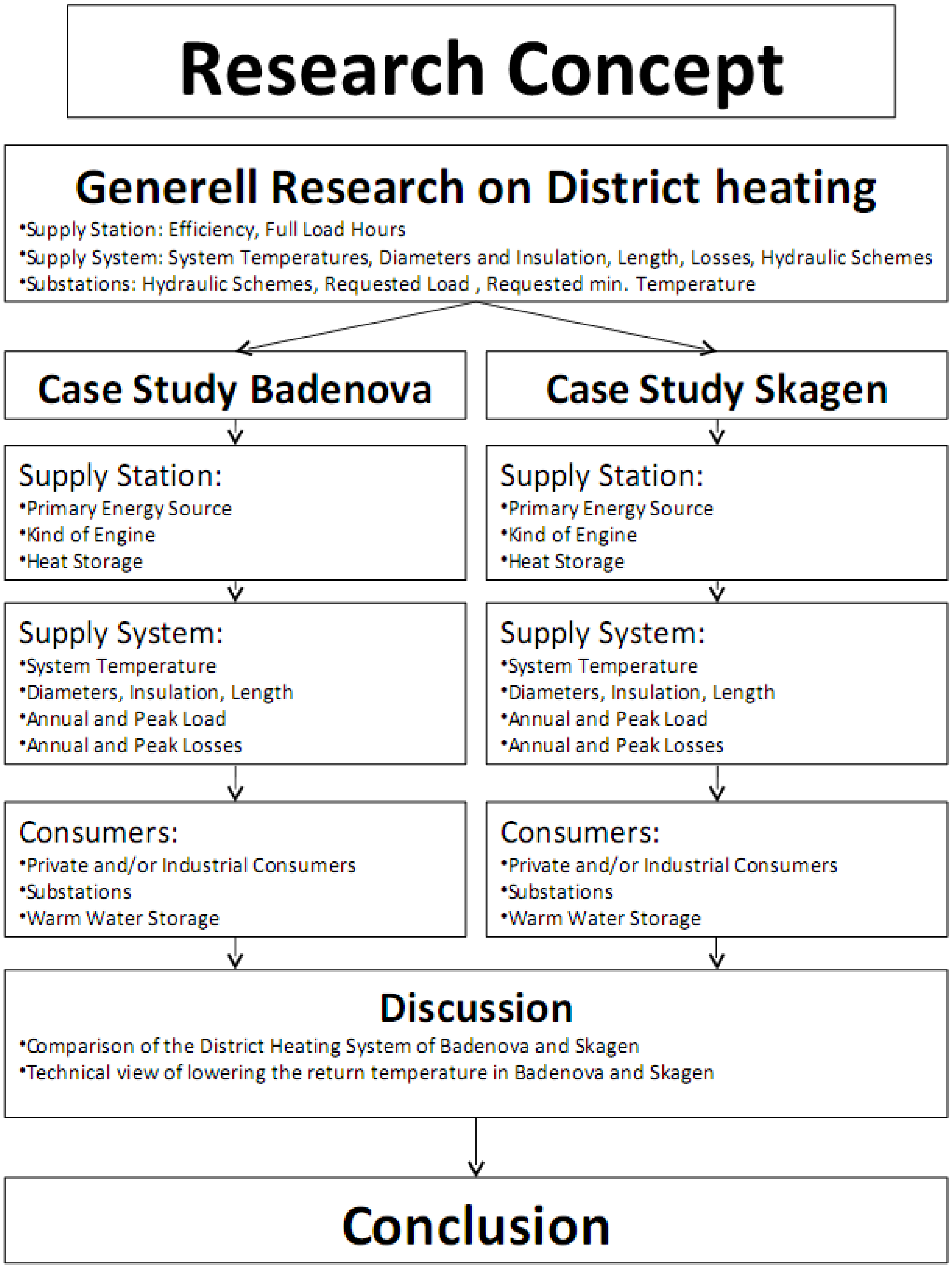

Figure 2.2 Research Concept

The research Concepts includes a general literature research on District Heating summarized in Chapter 3.1. This Chapter also gives a technical overview how District Heating works and explains most of the different components.

Two Case Studies on the District Heating Systems of Skagen in Denmark and Badenova in Germany have the same structure and are compared within the Discussion. Microsoft Excel and Energy Pro (EMD International A/S, 2008) were used within these Case Studies. How the Energy Pro is operating is described in the following Chapter.

2.4 Energy Pro 3.3.0.21 by EMD International A/S

The energyPRO models and calculates the optimal fuel consumption, heat production, electricity productions, electricity consumption and cooling production for production units within certain surroundings and supply conditions. The change of the model of the energy system and operation strategy as well as the performance of a sensitivity analyses can be done. The times of demand of electricity and heat differ, so can also the used thermal stores also be simulated. The uses of several fuel types can be optimized, as well as the fuel storage systems. The electricity production can be optimized to the local demand and also to the best selling opportunities on several electricity markets. (EMD International A/S, 2008)

The production units are described by power curves of fuel consumption, heat production, electricity production, electricity consumption and cooling production. The Thermal store is defined by a maximum content measured in MWh. This content can also be changed by different seasonal periods. Further on a heat blow off unit can also be used for the simulations. (EMD International A/S, 2008)

The so-called external data which is used in the Energy Pro belongs to outside temperature and heat demand of the consumers. This values can be added from libraries, like the Danish Test Reference Year (TRY) (see also Chapter 3.1.2) or defined directly.

The input data for calculations with the EnergyPRO Program is:

- Fuel,
- Demands,
- Energy Units,
- Electricity market and
- Operation Strategy.

Different libraries are included in the EnergyPRO where the different values of the input data can be chosen. There is also the possibility to add new kinds of e.g. other fuels. The demand can be added by Heat (and Process Heat), Electricity and Cooling. The amounts can be chosen by one over all time value or also be calculated with monthly amounts. The energy units can be production units, thermal stores, heat blow off and also wind farms. The Electricity market and the operation strategy define the way of calculating the most cost effective way. For the Electricity Market can fixed tariffs and spot markets can be chosen. (EMD International A/S, 2008)

Further and more detailed explanations of the calculations methods of the EnergyPRO are not part of this Thesis, and can be looked up in the Help Menu of the Program.

3 ANALYSIS AND RESEARCH

3.1 District heating

The following subchapter gives an overview on District Heating Systems and the operation principles. The technology analysed in the subchapter only summarizes the used District Heating Technology in Skagen and Badenova.

3.1.1 General Concept of District Heating

A District Heating System is made up of three major components (Stierhoff & Taylor, 1983):

- The Production Plant
- The Transmission and Distribution System
- The In-Building Equipment

These three components are shown in Figure 3.1. This figure also mentions that chilled water can be supplied.

The Production Plant provides steam and/or hot water; this can be produced by boilers, combined heat and power cycles (CHP) or waste incineration. The recovering of heat by electric generating processes reduces the community's consumption of primary fuels such as heating oil or natural gas thus the boilers and CHP-Plants also uses primary fuels. (Stierhoff & Taylor, 1983)

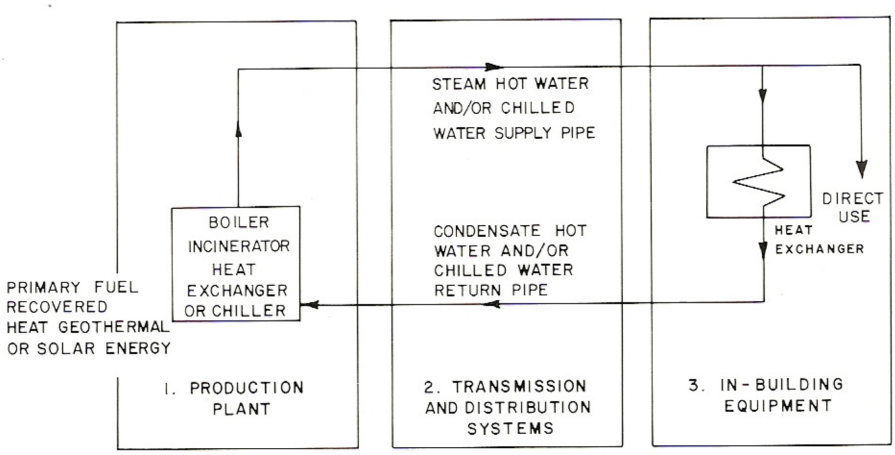

Figure 3.1 Three major components of a district heating system (Stierhoff & Taylor, 1983)

The second component is the transmission and distribution network. The energy is conveyed in form of steam and/or hot water through pipes from the thermal production plant to the consumer. (Stierhoff & Taylor, 1983)

The in-building equipment is the third component of a District Heating system. The so-called substation connects the transmission or distribution system indirect or direct to the heating system of the building.

3.1.2 Calculation of Heat Demand

To calculate the daily and annual heat demand a so-called Degree-Day Method is used. This Model used climate data of the design outside temperature and the reference temperature inside of the building. (Brandweiner, Dang, Napierala, & Trutnevytė, 2008)

Figure 3.2 shows the outside temperatures of the Test Reference Year of Denmark. The design outside temperature in Denmark is minus 12 °C. If the temperature is higher than plus 17 °C normally the heating systems in Denmark switches off. (Brandweiner, Dang, Napierala, & Trutnevytė, 2008)

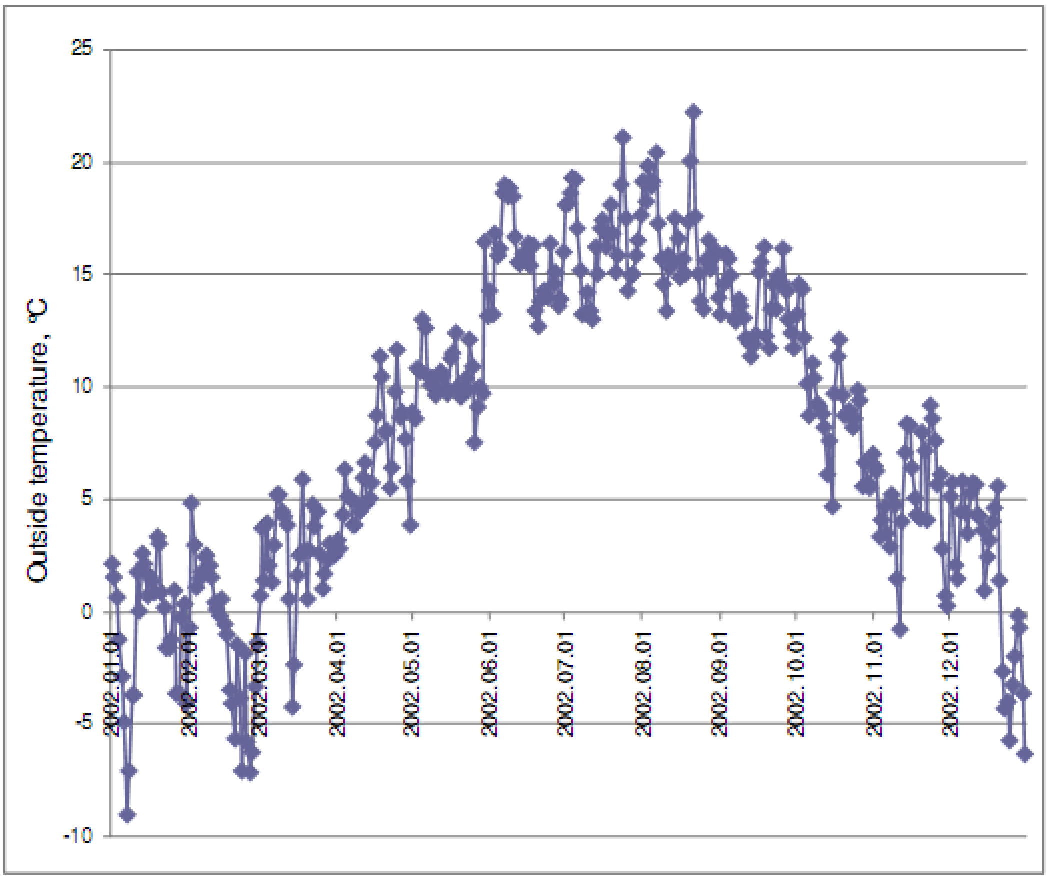

Figure 3.2 Variation of outside temperature in Danish Test Reference Year (EMD International A/S, 2008)

Formula 3.1 calculates the annual heat demand concerning the peak heat demand of space heating.

$$Q = \frac{\dot{Q}}{(t_{ref} - t_{out}^{min})} \cdot \sum a(t_{ref} - t_{out}) \qquad (3.1)$$

Q is the annual heat demand for space heating (kWh/year);

$\dot{Q}$ is the peak heat demand (W).

t_{ref} is the reference temperature;

t_{out}^{min} – design outside temperature;

t_{out} – outside temperature in Test Reference Year (°C).

a – hours when outside temperature is t_{out} (h). (Brandweiner, Dang, Napierala, & Trutnevytė, 2008)

The part of Formula 4.1 $\sum a(t_{ref} - t_{out})$ is the day degree hours of the Test Reference year in °C*h. Formula 4.1 covers the only the space heating demand.

Internal gains, like heat gains from lightning or cooking is not part of this calculation and so not part of the annual and daily heat demand calculation. (Brandweiner, Dang, Napierala, & Trutnevytė, 2008)

The Domestic Hot Water Demand is also not part of Formula 4.1 and is constant all over the year. The Heat Demand for the hot water production can be calculated with the caloric equitation (see Formula 1.1) and can be seen as base load for District Heating supplier. (Brandweiner, Dang, Napierala, & Trutnevytė, 2008)

The Degree-Day Model is used in Energy-Pro (EMD International A/S, 2008) which is used in the Case Studies (see Chapters 3.2 and 3.3) and is the basis of the Load Duration Curve described in the following Chapter.

3.1.3 Supply Station and Heat Storage

The central source of a District Heating System is a boiler unit and/or a cogeneration plant. The cogeneration plant produces primary electricity and secondary heat. The heat can be stored in a thermal store. The primary sources are the incineration of fossil fuel like coal, oil or gas, the incineration of waste or biomass (also biogas). Other option can be solar power, waste heat from industry or power plants or geothermal heat. (Stierhoff & Taylor, 1983)

Figure 3.3 shows the principle of combined heat and power. Steam is produced in the boiler and powers a high and low-pressure turbine, which drives an electric generator, which produces electricity. The condensate water has to be cooled down before it gets back to the boiler. This loss energy can be used for the District Heating System. The temperature differs from different production systems. (Stierhoff & Taylor, 1983) Also Engines can be used to produce power and heat. This technology is also called combined heat and power (CHP). Having lower return temperatures will also result in higher efficiency of the CHP-Plant, because more H_2O which is steam in the exhaust gas can be condensate.

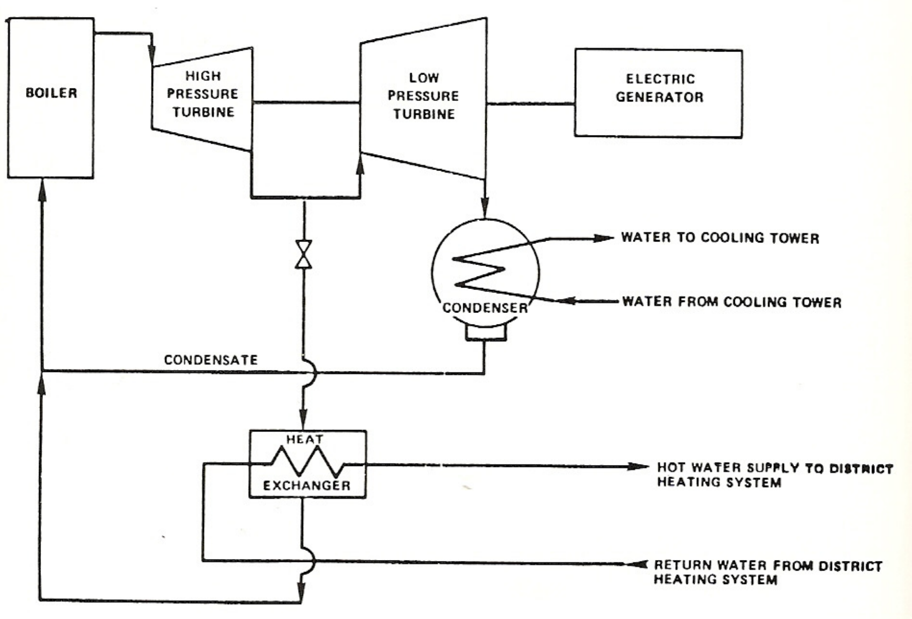

Figure 3.3 CDH Topping system combined heat and power (Stierhoff & Taylor, 1983)

The capacity of the production units Supply Station is sized by the Load Factor and the Load Duration curve. The Supply Station must be able to produce the heat that is needed within the hour where most heat is needed. Normally is that hour the coldest of the year; hence the load is depending on the outside temperature. Therefore, the Supply Station must cover the supplied heat demand and the losses of the transmission and distribution system. To make the supply station more efficient several production units are used. Most boilers and engines have one work point where they work most efficient. However to make the supply station most efficient it is necessary to run the supply station as long as possible at this most efficient operation point. Nevertheless, most of the time is than more heat produced than is consumed, so a thermal store is used. The energy that gets stored in such a thermal store belongs to the same caloric equitation as in the transmission system (see Formula 1.1). If the temperature difference in the transmission is higher more energy can be stored.

Figure 3.4 shows an example of a Load Duration curve. In this Figure is a waste incineration plant, two combined heat and power unit's and a boiler for the peak load used. The waste incineration is used all over the year and is used to cover the base load. The CPH 1 unit covers 57 % of the production. If more than 50 MW of heat is need the second CHP unit starts. At this moment, the CHP 1 unit drops a little down, because the second CHP unit has a minimum supply of about 5 MW. A CHP unit is quite more expensive than a boiler, which only produces heat. Normally about 5 % of the heat production is done with such a boiler because the payback time of a

CHP unit that only is used for 5 % of an annual production is not feasible. Nowadays is also the boiler be used to produce heat in times when the price of electricity is low.

The most important factor for a sustainable District Heating System is the number "Full-Load-Hours". The load curve of Figure 3.4 can be described by the function developed by Sochinsky in Formula 4.1 where $\beta(T)$ is the Load belonging to the Load hour, $\beta_{\min}$ the minimum Load and β_m the average Load. τ_b are the working hours of the annual working hours of the District Heating System; normally less than all hours of the year, because of maintenance. So the Full-Load-Hours T of the system are calculated in Formula 4.3 and 4.4. In Figure 3.5 are the Full-Load-Hours shown with the vertical line at about 2,700 hours. (Arbeitsgemeinschaft QM Holzheizwerke, 2004)

$$\beta(T) = 1 - \left((1 - \beta_{\min}) * T^{\left(\frac{\beta_m - \beta_{\min}}{1 - \beta_m}\right)} \right) \quad (3.2)$$

$$\beta(T) = \frac{P(T)}{P_{\max}} \; and \; T = \frac{\tau}{\tau_b} \;\; ; \;\; \tau_b < 8760 \; hpa. \quad (3.3)$$

$$\beta_m = \frac{Q}{P_{\max} * \tau_b} = \frac{P_{\max} * T_b}{P_{\max} * \tau_b} = \frac{T_b}{\tau_b} \quad (3.4)$$

$$\beta_{\min} = \frac{P_{\min}}{P_{\max}} \quad (3.5)$$

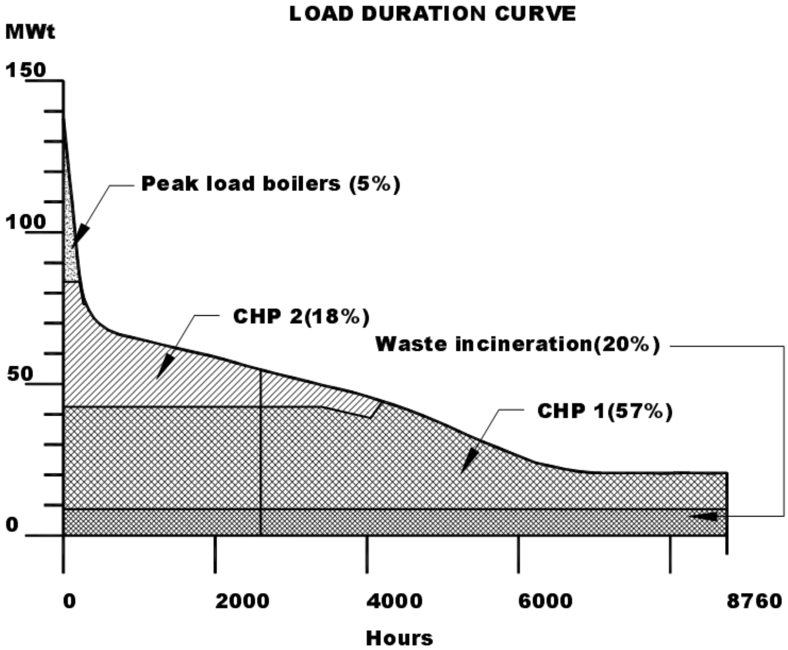

Figure 3.4 Example of a load duration curve indicating the proportion of different heat sources (Mildenstein & Skagestad, unknown)

Figure 3.5 shows the simulation of a load duration curve by using the Formula of Sochinsky. Compared to Figure 3.4 the curve is declining constantly and so can only be used to calculate optimal capacity of a peak-load boiler. (Arbeitsgemeinschaft QM Holzheizwerke, 2004) The Sochinsky curve will also be a part of the calculation in the two Case Studies in Chapters 3.2 and 3.3.

