ENERGY INVESTIGATION, GÄRTUNA

On the facilities of Astra Zeneca, with suggestions of energy optimizations

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ABSTRACT

AstraZeneca is one of the largest biopharmaceutical companies in the world, and one of the facilities they have is located in Gärtuna, Södertälje. The facility itself is very big with a floor area of 560,000m² and has a complex energy system. Caverion holds a facility management contract at AstraZenca, hence operates some of the energy system. The energy investigation of this thesis is part of the work of Caverion to ensure a sustainable energy system in Gärtuna. The energy investigation will include mapping of the energy distribution, seeking for potential of improvements and carry out suggestions for energy optimizations. The methods used during the investigation was a literature study, interviews with personnel of both Caverion and AstraZenca, study of the energy system and calculations relevant to the field of study.

The mapping of the energy system includes the heat, steam and cooling distribution. When the mapping of the system was done it was clear that the areas with most potential for improvements were the steam and cooling distribution. The mapping of the steam distribution shows a loss of nearly 46% of the steam at year 2014 and the corresponding cost of about 13,640,000 SEK. Even though the steam distribution showed great potential for improvements, it was found that the work of investigating the system would be too difficult for the scope of the thesis. The cooling distribution however is more accessible and the potential is still high due to low coefficient of performance.

Two suggestions for energy optimizations were carried out. The first suggestions involves upgraded electric fan motors for some of the cooling towers, and the second suggestion is to modify existing dry coolers in benefit to utilize free cooling during winter period. The fan motor upgrade based on calculations is estimated to result in a yearly energy saving of at least 1526 MWh and a corresponding cost saving of at least 800,000 SEK per year after the pay-off time (9 months). The dry cooler modification based on calculations is estimated to result in a yearly energy saving of 3053 MWh and a yearly cost saving of 2,083,449 SEK after the pay-off period of 5 months.

The investigation carried out in this thesis is relevant to both Caverion and AstraZeneca as it points out the areas with potential of improvements and also gives suggestions on energy optimizations that will reduce energy consumption and result in energy cost savings.

Keywords: AstraZeneca, Caverion, sustainable energy system, energy investigation, energy optimization, cooling, heat, steam, cost reduction.

Nyckelord: AstraZeneca, Caverion, hållbara energisystem, energiutredning, energioptimering, kyla, värme, ånga, kostnadsbesparing.
PREFACE

This thesis was carried out during spring at year 2015 for the school of business, society and engineering at Mälardalen University. The thesis work is the last part of the civil engineering program of sustainable energy systems and corresponds to 30 high school points. The work was carried out at the company Caverion® which holds a facility management contract in AstraZeneca® in Sweden. The energy investigation was done in one of the facilities of AstraZeneca in Gärtuna, Sweden.

I would like to take the opportunity to thank all the employees at Caverion and AstraZeneca that has supported me during the thesis work. I would like to give special thanks to my supervisor at Caverion, Patric Robertsson for providing me all the resources to accomplish my work, and my supervisor at Mälardalen University, Jan Sandberg for his guidance throughout the project. I would also like to thank the Engineer for Building and Operating Maintenance for Caverion, Johan Sandberg, for guiding me in rough times and sharing me his knowledge for energy physics.
SUMMARY

AstraZeneca is one of the largest biopharmaceutical companies in the world, and one of the facilities they have is located in Gärtuna, Södertälje. The facility itself is very big with a floor area of 560,000 m² and has a complex energy system. Among other reasons, due to economic aspects and the fact that the energy system is so complex, AstraZeneca has chosen to outsource some of their departments in Sweden, to a company named Caverion. Caverion holds a facility management contract at AstraZeneca and is therefore in charge of some of the energy system management in Gärtuna. One of the duties for Caverion is to maintain a sustainable energy system and as part of the work to fulfill that requirement, this thesis work has been carried out. The thesis work is to do an energy investigation of the Gärtuna facility in order to evaluate what flaws there is and what areas could be improved. The energy investigation will then comprehend a literature study, mapping of the energy system, seeking for potential areas of improvements and at later stage also include suggestions for energy optimization.

The mapping of the energy system in Gärtuna includes the cooling distribution, the heat distribution and the steam distribution. The mapping of the cooling distribution and some of the heat distribution included the making of block-schemes as it includes complex systems such as cooling machines, heat pumps and cooling towers. All energy distribution was marked out on a map of the approximate whereabouts of the distribution pipes and important facilities relevant to the distribution as well. The mapping also shows how efficient each energy distribution is in order to later find the potential for improvements. The efficiency of the heat and cooling distribution was showed by calculating the coefficient of performance based on retrieved data from Caverion. The efficiency of the steam distribution could simply be determined by how much steam loss there was in the distribution pipes from between the steam provider and to the different receiving facilities.

An evaluation of the efficiencies was part of the work of finding the areas with highest potential of improvements. The mapping of the steam distribution showed a large amount of lost steam for year 2014, corresponding to a steam loss of about 46% of the delivered steam which is 27,560 MWh of lost heat energy. The steam cost for AstraZeneca is 495 SEK/MWh so the cost for lost steam at year 2014 was about 13,640,000 SEK. The steam distribution is however a very large system and is difficult to access, this made it impossible to fit the time scope of this thesis which resulted in just an explanation of theoretical causes for the steam losses in chapter 8. The cooling distribution however, also showed big potential of improvement as the coefficient of performance was relatively low and the diversity of such complex system made it more accessible to find energy optimizations. There was also a general request from the supervisor at Caverion to look into the cooling system as Caverion themselves believes it can be improved in many areas. The heat distribution showed to be very efficient as it is, much thanks to the existing flash steam recovery system. Potential of improvement for the heat distribution was therefore considered low.

The area chosen for the seeking of energy optimization was the cooling distribution. Eventually it came down to two suggestions for energy optimization. The first energy
optimization involves an upgrade of fan motors for some of the cooling towers in Gärtuna. At
one of the facilities where Caverion is distributing water at 19 °C, they have cooling towers
and heat pumps to achieve the cooling power. The cooling towers consist of 18 separate
cooling towers and 16 of these are of the same brand and model and also installed at the same
time. The problem with these 16 cooling towers is that the electric fan motors are vulnerable
for condense inside the motors, and to prevent this they need to run the motors at minimum
speed even if the cooling towers are not cooling any water. This is causing an unnecessary
electric consumption as many of the cooling towers are not cooling water for plenty of time
during a year. A scenario was put up to calculate how much unnecessary electric power
consumption there was during a year, and this resulted in that approximately 1831 MWh per
year was lost due to unnecessary electric power consumption. The solution to prevent the fan
motors to being forced to run at minimum speed even though it was not necessary, was to
replace them with motors that has heat elements installed instead. The heat elements will
then prevent condense within the motor and the problem will be prevented. By replacing the
existing motors with the upgraded version, a yearly energy saving was calculated to be 1526
MWh with a corresponding energy saving cost of 801,000 SEK per year after the pay-back
period of 9 months.

The second suggestion for energy optimization was to utilize free cooling during winter by
modifying existing dry coolers in a facility in Gärtuna. The dry coolers original purpose is to
cool the condensing side of two cooling machines, but because the cooling machines are not
running during winter, these dry coolers can be abused during this period. The idea then is to
cool one of the cooling distribution systems with the cold air during winter. To simulate how
much cooling power the dry coolers could provide during winter, a collaboration with the
manufactures was made and they provided the cooling power for certain outside
temperatures. A calculation was made based on collected outside temperature data received
from a weather station nearby, to give a mean value of the amount of hours during a year that
desired temperatures would appear in order for the dry coolers to be effective. After that, the
cooling energy output was calculated for a normal year and was calculated to be around 3315
MWh. The electric energy consumption to achieve such cooling power was calculated to be
around 261 MWh per year. To evaluate how much this cooling energy was worth in economic
aspects, it was compared to the cost of producing the same amount of cooling energy with
cooling machines, which is expected to be around 670 SEK/MWh, thus giving an energy cost
saving of about 2,083,000 SEK per year if count in the electrical cost of running the dry
coolers. The investment cost was after calculations estimated to be 866,000 SEK, thus giving
a pay-off period of 6 months.

The energy investigation was overall successful but the calculations includes a few rough
adoptions due to the lack of appropriate equipment for some measurements. However, this
thesis provides additional suggestions for further work which also benefits AstraZeneca and
Caverion.
AstraZeneca är ett av de största biofarmaceutiska företagen i världen och har en av sina anläggningar placerade i Gärtuna, Södertälje. Anläggningen i sig är väldigt stor med en golvyta på ungefär 560 000 m² och har ett väldigt komplext energisystem. På grund av ekonomiska faktorer ihop med andra faktorer och det faktum att energisystemet är så komplext så har AstraZeneca valt att lämna ut delar av sin verksamhet (outsourca) till ett företag som heter Caverion. Caverion äger alltså ett Facility Management kontrakt som dels innefattar hanteringen av stora delar av energisystemet i Gärtuna. En del av kontraktet säger att Caverion måste arbeta för ett hållbart energisystem och som en del av det arbetet så har detta examensarbete tagits fram. Examensarbetet innefattar som helhet en energiutredning för att ta reda på vilka brister energisystemet har och vilka förbättringar som kan implementeras. Energiutredningen innehåller en litteraturstudie, kartläggning av energisystemet, sökande efter potential till förbättring och förslag på energieffektiviseringar.

Kartläggningen av energisystemet innefattar kyldistributionen, fjärrvärmedistributionen och ångdistributionen på anläggningen. Kartläggningen av kyldistributionen och delar av fjärrvärmedistributionen bestod delvis av att rita blockschema för att få en enklare överblick på systemen då dessa är så pass komplexa. All energidistribution med dess distributionsledningar och viktiga byggnader har markerats på överblickskartor med ungefärliga placeringar för att ge en förbättrad förståelse. Kartläggningen användes sedan som verktyg för att kunna ta reda på hur effektivt energidistributionen sker och därefter även se hur stor potentialen till förbättring är. Effektiviteten på kyl och värmidistributionen kunde bestämmas genom att beräkna ett slags OCOP-värde (overall coefficient of performance) baserat på data hämtat från Caverion. Effektiviteten av ångdistributionen kunde bestämmas genom att avläsa hur mycket ångförluster som skett i distributionsledningarna från leverantören tills det att ångan når de olika byggnaderna inom anläggningen.


Energiutredningen blev i sin helhet väl utförd men en del beräkningar innefattar dock ett fåtal uppskattningar till följd av begränsad mätutrustning. Slutligen bör nämnas att arbetet även anger förslag till fortsatt arbete som gynnar både Caverion och AstraZeneca.
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## TERMS AND ABBREVIATIONS

- **B653, B654, B661, B869**: Names for the important facilities within Gärtuna when it comes to heat and cooling production.
- **V2, KB1, KB2-system**: Different cooling distribution systems within Gärtuna with different properties.
- **RPM**: Revolutions per minute.
- **PFE**: The Program for Improving Energy Efficiency in Energy-Intensive Industries.
1 INTRODUCTION

Planet earth has a limited amount of resources. All resources are valuable in order for nature to survive as all living beings depend on and therefore comes big responsibility for those who exploit it. At this time being humans have an unsustainable way of using the world’s resources. High water consumption makes water a luxury that very few people have access to. The high energy demand leads to a large consumption of fossil fuels which causes depletion and at the same time consuming the fossil fuels makes earth suffer from toxic emissions and greenhouse gases. These are just fragments of examples on unsustainable habits of which humans must cope with if we value life on earth. The more people consume of the world’s resources, the greater the responsibility grows.

The consumption of the resources of the world appears in many ways. A high energy demand often goes hand in hand with stretching of the world’s energy resources since far from all energy are generated directly by infinite resources. A human sector which tends to use relatively much energy is the industry which has to consume a lot of energy in order for the different processes to work. The biopharmaceutical company AstraZeneca is no exception.

AstraZeneca is a large energy consumer, and therefore the company has a great responsibility to manage their consumption in a sustainable way. Because their energy management is so complex by many means, the company has chosen to outsource some of their activities in Sweden to other companies. One of these companies is Caverion that serves AstraZeneca in several areas where one of the main services is the energy production and distribution.

One of AstraZeneca’s many facilities is located in Gärtuna, Södertälje in Sweden. AstraZeneca has a facility management contract with Caverion which includes operation and maintenance of the company’s facility in Södertälje (Caverion, 2014). This includes responsibility for most of the energy management in Gärtuna, hence also the responsibility to run a sustainable energy system.

On behalf of Caverion, this thesis will cover an energy investigation as a tool to ensure a sustainable energy system in AstraZeneca’s facility in Gärtuna. The investigation will include mapping of the energy consumption, distribution and production of heat, coolant and electricity that is distributed by Caverion within the facility. The mapping of the energy system will lay as ground to later determine within which areas energy optimization is necessary and what types of optimization solutions that are possible and how beneficial these are.
1.1 Background

1.1.1 AstraZeneca

AstraZeneca is a global biopharmaceutical company that operates in more than 100 countries and their medicines are used by millions of persons worldwide. They employ around 51000 people world-wide and Sweden is one of 16 manufacturing countries. Gärtuna is the location of one manufacturing facility. (AstraZeneca, 2015a)

AstraZeneca is very ambitious in their work against climate change. To keep a long-term commitment towards a more sustainable environment they have set up certain goals from 2011 to 2015. Some of the goals are to deliver a 20 % reduction of their operational greenhouse gas footprint, improving their energy efficiency of their assets by 30 %, raise the contribution of renewable sources to their energy mix by 50 % and improve their fuel efficiency on the world-wide sales and marketing vehicle fleet by 20%. Another important goal is to decrease their water consumption by 25 %. All of these goals are set from 2010 measurements. (AstraZeneca, 2015b)

It should be mentioned that some goals are already met, e.g. the emissions of greenhouse gases had decreased with 20 % globally and 24 % in Sweden at year 2013. The water consumption at year 2013 had decreased with 19 % globally and 18 % in Sweden, compared to the goal of 25 %. (AstraZeneca, 2013)

1.1.2 Caverion

Caverion states on their website that “Caverion designs, builds, operates and maintains user-friendly and energy-efficient technical solutions for buildings and industries in Northern and Central Europe.” (Caverion, 2015). They have approximately 17000 employees in northern and central Europe (12 countries) and their head office is located in Helsinki, Finland. Caverion itself is a pretty new company since it was established at year 2013. The establishment was made from the demerger of building services- and industrial services business from YIT Group which has a well-grown history and therefore makes Caverion an already experienced company. (Caverion, 2015)

1.1.3 AstraZeneca’s facility in Gärtuna

Gärtuna is one of two locations in Södertälje, Sweden where AstraZeneca commits research and manufacturing of medicine. The facilities in Södertälje is one of the world’s largest in space and efficiency, with a floor area of 560.000 m².

