The Factory of the Future

An analysis on buildings, HVAC, and heat recovery systems in order to reduce energy consumption

Christina Naumburg

Thesis for the degree of Master of Science in Engineering
Division of Efficient Energy Systems
Department of Energy Sciences
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April 2022, Lund

This degree project for the degree of Master of Science in Engineering has been conducted at the Division of Efficient Energy Systems, Department of Energy Sciences, Faculty of Engineering, Lund University, and at Alfa Laval.

Supervisor at the Division of Efficient Energy Systems was Professor/Dr Martin Andersson.
Supervisors at Alfa Laval were Anna Wenemark, Christian Hörnkvist and Magnus Roth.
Examiner at Lund University was Professor/Dr Kerstin Sernhed.

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The Factory of the Future: An analysis on buildings, HVAC and heat recovery systems

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Abstract

The industrial sector in Sweden accounted for 38 percent of the country's total energy consumption in 2019. As the world's focus has shifted drastically on energy consumption, the industry sector's has as well due to energy initiatives and government-driven regulations. The energy issue is currently of great relevance for energy-intensive industries where enormous potential remains due to factors e.g., lack of energy-efficiency policies and insufficient investments in sustainable buildings.

This paper presents an analysis of energy consumption for active and passive building envelopes, focusing on buildings and heating, ventilation, and air-conditioning systems (HVAC-systems). The focus on buildings and HVAC-systems enabled an analysis that highlighted key areas for energy-savings solutions outside the scope of production processes. The project was carried out at three different production facilities within Alfa Laval: Lund, Sweden; Ronneby, Sweden; Kolding, Denmark. The methodology for this project provided for the use of literature, benchmarking with energy-intensive industries, a regression analysis of heating degree days, data analysis for energy consumption from sub-meters as well as the participation during Energy Mapping of two of the sites. The analysis investigated the three production facilities' building structures, lighting solutions, district heating systems, ventilation systems and heat recovery possibilities.

The work developed presented an indicative assessment of the overall potential for certain energy measures to contribute to minimizing each production site's energy consumption. The greatest potential in terms of saving energy for reusing waste heat from major energy users was found to be recovery at low temperatures ($< 50°C$) by utilizing heat pumps and heat exchangers. Current ventilation systems at all sites are outdated in regards to how the majority of ventilation units not having been upgraded since the initial builds and the incompatibility with new control systems. The modernization of ventilation units to enable recovery at low temperatures was seen as a key area and highly profitable for optimal energy consumption. Implementing a building management system for controlling and monitoring the HVAC-system was also regarded as vital for maximizing regulating capabilities, allowing for energy savings during off-peak hours as well as removing manual labor. In addition to common measures for all three production facilities, a variation of alternative energy measures were discussed for each site separately.

Popular Science Summary

An analysis on buildings, HVAC and HRV-systems

Energy can be defined as the capacity for doing work and exists in many forms. To measure and monitor energy consumption, its sources can be divided into three sectors: residential and service, transportation and industrial. The industrial sector is expected to undergo an upcoming increase in electrification due to major changes in the industry i.e., electric vehicles and HYBRIT (Hydrogen Breakthrough Ironmaking Technology). A project was conducted at Alfa Laval to evaluate energy savings solutions when it comes to their production facilities; more specifically, their heating, ventilation and air conditioning (HVAC) systems and heat recovery solutions. Focusing on three production sites (Lund, Sweden; Ronneby, Sweden; Kolding, Denmark), it was possible to give proposals in all three areas for energy efficiency solutions.

In energy-intensive industries, it's simplest to separate the energy consumption into two parts: consumption for manufacturing processes and consumption for the building's operation. Energy efficiency within manufacturing processes has increased the past few decades. It's even become easier to be more aware of how efficient equipment (just like those energy stickers on every new refrigerator).

On the other side, the operational energy consumption includes that which helps the building do what's needed day-to-day (space and water heating, lighting, etc.). This is where efficiency and awareness lacks behind because of unsustainable and unimproved buildings.

By focusing on Alfa Laval's buildings, their HVAC-systems and possible heat recovery solutions, the biggest area of improvement was to reuse waste heat from the manufacturing processes. This would help to "recycle" the energy that is already used for production purposes. Another key area was to implement a digital monitoring system that can help regulate the HVAC-systems. With such a system, the need for manual labor to optimize the HVAC-system would be removed and open the door for more energy savings. Specific energy-savings solutions for each production site were also proposed, giving a variety of alternatives for implementation.