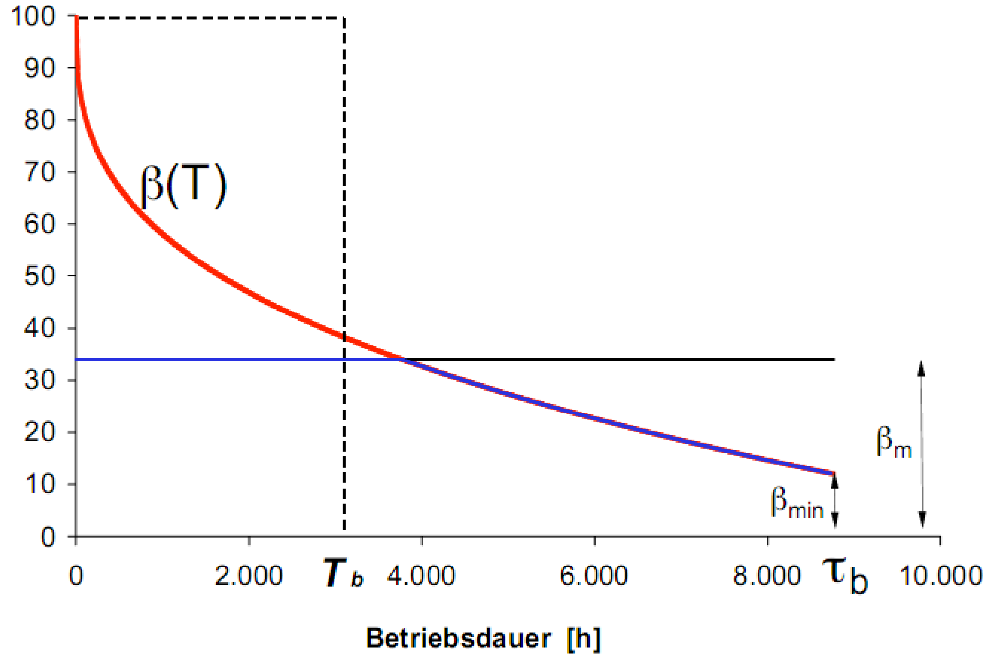

Figure 3.5 Load duration curve calculated by the formula of Sochinsky (Arbeitsgemeinschaft QM Holzheizwerke, 2004)

The Formulas 4.2 to 4.5 and the load duration curve in Figure 3.5 are used to design a sustainable District Heating System.

The technologies used in the District Heating Systems of Badenova and Skagen to produce heat are described in the case studies (see Chapters 3.2 and 3.3).The EnergyPRO 3 uses the Load duration curve and the day degree model to simulate the annual amount of CHP production and is described in Chapter 3.1.2**Fehler! Verweisquelle konnte nicht gefunden werden.**.

The Transmission of the heat from the Production Station to the buildings is summarized in the following chapter.

3.1.4 District Heating Transmission and Distribution System

The Thermal transmission and distribution system contains three different parts:

- Transmission Line
- Distribution Line
- and Service Line.

Figure 3.6 illustrates these three parts. The Transmission Line transports the whole heat from the Thermal Production Plant to the Distribution system. The Distribution Line covers the supply of different housing areas. In Figure 3.6**Fehler! Verweisquelle konnte nicht gefunden werden.** is a ring system shown. The Service Line is the connection between the Distribution System and the supplied building.

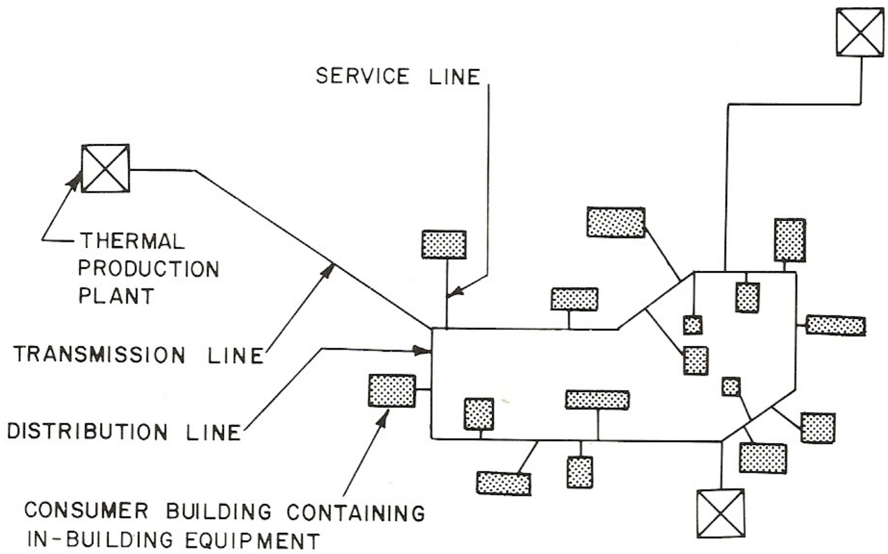

Figure 3.6 Schematic layout of a simplified district heating system (Stierhoff & Taylor, 1983)

Nowadays District Heating Systems uses a two-pipe system. Figure 3.7 shows the two main principles of heat distribution. The upper part shows the direct return system, where each part of the return pipe can have different system temperatures. In addition, the transported water in the system parts contains other specific volumes. The other part is the reversed-return two-pipe system, where the specific volumes are normally constant and the temperatures are the same.

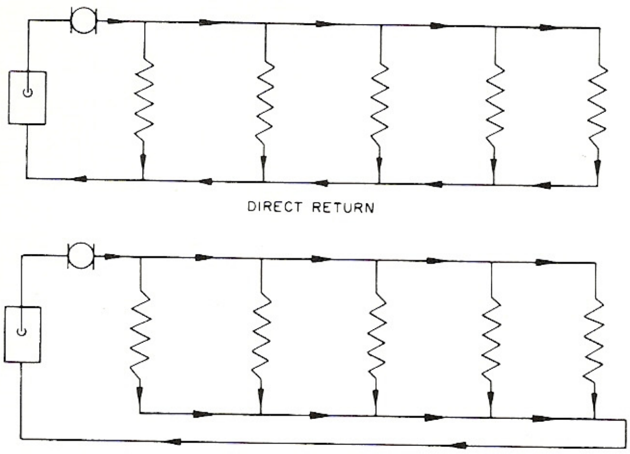

Figure 3.7 Direct- and reversed-return two-pipe system (Stierhoff & Taylor, 1983)

With the Service Line gets the Distribution System connected to the consumers, where the In-Building Equipment transfers the heat to the HVAC (Heating, Ventilating and Air Conditioning) System of the building. The different systems used within the In-Building substations are summarized in the following chapter.

3.1.5 Consumer Building Containing In-Building Equipment - Substation

The connection between the Service Line and the HVAC (Heating, Ventilating and Air Conditioning) system of the building can be in a direct or indirect way. Table 3.1 shows an example of a District Heating system and the secondary design temperatures with a supply temperature of 105° C and illustrates the difference between theory and reality. The border between the primary and secondary system is shown Figure 3.9, the so-called secondary system is the part belonging to the In-building equipment. The ideal conditions shown in this example reduce operating costs for the consumer and energy use for the District Heating operator. (Mildenstein & Skagestad, unknown)

Table 3.1 Comparative design temperatures (Mildenstein & Skagestad, unknown)

	Probable	Realistic	Ideal
DH supply temperature	105°C	105°C	105°C
DH return temperature	73°C	67°C	42°C
Secondary supply temperature	82°C	85°C	70°C
Secondary return temperature	71°C	65°C	40°C

The domestic hot water supply in buildings is all over the year the same. Table 3.2 shows an example of a primary supply temperature of 85° C and a cold-water temperature of 10° C. The temperature of the cold-water can differ according to the season, normally between 8° and 11° C, so domestic hot water production is able to cool the return temperature of the District Heating system to a minimum of 25° C. However, the domestic hot water temperatures have to comply with the national standards. (Mildenstein & Skagestad, unknown)

Table 3.2 Domestic hot water design temperatures (Mildenstein & Skagestad, unknown)

DH supply temperature	85°C
DH return temperature	25°C
Hot water supply temperature	55-65°C
Cold water temperature	10°C

Table 3.3 summarizes the supply and return temperatures of the different heating system used in buildings which are today state of the art. There are also situations where lower temperatures are used, e.g. radiator systems can use supply/return temperatures of 70/30° C and modern air handling units can have return temperatures below 20° C. (Mildenstein & Skagestad, unknown)

Table 3.3 Design temperatures for secondary heating circuits (Mildenstein & Skagestad, unknown)

	Supply	Return
Radiator circuit	85°C	60°C
Heating coils	85°C	55°C
Under floor heating	45°C	30°C
Embedded panel	55°C	35°C
Domestic hot water	55°C	10°C

As mentioned above two main kinds of connection between the In-building Heating equipment and the District Heating system:

- Indirect and
- Direct.

Figure 3.8 gives an expression of a District Heating substation with all ancillary equipment. This ancillary equipment are things like pressure gags, thermometers and shut-off valves, installed for controlling, monitoring and maintenance.

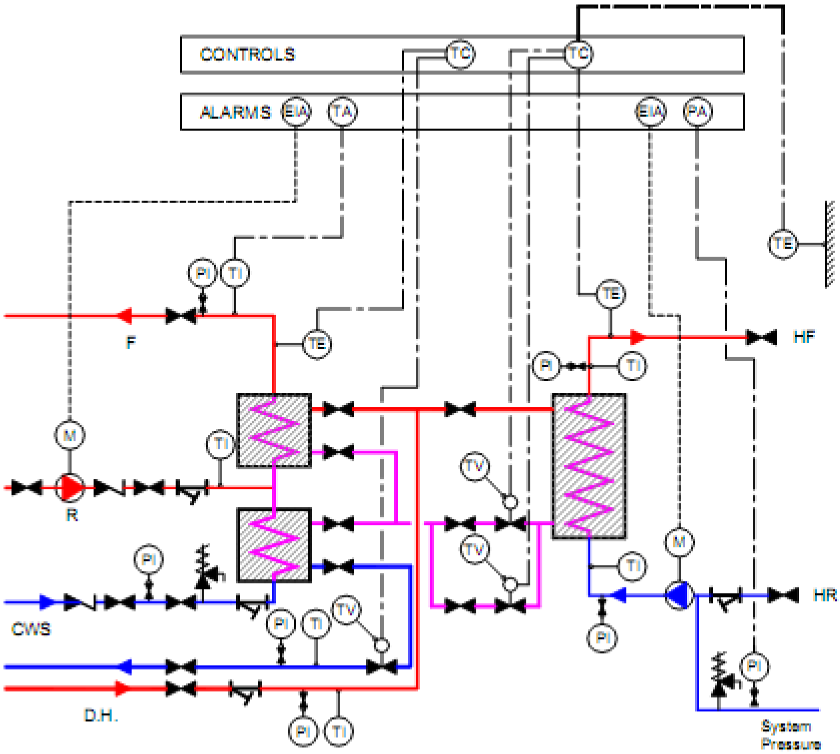

Figure 3.8 Schematic of a heat exchanger Substation (Mildenstein & Skagestad, unknown)

Figure 3.9 illustrated a simple indirect connection. The principle of indirect connections is a heat exchanger between the fluid of the District Heating system and the fluid of the heating system of the supplied building. This hydraulic schematic supplies only one temperature to the building.

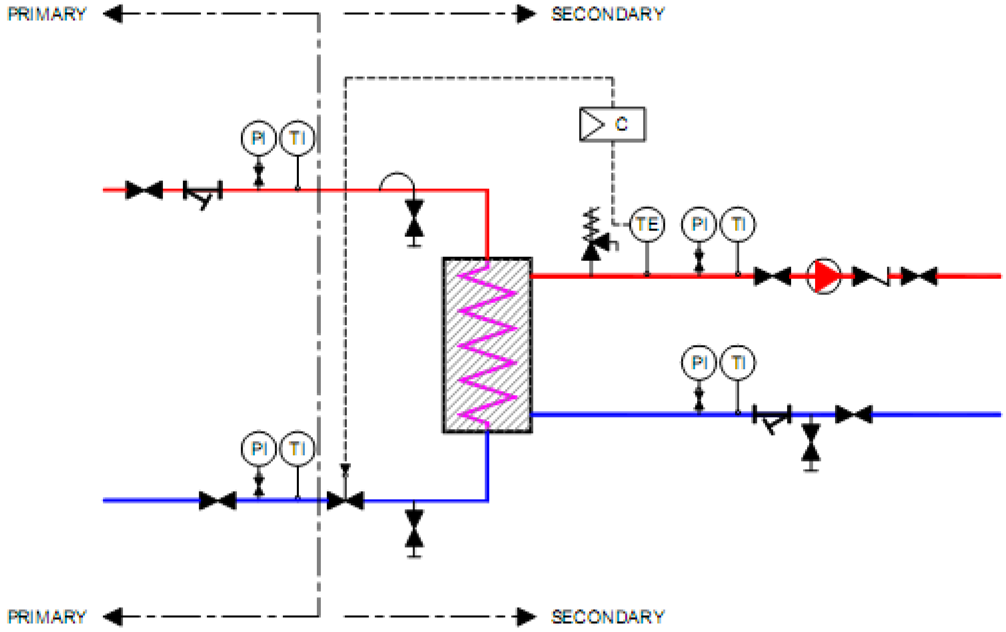

Figure 3.9 Schematic representation of an indirect connection (Mildenstein & Skagestad, unknown)

To reach different supply temperatures the supply pipe can add cooler water from the return pipe, this would lead to lower temperatures. Formula 4.5 shows the specific mass balance of a pipe system. The flow 1 and flow 2 are mixed and results in the flow $\dot{m}_m$ with a temperature T_m. The resulting temperature T_m can be calculated with the formula 4.6.

$$T_m * \dot{m}_m = T_1 * \dot{m}_1 + T_2 * \dot{m}_2 \quad (3.5)$$

$$T_m = \frac{T_1 * \dot{m}_1 + T_2 * \dot{m}_2}{m_m} \quad (3.6)$$

$$m_m = \frac{T_1 * \dot{m}_1 + T_2 * \dot{m}_2}{T_m} \quad (3.6)$$

Figure 3.11 shows an example of cooling the fluid temperature by mixing the supply fluid with the return fluid. Another way to generate different supply temperatures can be done by using the return temperature of the high temperature circle as supply temperature of the low temperature circle. Figure 3.11 illustrates an example. If the return temperature is too low or too high and the flow is too much or too less specific mass, water from the supply or return pipe can be added by the same principle like it is shown in formula 4.6 and 4.7.

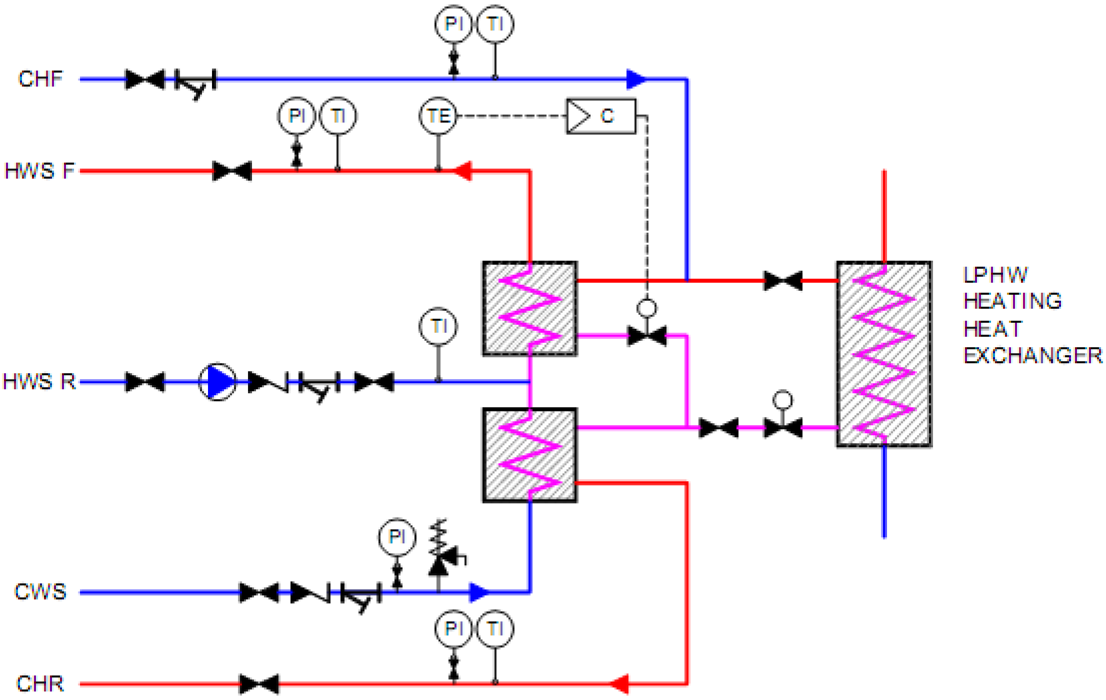

Figure 3.10 Schematic representation of domestic hot water pre heating (Mildenstein & Skagestad, unknown)

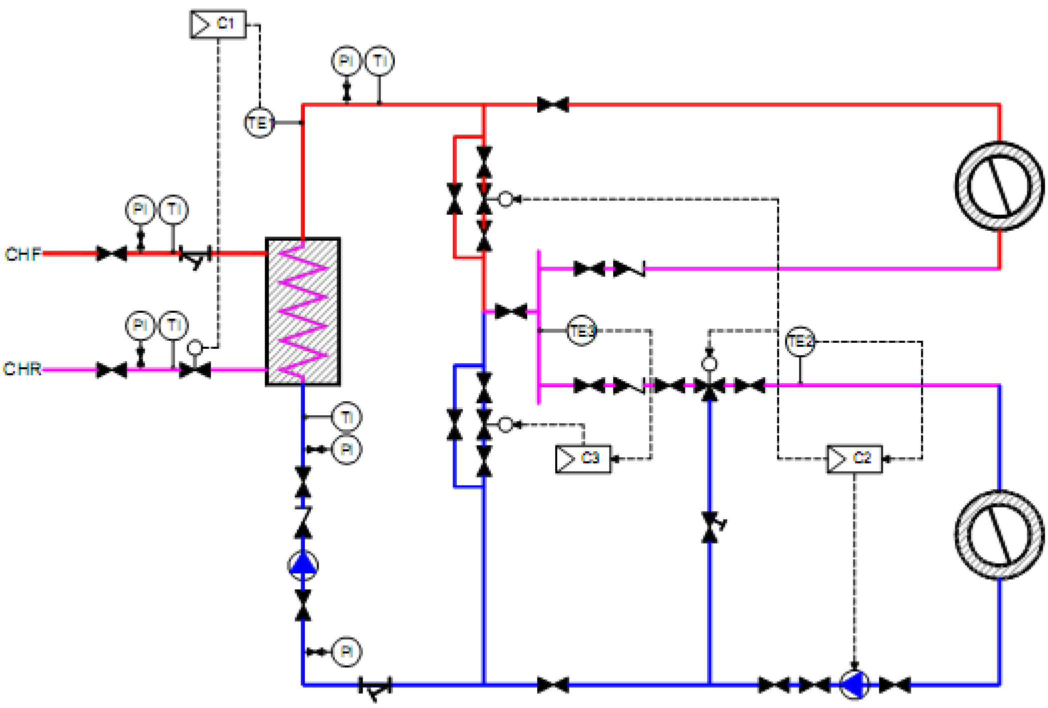

Figure 3.11 Schematic representation of circuit mixing (Mildenstein & Skagestad, unknown)

The other supply method is the direct connection and is normally only used within supply temperatures below 90° C. However, lower supply temperatures leads to higher water flows in the District Heating system, as well as that more water flow is necessary, because the water also flows through the Heating system of the supplied building. Figure 3.12 shows a simple direct connection with one pipe connecting the supply and return pipe. This connection is used to cool the supply temperature (see formulas 4.5 to 4.6). (Mildenstein & Skagestad, unknown)

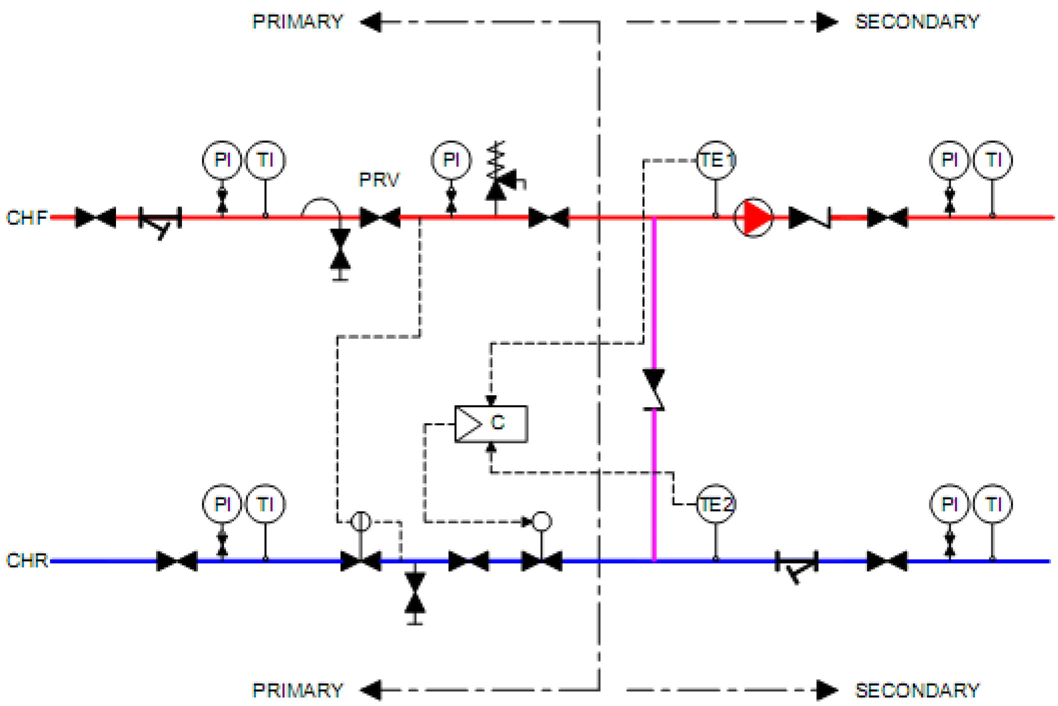

Figure 3.12 Schematic representation of a direct connection (Mildenstein & Skagestad, unknown)