Caverion states the following on their website regarding what their duties are for AstraZeneca in Sweden:
Gärtuna is a facility with high energy consumption. In order for their research and manufacturing to work they need coolant, heat water and steam and electricity. Caverion is responsible for a lot of the distribution of energy within Gärtuna which includes coolant and heat production facilities within AstraZeneca, and import of heat and steam from “Igelstaverket” power plant which is located nearby. The electricity is bought from an electricity supplier.

1.1.4 Problem definition

As mentioned earlier, both AstraZeneca and Caverion have great interest in keeping a sustainable energy system. With such a large energy system like Gärtuna, there are always room for improvements, especially as many parts of the energy system is growing old and inefficient (Sandberg, 2015a). An energy investigation is necessary to point out where the potential of improvements is highest and what actions could be made for energy optimization.

1.2 Purpose

The purpose for this thesis is to investigate the energy system managed by Caverion in AstraZeneca’s facility in Gärtuna. The investigation includes mapping the energy system and then analyze the potential to optimize certain systems. The investigation should later give suggestions for improvements such as energy optimization.

1.2.1 Objectives

The goal for this investigation is to find solutions for energy optimization on the facility in Gärtuna in order to minimize energy usage and provide a more sustainable energy system. Main parts in the objectives can be divided into the following parts:

- Mapping and understanding of the energy system in Gärtuna
  - Principle schemes
  - Energy balances
- Identify energy systems with the highest potential for implementation of energy efficiency improvements
• Develop one or more solutions to improve the energy efficiency
  o Technical solutions
  o Performance
  o Economical credibility
• Investigate practical and financial credibility

1.3 Delimitations

This thesis is an energy investigation that comprises the energy distribution in AstraZeneca’s facility in Gärtuna, of which is managed by Caverion. The thesis will only cover the distribution of district heating, steam and cooling within the facility which all have their own delimitations. The district heating covered in the thesis includes the district heat produced by heat pumps and heat recovery systems such as steam condensate heat exchangers. This includes the district heating production and the distribution until it reaches a building that consumes it for heating of any kind. So the parts of the process where the district heating is consumed for heating or used for medicine production purposes is not included. Due to an unfortunate event explained in chapter 2, the performance of two heat pumps (in building B654) could not be measured properly, even though the original plan was to include it in the thesis work. The investigation of the cooling system includes the cooling production in cooling machines and cooling towers, and the distribution of cooling up until it reaches a building that uses it for cooling of any kind. The steam system includes the distribution of steam in pipelines from the point where it is delivered from a nearby combined heat and power plant, to the point where it reaches a building that uses the steam for a process of any kind.

These delimitations were set to fit the scope of time available for this thesis. If more time and resources had been available it would be essential to include the whole energy system in the energy investigation, such as processes and equipment that consumes the energy within the different buildings in Gärtuna.
2 METHODOLOGY

The method for this thesis started with a literature study on how an energy investigation is carried out and how to scale it perfectly for expected purpose. The literature study also includes parts that are relevant to the work of this thesis such as the fundamentals of some of the energy systems that are necessary to know of and how to measure the performance of these systems.

Furthermore, a mapping of the energy system in Gärtuna has been carried out. The mapping start with general description of each energy system in Gärtuna and this was done by looking at data collected from maps and process schemes retrieved from Caverion. To showcase the distribution systems, Google Maps was used to collect overview maps and then the maps were edited in Microsoft Paint. To simplify the understanding processes even further, block-schemes of the cooling system and some of the district heat system were made with the program yEd graph editor.

The mapping continued with an inspection of measured data retrieved from Caverion in order to find out how the energy input and output for each energy system. The retrieved data for the steam distribution was collected for year 2014 and the values retrieved represents the mass flow \( \frac{\text{ton}}{\text{month}} \) of steam per month. The data illustrates the steam levels of the whole facility of Gärtuna, and also how much steam that has been distributed to each building within Gärtuna. The retrieved data for the heat distribution was collected for year 2014 and represents the energy distribution in \( \frac{\text{MWh}}{\text{month}} \). The data of the heat distribution is divided as described below:

- The total electric energy consumption for the two heat pumps in facility B653 and the total heat energy provided by these two heat pumps as one number;
- The total electric energy consumption for the two heat pumps in facility B654 and the total heat energy provided by these two heat pumps. It was later found that the electric consumption meter is malfunctioning in B654, so the data was unfortunately excluded from the investigation due to this problem;
- The heat energy provided from condensate heat exchangers;

The retrieved data for the cooling distribution was collected for year 2013. Unfortunately Caverion could not provide data for year 2014 due to an administrative problem. This was unfortunate because these type of data is always varying from year to year, so to make more reliable calculations it would have been preferable to have data from several years. When using data from a single specific year it is always possible that something unusual happened during that specific year, which makes the data incomparable to a “normal” year. The retrieved values represents the cooling energy distribution in \( \frac{\text{MWh}}{\text{month}} \). The provided distribution data was divided as follows:

- For the B661 facility:
  - Total electric input for cooling machine 1, 2 and 3 as one number;
  - Total electric input for cooling machine 4 and 5 as one number;
  - Total electric input for cooling machine 6 and 7 as one number;
- Total cooling energy provided from all cooling machines as one number;
- For the B653 and B654 facility:
  - Total electric input for cooling machine 1 and the cooling towers (V2-system) in facility B653 as one number;
  - Total electric input for cooling machine 2 and 3 in facility B653 as one number;
  - Total electric input for cooling machine 1 and 3 in facility B654 as one number;
  - Total electric input for cooling machine 2 and 4 in facility B654 as one number;
  - Total electric input for cooling machine 5 in facility B654 as one number;
  - Total cooling energy provided to the KB2-system from the B654 facility as one number;
  - Total cooling energy provided to the KB2-system from the B653 facility as one number;
- Total cooling energy provided to the KB1-system from the B654 facility as one number;
- For the B869 facility:
  - Total electric input for cooling machine 1;
  - Total electric input for cooling machine 2 and 3 as one number;
  - Total electric input for pumps etc. in facility B869 as one number;
  - Total electric input for cooling machine 4;

The collected data were later used in order to measure the performance for each energy system. The performance of the steam distribution was decided by determine how much of the provided steam from the power plant that successfully reached the buildings inside Gärtuna for consumption. The performance was calculated as described below:

$$\eta_{\text{steam}} = \frac{E_{\text{steam, internal buildings}}}{E_{\text{steam, Gärtuna}}}$$  \hspace{1cm} \text{Equation 1}

Where

- $E_{\text{steam, internal buildings}}$ = steam energy provided to all the internal buildings in Gärtuna [MWh]
- $E_{\text{steam, Gärtuna}}$ = steam energy provided to the whole facility of Gärtuna [MWh]

How the performance of the heat energy production and cooling energy production is calculated is described in chapter 3.2.1 and chapter 3.2.2.

Based on the performance of the different energy systems it could be decided how much potential of improvement there was for each energy system that was part of the investigation. The cooling energy system was chosen for further search for energy efficiency as it had great potential of improvement and there was also a request from Caverion to further investigate it.

At this stage of the investigation there were several calculations done to quantify the implementation of the improvements. A common calculation was to determine how much electric energy was consumed by motors, and was calculated with the following formula:

$$E_{\text{motors}} = P \times t \ [\text{Wh}]$$  \hspace{1cm} \text{Equation 2}
Where

- $P$ = electric power consumption [W]
- $t$ = time [h]

The heat energy output from a heat exchanger such as a dry cooler is calculated with the following formula:

$$P = C_p \cdot \dot{m} \cdot \Delta t \ [kW] \quad \text{Equation 3}$$

Where

- $C_p$ = specific heat capacity [kJ/kg, K]
- $\dot{m}$ = mass flow [kg/s]
- $\Delta t$ = temperature difference [$^\circ$C]

To calculate the maximum heat transfer in a counter flow heat exchanger, the following formula was used:

$$q_{max} = C_{min} \times (T_h, i - T_c, i) \ [kW] \quad \text{Equation 4}$$

Where

- $C_{min}$ = minimum heat capacity rate $= C_p \times \dot{m} \left[ \frac{kJ}{s} \times \frac{kJ}{kg, K} = \frac{kJ}{s, K} \right]$
- $T_h, i$ = incoming temperature on the hot side [$^\circ$C]
- $T_c, i$ = incoming temperature on the cold side [$^\circ$C]

To calculate the effectiveness of a counter flow heat exchanger, the following formula was used:

$$\varepsilon = \frac{ch(Th,i-Th,o)}{Cmin(Th,i-Tc,i)} \quad \text{Equation 5}$$

Where

- $Ch$ = maximum heat capacity rate $[\frac{kJ}{s, K}]$
- $Th, o$ = outgoing temperature on the hot side [$^\circ$C]

To calculate the heat transfer rate for counter flow heat exchangers, the following formula was used:

$$q = \varepsilon \times C_{min}(Th, i - T_c, i) \ [kW] \quad \text{Equation 6}$$

To calculate what the electric consumption corresponds to in economic costs, the following formula was used:

$$Costs = E_{electric} \times El. \ Price \ [SEK] \quad \text{Equation 7}$$

Where
- $E_{electric}$ = electric energy consumption [MWh]
- $El.Price$ = electrical price [SEK/MWh]

To calculate the pay-off time for the investments the following formula was used:

$$Pay\text{–}off\ time = \frac{Investment\ costs\ [SEK]}{Yearly\ savings\ [SEK/year]} \quad \text{Equation 8}$$

Regarding the energy efficiency implementations, several methods were used to find data and circumstances in order for the calculations to be done. These methods are further described in chapter 5.2 and 5.3.
3 LITERATURE STUDY

3.1 Fundamentals of energy investigations

In order to make a proper energy investigation for this thesis, this part of the literature study will focus on how others have executed an energy investigation and what importance lies within the different parts of it. This thesis will especially look into the guidelines carried out by the Swedish Energy Agency of how to make a proper energy investigation. These guidelines were part of “The Program for Improving Energy Efficiency in Energy-Intensive Industries” also called PFE (Swedish Energy Agency, 2011). The program was introduced in 2005 with the intention to increase the energy efficiency in energy intensive industries (EII).

An energy investigation is made in order to find improvements for a company’s energy system. This is especially beneficial for companies with big energy systems because it could be hard to focus on the correct area of where energy optimization should be made. There could be an obvious room for improvement in a certain component of a process, but it is not sure if that is the best improvement to do if there are other possible improvements on the energy system. It is therefore necessary to make a proper investigation to map the energy system, find all possibilities of improvements and then analyze the priorities of these different improvements.

An energy investigation should include three main steps: description of the facility, mapping of the energy system and the search for energy optimization (Swedish Energy Agency, 2004).

3.1.1 Description of the facility

The facilities involved in the investigation should be described clearly. It is important to describe each facility and its contribution to the energy system that the energy investigation involves. Every each of the different processes within the facilities must be described. A good comprehensive way to describe a facility or process is a flow-scheme or block-scheme that shows a process line and its general components which consumes or produces energy. The block-scheme can later be used to add further details regarding energy usage for certain components (Swedish Energy Agency, 2004).

3.1.2 Mapping of the facility’s energy system

This is where the pre-study work is executed. The work should lay as ground for the oncoming analysis and therefore it should provide energy flows and energy balances. The mapping should comprise the energy usage for each facility and process during one year. The data would preferably be brought from previous energy reports or other sources. You could even be forced to make measurements of your own but at this stage of the investigation the data does not need to be very detailed hence the main objective is to map how the energy
usage is divided between the different processes/components, and to provide reasonable energy balances (Swedish Energy Agency, 2004).

A lot of processes will vary in energy usage during a year so it is important to describe which factors are affecting the processes during a year. Such factors could be of natural cause but it is also important to mention if a problem has occurred during the year forcing a downtime or some kind of deviation.

The mapping should include the whole facility’s energy distribution which displays the relationships between its different energy systems, imported energy and distributed energy, e.g. electricity, heat and fuels. For example, if the facility has systems to produce heat with help of electricity, those systems must have their own energy balances. Also, as mentioned above, factors causing variations in the system must be explained (Swedish Energy Agency, 2004). In investigations where outside temperature is an important factor, it could be necessary to decide how many hours per year a certain temperature occur (also called degree days).

Energy balances describe the relationship between energy flow input and output of a system. The energy balance can later be used for the work of finding how efficient a system is. For example the efficiency of an electrical motor, where the electrical input in relation to the kinetic energy output can show how efficient the motor is. A good way to display an energy balance is to make a Sankey-diagram or show the efficiency of the system, as it shows the relation between consumed and produced energy.

### 3.1.3 Search for energy efficiency measures

The pre-work in form of describing and mapping the facility is fundamental for later stages of the investigation. It is therefore important to do a proper pre-study in order to easier find optimization alternatives at this stage.

The first step is to find where in the facility the potential for improvement is, and study how big the potential is compared to other areas. At this stage it is not necessary to think too much on the economical perspective, as it is more important to find the technical potential of energy optimization in different equipment, and in a later stage find cost effective solutions.

The following parts should be documented when clarifying the potential for system improvements, according to the Swedish Energy Agency: (Swedish Energy Agency, 2004)

- Potential of optimization;
- An estimation of the credibility in the assessment of the potential;
- The reason for the potential;
- Eventual conditions for a realistic potential.