Acknowledgment

This Masters Thesis project was carried out for Alfa Laval in Lund, Sweden, and the Department of Energy Sciences at the Faculty of Engineering at Lund University. As this marks the end of my time at LTH, I would like to acknowledge family, friends and loved ones for their support during my entire journey. Throughout all of the hardships, I have had so much support and love all around me.

I would also like to thank Anna Wenemark for giving me the opportunity to conduct my thesis project at Alfa Laval and being such an encouraging boss. Together with the entire ALEM team, I have felt inspired and passionate about the work that we have done together. In addition, thank you to both my supervisor, Dr. Martin Andersson, and examinator, Dr. Kerstin Sernhed. All of your feedback and patience was supportive and very much appreciated!

Sincerely,
Christina Naumburg

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Nomenclature

AL = Alfa Laval
BMS= Building management system
BREEAM= Building Research Establishment's Environmental Assessment Method
DH = District heating
EKL = Energikartläggning (eng. Energy mapping)
HDD = Heating Degree Day
HRV = Heat recovery ventilation
HVAC = Heating, ventilation and air conditioning
SFP = Specific fan power

Chapter 1

Introduction

1.1 Background- current energy scenario

The industrial sector consumes more delivered energy than any other end-use sector and accounts for 54 percent of the world's total delivered energy. The majority of the energy consumed in the sector is utilized for process and assembly, process heating and cooling, lighting solutions and HVAC-systems (heating, ventilation and air-conditioning systems) for buildings [1].

The industrial sector's contribution to the total energy consumption in Sweden has been unwavering from at least 1970. In 2019, the industrial sector in Sweden accounted for 38% of the total energy consumption. In total, the sector's energy consumption was 142 TWh that same year [2].

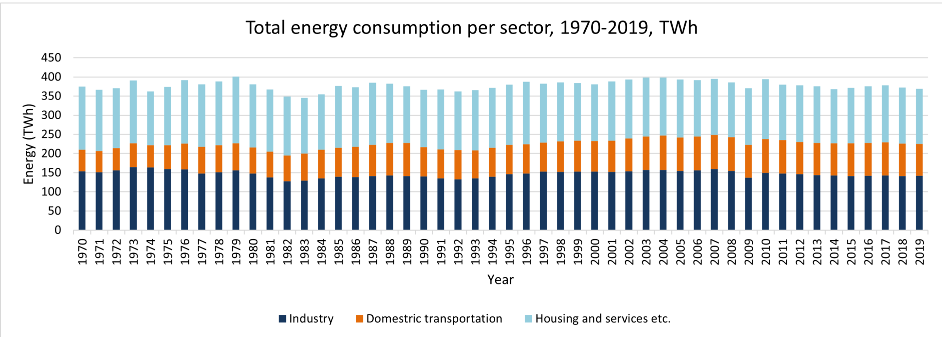

Figure 1.1: Total energy consumption in Sweden per sector between 1970 and 2019 [3].

The industrial sector can be split up into several energy users: electricity, district heating (DH), bio-fuel, coal, petroleum, natural gas and other fuels. Figure 1.2 below shows each user's trend, starting from 1970. Electricity and DH levels were highlighted, as they are further discussed in Chapter 5.

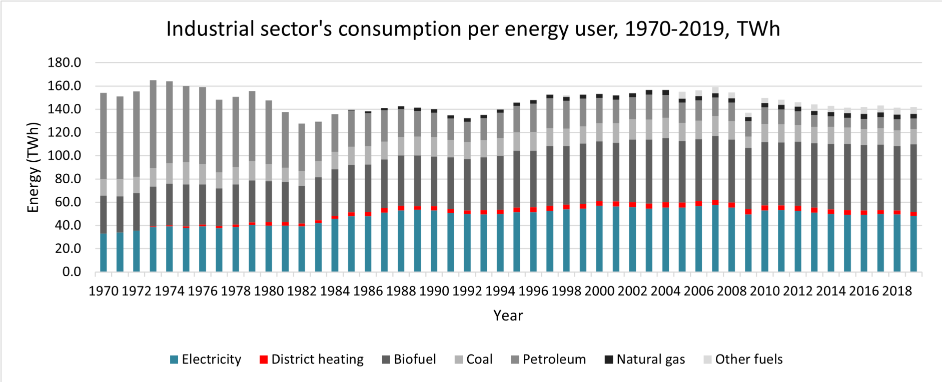

Figure 1.2: Total energy consumption the industrial sector in Sweden per energy user between 1970 and 2019 [4].