By using direct connections, the heating system of the supplied building has to be conforming to this technology, so it is useful to establish direct connections only within new build District Heating systems. (Mildenstein & Skagestad, unknown)

If the District Heating supplier has to use a higher supply temperature because of technical reasons, or some consumers needs it, the supply pipe can be cooled twice. Figure 3.12 illustrates this compensation. (Mildenstein & Skagestad, unknown)

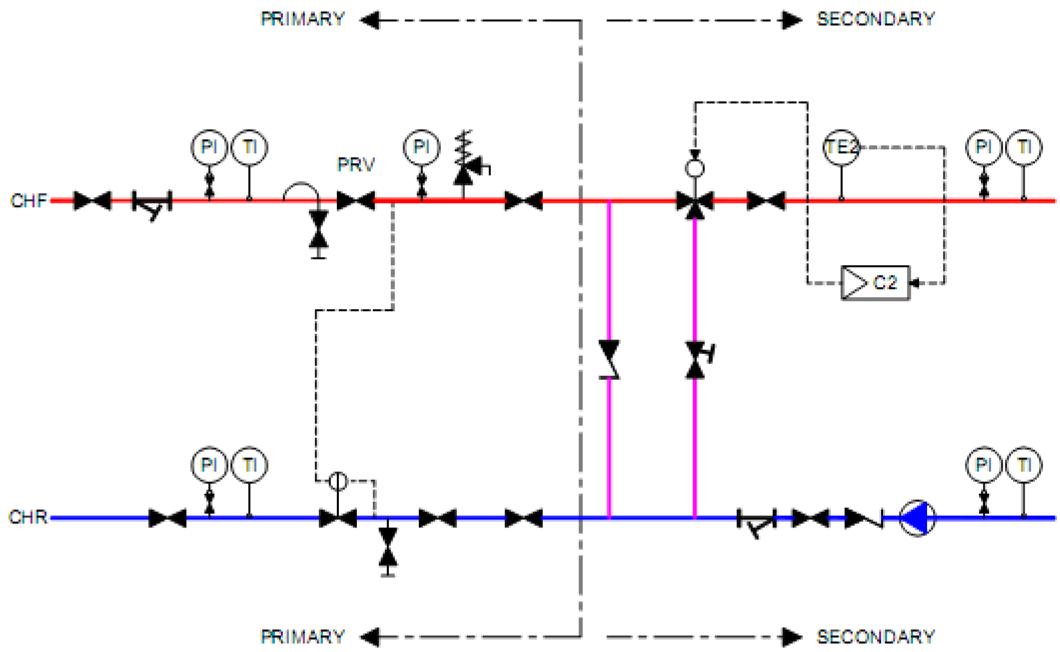

Figure 3.13 Schematic representation of a compensated direct connection (Mildenstein & Skagestad, unknown)

The domestic hot water supply can be achieved with conventional storage tanks or a secondary heat exchanger. If the supplied building has a second heat supply like using solar energy to produce domestic hot water a storage tank is necessary. Figure 3.14 illustrates a direct connection with a domestic hot water storage tank. (Mildenstein & Skagestad, unknown)

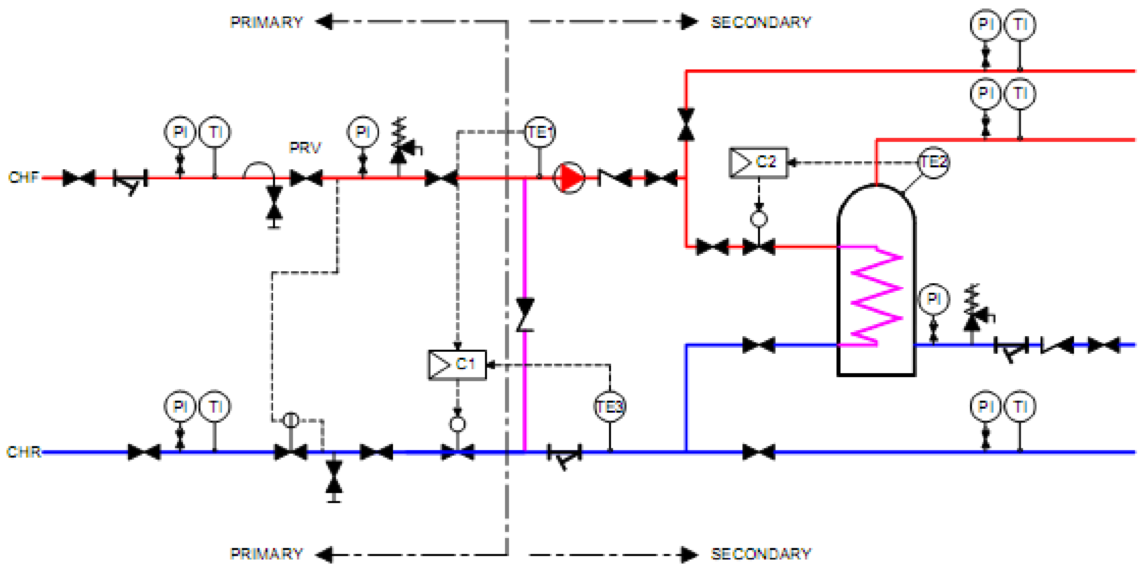

Figure 3.14 Schematic representation of domestic hot water generation in a direct connection (Mildenstein & Skagestad, unknown)

The advantage of using a heat exchanger to generate domestic hot water is the instantaneous hot water supply. Figure 3.15 illustrates this alternative. (Mildenstein & Skagestad, unknown)

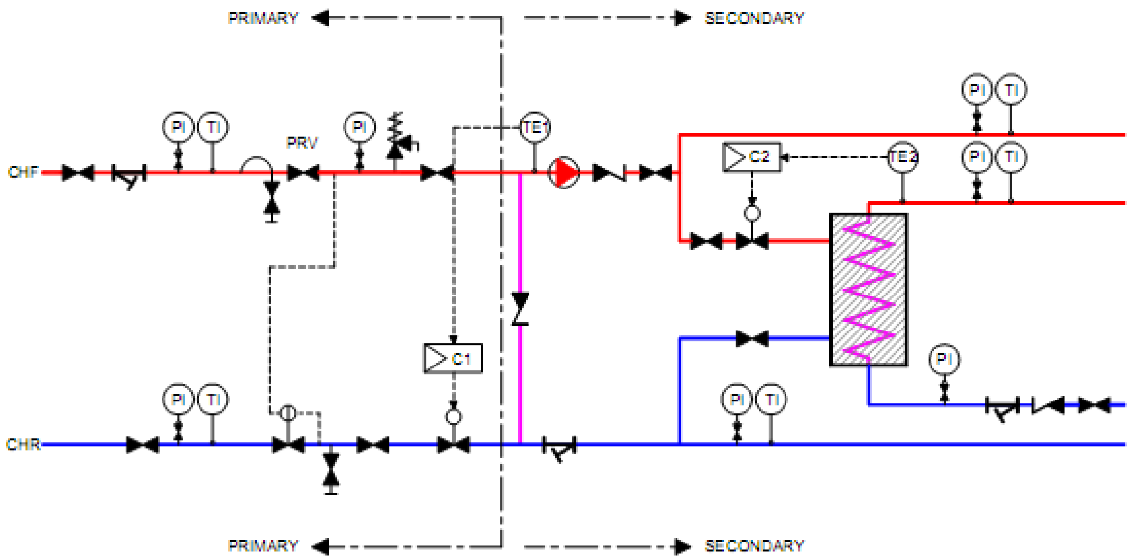

Figure 3.15 Schematic representation of domestic hot water generation in a direct connection through a heat exchanger (Mildenstein & Skagestad, unknown)

The two following case studies, is the technology of both District Heating suppliers, Badenova in Germany and Skagen in Denmark, analysed and summarized. Both case studies are analysed with the Energy Pro Program of EMD which will be described in the following Subchapter.

3.1.6 Losses in the Transmission and Distribution System

The *second law of thermodynamics* predicts that

> "Heat flows from a hotter to a colder body." (Penrose, 2005)

That predicts that the higher the temperature difference between two bodies is the higher is the heat transfer, what means that the losses in the supply pipe are higher than the losses of the return pipe. Formula 3.7 describes the heat losses through a pipe; Formula 3.8 describes the losses over the whole length of the system. The integration of Formula 3.8 is calculated in 3.9 and 3.10 and Formula 3.11 describes the heat transfer through a pipe.

$$\dot{Q} = -\lambda A \frac{\mathrm{d}t}{\mathrm{d}r}$$
$\dot{Q}$ ... thermal heat transfere
λ ... heat transfere coefficent
A ... surface
$\mathrm{d}t$ ... Temperature difference
$\mathrm{d}r$ ... Radius Difference (thinkness of pipe) (3.7)

$$\dot{Q} = -\lambda 2\pi l \frac{\mathrm{d}t}{\mathrm{d}r} \qquad (3.8)$$
l ... lengh of pipe

$$\int_1^2 \mathrm{d}t = -\frac{\dot{Q}}{\lambda 2\pi l} \int_1^2 \frac{\mathrm{d}r}{r} \qquad (3.9)$$

$$t_2 - t_1 = -\frac{\dot{Q}}{\lambda 2\pi l} \ln\frac{r_2}{r_1} \qquad (3.10)$$

$$\dot{Q} = -\lambda 2\pi l \frac{(t_2 - t_1)}{\ln\frac{r_2}{r_1}} \qquad (3.11)$$

Assuming that the length of the forward and return pipe have the same length it can be assumed that the whole heat loss can be calculated as the sum of the losses of both pipes although both losses are not the same. Further on, belonging to the second principle and assumed that the surrounding temperature of the supply and return pipe is the same, the whole losses of the system can be parted in a supply and return part what is shown in Formula 3.12.

$$\dot{Q}_{\mathrm{Losses}} = \dot{Q}_{\mathrm{supply}} + \dot{Q}_{\mathrm{return}} = -\lambda \pi l \frac{(t_{\mathrm{supply}} - t_{\mathrm{surrounding}})}{\ln\frac{r_2}{r_1}} + -\lambda \pi l \frac{(t_{\mathrm{return}} - t_{\mathrm{surrounding}})}{\ln\frac{r_2}{r_1}}$$
$$= \frac{-\lambda \pi l}{\ln\frac{r_2}{r_1}} \cdot (t_{\mathrm{supply}} + t_{\mathrm{return}} + 2 \cdot t_{\mathrm{surrounding}}) \qquad (3.12)$$

The Transmission and Distribution System of the two Case Studies in Chapters 3.2 and 3.3 are already installed and cannot be altered, hence the heat transfer coefficient λ, the length l and Radius Difference of the pipes can be assumed as constants. Also the surrounding temperature is constant because the mass of the surrounding, compared to the flowing water is much bigger. So the Losses of the District Heating System are only a function of the system temperatures. A change of the supply and return temperature will change the losses, and with a sensitivity analyses of the surrounding temperatures the gain of this change can be calculated which is done in the Case Studies.

3.2 Case Study Badenova (Friesenheim)

3.2.1 General Information about Badenova and the DH System of Friesenheim

The Badenova AG & Co. KG, short called Badenova, is the largest Energy supplying company in Southern Baden in Germany. The Energy Supply includes Natural Gas, Electricity, Heat and Water. In 2007 sold Badenova 86.2 Mil. kWh heat (1,140.8 Mil. kWh by 149 subsidiary companies). 815.5 Mil. kWh electricity were produced with CHP Units and the whole District Heating Transmission System was 60.2 km long. (Badenova AG & Co. KG, 2009) The following Table 3.4 shows the basic data of the ten lagers CHP-Plants of Badenova. The Plant of Friesenheim is analyzed within this Thesis.

Table 3.4 Basic Data about the ten largest District Heating Plants of Badenova (Andersen, 2008)

Plant number	Plant name	Electric capacity	Yearly amount of heat delivered to district heating system	Average heat delivered in summer month		Minimum space heat	Fuels	Thermal store
		kW	MWh	MWh	MW	%		M³
1	Frbg. Weingarten	5.800	39000	9000	2,08	54%	natural gas	350
2	Frbg. Landwasser	2.100	26000	8500	1,97	35%	landfill gas	
		1.300					natural gas	
3	Lahr Mauerfeld	3.800	13000	3500	0,81	46%	natural gas	200
4	Friesenheim	2.300	4200	800	0,19	62%	natural gas	90
5	Frbg. Stadttheater	698	5000	1000	0,23	60%	natural gas	No store
6	Frbg. Haslach Bad	416	1500	600	0,14	20%	natural gas	No store
7	Frbg. Westbad	416	2200	600	0,14	45%	natural gas	No store
8	Frbg. Mathias Blanck Str.	360	3200	1100	0,25	31%	natural gas	No store
9	Frbg. Offenburger Str.	314	New in 2007	New in 2007			natural gas	No store
10	Stetten Süd	2.370	2400	900			natural gas	No store
	SUM	19.874						

The District Heating System of Friesenheim uses five Natural Gas Fired CHP Units, one peak-load Boiler and a Thermal Store. Each CHP Unit covers an electrical capacity of 460 kW and a thermal capacity of 680 kW. The Boiler has a heat capacity of 1260 kW and the thermal store a capacity of 90 m³. The temperature difference of the thermal store is 35 °C. (Andersen, 2008)

Figure 3.16 shows the annual graph of the outside temperature in Friesenheim.

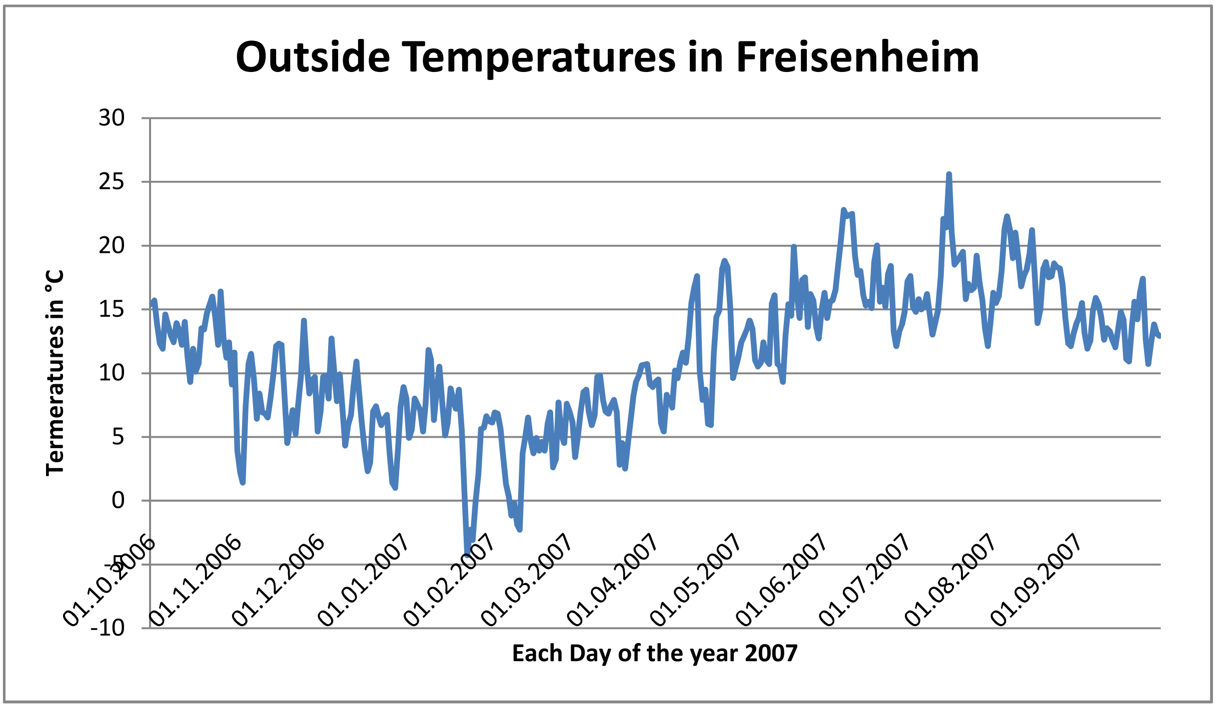

Figure 3.16 Outside Temperatures in Friesenheim (EMD International A/S, 2008)

The following Chapter analyses an EnergyPRO model of the District Heating System of Friesenheim in the year 2008.

3.2.2 Friesenheim District Heating System modelled in EnergyPRO

Andersen (2008) modelled the District Heating System of Friesenheim at Badenova, which is used as basis for this case study for the reference year 2008. The technical and economical assumptions and reports in the EnergyPRO Model can be found in Appendix Energy Pro Models. The sold electricity was calculated with a fixes tariff. This fixed tariffs is also used for the optimisation within the following chapters in this case study.

In the District Heating System the thermal losses were calculated with 600 MWh which was 12 % of the annual production. The EnergyPRO also calculated 190 Starts for the first CHP-Unit, 119 for the second, 6 for the third and none for the two others. The Peak-Load-Boiler started 14 times. The total revenues belonged to € 800,918.- and the total operating expenditures to € 690,712.- (look Appendixes Energy Pro Models). The operation strategy was to use the CHP units produce to the thermal store and the peak-load boiler was only allowed to produce partial.

The following chapters analyses the whole potential optimizations of the District Heating System of Friesenheim at Badenova by using the EnergyPRO and other simulations.

3.2.3 Supply Station and Heat Storage

The EnergyPRO model Andersen (2008) calculated showed that the CHP units 4 and 5 at Friesenheim were not used. The maximal heat demand was 2.6 MW. Figure 3.17, Figure 3.18 and Figure 3.19 shows the Duration Load Curve calculated with the EnergyPRO. The Peak-Load-Boiler started 14 times, because the used operation strategy allowed only partial loading. By also allowing that the Peak-Load-Boiler produce directly to the thermal store, it would only have to start 4 times and that wouldn't influence the gas Demand, and so also not influence the revenue and costs.

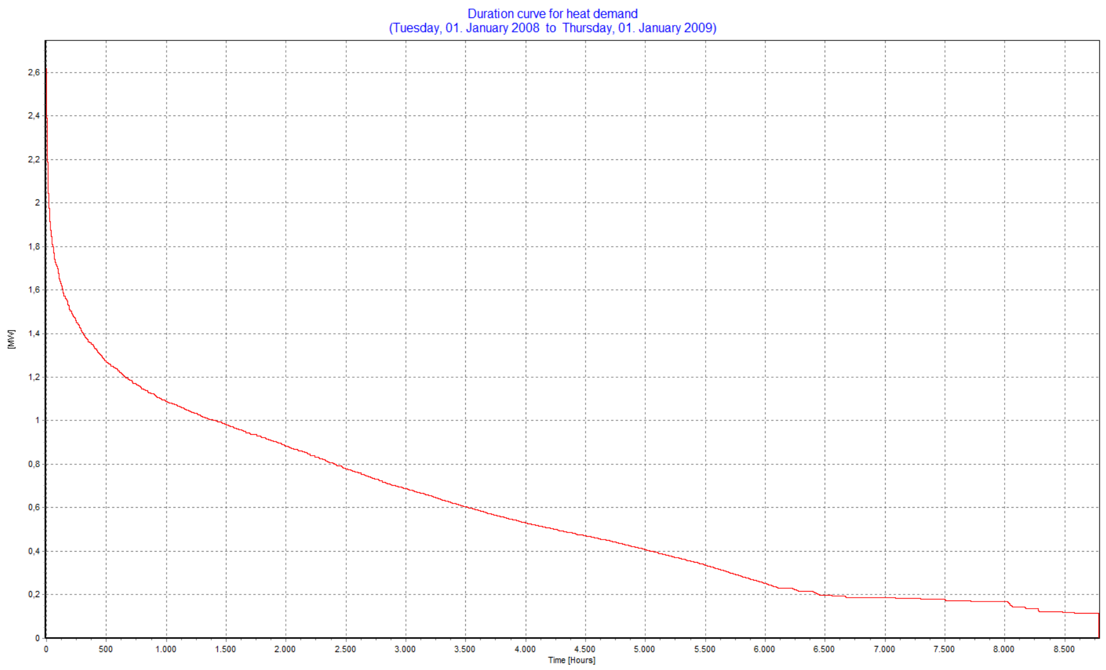

Figure 3.17 Load Duration curve of the District Heating System of Friesenheim of Badenova in Germany (Andersen, EnergyPRO Model of Friesenheim at Badenova, 2008)