When the potential of improvement is found, it is time to find solutions for energy optimizations. The solutions are of course unique for each facility, but in general there are two kinds of optimization, direct and indirect.
Direct optimization is directly related to the existing equipment that is part of the investigation. The optimization would then consider the potential of improving the equipment, regarding if there are any more modern alternatives on the market, what the technical health of the equipment is, if any new technical solutions could be implemented and how big impact the equipment has on the overall energy consumption of the facility (Swedish Energy Agency, 2004). An example of a simple direct optimization in the industry would be to upgrade existing electrical motors to high efficiency electrical motors. A review on energy saving strategies in the industrial sector shows that switching to energy-efficient motor-driven systems in Europe can save up to 10 billion euros per year in operating costs for the industry. The same study also mention that the pay-off periods by switching to high efficiency motors with 1.5 horse power, is less than two years which later in the literature review will show of great importance (Abdelaziz, Saidur and Mekhilef 2010, 160-161).

Indirect optimization could be preferred if the equipment is part of a larger energy system. The energy consumption in that particular equipment could then be lowered by implementing efficient technical solutions to other parts in the energy system that will benefit the energy usage in the equipment in an indirect way (Swedish Energy Agency, 2004). Such optimization could be to prevent leakage in an air compressor systems. The actual compression of the air in compressor is not touched, but instead the leakages are prevented in other parts of the system such as in leaking joints, untightened connections etc. It is shown that air leaks is the single greatest source of energy loss in manufacturing facilities with compressed-air systems and can correspond to a waste of 20-50 % of the compressor’s output (Abdelaziz, Saidur and Mekhilef 2010, 161).

When a technical solution has been found that will enhance the energy system it is necessary to also reason whether it is practically possible or economically viable. The solution can be practically impossible due to surroundings causing problems or that the operation of updating the system is too severe. The most common problems are of course too high investment costs or running costs, but the solution should yet be documented for future use as there is a potential of lower investment cost. Project Highland was a similar program to the PFE, but included 340 energy audits in six municipalities of which 139 audits were made at manufacturing industries. 47 of the manufacturing industries were evaluated and the study shows that the total number of proposed energy efficiency measures for the evaluated companies was 643. Furthermore, only 142 measures have been implemented and 139 measures were planned at that point of time (Thollander, Danestig and Rohdin 2007, 5779). This shows that it is important to document every single measure, even if it is not investigated any further than just the idea of it.

Each and every solution for optimization must be documented for further work. According to the Swedish Energy Agency the following points should at least be part of the optimization solution documentation:

- Which types of optimization measures considered,
- The result from the assessment of the solution should be presented, as in practical credibility, economical aspects and energy savings (in rough numbers),
• In what extent and when actual technical measures should be investigated further. (Swedish Energy Agency, 2004)

If a solution is considered worthy an implementation to the system it should be neatly quantified with assessments and calculations. After all, the technical solution should lay as ground for the investment basis and should therefore include properly performed technical and economical calculations. The following points should part of the documentation of the investment basis according to the Swedish Energy Agency:

• A description of which measures that should be taken, which equipment and systems that is affected and the function of the measures. It should also be mentioned under which circumstances the measures should take place,
• Predicted yearly reduction of energy usage regarding energy system effects,
• Predicted yearly reduction of energy costs,
• Investment cost,
• Payback time,
• Expected impact on other energy usage and other costs,
• When the measure can take place.
(Swedish Energy Agency, 2004)

In terms of the PFE project, it was necessary for the participating companies to implement energy efficiency measures with pay-back times of no longer than 10 years (Swedish Energy Agency, 2014). However, other studies shows that the required pay-back period for energy efficiency measures are much lower for many companies. In an empirical study made, covering 500 small to medium sized German companies representing eight different industries, it was shown that less than 50 % of the companies conduct a systematic economic calculation to determine the return of the investment. Out of those 50 %, the average required pay-back time was at that point of time about four years (Gruber and Brand 1991, 279-287). A study of the energy management practices in Swedish EII studied among other things the pay-off criteria for the pulp and paper industry and the foundry industry, of which contributes to more than 50 % of Sweden’s annual energy use. The study shows a pay-off criterion of three years or less in most companies when it comes to the energy efficiency investments (Thollander and Ottoson 2010, 1128).

3.2 Fundamentals of the vapor compression cycle

A big part of this energy investigation is about the cooling and heat production in Gärtuna. For the energy investigation to proceed as smooth as possible it is fundamental to have knowledge about refrigeration and how the vapor compression cycle works, as all the cooling machines and heat pumps uses this concept.
The cycle for cooling machines and heat pumps can be very similar. The purpose of refrigeration is to reduce the temperature of a substance below the temperature of the surroundings, while the purpose with heat pumps is to extract heat from a lower temperature source and reject it to a higher temperature source. Hence the difference between a heat pump and a refrigeration system is the choice of temperature levels (Granryd et al. 2005, 3:1).

The typical vapor compression cycle consist of four main components; the compressor, condenser, expansion valve and the evaporator. Within the cycle there is a decided refrigerant working which has characteristics suited for its purpose. The choice of refrigerant is always depending on the characteristics of the system. As displayed in Figure 1, the compressor gives an energy input to the system which is required to lift the refrigerant from the cold region ($T_C$) to the higher temperature region ($T_H$). After the compressor the refrigerant is now heated with a higher pressure and is in gaseous form. The condenser later extracts the heat in the refrigerant to another medium (this is where a heat pump provides heat) and gets liquidified. The refrigerant then reaches the expansion valve where the pressure is lowered hence lowered temperature. The refrigerant is then heated by a medium in the evaporator (hence it is here a refrigerating system is providing cooling) and is gasified once again (Moran et al. 2011, 592-596).

Figure 1. A TS-diagram of a general vapor compression cycle to the left, and the main components of the cycle to the right (Moran et al. 2011, 592-596).

### 3.2.1 The coefficient of performance

In a refrigerant cycle there is always work sacrificed in order to have a refrigerating effect. The ratio between the refrigerating effect and the cost of work is called the coefficient of performance of the refrigerating cycle and is named COP2. Independent of which type cycle, the coefficient of performance always has the general definition (Granryd et al. 2005, 3:1):

$$COP_2 = \frac{\dot{Q}_{\text{in}}}{E} \quad \text{Equation 9}$$
Where

- \( Q_{in} \) = the heat transferred to the cycle, corresponding to the refrigerating effect [kW]
- \( E \) = the required work input for the system to work [kW], hence not only the compressor work \( W_c \)

The COP value for heat pumps is similar, but instead of using the refrigerating effect it uses the heat rejected from the cycle (\( Q_{out} \)), hence:

\[
COP_1 = \frac{Q_{out}}{E}
\]  \hspace{1cm} \text{Equation 10}

Where

- \( Q_{out} \) = the heat rejected from the cycle, corresponding to the heat effect [kW]
- \( E \) = the required work input for the system to work [kW], hence not only the compressor work \( W_c \)

To calculate the theoretical COP-value one can also use the following formulas for COP1 and COP2 respectively:

\[
COP_2 = \frac{T_C}{T_H - T_C} \times \eta_C
\]  \hspace{1cm} \text{Equation 11}

\[
COP_1 = \frac{T_H}{T_H - T_C} \times \eta_C
\]  \hspace{1cm} \text{Equation 12}

Where

- \( T_H \) = the temperature on the condenser side of the cooling machine or heat pump [K]
- \( T_C \) = the temperature on the evaporator side of the cooling machine or heat pump [K]
- \( \eta_C \) = correction factor

Without the correction factor \( \eta_C \) in the equation, the COP-value is calculated for an ideal cycle that is made up of a completely reversible process, hence no energy losses. However, no existing system is ideal and therefore the correction factor is added to include the energy losses for the system. The correction factor could be calculated but has a recommended value of 0.4 - 0.6 (Granryd, et al. 2005, 2:10). The correction factor depends on several efficiencies in the different components of a cooling machine or heat pump and is calculated as described below:

\[
\sum \eta_{elm} \times \eta_{mt} \times \eta_{mk} \times \eta_{cd}
\]  \hspace{1cm} \text{Equation 13}

Where:

- \( \eta_{elm} \) = the electric motor efficiency
- \( \eta_{mt} \) = the transmission efficiency
- \( \eta_{mk} \) = the total isentropic compression efficiency
- \( \eta_{cd} \) = the Carnot efficiency of the refrigerant
Ultimately the COP value should be as high as possible as the less of the energy input is, compared to the energy output, the more efficient the system will be.

### 3.2.2 The overall coefficient of performance

The cooling systems in Gärtuna are very big and involves many cooling machines and cooling towers to provide cooling energy. Additionally, the measured electric energy consumption and generated heat or cooling energy are not divided for each and every cooling machine which makes it impossible to calculate the COP-value for each cooling machine and heat pump specifically. To measure the performance of the cooling and heat systems, the performance of the cooling systems and the heat pumps will instead be measured on the overall performance for each facility that contributes to the cooling energy production and the district heat energy production produced by heat pumps. The performance for each cooling and heat production facility will still be based on the same principle as the coefficient of performance, where the overall energy input to the process is compared to cooling or heat energy output. The overall COP-value will be calculated with the formulas presented below:

\[
OCOP_1 = \frac{E_{\text{out}, \text{heat}}}{E_{\text{in}}} \quad \text{Equation 14}
\]

\[
OCOP_2 = \frac{E_{\text{out}, \text{cooling}}}{E_{\text{in}}} \quad \text{Equation 15}
\]

Where

- \(OCOP_1\) = the overall heat coefficient of performance
- \(OCOP_2\) = the overall cooling coefficient of performance
- \(E_{\text{out}, \text{heat}}\) = the total heat energy output [MWh]
- \(E_{\text{out}, \text{cooling}}\) = the total cooling energy output [MWh]
- \(E_{\text{in}}\) = the total electrical energy input [MWh]

This way of measuring the performance of more than one heat pump or cooling machine is not common, but it has been used in other studies. In a study of “A versatile energy management system for large integrated cooling systems” where parts of the study was the performance of mine cooling systems, they calculated the total system COP-value for a total of four chillers connected to each other (Du Plessis et al. 2012, 321). In another project to investigate how energy consumption and annual costs depends on the designed temperatures of a heat recovery battery, the overall coefficient of performance was used to calculate the performance of heat pumps and heat recovery batteries used in the same system (Berglund 2012, 17).
3.3 Flash steam recovery system – a part of the heat recovery system

Gärtuna receives steam from a nearby power plant. The steam itself has a high pressure and a high temperature. This steam is utilized within the buildings of Astra Zeneca for usage to processes and climate control. At the point where steam turns into condensate it is either sent to the sewage or to the condensate pipeline back to Igelstaverket. The condensate itself can be of a very high temperature and pressure, thus having a high energy content. The condensate will at some point experience a pressure drop from the steam pressure to e.g. atmospheric pressure. If the condensate at high pressure and near saturation temperature suddenly experience a pressure drop below saturation, it will instantaneously produce so called flash steam (Vedavarz, Kumar, Hussain 2007, 15-39).

Let’s say that the steam provided from the power plant has a pressure of 10 bar (gauge pressure). When the steam has liquefied to condensate, the saturated water in the condensate will have a temperature of about 184°C and a specific enthalpy of 782 kJ/kg. When the condensate is sent back to the power plant it has a pressure of for example 0.5 bar (gauge pressure) thus a saturation temperature of about 111°C and a specific enthalpy of about 468kJ/kg. At some point the condensate at 10 bar will experience the pressure drop to 0.5 bar and must immediately assume the saturation conditions at the lower pressure. This means that a lot of excessive energy is released with the pressure drop. This excessive energy is a proportion of the water turning into so called flash steam. This flash steam can either be released to the atmosphere or be utilized to recover the heat energy by condensing the flash steam (Spirax-Sarco 2007, 3.13.1-7). This can be done in so called flash vessels and how the vessel looks and how the heat recovery is made depends from case to case, but this technology is used in a numerous of places within Gärtuna facility in order to recover the heat from flash steam.

A picture of a general flash vessel is displayed in Figure 2. Steam/condensate enters at “blowdown” and is divided to either flash steam or condensate. The flash steam is later
distributed to some sort of heat recover system.

*Figure 2. Flash vessel (Spirax-Sarco 2007, 3.13.5).*
4 DESCRIPTION AND MAPPING OF THE FACILITY IN GÄRTUNA

The facility is situated south-east of Södertälje, in a small area called Gärtuna. AstraZeneca runs both medicine production and research within the facility and has around 3000 employees (LIFe-rime.se, 2014-03-14). The whole facility viewed from above is displayed in Figure 3. Note that not all buildings are included in this thesis work, this will be explained further in the description.

![Facility View](image)

**Figure 3. The facility in Gärtuna viewed from above.**

By looking at the facility from an energy perspective it has a very large energy system. First of all the buildings within the facility has a complex climate system that uses both district heat, steam and cooling to maintain climate control such as humidity and temperature. The ventilation is also crucial in order to keep a clean environment in favor of medicine production quality and a healthy working environment. To provide heat to the climate control, AstraZeneca (managed by Caverion) both import heat from the power plant Igelstaverket, and produce their own heat with heat pumps and condensate heat exchangers. The cooling is produced by cooling machines in different buildings which will be described more detailed in chapter 4.2.

Apart from the climate system, AstraZeneca also needs heat, steam and cooling for their different medicine production units to operate. The steam is directly imported from Igelstaverket and the cooling is produced in different buildings operated by both AstraZeneca and Caverion, within the facility. All electricity is produced outside of the facility and is bought from the company Telge Energi.
As mentioned earlier in chapter 1.1.3, this thesis does not include the whole energy system in Gärtuna, but only the distributed energy managed by Caverion. The main distributed energy both managed by Caverion and included in this report is the following:

- The steam distribution; from the input point of the steam provided by Igelstaverket, until the steam enters a building for utilization at some kind of process (also the distribution of the condensate back to the power plant).
- The heat distribution; from the input point of the district heating provided by Igelstaverket, to the point where the heat enters a building for consumption.
- The heat recovery system is also a part of the thesis work which includes heat pumps and flash steam recovery exchangers managed by Caverion.
- The cooling systems managed by Caverion.

4.1 The steam distribution

Figure 4 shows the steam being produced by the power plant Igelstaverket and then directly distributed to the facility in Gärtuna. The steam inside the facility of Gärtuna is distributed through pipelines both underground and above ground. The red lines are roughly displaying the distribution of the steam.

Figure 4. Rough explanation of the steam distribution in Gärtuna.
Caverion is responsible for the maintenance of the pipelines within the facility in Gärtuna until the point where the steam is used on behalf of AstraZeneca. Caverion also manage some of the climate control systems that uses steam for certain purposes. The condensed water from the steam is later distributed back to Igelstaverket through pipelines located close to the input flow pipelines. Some of the heat recovery system is attached to the steam condensation side as well to recover the heat generated from flash steam.

### 4.1.1 Mapping of the steam distribution

The steam distribution might seem to be pretty simple to map as it is only a matter of distributing steam through pipes from one point to another. However there is a lot to comprehend as steam contains high amounts of energy. The point where the steam is led through heat exchangers or used for some kind of processes is not included in this thesis work, but there are several components to consider as there are also some heat recovery systems attached to the condensate side of the steam distribution.

When mapping the distributed steam, the interest lies in knowing where the heat losses can and do occur. Heat losses in steam distribution are mostly caused by condensation of steam in the pipes, as the heat is lost to the surroundings of the pipes. The rate of the condensation is depending on the steam temperature, the ambient temperature and the efficiency of the insulation material (Spirax-Sarco 2007, 2.12.4). Throughout the distribution of the steam there are also important components to consider such as steam traps, air vents and valves.

The energy balance of the steam distribution can be made from measurements done by Caverion. They measure the amount of steam imported from Igelstaverket and then measure the delivered amount of steam to each building within the facility. The efficiency of the steam distribution for 2013 did not look particularly good. Out of 78000 tons of bought steam at year 2014 from Igelstaverket, the distributed steam to all buildings within Gärtuna was only 42000 tons, which means a total loss of about 46 % of bought steam during the whole year. The efficiency of the steam distribution system can be calculated by dividing the delivered steam with the bought steam. The steam distribution efficiency during year 2014 is presented monthly in Figure 5:
To see how the steam efficiency was calculated and what numbers were used such as mass of delivered steam and consumed steam, proceed to the appendix 1.

The numbers presented in Figure 5 are obviously alarming as it is not expected that the steam delivery system should lose close to 50% of all the steam supplied.

4.2 The cooling distribution

There are several cooling machines within the facility providing cooling for both climate control and production processes. Caverion manages some of the cooling where they are responsible both for the refrigeration processes and the distribution. The area of distribution then covers the produced cooling input up until the point where the cooling energy is consumed by a building or process ran by AstraZeneca. Figure 6 displays where the cooling machines managed by Caverion are located within the facility.
The cooling distribution system is sectioned in a certain way so that it has two different modes to distribute cooling energy in Gärtuna. One summer mode and one winter mode. How this works more in detail will be explained further in the chapter 4.2. In general, the facilities consists of the following heat and cooling energy producing systems:

- B661: 7 cooling machines
- B654: 3 comfort cooling machines (+2°C), 3 process cooling machines (-25°C) and 2 heat pumps
- B653: 3 cooling machines, 2 heat pumps and a large cooling tower facility

Table 1 shows how the distributed cooling energy is produced between the different cooling production facilities (with the heat pumps included).

*Table 1. Distributed heat and cooling between the different cooling production facilities.*
The cooling system in Gärtuna is very complex due to several distribution systems with different cooling temperatures and a varying cooling demand that obviously reaching its peak during the summer. Due to the different distributing temperatures, there are several types of refrigerants distributing the cooling energy. The most common distributed cooling temperature in Gärtuna is +2 °C and the system delivering this is called “KB2”. The cooling media distributing this temperature consists of a mixture between water and ethylene glycol. Another cooling media with the same properties of mixture of water/ethylene glycol and temperature as the “KB2” system is called “KB1” and is distributed from the B661 facility. Another distributing temperature is as high as +19 °C and the “refrigerant” is pure water. This system is called “V2”. There is also process cooling system which delivers a temperature of -25 °C, this system is not managed by Caverion but is still connected to the other systems on the condenser side of the machines.

These different systems are operated differently depending on season of the year and some systems are also connected to heat pumps which makes this part of the facility very complex. To explain the cooling and some of the heat distribution as accurate as possible, this chapter will start by describing the different cooling systems depending on which distribution temperature system there are connected to. Note that there can be several different distribution systems for the same distribution temperature that are still named the same. For example the “KB2” system with a distributing temperature of +2 °C is actually several different systems independent from each other.
When each system is described more closely, the OCOP2-value will be presented for each facility in order to show how efficient the systems are.

### 4.2.1 The V2 system (+19°C)

The V2 system is the most simple as there are no cooling machines involved and it is operated from only one facility called B653. However, the system is also connected to two heat pumps and provides cooling energy for almost the whole facility of Gärtuna. Appendix 2 displays a created block-scheme representing the facility and how the heat pumps are connected to the cooling system.

The V2 system is supplying the same buildings during the whole season, and as can be seen in appendix 2 the only cooling systems are the heat pumps and cooling towers. When the returning water enters the facility it enters a tank and is later cooled by the evaporator side of the two heat pumps, and by cooling towers. After the water is cooled it is sent to a cool water tank and is later fed via pumps and filter to the cooling system. Because of the open system where water is directly cooled from air, the water system can get dirty and is therefore filtered before leaving the facility. There is also chemical treatment of the water to prevent legionella and high amounts of certain substances such as lime.

The cooling towers use the outdoor air to cool the water and some of the water is evaporating to the air when cooled. As the system loses water in the evaporation there is a need of additional water to fill the system which is brought from the city water. During hot summer days the fill water can also work as a coolant to the cool water tank as the tap water is cool enough to lower the temperature in the tank.

The V2 system is the only system that has not been mapped in terms of measures on the performance, such as how much electricity the cooling towers have consumed or how much cooling energy has been delivered.

### 4.2.2 The KB2 and KB1 system (+2°C)

The KB2 and KB1 system is much more complex than the V2 system. It could be said that during the winter, the KB2 and KB1 system is connected between the facilities B653, B654 and B661. It is then only the cooling machines at B654 that are running and supplying the whole cooling distribution net of which delivers a temperature of 2 °C. The facility B869 with its cooling machines is also delivering a temperature of 2 °C but is always connected to its own system which supplies two buildings. Appendix 3 shows a block-scheme that gives a general overview of the relationship during winter sectioning.

During the summer when the cooling demand rises, the KB2 and KB1 system is sectioned in a special way so that each cooling production facility (B654, B53, B661 and B869) delivers cooling media to their own separate buildings. This can be seen in an overview of the sectioning in appendix 4.
The sectioning itself will not be described in detail as the distribution system is too big to be covered in this thesis. It should be enough for the mapping to cover which machines and facilities that is operated at which time.

As B654 is connected to both B653 and B661, it could be said that this facility is the heart of the cooling distribution system in Gärtuna. Therefore it becomes natural to describe this facility first. It has three cooling machines supplying the KB2 system. This is visualized in a rough overview of the B654 KB2 system in appendix 5. The three cooling machines uses a mix of the V2 water and the media from the evaporator side of two heat pumps as cooling liquid on the condensing side of the machines. As mentioned above, during winter the three cooling machines supply cool to the KB2 system via different sectioning in the distribution pipes, and to the KB1 system via a heat exchanger in the B661 building.

The B661 facility is as mentioned distributing cooling to the KB1 system. During winter the cooling is produced only by the heat exchanger connected to the KB2 system, but during summer it has seven cooling machines to provide cooling production. How the B661 cooling distribution works is briefly described in a block-scheme that can be viewed in appendix 6. Two of the cooling machines are using dry coolers to cool the media on the condensing side. The rest of the machines uses a media that is cooled via a water tank and cooling towers.

The B653 facility provides as mentioned both cooling media to the V2 system and KB2 system. The general overview of how the process look is displayed in a block-scheme in appendix 7.

The smallest facility both in size and cooling power is the B869 facility. It was once built as a temporary building to provide cooling but is still used. The cooling machines are small and simple and has a direct cooling on the condense side of all machines. The basic overview of the facility is displayed in appendix 8.

### 4.2.3 Process Cooling

B654 also contains two cooling machines supplying process cooling which is operated by AstraZeneca and delivers a temperature of -25°C. The only way that this is connected to Caverion’s part of the system is a heat exchanger on the condenser side of the cooling machines that pre-cools the media before it is cooled further in cooling towers. This can be viewed in a block-scheme in appendix 9.

### 4.2.4 Mapping of the cooling production

To investigate how efficient the cooling production is in Gärtuna, it is necessary to calculate the overall coefficient of performance. The OCOP-values have been calculated with the

\[
OCOP_2 = \frac{E_{\text{out, cooling}}}{E_{\text{in}}} \quad \text{Equation 15 presented in chapter 3.2.2.}
\]
All OCOP2-values will be compared to a theoretical calculated OCOP2-value that represents the general cooling distribution in Gärtuna. The theoretical OCOP2-value will be calculated based on the temperatures on the condenser and evaporator side of the cooling machines. The calculation of the theoretical OCOP2-value is based on the calculation of the COP2-value as described in \( \text{COP}_2 = \frac{T_C}{T_H - T_C} \times \eta_C \) Equation 11 but modified to calculate the overall coefficient of performance. To do this, a mean distributing temperature on the condenser side and the evaporator side of the cooling machines will be calculated. The largest cooling distribution systems in Gärtuna is distributing a temperature of 2 °C. The evaporator side of the machines is exchanging heat energy so that the distributing temperature is achieved. The evaporator temperature is thus assumed to be -3 °C because of an expected temperature difference of 5 degrees in the evaporator (Ekman, 2015). The temperature on the condensing side differs between the different machines but a general temperature of 29 °C has been brought out as a mean value on the “cooling” media on the output of the condenser for each cooling machine by looking at the live process overview provided by Caverion. The expected temperature difference is assumed to be 2 °C in the condenser (Ekman, 2015), hence a condensing temperature of 31 °C is decided. The correction factor is set to be 0.6 because it is expected to have a greater value since the machines are of such relatively big scale (Ekman, 2015). The theoretically calculated OCOP2-value is thus calculated with the following formula:

\[
\text{OCOP}_{2,\text{theoretical}} = \frac{T_2}{T_1 - T_2} \times \eta_C = \frac{270}{304 - 270} \times 0.6 = 4.76
\]  

Equation 16

- \( T_1 \) = the temperature on the condenser side of the cooling machines [K]
- \( T_2 \) = the temperature on the evaporator side of the cooling machines [K]
- \( \eta_C \) = correction factor

The values assumed for above calculation was brought during winter on the machines that was running for that time. The OCOP2-value is varying during the season because of the low cooling energy demand during winter but is rising to much higher levels during summer. The cooling energy demand is rising during summer season because the facilities need to be cooled more when it is hot outside. This forces a lot more machines and sub-processes to run during summer to meet the cooling demand. The OCOP2-value should especially be high during winter due to that it is easier to achieve low condenser temperature. The amount of energy that is needed to provide the low condenser temperature is also higher during summer, which affects the OCOP2-value negatively according to \( \text{OCOP}_2 = \frac{E_{\text{out, cooling}}}{E_{\text{in}}} \)

Equation 15. An example of how easier it is to cool the condenser side during winter is the heat pumps. The heat pumps works as coolers for the condensing side of the cooling machines, and winter season is the season where heat pumps in Gärtuna works best and provides most heat (and cooling for the cooling machines), hence the cooling machines has no problem of achieving good temperatures for the condensing side during winter. The cold outside air temperature also contributes to easier cooling for some of the cooling towers.
4.2.4.1. Cooling production facility B869

The COP-value of B869 is calculated as the achieved cooling energy divided by the electric energy input for all cooling machines, pumps and miscellaneous components needed for the cooling production. The data is measured at year 2013 and the OCOP2-value during that year is displayed in Figure 7. As mentioned above the B869 uses 4 cooling machines and the data used for the calculation of OCOP2 is provided in appendix 10.

Figure 7. OCOP2-value for the B869 facility.

4.2.4.2. Cooling production facility B661

The OCOP2-value for the B661 facility is calculated in the same way as B869. The data is measured at year 2013 and displayed in Figure 8. During winter the cooling is provided by a heat exchanger connected to the B654 facility which produces enough cooling energy to not being forced to run any cooling machines within the B661 facility. The OCOP2-value gets higher during winter due to less energy input for the facility as it only need pumps and various peripherals to acquire the energy demand. The data provided to calculate the OCOP2-values is displayed in appendix 11.

Figure 8. OCOP2-value for the B661 facility.
4.2.4.3. Cooling and heat production facility B653 and B654

The calculation of the OCOP2-value for the B653 and B654 facilities differs from the previous facilities. The optimal scenario for the calculation of OCOP2-value would be to have the electric energy input for every cooling energy achieved from each facility or system, but in this case the energy inputs and outputs are somehow misleading.

The electric energy input is measured for the whole B653 facility but at the same time the overall cooling production is not covered. The cooling energy achieved from the V2 system is not measured but the electric energy input still is. Another source of error is that the B653 facility contains two heat pumps that uses part of the electric energy input data provided, but at the same time the heat energy achieved is not provided. All these errors contributes to a lower OCOP2-values as the electric energy input is overrepresented. It should also be mentioned that the production of process cooling energy is part of the calculation. All data is measured at year 2013 and the OCOP2-value during the year is displayed in Figure 9. The data provided in benefit for the OCOP2-calculation is displayed in appendix 12.

![Cooling Production OCOP2 B53 and B654](image)

*Figure 9. OCOP2-value for the B653 and B654 facility.*

The total achieved cooling energy divided by the total energy input for mentioned systems will retrieve the overall coefficient of performance of the cooling production. The total OCOP2-value during year 2013 is displayed in Figure 10. The data provided for the calculation is presented in appendix 13.

![Cooling Production OCOP2 in Gärtuna](image)

*Figure 10. The overall COP-value for the cooling production in Gärtuna.*
4.3 The heat distribution

The heat system consists of both district heat water and heat water produced by the heat recovery system. The heat provided by Igelstaverket is supplied via the district heat system and is roughly displayed in Figure 11. As can be seen in Figure 11, the district heat is not only supplying Gärtuna, but also parts of southern Stockholm and a prison called Hall which is located south of Gärtuna. The red lines roughly representing the district heat pipelines.

![District heat distribution in Gärtuna.](image)

The management of the district heat distribution is similar as for the steam distribution. Caverion is responsible for the maintenance of the pipelines from the intake point up until the actual consumption within a building, and also the management of some of the climate control within the different buildings.