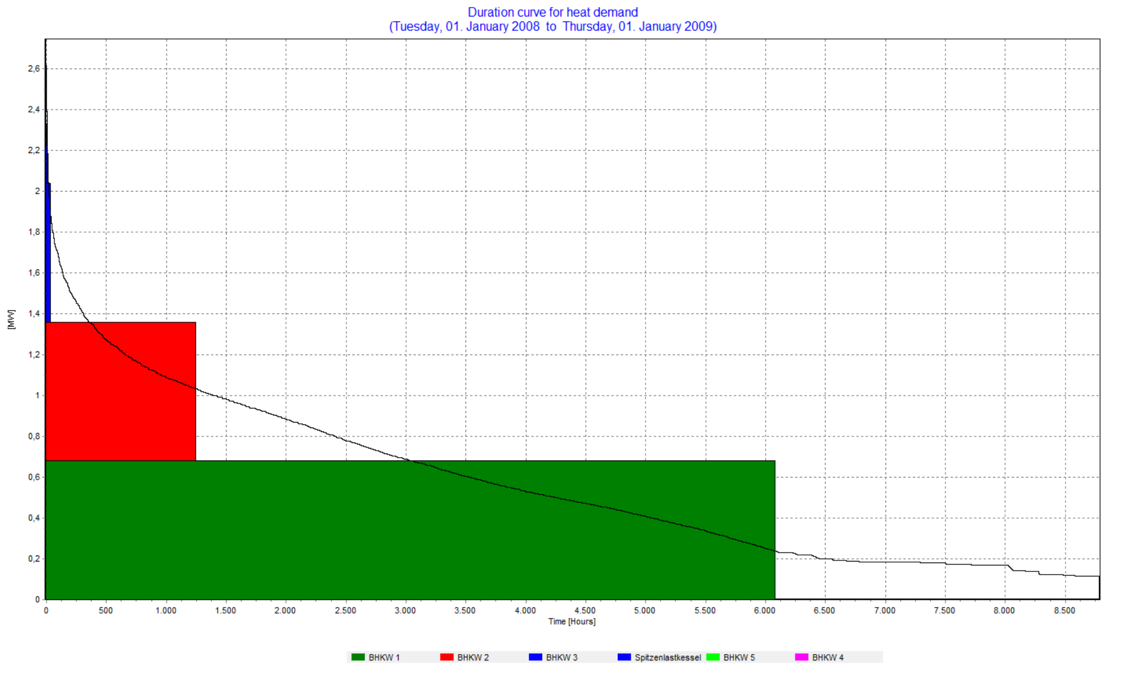

Figure 3.18 Heat supply by different plants sorted in blocks of the District heating system of Friesenheim of Badenova in Germany (Andersen, EnergyPRO Model of Friesenheim at Badenova, 2008)

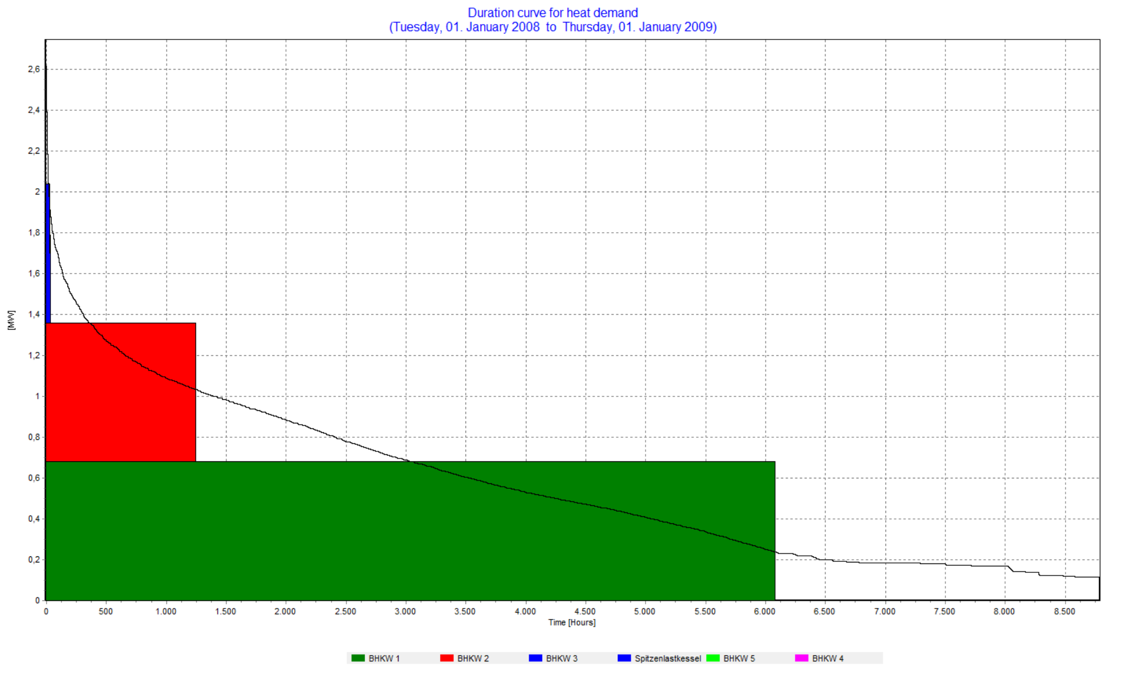

Figure 3.19 supply by different plants sorted in production of the District heating system of Friesenheim of Badenova in Germany (Andersen, EnergyPRO Model of Friesenheim at Badenova, 2008)

How the change of the system temperatures influences the losses in the Transmission system is described in the following chapter. This change also influences the capacity of the storage. Using 40 °C as return temperature would change the capacity of the storage from 3.5 MWh to 5.4 MWh, and minimize the losses to 511 MWh per year (see Chapter 3.2.4). This Change within the EnergyPRO model is summarized in the following Table 3.5.

Table 3.5 Comparison of Production with higher and lower return temperature

		Unit	Before	Optimised	Difference	%
	Losses	MWh	600.0	511.0	-89.0	-14.83
Heat Productions	CHP Unit 1	MWH/year	4,132.3	4,094.7	-37.6	-0.91
	CHP Unit 2	MWH/year	845.6	801.3	-44.3	-5.24
	CHP Unit 3	MWH/year	20.9	15.1	-5.8	-27.75
	CHP Unit 4	MWH/year	0.0	0.0	0.0	0.00
	CHP Unit 5	MWH/year	0.0	0.0	0.0	0.00
	Peak-Load-Boiler	MWH/year	1.2	0.0	-1.2	-100.00
	Sum	MWH/year	5,000.0	4,911.0	-89.0	-1.78
Electricity production	CHP Unit 1	MWH/year	2,795.4	2,769.9	-25.5	-0.91
	CHP Unit 2	MWH/year	572.0	542.0	-30.0	-5.24
	CHP Unit 3	MWH/year	14.2	10.2	-4.0	-28.17
	CHP Unit 4	MWH/year	0.0	0.0	0.0	0.00
	CHP Unit 5	MWH/year	0.0	0.0	0.0	0.00
	Sum	MWH/year	3,381.6	3,322.1	-59.5	-1.76
Hours of operation	CHP Unit 1	h/year	6,076.9	6,021.6	-55.3	-0.91
	CHP Unit 2	h/year	1,243.6	1,178.3	-65.3	-5.25
	CHP Unit 3	h/year	30.8	22.2	-8.6	-27.92
	CHP Unit 4	h/year	0.0	0.0	0.0	0.00
	CHP Unit 5	h/year	0.0	0.0	0.0	0.00
	Peak-Load-Boiler	h/year	7.3	0.0	-7.3	-100.00
Turn ons	CHP Unit 1		190.0	120.0	-70.0	-36.84
	CHP Unit 2		119.0	83.0	-36.0	-30.25
	CHP Unit 3		6.0	5.0	-1.0	-16.67
	CHP Unit 4		0.0	0.0	0.0	0.00
	CHP Unit 5		0.0	0.0	0.0	0.00
	Peak-Load-Boiler		14.0	0.0	-14.0	-100.00
Fuel	Total	MWh	10,660.6	10,472.0	-188.6	-1.77
Revenues		€	800,918.0	796,572.0	-4,346.0	-0.54
Operating Expenditures		€	690,712.0	681,236.0	-9,476.0	-1.37
Operation Income		**€**	**110,205.0**	**115,336,0**	**5,131.0**	**4.66**

The lowering of the return temperature would increase the annual operation income by 4.66 %. The Peak-Load-Boiler would not be operating and all CHP units would operate less.

Calculating the full-load-hours of the District Heating System of Friesenheim at Badenova by the Formulas of Sochinsky, the District Heating System has 1,087 full-load-hours by using 60 °C as return temperature. By using 40 °C the District Heating System would have 1.068 full-load hours. Both numbers are very low, the amount of full-load-hours for Germany are more than 1.600 full-load-hours. Exemplaria graticia, in Austria are plans to build District Heating Systems with less than 4.000 full-load-hours not feasible. (Arbeitsgemeinschaft QM Holzheizwerke, 2004) How to raise this number is part of the Discussion.

3.2.4 District Heating Transmission and Distribution System

Lowering the return temperature from 60 °C to 40 °C would lower the losses within the return pipe. By analysing the losses of 600 MWh (68,31 kW) in the year 2008 (Andersen, EnergyPRO Model of Friesenheim at Badenova, 2008) by the calculation method of Chapter 3.1.6 the lost heat would be 511 MWh (58,19 kW) by using a return temperature of 40 °C instead of 60 °C by assuming a surrounding temperature of 10 °C. Figure 3.20 shows a graph of the influence of the surrounding temperature belonging to the surrounding temperature.

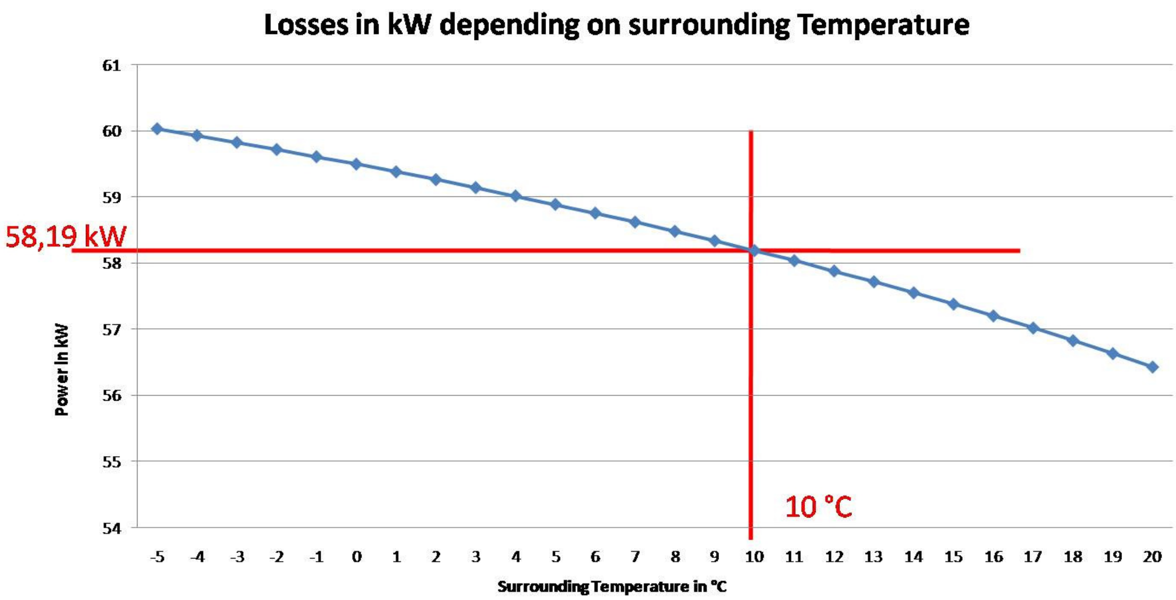

Figure 3.20 Losses in kW depending on the surrounding temperature in Friesenheim at Badenova

Figure 3.21 shows the sensitivity analyses of the losses of the District Heating System of Friesenheim at Badenova depending of the return temperature by assuming that the surrounding temperature is 10 °C.

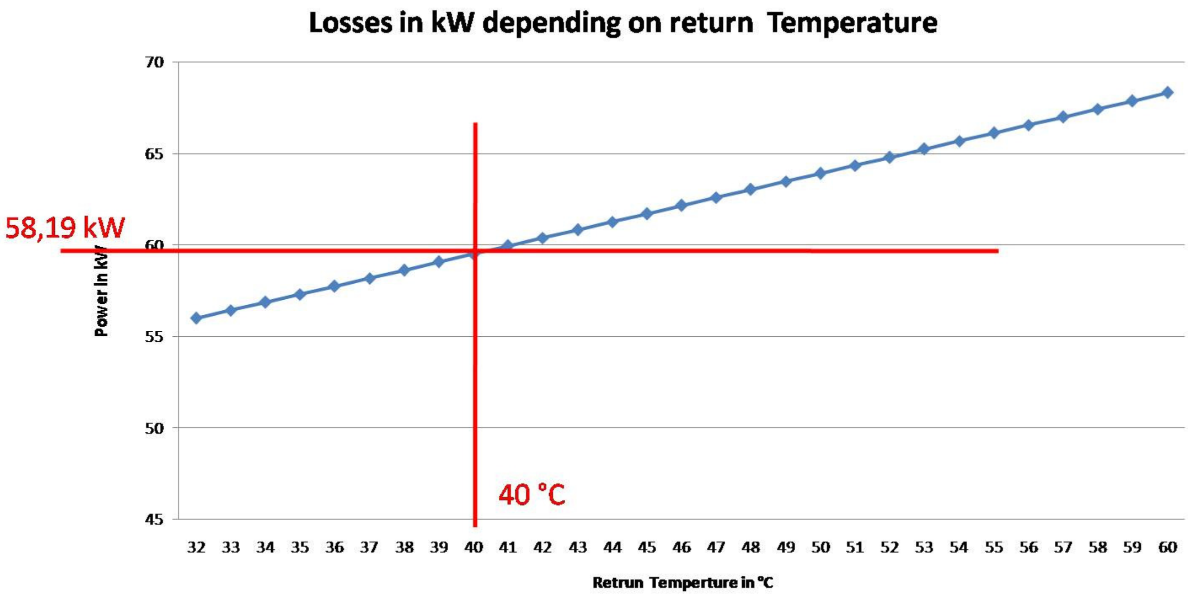

Figure 3.21 Sensitivity analyses of the losses of the District Heating System of Friesenheim depending on the return temperature

Lowering the return temperature by 20 °C would lower the losses in the whole system by 14.83 %. This change would influence the substation, which is analyzed in the following chapter.

3.2.5 Substation

At Badenova are indirect and also direct connection used. The domestic hot water can be arranged by simple heat exchanging or layer storage systems. Figure 3.22, Figure 3.23 and Figure 3.24 shows the three possible substation connections which are used at Badenova.

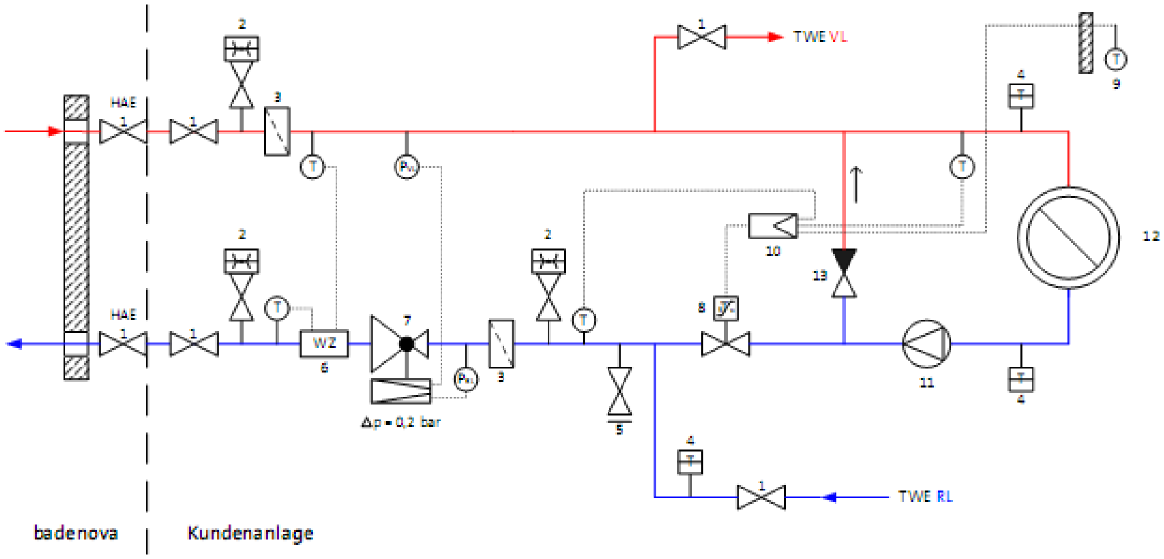

Figure 3.22 Possible direct connection at Badenova (Badenova AG & Co. AG, 2006)

Figure 3.22 above shows the way Badenova uses for direct connections. The domestic hot waster production is also direct connected (TWE is German for "Trink-Wasser-Erwärmung" what means domestic hot water). This principle of hydraulic connection is the same which is shown in Figure 3.12. This type of connection lowers the supply temperature with a certain amount of return water for the heating system of the building. The return temperature can be cooled down with the return water from the domestic hot water production, but this production is limited by the need of domestic hot water of the consumer.

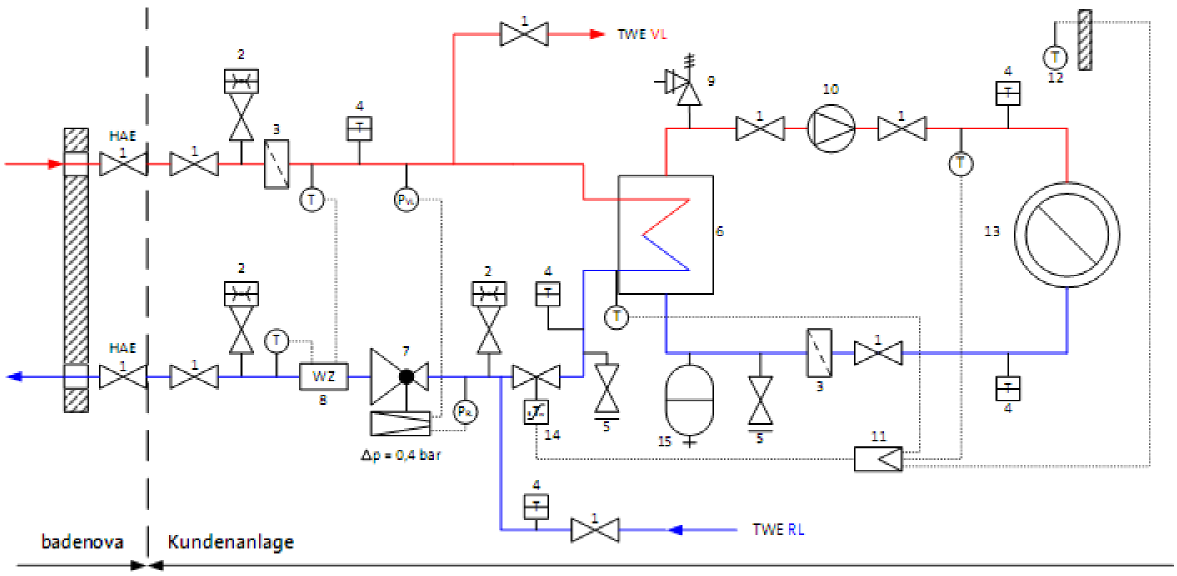

Figure 3.23 Possible indirect connection at Badenova with direct domestic hot water production (Badenova AG & Co. AG, 2006)

Figure 3.23 is an indirect connection with a direct connection to the domestic hot water production system. So the return water from the domestic hot water production cools the return water from the heat exchanger further down. This hydraulic system has the same principle which is shown in Figure 3.10.

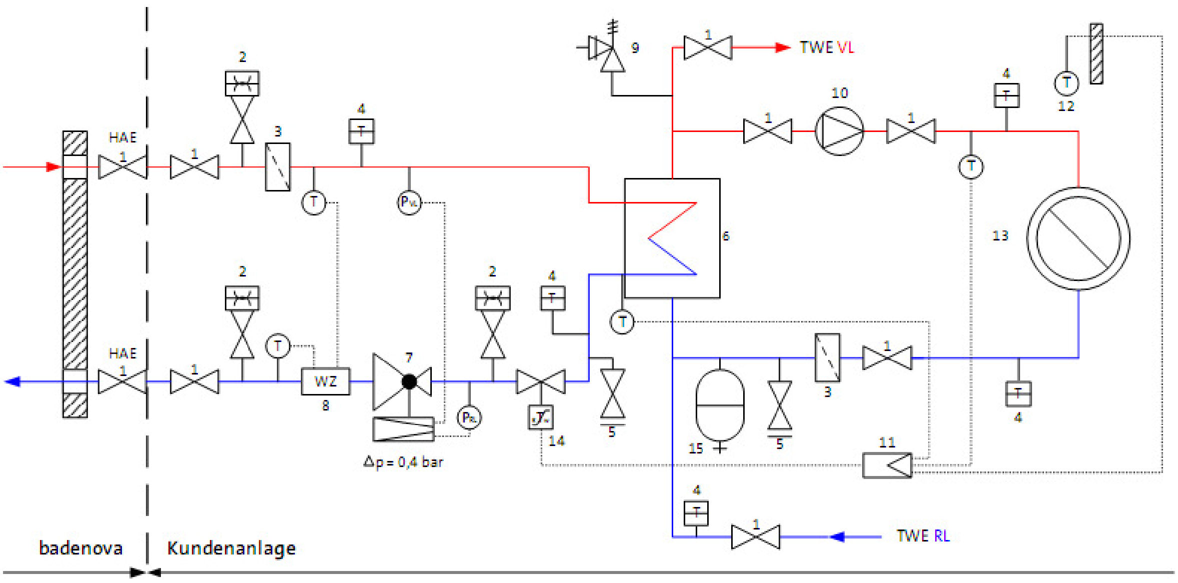

Figure 3.24 Possible indirect connection at Badenova with indirect domestic hot water connection (Badenova AG & Co. AG, 2006)

The domestic hot water can also be produced with an indirect connection. This system has the disability that the supply water for the domestic hot water production is lower than the supply temperature from the District Heating System because of the heat exchanger. Further on the return water from the domestic hot water production is used within the heat exchange system. This hydraulic schematic is shown in Figure 3.24.