Additionally the facility has a heat recovery system which includes several heat pumps and heat recovery exchangers. Most of the heat recovery system is managed by Caverion, but there are a few exceptions. How the heat recovery system works will be explained further in chapter 4.3.1, but the heat pumps managed by Caverion is located in the two buildings B654 and B653 which is displayed in table 1.
4.3.1 Mapping of the heat distribution

The heat production comes from heat pumps, district heat system and heat recovery system. The heat pumps are described in chapter 4.2 and how they interact with the cooling system. The heat produced by the heat pumps are used in the local district heat system in Gärtuna together with distributed heat from the district heat system from Igelstaverket. Also, there are flash heat recovery systems installed in various places around in Gärtuna. The performance of the heat distribution is determined by looking at the different OCOP1-values of the heat pumps and steam recovery systems.

To see the performance of the heat pumps it is necessary to measure the produced heat and the electric energy input for the heat pumps. The OCOP1-value can then be calculated with the $OCOP_1 = \frac{E_{\text{out, heat}}}{E_{\text{in}}}$ Equation 14 presented in chapter 3.2.2.

To understand how good or bad the performance is, a theoretical OCOP1-value will be calculated based on the temperatures of the condenser and evaporator side of the heat pumps. The calculation of the theoretical OCOP1-value is based on the calculation of the COP1-value as in $COP_1 = \frac{T_H}{T_H - T_C} * \eta_C$ Equation 12 but modified to show the overall coefficient of performance. To do this, a mean distributing temperature on the condenser side and the evaporator side of the heat pumps in B654 and B653 has been calculated. The mean heat distribution temperature for the district heat is 49 °C. As mentioned in chapter 4.2.4, a temperature difference of 2 °C can be assumed, hence a condensing temperature of 51 °C is achieved. A mean value of the outgoing temperatures on the evaporator side of the heat pumps is 14 °C and according to the assumption made in chapter 4.2.4, the temperature on the evaporator side is assumed to be 9°C. The correction factor is assumed to be 0.6, hence the OCOP1-value can be calculated with the following formula:

$$OCOP_{1, \text{theoretical}} = \frac{T_1}{T_1 - T_2} * \eta_C = \frac{324}{324 - 282} * 0.6 = 4.63$$  \hspace{1cm} \text{Equation 17}

- $T_1$ = the temperature on the condenser side of the heat pumps [K]
- $T_2$ = the temperature on the evaporator side of the heat pumps [K]
- $\eta_C$ = correction factor

The COP1-value will vary during the season. The temperatures achieved for the calculation above is achieved during winter, but during summer the value can differ a lot. During winter there is a high heat demand because of the obvious reason that it takes more heat to heat the facilities. The consequence of a high heat energy demand is that much of the heat delivered is also consumed, which leads to a higher temperature difference between the output and input temperature for example the heat pumps. During summer however, the heat demand is much lower, hence a lower mass flow and a smaller temperature difference. By looking at $e_P = C_p \cdot \dot{m} \cdot \Delta t$ [kW] \hspace{1cm} \text{Equation 3}, a temperature difference and mass flow will cause a decrease in heat power output, hence the heat pumps will deliver less heat energy. The smaller heat demand forces the heat pumps not to run at all or run at small loads which is highly affecting the efficiency of the machines and causes smaller OCOP1-values. The outcome is that the OCOP1-values will be smaller during summer than during winter.
As mentioned before there are two heat pumps in the B653 facility and two heat pumps placed in the B654 facility. The OCOP1-value for B653 during year 2014 is displayed in Figure 12. The data of electric energy input and heat energy output for the facility is provided in appendix 14.

**Figure 12. OCOP1 value for B653 during 2014.**

The OCOP1-value for B654 was not calculated due to an unfortunate event explained in chapter 2.

The heat recovered from the flash steam heat recovery systems (or condensate heat exchangers) is very beneficial as it uses very little electric energy input to achieve the recovered heat. The required energy for pumps and various peripherals to make the systems work is not measured but can be expected to be irrelevant.

Figure 13 displays the total local heat production from all the heat pumps and the condensate heat exchangers in Gärtuna for year 2014.

**Figure 13. Total local heat production in Gärtuna at year 2014.**
To give a good perspective of how good the performance is on the local heat production, a total OCOP1-value has been calculated for Gärtuna, where the total heat produced from the heat pumps in B653 and heat recovery system is divided with the electric energy input for the heat pumps in B653. The data for the calculations are displayed in appendix 15. It should be remembered that the heat pumps in B654 is not included due the error explained in chapter 2. The OCOP1-value for the total local heat production in Gärtuna is presented in Figure 14.

![Total OCOP1 in year 2014, Gärtuna](image)

*Figure 14. COP1-value for the total local heat production in Gärtuna for year 2014.*

5 SUGGESTIONS FOR ENERGY EFFICIENCY SOLUTIONS

5.1 Potential of improvement

The mapping of Gärtuna provides information of how the energy flows looks for steam distribution, district heating and cooling distribution. Thanks to the information, a general perspective of which areas the potential of improvements and energy optimization are highest can be found. This chapter will present the potential of improvement for each energy distribution (steam, heat and cooling) and also conclude what the thesis will focus on for that specific energy distribution.

5.1.1 Potential of improvement for steam distribution

According to the mapping of the steam distribution it is pretty clear that this area has a huge area of improvement. With a mass flow loss of about 50 % at some months it is clear that something is wrong. If the numbers are correct, the total loss of steam in year 2014 was
35792 tons. Caverion themselves has done an approximate estimation of the amount of energy in each ton of steam to be 770 kWh for the set pressure, temperature and flow in the steam distribution system. The exact data for of the pressure, temperature and flow could not be retrieved for this thesis which makes it impossible to confirm said estimation. Given the data of how much steam losses there was at year 2014, the amount of heat loss just in the loss of steam would be:

\[ 35792 \times 0.77 = 27560 \text{ [MWh]} \]

The price that AstraZeneca pays for the steam distribution from Igelstaverket is 495 SEK/MWh. Given the heat loss and the price, the amount of lost money due to steam losses is:

\[ 27560 \times 495 = 13 \, 642 \, 087 \text{ SEK} \]

It should be mentioned that Gärtuna is sending (selling) some of the condensate back to Igelstaverket for a small amount of money compensation, but it has been told that this sum is irrelevant in proportion to what the steam cost to buy, as both the price is small and the amount of condensate sent back is small.

There are several possible reasons why the loss of steam shows to be so high. The most likely would be that several of the steam flow meters are broken an unrealistic amount of steam loss. Another reason for the steam loss could be leakage in some of the pipelines.

Another big heat loss factor could be wet insulation material. There has been cases in Gärtuna where the ground water has leaked into big parts of the pipe’s insulation so that the insulation becomes wet. If the insulation becomes wet, the heat loss can be as much as 50 times greater than if the pipe was surrounded by air (Spirax-Sarco 2007, 10.5.3). If the pipe has more heat losses, the higher amount of steam will condensate on the way of distribution and the more steam will be lost.

The potential of optimization for the steam distribution can seem both high and necessary. However, the amount of work to investigate the area is not in comparison with the amount of time available for this thesis. It is also said by the personnel at Caverion that the probability of reading errors of the steam flow is high, and since these data are substantial for further investigation it is better to look elsewhere for optimizations. Instead it will be a topic for the chapter 8.

### 5.1.2 Potential of improvement for cooling distribution

By looking at the mapping of the cooling distribution, where the OCOP-values should be as high as possible, the potential of improvement is definitely arguable. Since the OCOP2-values are rarely above 3, and the calculated theoretical OCOP2-value is 4.76, the potential of improvement can be expected to be high. There are a lot of areas which needs or can be improved and because of the complex system it is suitable for the thesis work. By comparing the cooling system with the steam distribution, where the only system to investigate further would be the pipelines, the cooling distribution has a lot more areas with potential of
improvements. For example the cooling machines have its many components and surrounding systems (e.g. pumps, compressors, cooling towers etc.) and they also have different synergies with other systems such as the heat pumps.

The cooling system is more diverse when it comes to its different components and processes. Every cooling tower, every pump and every component has its own energy balance which can be improved and it is therefore easier to find improvements that won’t take too much time investigate. Caverion has also requested further investigation for the cooling system.

Because of the relatively high potential of improvement, easy access and the fact that Caverion requested further investigation of the system, this thesis will focus on finding energy efficiency solutions for this area.

### 5.1.3 Potential of improvement for the heat distribution

Overall the heat distribution seems to be working very well by looking at the overall coefficient of performance where the actual OCOP1-values are much higher than the theoretical OCOP1-value of 4.63. The heat pumps all have a high OCOP-value and the condensate heat exchangers contributes to the heat distribution in a satisfied way. The delivered heat from Igelstaverket cannot be judged due to lack of data. The heat pumps also contributes to the cooling system which is good. However the reading error for the heat pumps in B654 will be a topic for chapter 8.

The potential of improvement seems to be low for the heat distribution. The thesis work will not focus on this subject in search for energy optimization improvements.

By mapping and analyzing the potential of improvements for Gärtuna it was clear that the cooling distribution showed a potential of improvement and it was also requested by Caverion to investigate it further. To implement energy efficient solutions usually means reducing the energy consumption for the facility and make it more efficient so that the energy systems can utilize more of the potential energy. This thesis will suggest two energy optimization solutions in order to reduce the electrical energy consumption and thereby lower the energy consumption costs for AstraZeneca.

### 5.2 Suggestion for energy efficiency solution 1: upgrade of fan motors

As mentioned in chapter 4.2.1, the cooling of the V2 system is done both by heat pumps and cooling towers in building B653. There are in fact two heat pumps and 18 cooling towers. During the period of October-May, the cooling can easily be achieved by running the two heat pumps and four of the cooling towers. It is not until the temperature gets in the area of 20-30 °C (which usually takes place during summer in June-September) that all of the cooling towers are running. 16 out of the 18 cooling towers has the principle scheme
according to Figure 15. This type of cooling tower has one fan at the top of the tower, powered by one electrical motor.

The towers themselves are divided in groups. Two out of the 18 cooling towers are newer and are separated from the rest so that each of the two towers has its own water feed and output. The remaining 16 towers were installed in year 1999 and is therefore a bit older. These 16 cooling towers are divided in groups of 4, so that each group gets one feeding pipe of water to cool (one pump to feed four towers). This means that there is always one group of older cooling towers that are running. The overview of the process can be seen in Figure 16. As displayed in the Figure 16, the electric motors of the fans are frequency controlled, which means that the power output from the electrical motors can be controlled. The span of frequency the motors are running is between 7-50 Hz and when the cooling towers are fed with water the minimum frequency is 15 Hz.

Figure 15. Principle scheme of one of the cooling tower types that cools the V2-system (Paragon, 2015).
Figure 16. Process overview of the cooling towers of the V2-system.

The problem here is that the electric motors for the fans on the cooling towers easily gets damaged by condense in the bearings and shaft if the fans are not running. This forces Caverion to run the engines at minimum frequency (7 Hz) even if there is no flow of water. The outcome is that 3*4=12 cooling towers are not practically in use for a large amount of time during a year, but still has to be running at 7 Hz. By looking at the frequency converter for each electric motor on the cooling towers, it can be determined that the power acquired for each electric motor to run at 7 Hz is 300 W.

There is a modern solution to prevent this kind of problem. Instead of running the engines at minimum frequency, the motors can be replaced with similar ones that has installed heat elements. The heat elements prevent condense on shaft and bearings in the motor and only consumes 50 W. To quantify how much electric power consumption can be saved by implementing new modern motors, two scenarios has been put up in collaboration with Caverion. The scenarios are based on the usual run-time for the motors during a year. The first scenario is that 12 of the 16 cooling towers are running at minimum frequency from October to May, and the rest of the time on higher frequency than minimum frequency. The remaining four cooling towers are running on higher frequency than minimum the whole year. The second scenario is that 12 of the cooling towers are running on minimum frequency from October to May and higher than minimum frequency the rest of the year. The remaining 4 cooling towers are running on minimum frequency in January to February and higher frequency than minimum frequency the rest of the year. The electric energy consumption to run the electrical motors on minimum frequency during a year was calculated with

\[ E_{motors} = P \times t \ [Wh] \quad \text{Equation 2.} \]

The same formula is used to calculate the electric consumption by the heating elements in the new motors but replacing the power from the motors at 7 Hz with the 50 W which the heating elements consume. The amount of saved money from the upgrade was calculated by using
\[ Costs = E_{electric} \times El.\ Price \ [SEK] \]

Equation 7 and using the electric price that AstraZeneca pays (525 SEK/MWh). The calculations for the two scenarios is displayed in table 2 and table 3.

**Table 2. Calculations for energy saving scenario 1.**

<table>
<thead>
<tr>
<th>12 motors min. frequency October-May</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of motors running on min. frequency</td>
<td>12</td>
</tr>
<tr>
<td>Hours</td>
<td>5 086</td>
</tr>
<tr>
<td>Pmotor at 7Hz</td>
<td>300 W</td>
</tr>
<tr>
<td>Electric energy consumption motors</td>
<td>1 831 MWh</td>
</tr>
<tr>
<td>Pheat element</td>
<td>50 W</td>
</tr>
<tr>
<td>Electric energy consumption heat element</td>
<td>305 MWh</td>
</tr>
<tr>
<td>Energy saving</td>
<td>1 526 MWh</td>
</tr>
</tbody>
</table>

**Table 3. Calculations for energy saving scenario 2.**

<table>
<thead>
<tr>
<th>12 motors min. frequency Oct.-May, 16 motors min. frequency Jan.-Feb.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of motors running on min. frequency</td>
<td>12 4</td>
</tr>
<tr>
<td>Hours</td>
<td>5 086 1415</td>
</tr>
<tr>
<td>Pmotor at 7Hz</td>
<td>300 W</td>
</tr>
<tr>
<td>Electric energy consumption motors</td>
<td>2 001 MWh</td>
</tr>
<tr>
<td>Pheat element</td>
<td>50 W</td>
</tr>
<tr>
<td>Electric energy consumption heat element</td>
<td>305 MWh</td>
</tr>
<tr>
<td>Energy saving</td>
<td>1 696 MWh</td>
</tr>
</tbody>
</table>

The investment cost is based on the cost of the new motor, with the installation costs excluded. The new motor cost is 35 509 SEK. The delivery cost is 3 750 SEK. The pay-off time with this investment is calculated with

\[ Payoff\ time = \frac{\text{Investment costs [SEK]}}{\text{Yearly savings [SEK/year]}} \]

Equation 8. The result for investment cost and pay-off time is presented in table 4. Due to such short pay-off time as it is less than one year, the pay-off time can be calculated without considering any interest rate.

**Table 4. Calculations for investment cost and pay-off time.**

<table>
<thead>
<tr>
<th>Costs for new electric motors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ABB motor</td>
<td>35 509 SEK</td>
</tr>
<tr>
<td>Number of new motors</td>
<td>16</td>
</tr>
<tr>
<td>Delivery costs</td>
<td>3 750 SEK</td>
</tr>
<tr>
<td>Total costs</td>
<td>571 894 SEK</td>
</tr>
<tr>
<td>Pay-off time</td>
<td></td>
</tr>
<tr>
<td>Scenario 1</td>
<td>0,71 Year</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>0,64 Year</td>
</tr>
</tbody>
</table>

If the new electric motors are implemented there is a reduction of electric energy consumption by at least 1 526 MWh per year. If the implementation of the update is considered for the calculation of OCOP2 values for year 2013 and 2014 for the facilities B654
and B653, the OCOP2-value will increase of about 15 % and 20 % respectively according to Figure 17.

![Figure 17. Comparison between new COP2-values with the motor update, and the old calculated COP2-values without the update.](image)

The calculations made in this chapter is only based on the upgrade to motors with heat elements and that the specific feature of a heat element as the upgrade. One could also argue that the old existing motors have worse electric efficiency than the new motors. Thanks to this the upgrade would also mean an addition power saving in terms of better electric efficiency. However, the existing motors are too old to find the electric efficiency of, so a comparison could not be done.

5.3 **Suggestion of energy efficiency solution 2: utilization of free cooling in dry cooling towers**

The term “free cooling” is based on the direct utilization of the heat in outside air or water. No or little more machinery than pumps or fans should be needed. The idea is to utilize the colder outside air or water to cool a room or system with higher temperature. For example a system could utilize the outside cool air with a heat exchanger between a medium (liquid) and the air and then exchange the cool energy in the medium to another environment with higher temperature than the outside air. The only machinery used to accomplish this would be fans and pumps. Another example of free cooling is to utilize the cold water in the bottom of a sea and pump it up to a heat exchanger to provide cooling to another system or environment with higher temperature than the bottom of the sea. The suggestion of optimization in this chapter is based on the idea of the first example.

As mentioned in chapter 4.2.4.2 there are two cooling machines in building B661 which uses dry coolers to cool the media on the condensing side of the cooling machines. As also mentioned in the same chapter, the cooling machines are not used during the winter in B661. The media used in these dry coolers consist of 40 % ethylene glycol and water to prevent the
media from freezing during the winter. The fact that this system is not used during winter and that the media is prevented from freezing makes it an available source for free cooling. The idea is to exchange heat with the cold air during the winter to provide the KB1-system with cooling. As mentioned in chapter 4.2.4.2 the KB1-system has a delivering temperature of 2 °C. The set temperature can also be a bit higher so usually the temperature is within the span of 2–4 °C. If the outside temperature is lower than the delivering temperature it means that these dry cooling towers have the potential of exchanging heat and utilize free cooling.

The dry coolers differ from the cooling towers as the system is closed, which means the media inside the coolers never is directly in contact with the outside air. Instead the media is running through loops of pipes within the cooler and to cool the media there is fans above the pipes to suck the air from beneath the pipes, through them and out from the fans. There is also water spraying on the pipes from beneath to enchant the heat exchange.

There are four dry coolers in total, three of which cools the condensing side of the cooling machine “VKA2” which has a delivering cooling power of 1470 kW. These three dry coolers have the name “KM2”. The fourth dry cooler called “KM1” cools the condensing side of the cooling machine “VKA1” which has a delivering cooling power of 533 kW. KM1 is a bit larger than the others as it has 170 loops of pipes for the liquid within the cooler, instead of 136 loops which the other coolers have. Figure 18 shows a process overview of the dry coolers.

![Figure 18. Process overview of the dry coolers.](image)

As displayed in the Figure 18, there are 10 fans of each dry cooler. The electric motor for each fan has a power of 1.2 kW on the shaft. To circulate the media in the cooling towers, both KM1 and KM2 has a pump each. The pump for KM1 has a power of 11 kW and the pump for KM2 has a power of 30 kW.

It is very important to calculate the cooling power output from the dry coolers. First of all it is necessary to know the maximum flow of the media within the dry coolers that can be provided. This was first to be measured, but the flow meter available did not work. Instead
the designed flow for each pump was determined and later compared to pump curves for respective pump to see if it was correct (the pump curves could be used after measuring the pressure drop over the pump and reading what frequency and rotor speed the pump has).

After inspecting each pump, the decided flow for the KM1 pump was 25.8 kg/s and 24.2 kg/s for the KM2 pump.

The next step is to decide what temperatures to be looking for. The KB1-system has an incoming temperature of about 7-8 °C, and the delivering temperature should be 2-4 °C. A heat exchanger needs to be installed between the KB1-system and the dry cooler system and it is necessary to determine what the temperature properties should be. It is expected to have a temperature difference between the input on the cold side and the output on the hot side of the heat exchanger to be around $\Delta t = 2$ °C. This means that the input temperature of the cold side should be about 0°C. Furthermore the output on the cold side will always be around 5.5 °C if a mean value of 7.5 °C is decided for the input in the hot side. The temperatures for the heat exchanger would then be according to Figure 19.

![Figure 19. Principle scheme of the temperatures on the heat exchanger.](image)

We now know the expected returning temperature from the heat exchanger on the cold side. The next step was to ask the dry cooler company Carrier® for help to simulate how much power the dry coolers can deliver at different outside temperatures. The input for their simulation program was the inlet temperature of the media into the dry cooler (5.5°C), the flow of the media and the outside temperatures of -5°C and -10°C. They could not provide more simulations than that. Carrier provided the simulation results with the warning that the simulation was for an undamaged and clean system. The simulation results is presented in appendix 16, note that the simulation was done on the two different dry coolers (136 and 170 loops).

The result from the simulation was satisfying. The output temperatures from the dry coolers is displayed in table 5.
The resulting output temperature from the simulation is presented in Table 6.

The Cp-value for water mixed with 40% ethylene glycol is about 3.5 kJ/kg according to a salesman on Armatec®. As the flow, temperature difference and Cp-value are low determined, the cooling power can be calculated for the dry coolers with the formula based on:

\[ P = C_p \cdot \dot{m} \cdot \Delta t \ [kW] \quad \text{Equation 3.} \]

The power from each cooler at given outside temperature is then calculated and presented in table 6.

### Table 6. Calculated cooling power for dry cooler, given outside temperatures and size.

<table>
<thead>
<tr>
<th>Outside temp.</th>
<th>-5</th>
<th>-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pdry cooler [W]</td>
<td>415.03</td>
<td>403.172</td>
</tr>
</tbody>
</table>

The cooling power is interesting to determine for all temperatures during winter (e.g. 0 °C to -10 °C), so it is necessary to find a method to decide the cooling power for the other remaining temperatures between 0 °C to -10 °C. At this stage the inlet temperatures are known and also the cooling power for certain temperatures. Based on this information and the fact that the dry cooler can be assumed to be a counter-flow heat exchanger, the use of the NTU-method (Number of Transfer Units) is suitable. According to the NTU-method, the maximum heat transfer rate available can be decided if both the inlet temperatures on either side of the heat exchanger are known. The maximum heat transfer rate can be calculated by using:

\[ q_{max} = C_{min} \cdot (T_h, i - T_c, i) \ [kW] \quad \text{Equation 4 which is described in chapter 2.} \]

To calculate the heat capacity rate for both mediums (mixed water and air) it is necessary to know the mass flow and the specific heat for each media as the formula looks as follows:

\[ C_x = \dot{m} \cdot c_p \quad \text{Equation 18} \]

Where

- \( \dot{m} \) = mass flow [kg/s]
- \( c_p \) = specific heat capacity [kJ/kg, K]

The mass flow for the air is yet unknown but can be calculated by making an energy balance (based on \( P = C_p \cdot \dot{m} \cdot \Delta t \ [kW] \quad \text{Equation 3} \)) over the dry cooler for one of the simulation cases:

\[ P_{air} = P_{liquid} \]

\[ \dot{m}_{air} \cdot c_{p_{air}} \cdot \Delta t_{air} = \dot{m}_{liquid} \cdot c_{p_{liquid}} \cdot \Delta t_{liquid} \]
\[ \dot{m}_{\text{air}} \times 1,001 \times (0,8 - (-5)) = 24,2 \times 3,5 \times (5,5 - 0,74) \]
\[ \dot{m}_{\text{air}} = 69,44 \left( \frac{kg}{s} \right) \]

Now the heat capacity rate for both air and the mixed water can be calculated. The result is displayed in table 7. As the heat capacity rate for air is less than the mixed water, it becomes the \( C_{\text{min}} \) value.

**Table 7. Heat capacity rates for both air and mixed water.**

<table>
<thead>
<tr>
<th></th>
<th>( \dot{q}_{\text{mix}} ) [kJ/s, K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch</td>
<td>84,7</td>
</tr>
<tr>
<td>Cmin</td>
<td>69,50944</td>
</tr>
</tbody>
</table>

The \( q_{\text{max}} \) can now be calculated for each simulated case and is presented in table 8.

**Table 8. Calculated \( q_{\text{max}} \) for the simulated outside temperatures.**

<table>
<thead>
<tr>
<th>( q_{\text{max}} )</th>
<th>kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5°C</td>
<td>729,85</td>
</tr>
<tr>
<td>-10°C</td>
<td>1077,40</td>
</tr>
</tbody>
</table>

Next step is to decide the effectiveness for the dry coolers. The calculation formula for effectiveness as the ratio of the actual heat transfer rate for the heat exchanger to the maximum possible heat transfer rate is as follows:

\[ \varepsilon = \frac{\dot{q} \left( T_{h, i} - T_{h, o} \right)}{C_{\text{min}} \left( T_{h, i} - T_{c, i} \right)} \]

The result from the calculations on each different case is presented in table 9. As displayed in the result, the effectiveness changes ever so slightly between the outside temperatures for each case. This means that the effectiveness will not change significantly with the change of outside temperature. Thanks to this it can be decided that the delivered cooling power will be almost linear depending on the outside temperature change.

**Table 9, calculated effectiveness of the dry coolers for each simulated case**

<table>
<thead>
<tr>
<th>( e )</th>
<th>loops</th>
<th>( e )</th>
<th>loops</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5°C</td>
<td>136</td>
<td>-5°C</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>0,552</td>
<td></td>
<td>0,569</td>
</tr>
<tr>
<td>-10°C</td>
<td>136</td>
<td>-10°C</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>0,551</td>
<td></td>
<td>0,566</td>
</tr>
</tbody>
</table>

The actual heat transfer rate for the dry coolers can now be calculated with the formula from

\[ q = \varepsilon \times C_{\text{min}} (T_h, i - T_c, i) \ [kW] \]

Equation 6.

As the effectiveness didn’t change remarkably for the two outside temperatures, the decided effectiveness is set to be 0,55 and 0,56 for the two different heat exchangers respectively. The heat transfer rate can then be calculated for the outside temperatures in the range of 0 °C to -10 °C for each different dry cooler respectively. The result from that calculation is presented in table 10 and Figure 20. Because the effectiveness was relatively constant, a linear relation between outside temperature and the calculated heat transfer rates can be assumed, which shows in Figure 20.
Table 10. Heat transfer rates for both the different dry coolers depending on outside temperature.

<table>
<thead>
<tr>
<th>Outside Temperature °C</th>
<th>q 136 loops W</th>
<th>q 170 loops W</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>210,27 W</td>
<td>214,09 W</td>
</tr>
<tr>
<td>-1</td>
<td>248,50 W</td>
<td>253,01 W</td>
</tr>
<tr>
<td>-2</td>
<td>286,73 W</td>
<td>291,94 W</td>
</tr>
<tr>
<td>-3</td>
<td>324,96 W</td>
<td>330,86 W</td>
</tr>
<tr>
<td>-4</td>
<td>363,19 W</td>
<td>369,79 W</td>
</tr>
<tr>
<td>-5</td>
<td>401,42 W</td>
<td>408,72 W</td>
</tr>
<tr>
<td>-6</td>
<td>439,65 W</td>
<td>447,64 W</td>
</tr>
<tr>
<td>-7</td>
<td>477,88 W</td>
<td>486,57 W</td>
</tr>
<tr>
<td>-8</td>
<td>516,11 W</td>
<td>525,49 W</td>
</tr>
<tr>
<td>-9</td>
<td>554,34 W</td>
<td>564,42 W</td>
</tr>
<tr>
<td>-10</td>
<td>592,57 W</td>
<td>603,34 W</td>
</tr>
</tbody>
</table>

Figure 20. Diagram showing how linear the heat transfer rate depends on the outside temperature.

By the assumption that the relation between the cooling power from the dry coolers and the outside temperature is linear, a line (trend line) can be made between the simulation results and retrieve the linear expression for that relation. The linear expressions is presented in Figure 21, where x is the outside temperature.
Figure 21. The trend line expression for the line drawn between the different cooling powers for the different outside temperatures in the simulation result.

The expected cooling power can now be achieved for each dry cooler depending on outside temperature.

The next step is to simulate how many hours per year the dry cooler can be utilized. For this it is necessary to know the mean value of how many hours per year the outside temperature of less than 0 °C will appear. This can be done in many different ways. The decided way to calculate that for this thesis is to use the data from a near-by weather station (SMHI, 2015). The weather data gives the temperature for every hour in the past 25 years in Tullinge, which is a nearby city to Gärtuna. A calculation was then done in excel based on the SMHI data to retrieve the amount of hours that every outside temperature below 0 °C had appeared in the past five years. Then a mean value of hours for every specific temperature was calculated. The result is presented in table 11. The amount of hours representing temperatures below -10 °C is added to the “-10 °C temperature” since the cooling power for temperatures below -10 °C is too low to handle and will be settled in reality.