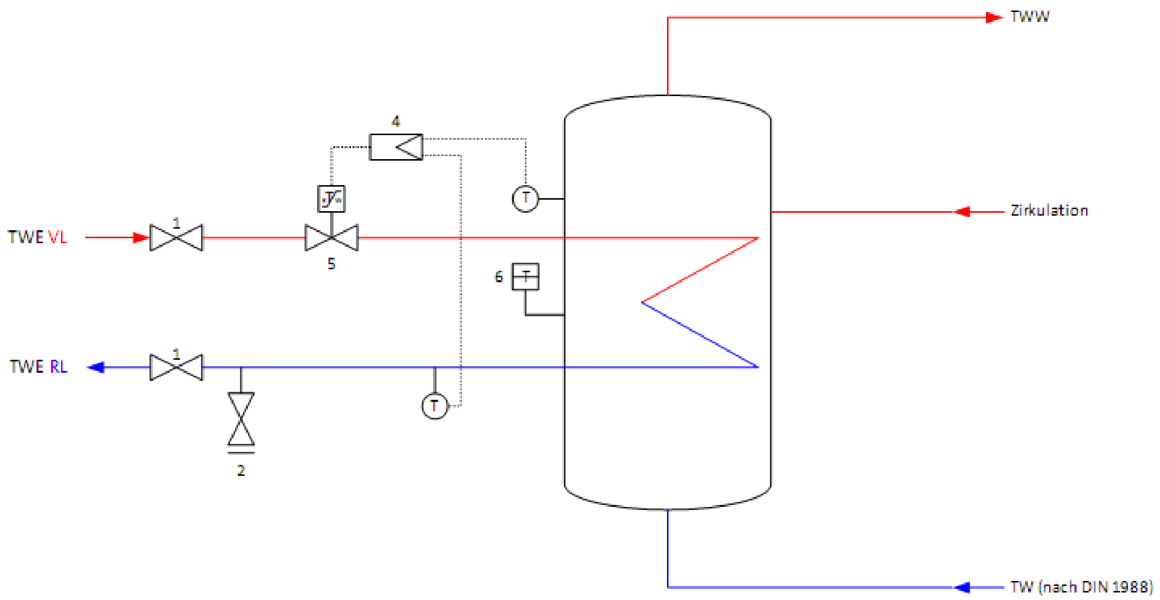

Figure 3.25 Domestic hot water production with integrated heat exchanger (Badenova AG & Co. AG, 2006)

Using an integrated heat exchanger in a hot water storage influences the return temperature from of the heat supply, because when the storage gets loaded, the temperature rises, and belonging to the second principle of thermodynamics the return temperature is the same as in the as the water in the storage. Figure 3.25 illustrates this principle. By using an extern heat exchanger and a layer storage system the return temperature of the supply system is constant till the storage is loaded. This hydraulic schema is shown in Figure 3.26.

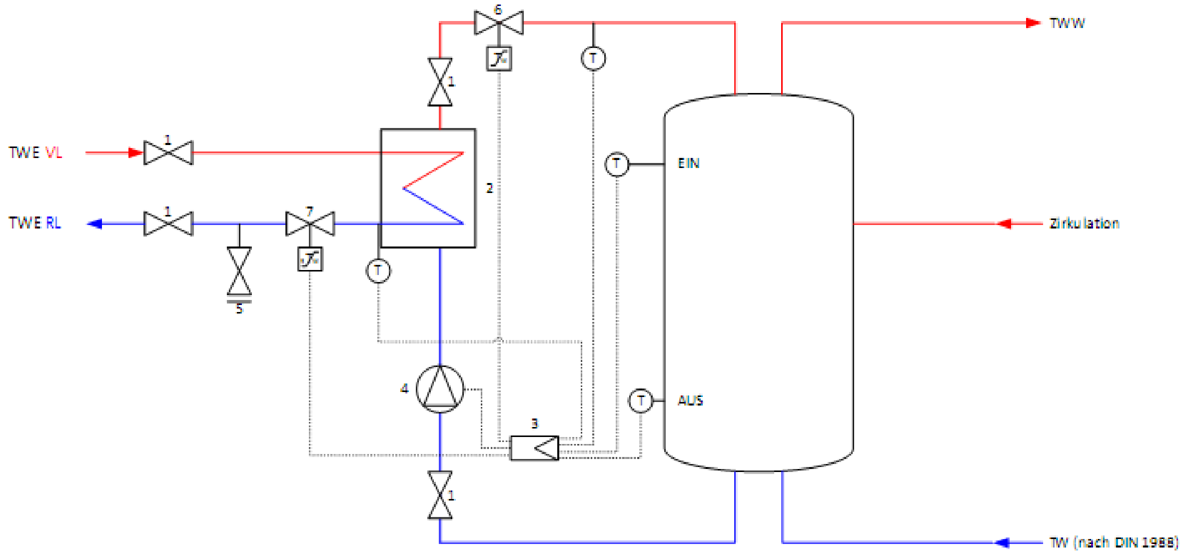

Figure 3.26 Domestic hot water production using layer loading (Badenova AG & Co. AG, 2006)

Badenova only requires that the heat demand of the connected buildings calculated by the European Standard EN 12831 and does not requires special in-building systems. Only the temperatures of the supplier are required with a minimum supply temperature of and also allow maximum return temperature from the domestic hot water production of 60 °C. (Badenova AG & Co. AG, 2006) This means that when the domestic hot water storage gets nearly full loaded that than the return temperature of the District heating system raises.

The following chapter is the case study of the District heating system of Skagen and analyses the same facts. The two case studies are compared in the Discussion.

3.3 Case Study Skagen

3.3.1 General Information about the DH System of Skagen

The District Heating System of Skagen has two supply sources:

- A waste incineration plant and
- a CHP Plant.

The waste incineration has a capacity of 2 t_{waste}/h. (ApS & Rambøll, 2004). The heat capacity is 4.3 MW. (Andersen, EnergyPRO Model of Skagen, 2008) The CHP Plant consists of

- 3 engines
- 4 boilers and
- 1 electrical boiler and
- 1 thermal store.

Each engine has a thermal capacity of 5.4 MW, one boiler 6.5 MW, one 11.4 MW and the two others 9.8 MW each. The electrical boiler has a thermal capacity of 10 MW and the thermal store has a capacity of 4,150 m³ with a temperature difference of 56 °C, so a thermal capacity of 250 MWh. (Andersen, EnergyPRO Model of Skagen, 2008) (EMD International A/S, 2009) The production of the CHP Plant of Skagen can be checked online by EMD. Figure 3.27 shows a screen-shot of the 1st of January of 2009 at 17:52:18. All 2 Engines were offline, the Gas boilers and the incineration plant were producing; also the thermal store was delivering heat to the District Heating system.

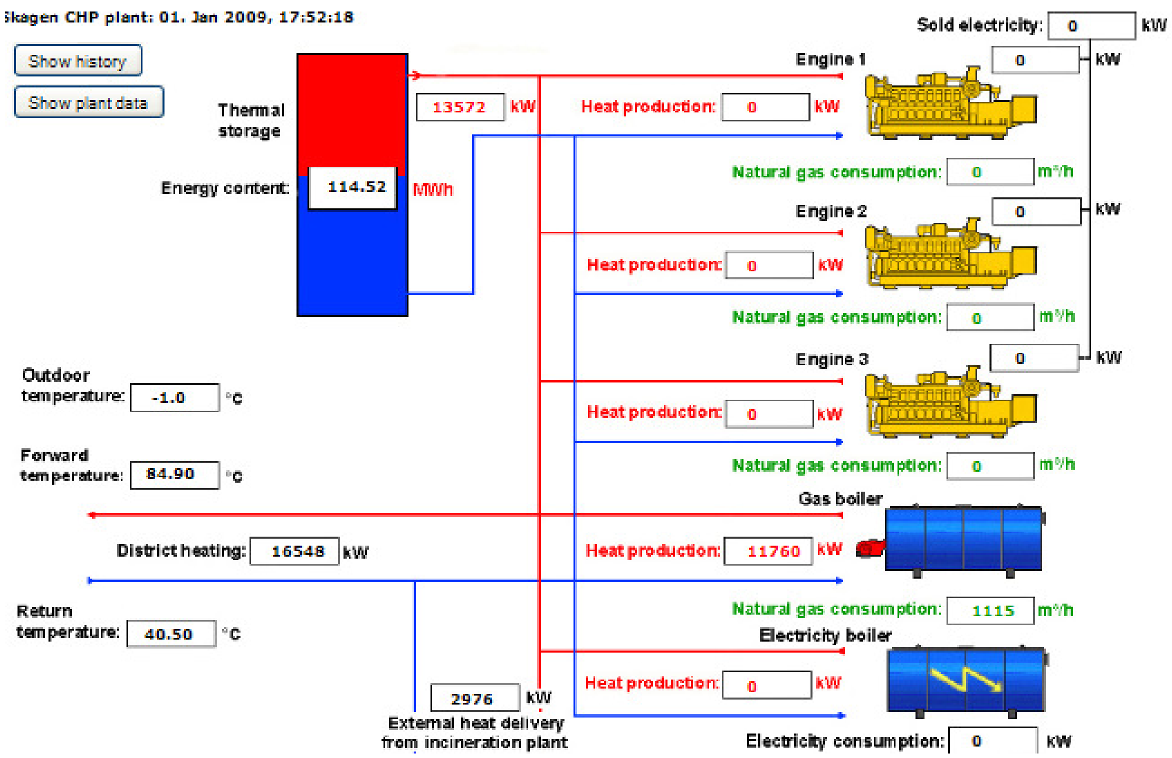

Figure 3.27 Online view of the Skagen CHP Plant (EMD International A/S, 2009)

The following chapters analyses the District Heating System of Skagen by using the EnergyPRO and other simulations.

3.3.2 Skagen District Heating System modelled in EnergyPRO

Andersen (2008) also modelled the District Heating System of Skagen, which is used as basis for this case study for the reference year 2008. The technical and economical assumptions and reports in the EnergyPRO Model can be found in Appendix Energy Pro Models. The sold electricity was calculated by selling condition of the Nord Pool Elspot market. These selling conditions are also used within the optimisation within this Case study.

3.3.3 Supply Station and Heat Storage

The EnergyPRO model Andersen (2008) calculated showed that the maximal heat demand was 19.8 MW and the minimum belonged to 2.9 MW. Figure 3.28, Figure 3.29 and Figure 3.30 show the Duration Load Curve calculated with the EnergyPRO. Within the simulation the incineration plant produced about 4.2 MW which is used as base load for the District Heating System. The electrical boiler is used for download regulation for times when too much electricity is in the grid. This unit can swallow electricity and heat the thermal store. The District heating supplier gets paid for download regulation, so there is only profit because the supplier gets paid to use that energy.

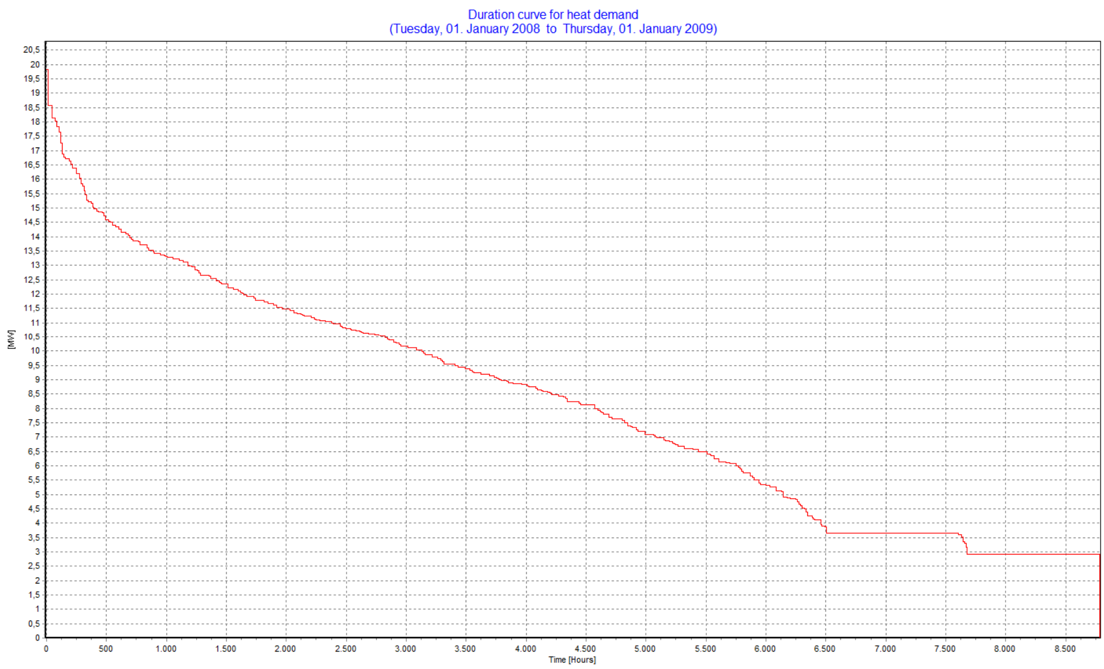

Figure 3.28 Load Duration curve of the District Heating System in Skagen in Denmark (Andersen, EnergyPRO Model of Skagen, 2008)

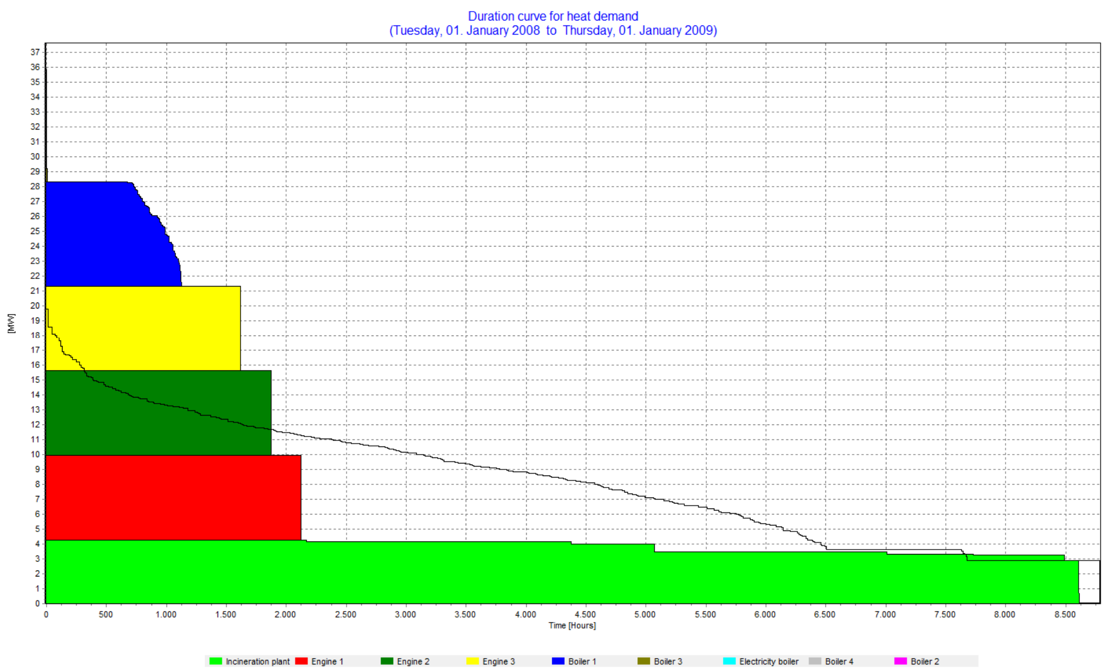

Figure 3.29 Heat supply by different plants sorted in blocks of the District heating system of Skagen in Denmark (Andersen, EnergyPRO Model of Skagen, 2008)

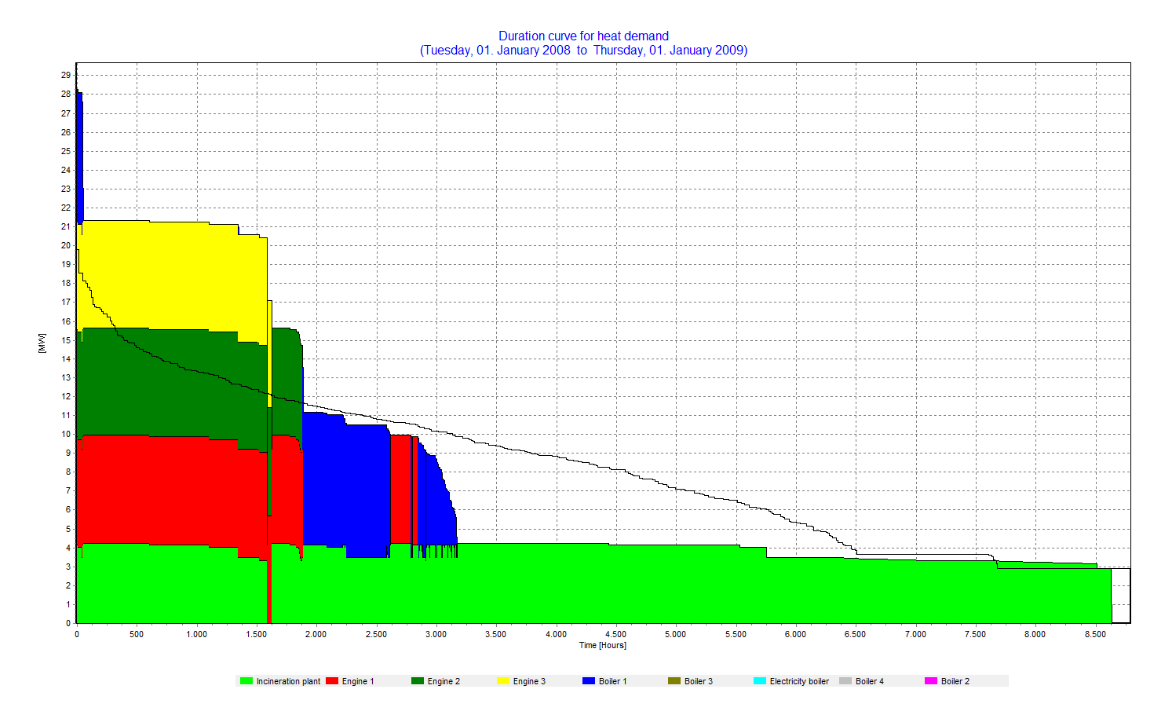

Figure 3.30 Heat supply by different plants sorted in production of the District heating system of Skagen in Denmark (Andersen, EnergyPRO Model of Skagen, 2008)

The production CHP plant of Skagen is shown online. Figure 3.27 shows the plant and Figure 3.31 shows the production of one week. The graph above shows the delivered energy in MWh in red and the green curve is the level of the storage. The grave below shows when which production unit were producing. In the very beginning was the electrical boiler working (orange field).

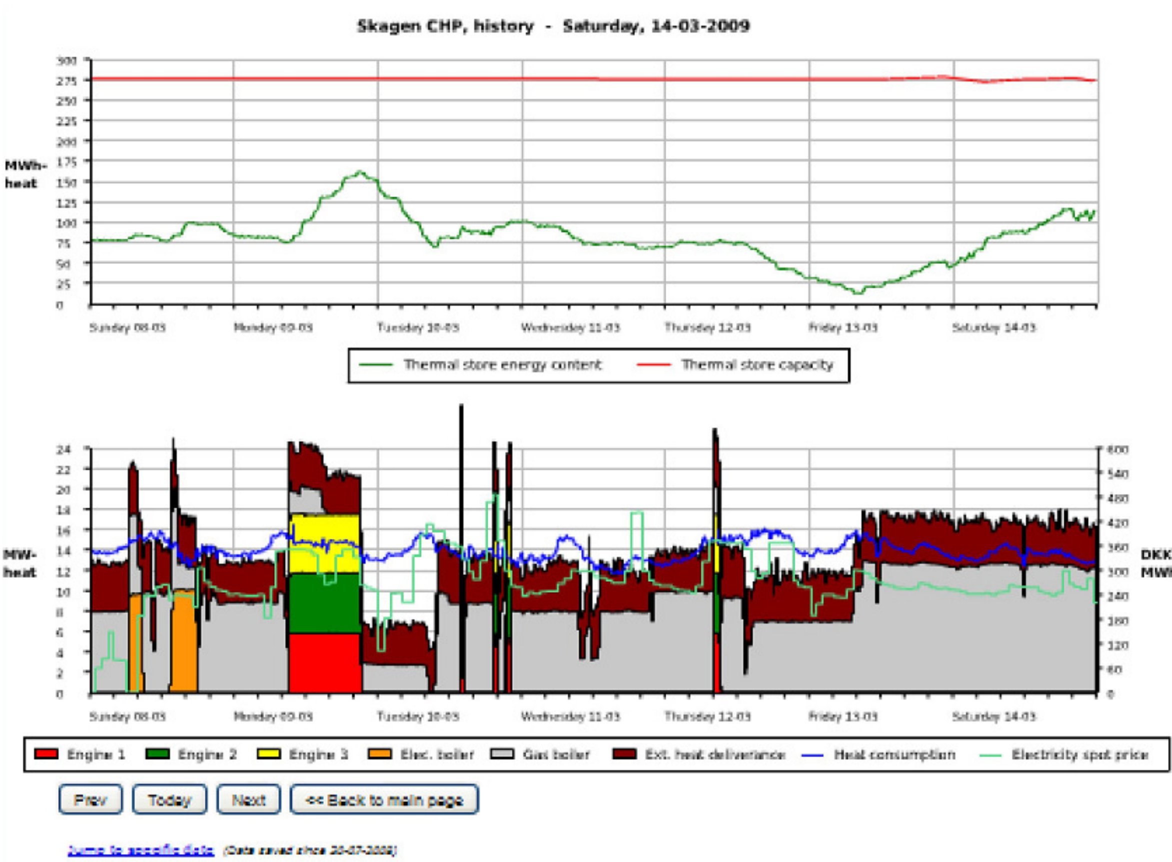

Figure 3.31 Skagen CHP, history of one week (EMD, 2009)

The following chapter summarizes the transmission and distribution system.

3.3.4 District Heating Transmission and Distribution System

The losses in a District Heating System in Demark are normally estimated by 20 % of the annual delivered heat. (Andersen, Basic Information on District Heating Plants of Badenova and Skagen, 2008) The annual delivered heat in Skagen is 72,000 MWh/anno, so the losses belong to 14400 MWh/anno which is a power of 1,639 MW. (Andersen, EnergyPRO Model of Skagen, 2008)

Figure 3.32 and Figure 3.33 shows the losses of Skagen analysed by the method of Chapter 3.1.6.

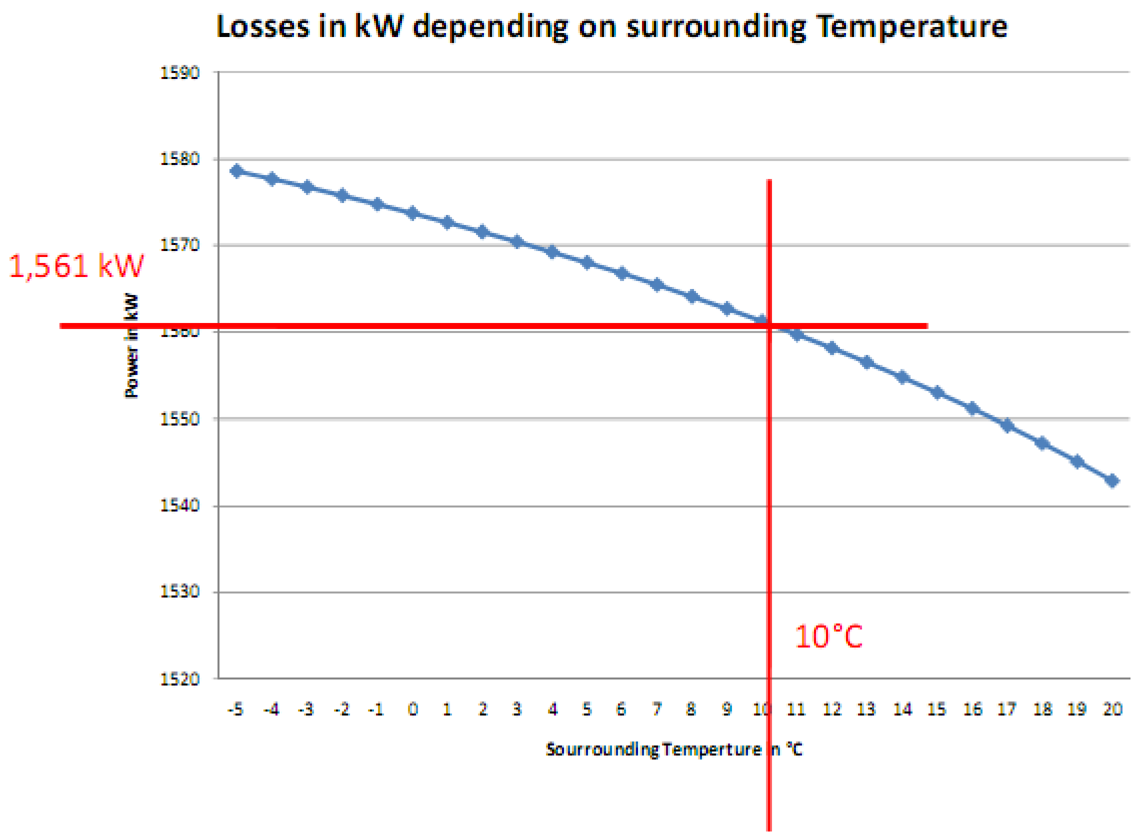

Figure 3.32 Losses in kW depending on the surrounding temperature in Skagen

In Skagen is the return temperature already by 40 °C. Lowering the temperature down to 35 °C would lower the losses in the Distribution and Transmission System from 1,639 kW to 1,561 kW what would lower the losses by 4,76 %.

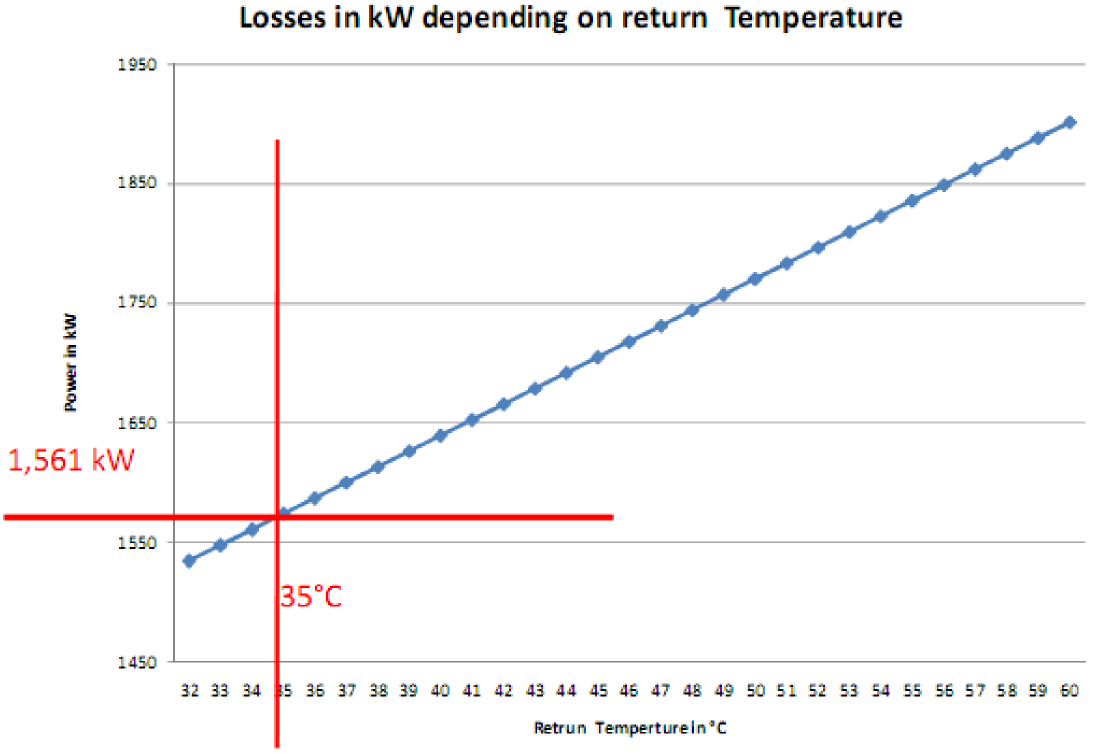

Figure 3.33 Sensitivity analyses of the losses of the District Heating System of Skagen depending on the return temperature

The following subchapter analyses the substation and requirements for the connected buildings in Skagen.

3.3.5 Substation

The District Heating System of Skagen uses only one type of hydraulic connection. This type is indirect with a direct connection for domestic hot water production. Figure 3.34 shows an illustration of the connection. The same connection type is also used in Friesenheim at Badenova in Figure 3.23.

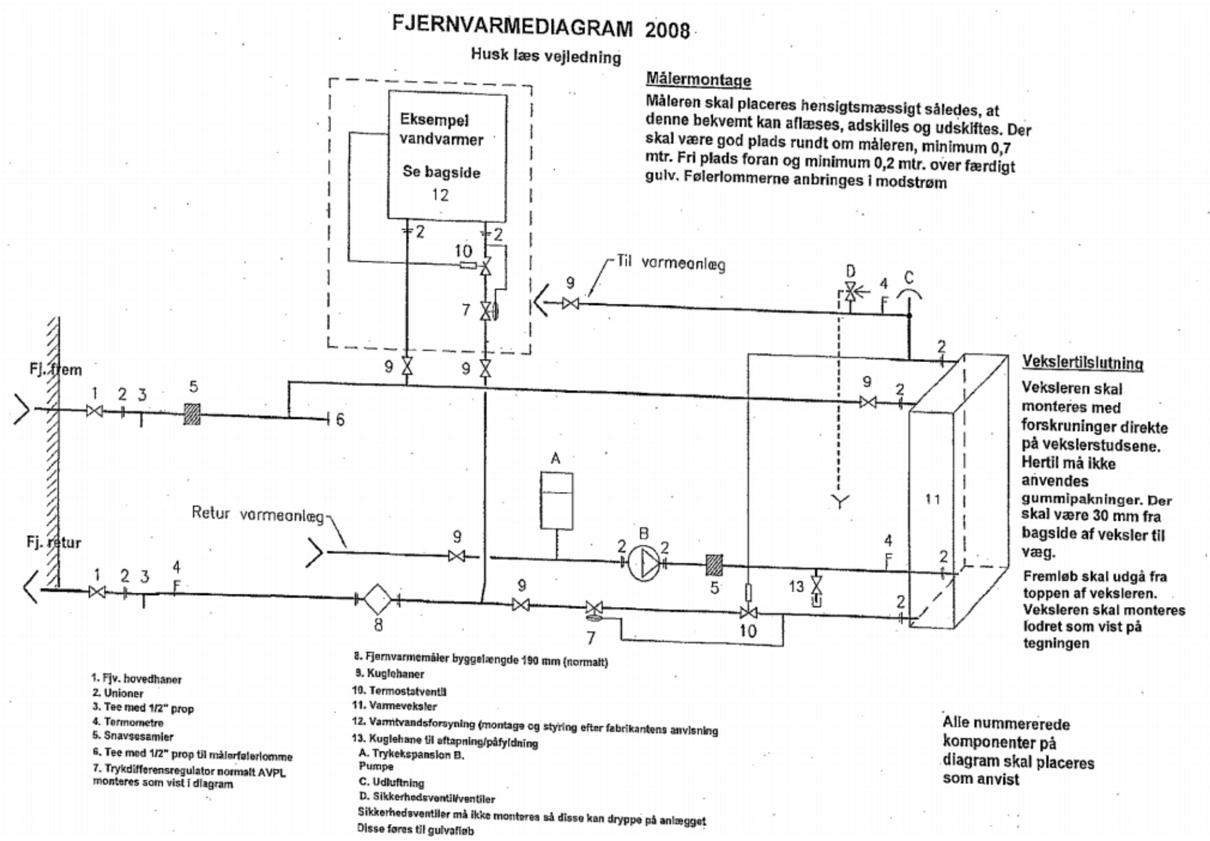

Figure 3.34 Substation connection used in Skagen (Skagen Varmevaerk, 2009)

Further on are the connected house owners required that they use radiators that are dimensioned for an inlet temperature of 65 °C and an outlet temperature of 35 °C. (Skagen Varmevaerk A.m.b.a., 2009)

4 DISCUSSION

Within this chapter are the two District Heating Systems of Skagen in Denmark and Friesenheim at Badenova compared and the differences that can influences the return temperatures of the transmission and distribution systems discussed.

4.1 Comparing the District Heating Plants

Within this subchapter are the District Heating Plants of Friesenheim and Skagen compared. To compare the plants are three key performance indicate numbers (KPI) calculated. All these numbers bases on the two EnergyPRO models of Andersen (2008). The first KPI are the full load hours, which is the quotient of the Delivered heat load divided by the installed capacity. The second KPI is the percentage of the heat storage capacity compared to the annual delivered heat. KPI number three is the annual delivered heat divided by the calculated peak load. The higher the percentage of the KPI number two is the higher is also the KPI number three, so the higher the capacity is the higher is the number of full load hours based on the annual peak load. However a bigger thermal stored results in higher losses. Table 4.1 shows the compartment of this KPI's.

Table 4.1 Comparison of the District heating pants of Friesenheim and Skagen

	Friesenheim	Skagen
Base Load Supply	With boilers and CHP Units	With the waste incineration plants
Peak Load	Boilers and CHP Units	Boilers, CHP units and an electrical boiler
Full Load hours (based of installed capacity)	1,048.22 hours	1.024,18 hours
Percent of storage capacity of annual delivered heat demand	0,07 %	0,34 %
Load hours based on peak load	1,923.07 hours	3,636.36 hours

Skagen has less full-load hours, but the fact of the bigger thermal store makes the plant more efficient.

The optimisation of the District Heating Plants is not target of this thesis. The following subchapter compares the two District Heating Transmission and Distribution systems.

4.2 Comparing the District Heating Transmission and Distribution Systems

Both district heating systems uses Transmission and Distribution pipes which are insulated and below the surface. The losses within the Transmission and Distribution System in Friesenheim are about 12 % (600 MWh/anno) and in Skagen about 20 % (14,440 MWh/anno). In the chapters 3.1.6, 3.2.4 and 3.3.4 are the losses and the methodology of the estimating of them described. Changing the infrastructure to lower the losses in the Transmission and Distribution System is not part of this thesis. The following chapter compares the Substations and In Building Equipment and describes the possibilities for improvements.

4.3 Comparing the Substations and rules for the In-Building Equipment

Both District Heating Systems uses the same hydraulic indirect connection which is illustrated in Figure 3.10. The heat curves are also quite similar, whereas Skagen has higher supply temperatures at the lowest temperature of -12 °C and also lower supply temperature in summer by 60 °C. (Skagen Varmevaerk A.m.b.a., 2009) Friesenheim has a minimum supply temperature of 70 °C because the technical standards for domestic hot water heating require that. (Badenova AG & Co. AG, 2006) In Skagen is the maximal required temperature for Domestic hot water production 60°C. Figure 4.1 illustrates the heat curves. The difference of the different supply temperatures results directly in the dimensions of the radiators, which further on results in the return temperatures of the District Heating systems.

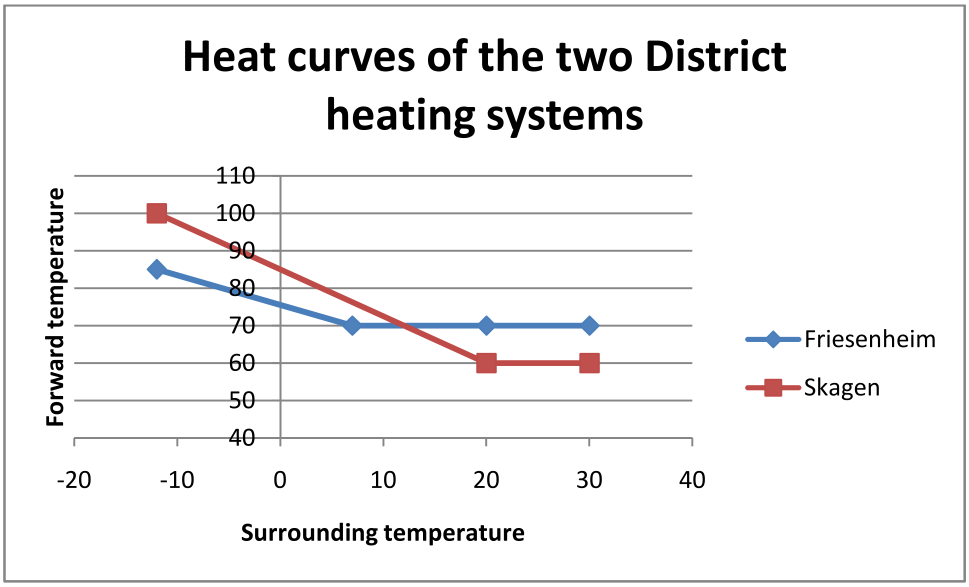

Figure 4.1 Heat curves of the two District heating systems

The District heating System of Friesenheim requires that the heating system of the supplied buildings are calculated by the European standard EN 12831, Skagen requires the Danish rule for buildings BR 95/98 and system temperatures for the In-Building heating system of 65 as supply and 35 as return temperature. (Badenova AG & Co. AG, 2006), (Skagen Varmevaerk A.m.b.a., 2009)

Badenova requires a max. Return temperature supply from the connected buildings of 45 °C and allows that to rise up to 60 °C for heating the domestic hot water production. Normally the return temperature is not the 45 °C, it is 60 °C. Skagen requires 40 °C and is normally not above.

The following subchapter stratifies the losses by different return temperatures by using different system temperatures within the connected buildings.

4.3.1 Stratification of losses in the return pipe by using different system temperatures within the connected buildings

The second principle of thermodynamics (see Chapter 3.1.6) tells that only heat (enthalpy) can flow from a warmer system to a colder. That means that in In-building heating systems the return temperature can never be lower than the temperature in the rooms that are heated. Further on the heat distribution in a building exemplaria gratia a radiator is nothing else than a simple heat exchanger with warm water on the primary and colder air on the secondary side.

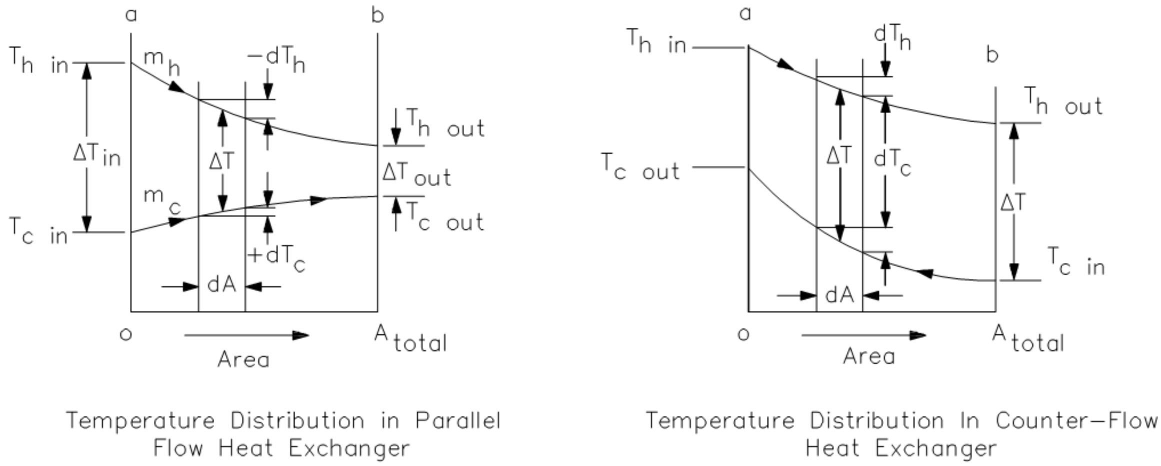

Figure 4.2 Heat Exchanger Temperature profiles (U.S. Department of Energy, 1992)

Figure 4.2 shows the temperature flows of the two main principles of heat exchangers. A radiator not a parallel or counter flow heat exchanger, because the air flow is turbulent and not constant, further on the heat exchanger also transfers heat by thermal radiation. However, Figure 4.2 shows that the temperature of the primary (warmer) fluid never can reach the inlet temperature of the secondary fluid. That means that the return temperature of heated rooms. This thermodynamic principle also appears with the heat exchangers at the District heating substation.

The system temperatures of heating systems differ from different installed heating systems. Exemplaria gratia are radiators for common heating systems dimensioned for 75 °C as supply and 65 °C as return temperature (EN 442).Low temperature systems use 70/50 °C systems. Oil and Gas burners that uses the gross heat value technologies requires systems of 60/35 °C and floor heating systems requires 45/35 °C (EN 1264). For District heating systems is no general standard requires, only the requirements for connections of the supplier can force the costumer to use special In-building temperatures. Hence, to lower the return temperature in a District Heating System, the return temperature in the In-building equipment has to be lowered.

Figure 4.3 shows a simulation of a District Heating System with 100 % of connected buildings with a 70/50 °C In-building heating systems. This simulation was calculated with an annual heat supply of 1,000 MWh and a District heating supply temperature of 95 °C.

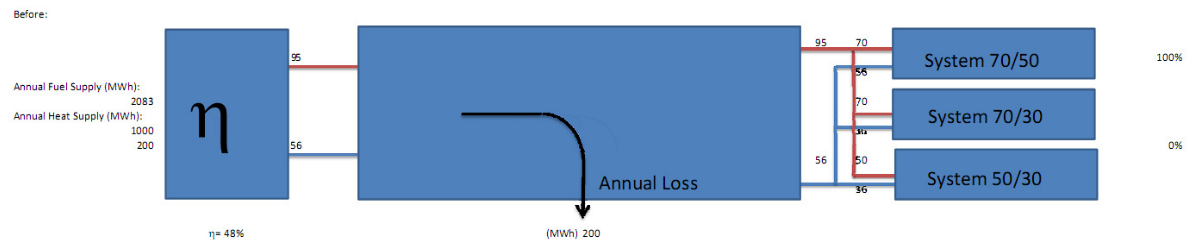

Figure 4.3 Stratification of losses with 100 % of 70/50 °C In-building equipment

Optimisations of that simulations shows that about 85 % of the In-building heating equipments have to be changed to systems that uses 30 °C as return temperature. This change is illustrated in Figure 4.4 and would lower the losses by 4.76 %.

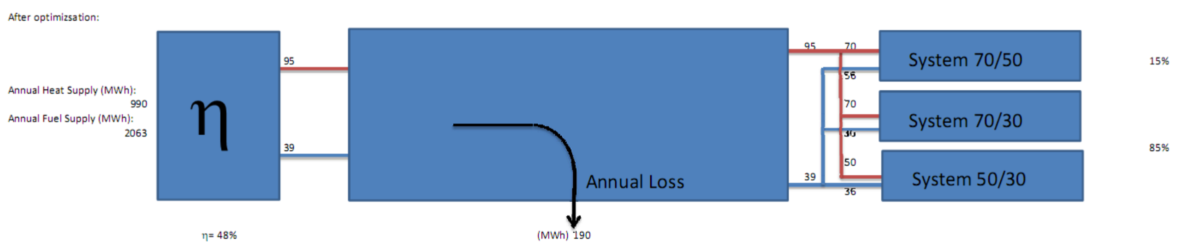

Figure 4.4 Stratification of losses with only 15 % of 70/50 and 85 % of 30 °C In-building return temperature

The whole losses simulation is shown in Appendix 6.6. The following subchapter summarizes the possibilities of changing the system temperatures within the In-building heating systems to achieve 30 °C as return temperatures.