Table 11. Calculated mean values of the amount of hours of every temperature below 0 degree’s.

<table>
<thead>
<tr>
<th>Year</th>
<th>Temp.</th>
<th>0</th>
<th>-1</th>
<th>-2</th>
<th>-3</th>
<th>-4</th>
<th>-5</th>
<th>-6</th>
<th>-7</th>
<th>-8</th>
<th>-9</th>
<th>tot</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Hours</td>
<td>304</td>
<td>246</td>
<td>272</td>
<td>260</td>
<td>187</td>
<td>304</td>
<td>245</td>
<td>240</td>
<td>167</td>
<td>137</td>
<td>783</td>
</tr>
<tr>
<td>2011</td>
<td>Hours</td>
<td>373</td>
<td>295</td>
<td>215</td>
<td>190</td>
<td>126</td>
<td>95</td>
<td>71</td>
<td>67</td>
<td>62</td>
<td>53</td>
<td>292</td>
</tr>
<tr>
<td>2012</td>
<td>Hours</td>
<td>317</td>
<td>324</td>
<td>339</td>
<td>285</td>
<td>187</td>
<td>135</td>
<td>90</td>
<td>117</td>
<td>108</td>
<td>69</td>
<td>286</td>
</tr>
<tr>
<td>2013</td>
<td>Hours</td>
<td>318</td>
<td>274</td>
<td>234</td>
<td>255</td>
<td>197</td>
<td>187</td>
<td>142</td>
<td>78</td>
<td>66</td>
<td>53</td>
<td>435</td>
</tr>
<tr>
<td>2014</td>
<td>Hours</td>
<td>273</td>
<td>150</td>
<td>176</td>
<td>192</td>
<td>204</td>
<td>103</td>
<td>51</td>
<td>44</td>
<td>47</td>
<td>37</td>
<td>48</td>
</tr>
<tr>
<td>Mean value</td>
<td>Hours</td>
<td>317</td>
<td>257.8</td>
<td>247.2</td>
<td>236.4</td>
<td>180.2</td>
<td>164.8</td>
<td>119.8</td>
<td>109.2</td>
<td>90</td>
<td>69.8</td>
<td>368.8</td>
</tr>
</tbody>
</table>

It is necessary to calculate an expected amount of electrical consumption for the dry cooler system. For this calculation the following input is assumed:

- 10 fans per dry cooler (total of 4 dry coolers), all with a fan motor shaft power of 1.2 kW. The electrical power is assumed to be 10 % higher than the shaft power, so the electric power consumption will be 1.2*1.1. The fans will also not run at full power all time so the electrical consumption should be divided by 2.
- The system will have 3 pumps. The respective power output from all pumps are 11 kW, 30 kW and 45 kW. The last pump is just an assumption as it doesn’t exist yet. The efficiency of the pumps is calculated to be 90 % so the electrical consumption will
be 10 % higher than the power output.

The electric power for the free cooling system could then be assumed to be:

\[ P_{\text{power consumption}} = \left( \frac{1,2 \times 1,1}{2} \right) \times 10 \times 4 + 30 \times 1,1 + 11 \times 1,1 + 45 \times 1,1 = 121 \, kW \]

The cooling energy produced over a mean year is calculated with the following formula:

\[ E_{\text{cooling energy}} = t_{\text{mean hours}} \times P_{\text{cooling, for each outside temp.}} \]  
\[ \text{Equation 19} \]

Where

\[ t_{\text{mean hours}} = \text{mean amount of hours that every temperature below 0°C appear [h]} \]
\[ P_{\text{cooling, for each outside temp.}} = \text{cooling power for the respective outside temperature [kW]} \]

The amount of produced energy and consumed energy over a mean year is presented in table 12.

**Table 12. Calculated cooling energy production and consumption of the dry coolers over a mean year.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Temp.</th>
<th>0</th>
<th>-1</th>
<th>-2</th>
<th>-3</th>
<th>-4</th>
<th>-5</th>
<th>-6</th>
<th>-7</th>
<th>-8</th>
<th>-9</th>
<th>-10</th>
<th>Tot.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epower consumption MWh</td>
<td>38</td>
<td>31</td>
<td>30</td>
<td>29</td>
<td>22</td>
<td>20</td>
<td>14</td>
<td>13</td>
<td>11</td>
<td>8</td>
<td>49</td>
<td>261</td>
<td></td>
</tr>
<tr>
<td>Eproduced power MWh</td>
<td>272</td>
<td>261</td>
<td>288</td>
<td>312</td>
<td>265</td>
<td>268</td>
<td>213</td>
<td>211</td>
<td>188</td>
<td>156</td>
<td>882</td>
<td>3 315</td>
<td></td>
</tr>
<tr>
<td>Etot MWh</td>
<td>234</td>
<td>230</td>
<td>258</td>
<td>283</td>
<td>243</td>
<td>248</td>
<td>198</td>
<td>198</td>
<td>177</td>
<td>148</td>
<td>837</td>
<td>3 053</td>
<td></td>
</tr>
</tbody>
</table>

To put the produced cooling energy in perspective, the actual cooling energy demand for the KB1-system can be analyzed. The KB1-system delivers cooling to a total of 8 buildings in AstraZeneca, and the energy demand for each building during winter in year 2013 and 2014 is presented in appendix 17. According to the numbers presented in appendix 17 the total cooling energy demand for the KB1-system during winter in 2013 and 2014 is 3090 MWh and 3475 MWh respectively. The theoretical cooling energy produced from the dry coolers is almost matching the cooling energy demand in 2014, and exceeds the demand in 2013. The expected OCOP2-value for the system is calculated below:

\[ OCOP_{\text{dry coolers}}^{2} = \frac{E_{\text{cooling energy production}}}{E_{\text{electric energy consumption}}} = \frac{3315}{261} = 12,68 \]

The B661 facility and the KB1-system is in existing conditions powered by the cooling machines in B654 during winter. The cooling power is achieved via a heat exchanger between the KB2-system and the KB1-system. The free cooling system will provide enough energy to cover the cooling production of a cooling machine in B654 during many hours per year. For example, at a specific time in February 2015, a cooling machine of 1400 kW of cooling power was running at 60 %. Hence the machine was providing a cooling effect of 840 kW. The free cooling system is expected to provide at least 860 kW for 2161 hours per year.

To set the energy calculations in an economical perspective, it needs to be looked at how much energy costs are reduced by producing cooling energy in the dry coolers instead of the cooling machines. The cost of running a cooling machine in AstraZeneca is said to be 670 SEK/MWh (Sandberg, 2015b). This assumption is based on investment, running costs and
electrical costs. To compare this to the dry coolers system it is necessary to find the expected investment costs. For this the following data has been assumed:

- Pipe cost: 400,000 SEK. A provisional design of the system was made with a colleague from Caverion. The included parts of the design was the length of pipes, dimension of pipes, types of pipes, number of curved pipes, number of valves, number of different temperature, flow and pressure readers and how long the installation job would take. Based on this information the price was guessed by a colleague in Caverion that is specialized on installation of pipes and such things.
- Pump cost: 50,000 SEK. The system needs an additional pump on the hot side of the heat exchanger. The cost is purely guessed due to lack of time to investigate such cost.
- Controlling system: 100,000 SEK. A colleague specialized in controlling systems was asked what he thought the costs of regulation and controlling sub-systems would cost for such system.
- Heat exchanger: 260,000 SEK. A price request was made at the company Armatech. They did a theoretical design and price suggestion.
- Frequency converter: 56,170 SEK. Frequency converters are needed for all pumps as it is non-existent today. The price was retrieved by a colleague at Caverion which contacted the company Danfoss.

The sum of all these investment costs is 866,170 SEK.

To calculate the pay-back time for this system, the first step is to calculate the savings for every year. Since the cost to produce cooling with a cooling machine is 670 SEK/MWh, and the amount of produced cooling with the dry coolers is 3315 MWh, the amount of saved money per year is calculated with $Costs = E_{electric} \times El.\ Price\ [\text{SEK}]$ Equation 7:

$\text{Saved money} = 670 \times 3315 = 2\ 220\ 727\ \text{SEK/year}$

The electrical cost per year to power the dry cooler system is calculated by once again using $Costs = E_{electric} \times El.\ Price\ [\text{SEK}]$ Equation 7:

$\text{Electrical costs} = 670 \times 261 = 137\ 278\ \text{SEK/year}$

The savings earned every year should then be the costs for running a cooling machine (because the energy that should have been produced without the dry coolers is now not needed with the new system) minus the cost of running the dry coolers (the new system will need very little maintenance costs). The result of the earned savings and pay-back time is presented in table 13.

<table>
<thead>
<tr>
<th>Costs for cooling machine</th>
<th>2 220 727 SEK/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power consumption cost</td>
<td>137 278 SEK/year</td>
</tr>
<tr>
<td>Savings from dry coolers</td>
<td>2 083 449 SEK/year</td>
</tr>
<tr>
<td>Investment cost</td>
<td>866 170 SEK</td>
</tr>
<tr>
<td>Pay-back time</td>
<td>0.42 year</td>
</tr>
</tbody>
</table>

Table 13. Calculation of pay-back time of the investment of free cooling.
5.4 Investments profitability

5.4.1 Investment profitability for upgrade of motors for cooling towers

The purpose of this measure is to lower the electric energy consumption for the B653 facility in general and for the cooling towers in the facility in particular. The suggestion is to exchange old fan motors on 16 cooling towers with new ones. The affected systems for the measure are only the cooling towers and its sub-systems such as the control system. The big difference between the old motors and the new ones is that the new ones are electrically heated to prevent condense in bearings and shaft. The existing motors need to run on minimum frequency even they are not in any practical use due to condense problems.

The exchange of engines can take place on any time except in high season which is in the middle of the summer (June-August). It is always possible to shut down 12 of the 16 cooling towers during rest of the season to make the exchange, and after that run the cooling towers in a different priority so that the 4 unchanged cooling towers can have the update too.

Expected yearly reduction of electric energy consumption is between 1526-1696 MWh. The yearly energy cost savings is expected to be at least 801,000 SEK. The investment cost will be approximately 572,000 SEK, and the pay-off time of less than a year (8 months).

The new motors are identical to the old motors considering the power output and RPM, so it will not affect the cooling towers themselves in any way. However the added function of a heat element may have some sort of special electric mount that needs a new electric feed.

5.4.2 Investment basis for utilization of free cooling in dry cooling towers

The purpose for this measure is to lower the electrical energy consumption in Gärtuna and at the same time lower the stress on cooling machines in the B654 facility, which are very expensive to run, during winter. The measures will take place at the B661 facility.

The investment require measures on several things. A Minor reconstruction is required on the dry coolers of the VKA1 and VKA2 cooling machines. Also a reconstruction of the pipelines for the KB1-system is required. A heat exchanger needs to be bought and be placed between the dry coolers and the KB1-system pipelines on the second floor in the B661 facility. Between the heat exchanger and both the dry coolers and the pipelines of the KB1-system, there needs to be new pipes installed together with sub-systems such as flow meters, temperature meters and valves. A new pump needs to be bought and placed between the heat exchanger and the pipelines of the KB1-system. New control systems are required such as frequency converters for three different pumps, and the synergy between the dry cooler system and the rest of the KB1-system needs to work.

The affected systems of the measures is the dry coolers on VKA1 and VKA2 and thus also the cooling machines themselves. The KB1-system is also affected in the pipes near the distribution pumps on the second floor in B661.
The function of the measures is to use the dry coolers to exchange heat against the cool air during winter and thereby achieve cooling energy. The cooling energy will then be applied to the KB1-system via a heat exchanger.

The cooling machines that utilizes the dry coolers are not running during winter time and therefore the dry coolers are available during that time. However, the fact that the cooling machines VKA1 and VKA2 needs to be shut down is a requirement, so it needs to be assured that the cooling machines will remain shut down during winters in the future. It should not be a problem as there are plenty of other resources for cooling in Gärtuna that can run instead of VKA1 and VKA2. It is also possible to run either of the two cooling machines while the other one is shut down because the dry coolers are separated between the cooling machines, and therefore the utilization of the free cooling can still be applied.

The B661 facility and the KB1-system is in the current condition powered by the cooling machines in B654 during winter. The cooling power is achieved via a heat exchanger between the KB2-system and the KB1-system. The free cooling system will provide enough energy to cover the cooling production of a cooling machine in B654 during many hours per year. For example, at a specific time in February 2015, a cooling machine of 1400 kW of cooling power was running at 60%. Hence the machine was providing a cooling effect of 840kW. The free cooling system is expected to provide at least 860kW for 2161 hours per year.

The expected cooling energy production per year is 3315 MWh which are basically free compared to the cooling machines. Only an electric consumption of 261 MWh per year is expected, so basically the yearly energy savings is 3053 MWh of cooling energy.

The free cooling system is expected to have little to no running costs and give a yearly energy saving cost of 2.083 000 SEK. The investment cost is expected to be 866 000 SEK so the pay-back time is half a year.

With the implementation of the system it is possible that additional media is required and those costs are not included.

The implementation of the system should take place in stages. The installation of valves on the pipes of the dry coolers can take place any time during winter when the coolers are not running. However the valves on the pipes on the KB1-system will need to take place during some kind of shut-down point where everything stands still, as the system is always running any time else. Maybe the action can take place during a weekend or at night time when the cooling demand is lower. The rest of the installation can take place any time of the year but the critical moments are as mentioned the valves to the existing system which the pipes from the heat exchanger should be mounted to.
6 DISCUSSION

6.1 The mapping of Gärtuna

The mapping of Gärtuna could be a thesis work itself. The facility includes so many processes and all of them has potential of improvement. I chose to prioritize only the energy distribution from Caverion’s side, but the side of AstraZeneca is just as important to investigate. The energy distributed to the different processes within AstraZeneca is only depending on the demand from the processes, so if the work of energy optimization should be as efficient as possible it is very important to make a detailed mapping of the processes on AstraZeneca’s side as well.

The mapping of the energy distribution made for this thesis could have went a lot smoother and the quality in the data could also be improved, as far from all data was correct. Every measured value used for this thesis had to be evaluated and analyzed. This problem can be solved by someone actually analyzing the data before submitting it to the basis of which all the energy data is submitted to. In the process of analyzing the data it would also be discovered if the data is not normal or incorrect. The quality of the data can also be improved as many meters (especially flow meters) seems to have some kind of error that results in misleading numbers. Also the way certain data is provided could be improved, for example if there is a demand to see the performance of the cooling machines in facility B653, the electricity consumed by the whole facility should not be included in the calculation as it involves more processes than just the three cooling machines and its energy distribution. The case now is that the cooling provided by the cooling machines is divided with the electricity consumption of the whole facility, which results in a lesser value than it should be. To get a more proper mapping of the system, every process should be measured separated from the other processes. However this would have taken too much time for the scope of this thesis.

There are some critical values that are missing in the mapping of Gärtuna, and that is the cooling production of the V2-system from the cooling towers in B653 and also the flow of condense water from the steam distribution back to Igelstaverket. It is interesting to see how effective the cooling towers are, especially as cooling during summer season has become a problem for Caverion. With measured values of the returning condense water to Igelstaverket it could both be decided how much money is gained by selling it back, and have a proper evaluation of the effectiveness of the steam distribution and the effectiveness of the condense water feed back to Igelstaverket.

6.2 Credibility of energy optimizations

The upgrade of the fan motors are reasonably urgent. The existing engines is starting to get old (>15 years) and if some motor would break down during the high season in the summer, it would cause big problems for both Caverion and AstraZeneca. In year 2014 the V2-system
failed for just a few hours during the summer to provide the set distribution temperature, and it was said to have cost AstraZeneca millions of SEK. If one or more motors break down during summer time, it would yet again cause problems for the medicine production. The fact that the new engines are improved with heat elements is just a part of the motivation of the investment together with the fact of the existing motors running old. One could also argue that the life time of the cooling towers will run out and therefore the need of new fan motors are unnecessary, but the cooling towers themselves have a very long life time and the only moving part is the fan.

The calculations for the free cooling upgrade are simplified. The simulation made with Carrier® is based on new coolers without damage nor dirt. The simulation is done for the exact identical type of coolers, but the existing coolers were installed at year 2000, so a degradation of the effectiveness of the coolers is possible. Another fact is that the max flow for the dry coolers was theoretically calculated which makes it uncertain. However, the flow of 24.2kg/s is in fact a lower value than the original expected value and was made to create a margin of the calculation. The result from calculations are yet so reassuring that even if the performance of the coolers would be half as good in reality, the pay-off time would still be less than a year.

Another dilemma with the free cooling system is the variation of outside temperature. The planning of the system includes that all pumps related to the system is controlled with frequency converters which means that different pumps could be operated at different speeds, hence control the flow of the fluids. Thanks to this, a controlling system will automatically control the pumps so that the cooling demand always is fulfilled. If it is very cold outside so the cooling demand is small, the pumps can be controlled to deliver a smaller cooling power output. If the outside temperature is too high for the free cooling system to deliver the wanted cooling energy output, additional cooling machines at B654 can make up for the additional cooling demand. It should also be remembered that the free cooling system will act as a pre-cooler before the heat exchanger between the KB1-system and the KB2-system, hence the delivered temperature from the free cooling system can be in range of 2–7 °C to still contribute to the cool the KB1-system (which cools a temperature from 8 °C to between 2-4 °C).

6.3 Comparison with the literature study

The energy investigation carried out in this thesis is comparable to the fundamentals of an energy investigation that is described in the literature study. The differences are that the other energy investigations studied, such as the PFE program or Project Highland, are much more comprehensive with more resources and time put into the work. This thesis work still managed to fulfill the important goals for an energy investigation, to make a proper description, mapping and search for energy efficiency measures for the facility. When it comes to the search for energy efficiency measures, both direct and indirect optimization was utilized. The direct optimization was the upgrade of the electric motors, leading to a direct energy efficiency solution for that certain component. The indirect optimization was the
utilization of the dry coolers during winter which affects the entire KB1 and KB2 cooling system by reducing the usage of cooling machines and by that reducing the cooling energy costs. The literature study also showed a great importance of short pay-off times, being one of the most important factors when arguing for the implementation of an energy efficiency measure. The energy efficiency measures carried out by this energy investigation has very short pay-off periods and thanks to that one could argue that the energy efficiency measures are preferable.
7 CONCLUSION

An energy investigation of the Gärtuna facility of AstraZeneca/Caverion has been made. The investigation included mapping of facilities and systems that are controlled by Caverion inside the Gärtuna facility, search for potential of improvements and search for energy optimizations. The investigation could proceed thanks to a literature study, contact with colleagues both within and outside of Caverion and AstraZeneca and calculations based on own experience.

The mapping included the heat, steam and cooling distribution on the Caverion side of Gärtuna. Even though the highest potential of improvement was found in the steam distribution, it was clear that the amount of time available for the thesis work was more suited for the cooling distribution. However it must be mentioned that the mapping of the steam distribution showed an energy loss equal to around 13 million SEK per year if assumed to have no or very small measuring errors in the data.

The work finding energy optimization potentials resulted in two proposals. The first suggestion is to exchange motors on some of the cooling towers to lower the electrical energy consumption. The second suggestion is to utilize dry coolers in a facility to achieve “free cooling” and thereby lower the electrical energy consumption and release some stress of the existing cooling machines. The implementation of the two optimizations will have an approximate energy saving by 4600 MWh per year and a cost saving of around 2.8 million SEK per year after the first year of the implementation.

The investigation was successful as it fulfilled the purpose of it. However it was also successful in the point of view of discovering several additional potential measurements that can be made and is presented in chapter 8.
8  SUGGESTIONS FOR FURTHER WORK

8.1  Further investigation of the steam distribution

As mentioned in the chapter 4.1, the steam distribution has high heat losses in form of loss of steam. For year 2014 the amount of heat losses was decided to 27 560 MWh which is worth about 13 642 000 SEK. This area is therefore considered to have a high potential of improvement.

The reason for the heat loss can be many. By asking the technical personnel at Caverion they suspect big reading errors on the different flow meters within the facility due to broken flow meters. The flow meters are as mentioned reading the incoming flow from Igelstaverket and the incoming flow to all the different facilities within Gärtuna that should be supplied with steam. If the meters have reading errors it could mean that the numbers are incorrect and therefore misleading. A serious inspection of the flow meters would then be relevant as a start of the investigation of the steam distribution. If the problem still exist after the inspection, further investigation methods must be taken into action.

If there are no obvious leaks from the steam distribution pipes, it must be considered how large the condensation rate per meter pipe is. The higher heat loss from the pipes it is (due to bad insulation for example), the higher condensing rate it will have. The expected condensing rate can then be calculated and be compared to the measured value for each part of the distribution system. The expected condensing rate can be calculated with the following formula:

$$m_s = \frac{3.6 \times Q \times L \times f}{h_{fg}}$$  \hspace{1cm} \text{Equation 20}

Where:

- $m_s$ = rate of condensation \left[\frac{kg}{h}\right]
- $Q$ = heat emission from pipes \left[\frac{W}{m}\right]
- $L$ = effective length of pipe, allowing for flanges and fittings \left[m\right] (the equivalent length of "pair of mating flanges" is 0.5m and "line size valve" is 0.5m)
- $f$ = insulation factor. For example 1 for bare pipes, 0.1 for good insulation
- $h_{fg}$ = specific enthalpy of evaporation \left[\frac{kJ}{kg}\right]
When the condensing rate is both calculated and measured it could be decided whether the insulation of the pipes is good or not, and furthermore conclude whether it is worth the cost to update or not for the specific part.

8.2 Further investigation of the cooling distribution

The cooling towers mentioned earlier in the report in relation with the change of electrical motors can be investigated further. The V2 system is known to have issues to cool the water to set temperature during summer. It should therefore be investigated if the cooling towers are working properly and maybe it would be smart to cooperate with the company that produced them. Interesting parts to look would be the rotation speed from the motors and the angle of the propeller. Maybe a change to a motor with higher rotation speed (motor with less poles) and a different propeller angle can increase the cooling power during summer to a reasonable energy cost.

Another suggestion for further work regarding the V2-system would be to use the heat pumps in B653 to cool the V2-system. The heat pumps are already designed for this purpose in the existing system, but as the heating demand decrease during summer, the heat pumps have a decrease in condensing effect and thus also in evaporating effect. The option here would be to install cooling towers or some other kind of cooler to cool the condensing side of the heat pumps during summer, and in this way earn more cooling energy to the V2-system.

The controlling system of the cooling towers could be investigated in general, and especially for the cooling towers mentioned in relation to the change of motors investment suggestion. The cooling towers are running in pairs of 4 which seems inefficient. This means that often when the cooling energy demand is not big enough, only 4 cooling towers will run and the fan motors need to run at 20 % of its maximum frequency which means a low load. With such low loads, the efficiency of at least the motors are decreasing which means a bigger waste of electrical energy. If the towers were separated one by one, the load of one tower could be much higher and with that comes better efficiency of the fan motors. It is possible that the efficiency of the cooling tower itself also benefits from running at higher load, but it is not known to me.

Another suggestion for further work would be the modification to lower the temperature of the V2-system. It is known that a cooling machines benefits in terms of efficiency from lower temperature on the condensing side to an extent. Because the V2-system acts as cooling for the condensing side of cooling machines, it could therefore be an optimization to lower the distributing temperature with perhaps one or two degrees to achieve higher efficiency of the cooling machines. The goal with this optimization would be to increase the cooling production of the V2-system with lower increase of electric energy consumption than the cooling machines decrease of electric consumption.

It is shown in the report that the implementation of free cooling is very profitable and it would therefore be interesting to look at investments of better free cooling systems. A suggestion for further work that is known by Caverion and AstraZeneca already is to exploit
free cooling from the water in a nearby sea. Caverion and AstraZeneca have another facility in Södertälje which uses free cooling from the sea water. The capacity of the sea water distribution is said to be around 6000m³/h with a temperature of around 4-7 °C, but during low season (October-May) the demand for sea water is only about 3000m³/h which means there is a large capacity of sea water that is not used and can be exploited. The idea is then to further distribute the cool sea water to the Gärtuna facility and exploit the cooling as free cooling. A benefit with this project is that there is already a culvert lying between the Facility in Södertälje and the facility in Gärtuna that has room for the prospective distribution pipes, this would otherwise be a big investment cost.
9 REFERENCES

9.1 Electronic sources


9.2 Printed sources


9.3 Unprinted sources


### Appendix 1: Calculations of the Steam Efficiency

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APPENDIX 2 PRINCIPLE SCHEME OF COOLING AND HEATING PRODUCTION
FACILITY B653, COOLING WATER V2 AND HEAT WATER VÅ9
APPENDIX 3  PRINCIPLE SCHEME OF THE COOLING AND HEAT DISTRIBUTION AT WINTER SECTIONING
APPENDIX 4 PRINCIPLE SCHEME OF THE COOLING AND HEAT DISTRIBUTION AT SUMMER SECTIONING
APPENDIX 5  PRINCIPLE SCHEME OF COOLING AND HEAT PRODUCTION FACILITY
B654, COOLING WATER KB2 AND HEAT WATER VÅ9
APPENDIX 6 PRINCIPLE SCHEME OF COOLING PRODUCTION FACILITY B661, COOLANT KB1
APPENDIX 7 PRINCIPLE SCHEME OF COOLING PRODUCTION FACILITY B653, COOLANT KB2
APPENDIX 8  PRINCIPLE SCHEME OF COOLING PRODUCTION FACILITY B869, COOLANT KB2
APPENDIX 9  PRINCIPLE SCHEME OF COOLING PRODUCTION FACILITY B654, LOW-TEMP COOLANT
| Media: Kyla, elkraft | År: 2013 | KYLCENTRAL B869 | 
|---------------------|----------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| januari | februari | mars | april | maj | juni | juli | augusti | september | oktober | november | december | Ackumul: |
| Kylenenergi (erhållen) | | | | | | | | | | | | | |
| KB2 B821 | 79 | 70 | 80 | 67 | 222 | 377 | 388 | 439 | 245 | 181 | 108 | 85 | 2341 |
| KB2 B841 | 70 | 63 | 73 | 57 | 198 | 344 | 358 | 426 | 232 | 164 | 96 | 72 | 2153 |
| Elenergi (tillförd) | | | | | | | | | | | | | |
| VKA1 | 8 | 1 | 10 | 15 | 22 | 33 | 3 | 53 | 31 | 24 | 103 | 231,053 |
| VKA2-3, pumpar mm. | 21 | 19 | 14 | 13 | 28 | 49 | 50 | 50 | 38 | 24 | 13 | 18 | 337,445 |
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<td>1 888</td>
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## APPENDIX 13
### DATA PROVIDED IN FAVOR FOR THE OCOP2 CALCULATION
### FOR GÄRTUNA

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<th>August</th>
<th>September/October</th>
<th>November</th>
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<td>Jun</td>
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### VÄRMEÅTERVINNINGSCENTRALER GÄRTUNA

**Media:** Värmeåtervinning, elkraft  |  **År:** 2014

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<th>Nov</th>
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## APPENDIX 16

**SIMULATION RESULT FROM CARRIER**

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<table>
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<td>Tryckfall:</td>
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<tr>
<td>Vatska:</td>
<td>EG35 %</td>
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</tr>
<tr>
<td>Luft ut:</td>
<td>-0.8%/38%</td>
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<th>Process (innanligt):</th>
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<th>Beräknad:</th>
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<td>Vattenfriskor:</td>
<td>27.0 l/h</td>
<td>24.2 kg/h</td>
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<td>Flodenhastighet:</td>
<td>1.06 m/s (Pa = 3387)</td>
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<td>Tryckfall:</td>
<td>31.3 kPa</td>
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<td>Vatska:</td>
<td>EG35 %</td>
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<thead>
<tr>
<th>Effekt / luftdanan:</th>
<th>Beteckning</th>
<th>Beräknad:</th>
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<tr>
<td>Total effekt:</td>
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<td>Luft in:</td>
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<td>Luft ut:</td>
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<th>Process (innanligt):</th>
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<td>Vatska in:</td>
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<td>Vatska ut:</td>
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