4.3.2 Possibilities to lower the return temperature in In-Building heating systems

To keep a heated room or a defined heated zone on a defined temperature level (mostly 20 °C) has a certain heat amount be added to that room or zone. This heat amount is exact the same that is lost by that room or zone in the same time and is called heat load. The so-called caloric Formula (see Formula 2.1) defines that heat load by the product of mass flow of water, the specific heat capacity of water and the temperature difference between the supply and return temperature of the heating equipment. Formula 4.1 shows how the heat load is calculated. Q, ρ, c and T_{sup} cannot be changed, so to lower T_{ret} only the volume flow can be lowered. This can be achieved by lowering the pressure that the central pump produces.

$$\dot{Q} = \dot{V} * \rho * c * (T_{\sup} - T_{ret}) \quad c = 4.18 \frac{J}{kg * K} \tag{4.1}$$

If exemplaria gratia the supply temperature is 75 °C and the return temperature is 50 °C and the return temperature should be lowered to 30 °C the mass (or volume) flow has to be lowered by 44.44 %. Formula 4.2 summarizes that calculation.

$$\dot{V}_1 * \rho * c * (T_{\sup} - 50°C) = \dot{V}_2 * \rho * c * (T_{\sup} - 30°C) \qquad T_{\sup} = 75°C$$
$$\Rightarrow \frac{\dot{V}_2}{\dot{V}_1} = \frac{(T_{\sup} - 50°C)}{(T_{\sup} - 30°C)} = \frac{4}{9} \Rightarrow \dot{V}_2 = \frac{4}{9} * \dot{V}_1 \qquad (4.2)$$

Lowering the mass flow would also lower the consumption of electrical power of the pump. Before the mass flow within an In-building heating equipment can be changed the whole hydraulic system has to be in balance and each valve has to adjusted to the amount of heat that has to transported via itself. Balancing the hydraulic system of In-Building equipment is not part of this thesis and will not be further described.

The following subchapter describes how the return temperature can be lowered by lowering the supply temperature in Buildings.

4.3.3 Lowering the return temperature by lowering the forward temperature

The caloric formula (see Formula 4.1) is used to calculate the power or heat supply. By changing the mass flow the return temperature falls and rises, when the supply temperature has a fix value. So, by keeping the mass flow constant and lowering the supply temperature the return temperature also falls.

Figure 4.5 shows a hydraulic schema of the temperatures by a indirect connection. In this hydraulic schemata is the supply temperature as high as possible, to make the heat exchanger most efficient, but that high supply temperature also results in an high return temperature.

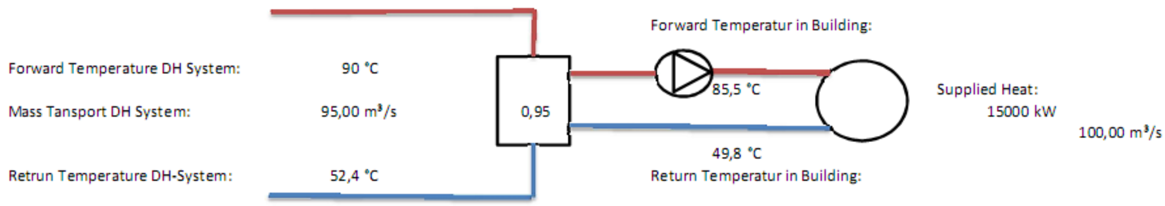

Figure 4.5 Indirect connection with direct supply to the IN-Building equipment

Not only the District Heating technology tries to achieve low return temperatures, exemplaria gratia oil or gas fired boilers which use the gross heat value of the fuel to have higher efficiencies, needs low return temperatures to condensate the water in the exhaust gases. These low return temperatures can be achieved by cooling the forward temperatures by mixing the supply flow with the return flow. Formula 4.3 shows how this new supply temperature is calculated. The Mixed value is the quotient of the two mass flows that are mixed.

$$T_{\sup-low} = \frac{\dot{m}_{\sup} * T_{\sup} + \dot{m}_{ret} * T_{ret}}{\dot{m}_{\sup-low}} \tag{4.3}$$

$$\text{Mixed value} = \frac{\dot{m}_{\sup}}{\dot{m}_{ret}} \tag{4.4}$$

Figure 4.6 illustrates a hydraulic schema where the supply flow is mixed with the return flow what directly results in lower return temperatures in the building and so also in the District Heating system.

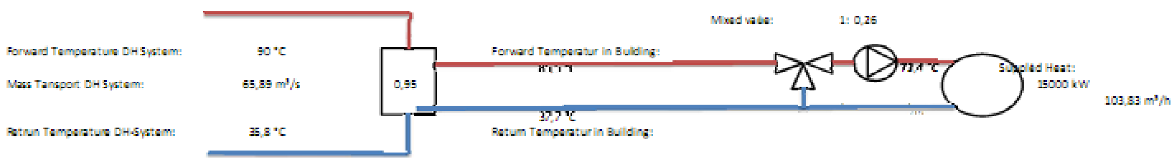

Figure 4.6 Indirect connection with cooling the forward temperature to lower the return temperature

Lowering the return temperature in the District Heating system results also in a lower mass flow (see Formula 4.1) and this will also directly lower the energy consumption of the pumps used in the District Heating Transmission and Distribution Systems.

The following chapter describes a plan how lower return temperatures in the In-building heating equipment can be achieved, by making that idea more attractive for the consumer.

4.4 Plan to make lower return temperatures more attractive for the consumer

The analysis and comparison have shown that lowering the return temperatures in a district heating systems can only be achieved by lowering the return temperatures in the In-building equipment of the consumers, so the District heating supplier has to make lower return temperatures in the In-building heating equipment more attractive for the consumer.

Anyway, most important by changing In-Building equipment is that the inhabitant doesn't lose any comfort. So it might be quite difficult to change already installed installation, but within new buildings the following introduced measurement system and costumer-bonus-plan can be installed.

Further on the costumer is only interest that the District heating system has lower return temperatures, when he has a benefit. Nowadays energy measurement equipment is able to lock measured temperatures hourly, so that the returned temperature from the In-building equipment can be saved in hourly values.

Both District Heating systems, have fixed return temperatures within their connection requirements, but not all connected costumers achieve that requirements. So, the one way to make them lower the return temperatures is to give them penalties, the other and nicer ways, is to give those who achieve the low temperatures a bonus.

Exemplaria gratia, the District heating supplier and connected costumer agreed with in the contract a return temperature of maximal 50 °C and the costumer return above that temperature, he will still pay the whole delivered heat belonging to the caloric formula (see Formula 4.1), because the amount of delivered heat is calculated by the mass flow and the supply and return temperature. So, if the costumer returns temperatures above the agreed 50 °C he doesn't consume the heat he pays for. On the other hand, if he return below the 50 °C, he gain, more heat and has less mass flow. Figure 4.7 illustrated that. Anyway, this example doesn't work, because the measured mass flow is on the secondary side of the heat exchanger and so property of the consumer and cannot be used for the calculate of the annual payment.

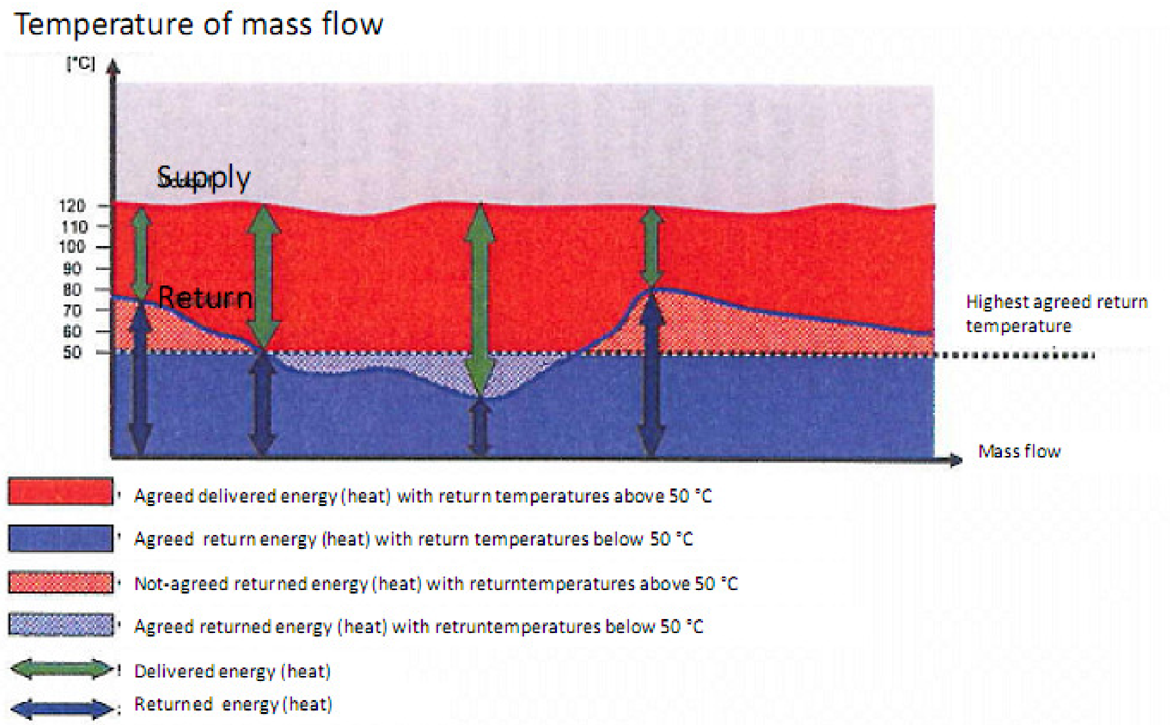

Figure 4.7 Difference of the heat supply with a return temperature above and below 50 °C (AGFW, 2009) (translated by Author)

The only way to control the return temperature for the District Heating supplier is to measure the return temperature from the primary side of the heat exchanger or the temperature in the service line to the connected building. By locking the hourly value with certain equipment, the consumer can be granted with a bonus, if exemplaria gratia is more than 80 % of the locked value below that agreed return temperature. The following Figure 4.8 illustrates that principle.

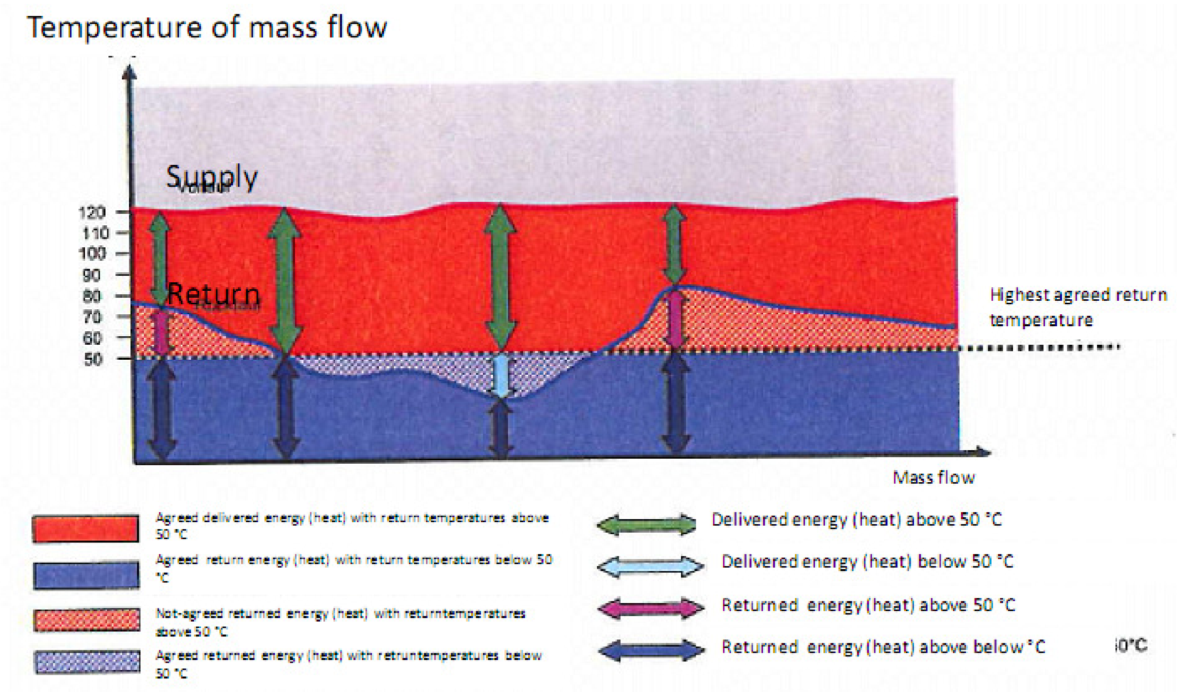

Figure 4.8 Difference of the heat supply with a return temperature above and below 50 °C with bonus-system (AGFW, 2009) (translated by Author)

The returned heat above and below the agreed return temperature can also be illustrated with the Load Duration Curve and Sochinsky Formula introduced in Chapter 3.1.3. Having lower return temperatures results in lower losses so the Load Duration Curve is lower, what also means the amount of Full-Load-Hours drop. Anyway, lower return temperatures also results in lager capacities of the thermal stores what makes the whole system more efficient and sustainable. The following Figure 4.9 illustrates that.

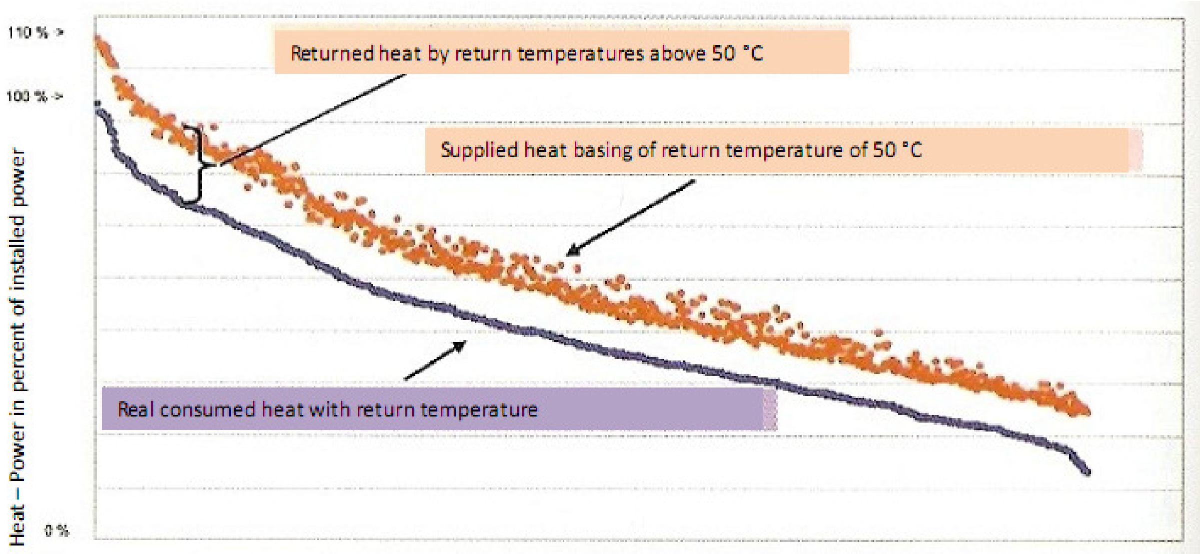

Figure 4.9 Load Duration curve illustrating the real consumed heat with return temperatures above and below the agreed return temperature of 50 °C (AGFW, 2009) (translated by Author)

Formula 4.5 describes the calculation of the delivered heat above the agreed return temperature. For that calculation only the volume flow v and the supply temperature T_{sup} has to measured, so it is the consumers fault if the return temperature is above the agreed level and pays also the return and not consumed heat.

$$A^{\geq \text{agreed retrun temperature}} = \int_{0}^{8760} c_p * \rho * \dot{V} * \left(T_{\sup} - T_{ret\,agreed}\right) dt \qquad (4.5)$$

For the calculation of the bonus Formula 4.6 can be used.

$$A^{\leq \text{agreed retrun temperature}} = \int_{0}^{8760} c_p * \rho * \dot{V} * \left(T_{ret\,agreed} - T_{ret\,real}\right) dt \qquad (4.6)$$

How and where the necessary measurement equipment exactly has to be installed within the substation and In-building heating equipment to control the return temperature is not part of that Thesis. Also the financial accounting system is not part of that Thesis.

The most important part is to make the consumer aware that he has also profit by lowering the return temperature. So it is in the hand of the supplier to inform the consumer and also help him to bring his heating equipment in hydraulic balance, and lower the return temperature within his heating equipment to lower the return temperature in the District Heating System.

5 CONCLUSION

Within the Conclusion is the research and the sub-questions answered and the whole Master Thesis summarized.

5.1 Main difference between the District heating System of Friesenheim and Skagen

The initiating problem was that the District heating System of Friesenheim at Badenova in Germany has a return temperature of 60 °C whereas Skagen has 40 °C. Within the Analysis and Research were first the Production plants, than the Transmission and Distribution System and finally the substation and In-building equipment with all requirements of the supply compared. There were no great differences found within the production plant and supply system. Both District heating Systems uses CHP Plants and have the pipes of the Transmission and Distribution system insulated and below the surface. Table 4.1 compares the two production plants.

The main differences were found within the In-building equipment. The domestic hot water production in Germany requires 70 °C whereas Denmark requires 60 °C. Further on are in Friesenheim there no strict requirements how the heating system of the connected buildings have to be designed. Anyway, Friesenheim at Badenova accepts return temperatures of 60 °C within their connection contracts whereas Skagen requires 40 °C. Why the return temperature in Skagen is lower is answered in the following sub-chapter.

5.2 Conclusion why the District heating System of Skagen has lower return temperatures than Friesenheim

The main reason why Skagen has a lower return temperature is that the heating systems of the connected buildings have lower return temperatures. The second principle of thermodynamics tells us that heat can only go from a higher to a lower temperature. So it’s in the hand of the owners of the connected buildings to lower the return temperature of a District heating system.

Lower return temperatures in buildings can be achieved by:

- Lowering the supply temperature or by
- Lowering the mass flow in the heating system.

The following sub-chapter summarizes the advantages of lower return temperatures in District heating systems.

5.3 Advantages of lower return temperatures within District heating systems

Lower return temperatures will lower the losses of the whole District heating System and also increase the efficiency. First the efficiency of the CHP-Units will rise, because the affiance of a power craft always depends on the surrounding and return temperature. Further on, the losses within the Transmission and Distribution System will decrease. The Losses Simulation in Figure 4.3 and Figure 4.4 illustrates that. Lower Return temperatures will also increase the capacity of the thermal stores and lower the energy consumption of the pumps.

Also the owner of the connected building will have lower losses within his own heating system. The following sub-chapter summarizes a plan how lower return temperatures become more attractive to the consumer.

5.4 Plan to make lower return temperatures more attractive for the consumer

How high the return temperatures within District heating Systems is, is in the hand of the owner of the heating system of the connected buildings. So to make lower return temperatures more attractive to them, it seems natural that they also want to profit.

The delivered heat is nowadays calculated by metering the forward and return temperature as well as the mass flow through the Substation. By using Formula 4.1 is than the delivered heat calculated. By that way of calculation the consumer can return each temperature and will only pay the consumed heat. Within the model introduced in Chapter 5.4 the return temperature is not measured any more. The value of the return temperature is fixed by exemplaria gratia 50 °C. So if the consumer returns above 50 °C he will pay for heat he hasn't consumed and if he returns below 50 °C he can consume heat for free. Anyway all the advantages listed in the sub-chapter above will also profit.

Lowering the return temperature within the heating systems of the connected building must be done very carefully, because the costumer shouldn't lose comfort. So the following steps must be followed within already existing buildings which are connected or will be connected to the District heating system:

- Check if the heating system is in balance
- Lowering the pump pressure (if possible)
- Lowering the forward temperature by mixing with return flow (if possible)
- Changing the contract to the bonus system

Within planned new houses the future house owners who plans to connect to the District heating system must be informed about the bonus model, so that they already can design the heating system of the building to have return temperatures which are low enough.

6 APPENDIXES

6.1 Literature

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6.4 Abbreviations and units

a	Countable hours
A	surface
Anno	Year
β	Load
c	Specific heat capacity
CHP	Combined Heat and Power
°C	Degree Celsius
dt or dT	Temperature difference
EN	European Norm
h	hour
km	Kilo-meter
kW	kilo Watt
kWh	kilo Watt hour
l	Length
λ	Heat transfer coefficient
m	Meter
m	mass flow
m^3	Cubic meter
max	maximum
min	minimum
MW	Mega Watt
MWh	Mega Watt hour
out	Outside
P	Power and/or Capacity
Q	Energy and/or Heat, thermal heat transfer
r	radius
ref	Reference
s	Second
sup	supply
t	tonne
T	Temperature
τ	working hours
TRY	Test Reference Year
V	Volume or volume flow
ρ	Density
%	Percent

€ Euro

6.5 Energy Pro Models

The following pages summarize the source of Andersen (2008):
(Andersen, EnergyPRO Model of Skagen, 2008)

6.5.1 Friesenheim at Badenova before optimisation

energyPRO 3.3.0.21 October 2008

Friesenheim at Badenova
Beispiel-Anlage
BHKW: 5Motoren je 0,46 MW-el und 0,68MW-th
Kessel: 1,2MW-th

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Catalogue of Technical Assumptions

1 Project Description

No assumption remarks attached to project description

2 External Conditions

Planning period: 01.2006 - 12.2008

Holidays	**Date**
Neujahr	01.01
Karfreitag	21.03
Ostermontag	24.03
C.Himmelfahrt	01.05
Pfingstmontag	12.05
Maifeiertag	01.05
Tag der Einheit	03.10
1.Weihnachtst.	25.12
2.Weihnachtst.	26.12

2.1 Timeseries

Temperatur 2006/07
Symbol: T

	[°C] Average	Minimum	Maximum
October, 2006	13,0	9,1	16,4
November, 2006	8,1	1,4	14,1
December, 2006	6,7	1,0	12,7
January, 2007	5,7	-4,3	11,8
February, 2007	3,9	-2,3	7,7
March, 2007	7,3	2,5	10,7
April, 2007	11,3	5,4	18,8
May, 2007	13,6	9,3	19,9
June, 2007	17,1	12,1	22,8
July, 2007	16,9	12,1	25,6
August, 2007	17,4	12,1	22,3
September, 2007	13,6	10,7	17,4
All Period	**11,3**	**-4,3**	**25,6**

2.2 Indexes

No INDEXES is defined

3 Fuels

Erdgas 1,0000 MWh/MWh
Hackschnitzel 750,0000 kWh/m³

4 Demands

energyPRO is developed by Energi- og Miljødata, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, Homepage: www.emd.dk

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Catalogue of Technical Assumptions

4.2 Heat demands

Demands

Wärmeverkauf:	Symbol: HD1
Netzverluste:	Symbol: HD2

Demand	**amount**	**Development**
Wärmeverkauf:	4.400 MWh	Not developing over the years
Netzverluste:	600 MWh	Not developing over the years
Total	**5.000 MWh**	

Demand		**Max demand**	**Min demand**
Wärmeverkauf	[MW]	2,5	0,0
Netzverluste	[MW]	0,1	0,1

Heat demands, Details

Wärmeverkauf:

Fraction of demand depending on Weather:	80,00 %
Reference temperature:	17,0 °C
Formular for daily weather ratios	Max(17,0-T;0)
Season for weather dependency:	01.09 to 31.05

Daily cycle

Time	Ratio
00:00	20,00
02:00	21,00
03:00	23,00
04:00	29,00
05:00	48,00
06:00	68,00
07:00	62,00
08:00	54,00
09:00	52,00
10:00	48,00
11:00	46,00
12:00	44,00
13:00	42,00
16:00	46,00
17:00	49,00
19:00	50,00
20:00	49,00
21:00	44,00
22:00	31,00
23:00	22,00

Netzverluste:

Monthly amounts

	MWh
January	50,82
February	47,54
March	50,82
April	49,18
May	50,82
June	49,18
July	50,82
August	50,82
September	49,18
October	50,82
November	49,18
December	50,82

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Friesenheim at Badenova
Beispiel-Anlage
BHKW: 5 Motoren je 0,46 MW-el und 0,68 MW-th
Kessel: 1,2 MW-th

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Catalogue of Technical Assumptions

5 Energy units

BHKW 1
Fuel type: Erdgas
Min. Operation time: 1 hours

	Fuel [kW]	Heat [kW]	Heat [%]	Electric power [kW]	Electric power [%]
1	1.450,0	680,0	46,9	460,0	31,7

BHKW 2
Fuel type: Erdgas
Min. Operation time: 1 hours

	Fuel [kW]	Heat [kW]	Heat [%]	Electric power [kW]	Electric power [%]
1	1.450,0	680,0	46,9	460,0	31,7

BHKW 3
Fuel type: Erdgas
Min. Operation time: 1 hours

	Fuel [kW]	Heat [kW]	Heat [%]	Electric power [kW]	Electric power [%]
1	1.450,0	680,0	46,9	460,0	31,7

BHKW 4
Fuel type: Erdgas
Min. Operation time: 1 hours

	Fuel [kW]	Heat [kW]	Heat [%]	Electric power [kW]	Electric power [%]
1	1.450,0	680,0	46,9	460,0	31,7

BHKW 5
Fuel type: Erdgas
Min. Operation time: 1 hours

	Fuel [kW]	Heat [kW]	Heat [%]	Electric power [kW]	Electric power [%]
1	1.450,0	680,0	46,9	460,0	31,7

Spitzenlastkessel
Fuel type: Erdgas
Min. Operation time: 0 hours

	Fuel [kW]	Heat [kW]	Heat [%]
1	1.370,0	1.260,0	92,0

Wärmespeicher
Net volume: 90,0 m3
Temperature difference: 35,0 °C
Utilization: 95,0 %
Capacity: 3,5 MWh

6 Electricity market

The Planning Period is not divided into Periods of Priority

energyPRO is developed by Energi- og Miljødata, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, Homepage: www.emd.dk

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Friesenheim at Badenova
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Kessel: 1,2 MW-th

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Catalogue of Technical Assumptions

7 Operation strategy

Operation Strategy is Userdefined

Priority of productions	Einheitstarif
BHKW 1	1
BHKW 2	1
BHKW 3	1
BHKW 4	1
BHKW 5	1
Spitzenlastkessel	2

Production to thermal store allowed

BHKW 1	Yes
BHKW 2	Yes
BHKW 3	Yes
BHKW 4	Yes
BHKW 5	Yes
Spitzenlastkessel	No

Partial load allowed

BHKW 1	No
BHKW 2	No
BHKW 3	No
BHKW 4	No
BHKW 5	No
Spitzenlastkessel	Yes

8 Emissions

CO2
CO2-Emissionen 242,0000 kg/MWh
NOx
SO2

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Friesenheim at Badenova
Beispiel-Anlage
BHKW: 5 Motoren je 0,46 MW-el und 0,68 MW-th
Kessel: 1,2 MW-th

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Operation Income from 01-01-2008 00:00 to 31-12-2008 23:59

(All amounts in €)

Revenues								
Stromerlös								
vNN-Leistung	:				■	90.000		
EEX-Base	:	3.381,6 MWh	at	73,137	■	247.318		
Stromerlös Total							**337.318**	
Wärmeerlös								
Wärme-Arbeit	:	4.400,0 MWh	at	94,0	■	413.600		
Wärme-Leistung	:				■	50.000		
Wärmeerlös Total							**463.600**	
Total Revenues								**800.918**
Operating Expenditures								
Erdgasbezug	:	10.660,6 MWh	at	47,7	■	508.508		
Erdgas Grundpreis	:				■	80.000		
Erdgassteuer								
Kessel	:	1,3 MWh	at	3,3	■	4		
Erdgassteuer Total							**4**	
Wartung und Instandhaltung								
BHKW 1	:	6.076,9 hour of operation	at	3,7	■	22.485		
BHKW 2	:	1.243,6 hour of operation	at	3,7	■	4.601		
BHKW 3	:	30,8 hour of operation	at	3,7	■	114		
BHKW 4	:	0,0 hour of operation	at	3,7	■	0		
BHKW 5	:	0,0 hour of operation	at	3,7	■	0		
Kessel	:				■	5.000		
Betriebsführung	:				■	70.000		
Wartung und Instandhaltung Total							**102.200**	
Total Operating Expenditures								**690.712**
Operation Income								**110.205**

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6.5.2 Friesenheim at Badenova after optimisation

Only pages where changes to the model above occur are listened.

energyPRO 3.3.0.21 October 2008

Friesenheim at Badenova
Beispiel-Anlage
BHKW: 5Motoren je 0,46 MW-el und 0,68MW-th
Kessel: 1,2MW-th

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Catalogue of Technical Assumptions

4.2 Heat demands

Demands

Wärmeverkauf:	Symbol: HD1
Netzverluste:	Symbol: HD2

Demand	amount	Development
Wärmeverkauf:	4.400 MWh	Not developing over the years
Netzverluste:	511 MWh	Not developing over the years
Total	**4.911 MWh**	

Demand		Max demand	Min demand
Wärmeverkauf	[MW]	2,5	0,0
Netzverluste	[MW]	0,1	0,1

Heat demands, Details

Wärmeverkauf:

Fraction of demand depending on Weather:	80,00 %
Reference temperature:	17,0 °C
Formular for daily weather ratios	Max(17,0-T;0)
Season for weather dependency:	01.09 to 31.05

Daily cycle

Time	Ratio
00:00	20,00
02:00	21,00
03:00	23,00
04:00	29,00
05:00	48,00
06:00	68,00
07:00	62,00
08:00	54,00
09:00	52,00
10:00	48,00
11:00	46,00
12:00	44,00
13:00	42,00
16:00	46,00
17:00	49,00
19:00	50,00
20:00	49,00
21:00	44,00
22:00	31,00
23:00	22,00

Netzverluste:

Monthly amounts

	MWh
January	43,28
February	40,49
March	43,28
April	41,89
May	43,28
June	41,89
July	43,28
August	43,28
September	41,89
October	43,28
November	41,89
December	43,28

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Friesenheim at Badenova

Beispiel-Anlage
BHKW: 5 Motoren je 0,46 MW-el und 0,68 MW-th
Kessel: 1,2 MW-th

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Catalogue of Technical Assumptions

5 Energy units

BHKW 1
Fuel type: Erdgas
Min. Operation time: 1 hours

	Fuel [kW]	Heat [kW]	Heat [%]	Electric power [kW]	Electric power [%]
1	1.450,0	680,0	46,9	460,0	31,7

BHKW 2
Fuel type: Erdgas
Min. Operation time: 1 hours

	Fuel [kW]	Heat [kW]	Heat [%]	Electric power [kW]	Electric power [%]
1	1.450,0	680,0	46,9	460,0	31,7

BHKW 3
Fuel type: Erdgas
Min. Operation time: 1 hours

	Fuel [kW]	Heat [kW]	Heat [%]	Electric power [kW]	Electric power [%]
1	1.450,0	680,0	46,9	460,0	31,7

BHKW 4
Fuel type: Erdgas
Min. Operation time: 1 hours

	Fuel [kW]	Heat [kW]	Heat [%]	Electric power [kW]	Electric power [%]
1	1.450,0	680,0	46,9	460,0	31,7

BHKW 5
Fuel type: Erdgas
Min. Operation time: 1 hours

	Fuel [kW]	Heat [kW]	Heat [%]	Electric power [kW]	Electric power [%]
1	1.450,0	680,0	46,9	460,0	31,7

Spitzenlastkessel
Fuel type: Erdgas
Min. Operation time: 0 hours

	Fuel [kW]	Heat [kW]	Heat [%]
1	1.370,0	1.260,0	92,0

Wärmespeicher
Net volume: 90,0 m3
Temperature difference: 55,0 °C
Utilization: 95,0 %
Capacity: 5,4 MWh

6 Electricity market

The Planning Period is not divided into Periods of Priority

energyPRO 3.3.0.21 October 2008

Friesenheim at Badenova
Beispiel-Anlage
BHKW: 5Motoren je 0,46 MW-el und 0,68MW-th
Kessel: 1,2MW-th

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Catalogue of Technical Assumptions

7 Operation strategy

Operation Strategy is Userdefined

Priority of productions	Einheitstarif
BHKW 1	1
BHKW 2	1
BHKW 3	1
BHKW 4	1
BHKW 5	1
Spitzenlastkessel	2

Production to thermal store allowed

BHKW 1	Yes
BHKW 2	Yes
BHKW 3	Yes
BHKW 4	Yes
BHKW 5	Yes
Spitzenlastkessel	Yes

Partial load allowed

BHKW 1	No
BHKW 2	No
BHKW 3	No
BHKW 4	No
BHKW 5	No
Spitzenlastkessel	No

8 Emissions

CO2
CO2-Emissionen 242,0000 kg /MWh
NOx
SO2

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energyPRO 3.3.0.21 October 2008

Friesenheim at Badenova
Beispiel-Anlage
BHKW: 5Motoren je 0,46 MW-el und 0,68MW-th
Kessel: 1,2MW-th

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Operation Income from 01-01-2008 00:00 to 31-12-2008 23:59

(All amounts in €)

Revenues								
Stromerlös								
NN-Leistung	:				■	90.000		
EEX-Base	:	3.322,1 MWh	at	73,137	■	242.972		
Stromerlös Total							332.972	
Wärmeerlös								
Wärme-Arbeit	:	4.400,0 MWh	at	94,0	■	413.600		
Wärme-Leistung	:				■	50.000		
Wärmeerlös Total							463.600	
Total Revenues								796.572
Operating Expenditures								
Erdgasbezug	:	10.472,0 MWh	at	47,7	■	499.514		
Erdgas Grundpreis	:				■	80.000		
Erdgassteuer								
Kessel	:	0,0 MWh	at	3,3	■	0		
Erdgassteuer Total							0	
Wartung und Instandhaltung								
BHKW 1	:	6.021,6 hour of operation	at	3,7	■	22.280		
BHKW 2	:	1.178,3 hour of operation	at	3,7	■	4.360		
BHKW 3	:	22,2 hour of operation	at	3,7	■	82		
BHKW 4	:	0,0 hour of operation	at	3,7	■	0		
BHKW 5	:	0,0 hour of operation	at	3,7	■	0		
Kessel	:				■	5.000		
Betriebsführung	:				■	70.000		
Wartung und Instandhaltung Total							101.722	
Total Operating Expenditures								681.236
Operation Income								115.336

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6.5.3 Skagen

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Skagen CHP plant

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Catalogue of Technical Assumptions

1 Project Description

No assumption remarks attached to project description

2 External Conditions

Planning period: 01.2008 - 12.2008

Using danish holidays

2.1 Timeseries

Danish outdoor temperatures
Symbol: T

	[°C] Average	Minimum	Maximum
January, 2002	-0,6	-9,0	3,2
February, 2002	-1,1	-7,0	4,9
March, 2002	2,6	-4,1	5,9
April, 2002	6,6	2,7	11,6
May, 2002	10,6	7,5	16,5
June, 2002	15,6	12,6	19,0
July, 2002	16,4	13,0	21,1
August, 2002	16,6	13,3	22,2
September, 2002	13,7	11,3	16,2
October, 2002	9,1	4,6	14,6
November, 2002	5,0	-0,8	9,2
December, 2002	1,6	-6,3	5,8
All Period	**8,1**	**-9,0**	**22,2**

Elspot prices 2007
Symbol: DK1spot07

	[DKK] Average	Minimum	Maximum
January, 2007	348,26	157,00	702,20
February, 2007	369,21	157,00	901,75
March, 2007	342,78	157,00	508,00
April, 2007	338,35	162,89	545,08
May, 2007	339,90	229,42	901,70
June, 2007	392,58	194,29	1.413,69
July, 2007	336,74	157,00	514,34
August, 2007	364,24	177,61	700,57
September, 2007	405,58	233,04	873,50
October, 2007	538,07	157,00	3.631,97
November, 2007	511,45	157,00	7.183,21
December, 2007	492,21	157,00	3.886,38
All Period	**398,36**	**157,00**	**7.183,21**

2.2 Indexes

No INDEXES is defined

3 Fuels

Natural gas	11,0000 kWh/Nm3	
Incineration	1,0000 MWh/MWh	Offered fuel: 33.897,00 MWh Storage capacity: 0,00 MWh

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Catalogue of Technical Assumptions

Offered fuel, details

Incineration	[MWh]
January	3.100,00
February	2.800,00
March	2.600,00
April	3.000,00
May	3.100,00
June	2.500,00
July	2.438,00
August	2.571,00
September	2.404,00
October	3.162,00
November	3.060,00
December	3.162,00

4 Demands

4.2 Heat demands

Demands
Heat delivered to town: Symbol: HD1

Demand	amount	Development
Heat delivered to town:	72.000 MWh	Not developing over the years
Total	**72.000 MWh**	

Demand		Max demand	Min demand
Heat delivered to town	[MW]	19,8	2,9

Heat demands, Details

Heat delivered to town:
Fraction of demand depending on Weather: 60,00 %
Reference temperature: 17,0 °C
Formular for daily weather ratios: Max(17,0-T;0)
Season for weather dependency: 01.09 to 31.05

Daily cycle

Time	Ratio
09:00	10,00
21:00	8,00

5 Energy units

Incineration plant
Fuel type: Incineration
Min. Operation time: 0 hours

	Fuel [MW]	Heat [MW]
1	4,3	4,3

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Catalogue of Technical Assumptions

Engine 1
Fuel type: Natural gas

Min. Operation time: 3 hours

	Fuel [MW]	Heat [MW]	Heat [%]	Electric power [MW]	Electric power [%]
1	11,3	5,7	50,4	4,6	40,7

Engine 2
Fuel type: Natural gas

Min. Operation time: 3 hours

	Fuel [MW]	Heat [MW]	Heat [%]	Electric power [MW]	Electric power [%]
1	11,3	5,7	50,4	4,6	40,7

Engine 3
Fuel type: Natural gas

Min. Operation time: 3 hours

	Fuel [MW]	Heat [MW]	Heat [%]	Electric power [MW]	Electric power [%]
1	11,3	5,7	50,4	4,6	40,7

Boiler 1
Fuel type: Natural gas

Min. Operation time: 0 hours

	Fuel [MW]	Heat [MW]	Heat [%]
1	6,6	7,0	106,1

Boiler 2
Fuel type: Natural gas

Min. Operation time: 0 hours

	Fuel [MW]	Heat [MW]	Heat [%]
1	12,3	11,6	94,3

Boiler 3
Fuel type: Natural gas

Min. Operation time: 0 hours

	Fuel [MW]	Heat [MW]	Heat [%]
1	9,4	10,0	106,4

Boiler 4
Fuel type: Natural gas

Min. Operation time: 0 hours

	Fuel [MW]	Heat [MW]	Heat [%]
1	10,6	10,0	94,3

Electricity boiler
Fuel type: (no fuel)

Min. Operation time: 0 hours

	Heat [MW]	Electric consumption [MW]
1	10,0	10,0

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Skagen CHP plant

Catalogue of Technical Assumptions

Thermal store
Net volume: 4.195,0 m3
Temperature difference: 56,0 °C
Utilization: 90,0 %
Capacity: 245,0 MWh

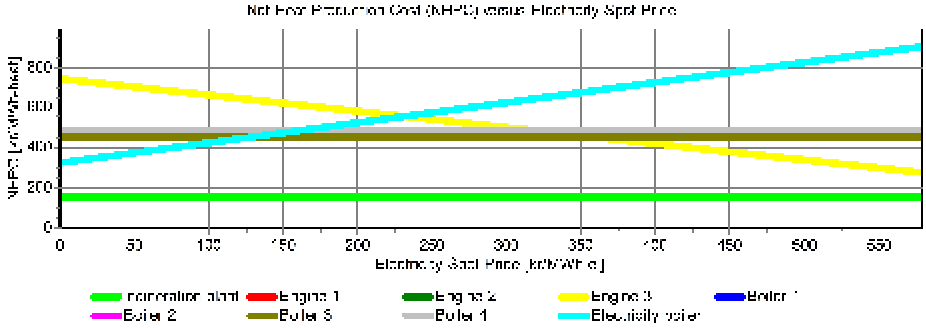
6 Electricity market

Name of Extern time-series: Elspot prices 2007

Quality of spot prognosis: Rough

7 Operation strategy

Operation Strategy is Calculated as Net Heat Production Costs



Note: Graph shows first month in calculation

Production to thermal store allowed

Incineration plant	Yes
Engine 1	Yes
Engine 2	Yes
Engine 3	Yes
Boiler 1	No
Boiler 2	No
Boiler 3	No
Boiler 4	No
Electricity boiler	Yes

Partial load allowed

Incineration plant	Yes
Engine 1	No
Engine 2	No
Engine 3	No
Boiler 1	Yes
Boiler 2	Yes
Boiler 3	Yes
Boiler 4	Yes
Electricity boiler	No

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Operation Income from 01-01-2008 00:00 to 31-12-2008 23:59

(All amounts in kr)

Revenues								
Sale at spot market	:				■	13.442.621		
Total Revenues								**13.442.621**
Operating Expenditures								
Purchase of gas	:	6.352.617,4 Nm3	at	3,12	■	19.820.165		
Taxes on engines and boilers								
Engine 1	:	815.777,4 Nm3	at	2,281	■	1.860.788		
Engine 2	:	719.250,9 Nm3	at	2,281	■	1.640.611		
Engine 3	:	621.423,7 Nm3	at	2,281	■	1.417.467		
Boiler 1	:	6.771,8 MWh	at	183,0	■	1.239.236		
Boiler 2	:	0,0 MWh	at	183,0	■	0		
Boiler 3	:	23,4 MWh	at	183,0	■	4.285		
Boiler 4	:	0,0 MWh	at	183,0	■	0		
Taxes on engines and boilers Total							**6.162.387**	
Operation and management								
O&M of engine 1	:	9.774,5 MWh	at	35,0	■	342.106		
O&M of engine 2	:	8.617,9 MWh	at	35,0	■	301.627		
O&M of engine 3	:	7.445,8 MWh	at	35,0	■	260.602		
Boiler 1	:	6.771,8 MWh	at	5,0	■	33.859		
Boiler 2	:	0,0 MWh	at	5,0	■	0		
Boiler 3	:	23,4 MWh	at	5,0	■	117		
Boiler 4	:	0,0 MWh	at	5,0	■	0		
Operation and management Total							**938.311**	
Value of Incineration heat	:	33.188,0 MWh	at	154,6	■	5.130.860		
Electricity for el. boiler	:				■	0		
Net tariff for el. boiler	:	0,0 MWh	at	140,0	■	0		
Tax on el. boiler	:	0,0 MWh	at	183,0	■	0		
Total Operating Expenditures								**32.051.724**
Operation Income								**-18.609.103**

6.6 Losses model