Between 1970 and 2008, the electricity consumption within the industrial sector saw an increase, ranging from 33 TWh to 58 TWh per year. This resulted partly from the conversion from oil to electricity, which occurred simultaneously in most industrial branches during the 1970's oil crisis. During the most recent years, in conjunction with stronger initiatives for efficient production processes and structural changes, the consumption levels have declined to 49 TWh. In regards to DH numbers, consumption has increased from 0 TWh in 1970 to 4.7 TWh in the beginning of the 2000's. A decline has been seen on this front, as well, with current levels at 3.4 TWh [2].

The future's energy consumption, though unpredictable, can be speculated by regarding today's technology trends. According to the Swedish Energy Agency's article "Scenarier över Sveriges Energisystem 2018" (eng.: Scenarios over Sweden's Energy System 2018), the industrial sector is expected to undergo an increase in electrification. This can be due to the increase in electric vehicles and major electrification changes in the industry such as Hydrogen Breakthrough Ironmaking Technology (HYBRIT) [5]. HYBRIT is expected to increase electricity consumption by cirka 15 TWh per year at its current production level. That figure corresponds to approximately 10 percent of Sweden's daily electricity generation [6]. An increasing number of data centers and heat pumps will also drive up the overall electricity consumption for Sweden. The expansion of data centers is predicted to increase electricity consumption with 8 Twh by 2050 [5].

1.2 Objective

Alfa Laval is one of many companies that are aiming to be carbon neutral by 2030. However, while that step is vital in ensuring a sustainable future, energy consumption also needs to be optimized in order to reduce environmental impacts. Enormous energy reduction potential remains due to numerous factors, including a lack of effective energy-efficiency policies and insufficient investments in sustainable buildings. This can be substantiated from previous projects at Alfa Laval, where it has been shown that the decentralized organizational system can hinder the implementation of global energy standards.

The overall objective of this project is to investigate solutions for Alfa Laval sites to reduce their energy consumption by 50 percent within the upcoming 10 years. The project includes data and recommendations for both passive and active building envelopes in terms of the insulation and HVAC-systems. Values for how much energy savings each solution can provide is not required. Instead, the 50 percent reduction is rather to be seen as a goal that will force the optimisation of energy in these sectors, ensuring that the remaining consumption is no more than necessary.

The intention is to view this thesis as a "pilot project" that can then be applied on any global company site. In this pilot project, the three sites that will be included are:

- Lund, Sweden
- Ronneby, Sweden
- Kolding, Denmark.

These sites are chosen due to their close proximity to one another and for the variation in product groups. This entails that their production facilities have differentiating layouts which allows for a broader variety of solutions.

1.3 Research questions

This report is based on the following research question:

- In what ways can the production site minimize their energy consumption regarding their building envelope and HVAC-systems?

In order to be able to answer this in a structured way, the main research question has been divided into the following underlying questions that this study intends to investigate:

- How efficient is the current building envelope (e.g., insulation and lighting solutions)?
- What is the current condition of the site's ventilation system in terms of age and compatibility with BMSs??
- Does the site currently have a heat recovery ventilation system (HRV-system)?
- Which major energy users are in place that can contribute to heat recovery possibilities?
- What does the energy consumption for heating and ventilation look like in terms of daily, weekly and monthly values and patterns as well as unprecedented peaks?
- How does each site compare to BREEAM-SE Excellent's requirements?

1.4 Disposition

Chapter 2 of the thesis consists of both background information as well as theory about topics that are deemed relevant and useful for the reader's understanding. In Chapter 3, the methodology used for the thesis project is explained, followed by an explanation of where limitations were drawn. In Chapter 4, calculation parameters are explained: more specifically for calculating Heating Degree Days. The results for the thesis project are presented in Chapter 5. A discussion and analysis on the results follow in Chapter 6. The chapter provides both a general and site-specific perspective on energy-savings solutions for the three production sites researched. In Chapter 7, a summary and conclusion to the thesis are presented together with proposals for further studies that can be done.

1.5 Limitations

Studies on the building were limited to indoor lighting solutions as well as insulation. Outdoor lighting solutions were not examined. The HVAC-systems for all three production sites did not include air-conditioning. Therefore, only heating and ventilation were investigated. The inclusion of production equipment in the research was restricted to those that had the possibility of contributing to an HRV-system. Energy-savings solutions discussed in Chapter 5 do not include a cost-benefit analysis.

Chapter 2

Theory

This section provides fundamental theory for key concepts in order to better understand the report. These concepts consist of regulations such as the EED (European Energy Efficiency Directive) and EKLs (Energikartläggningar i.e. Energy mapping), heat-recovery utilization as well as BREEAM-SE (Swedish Building Research Establishment's Environmental Assessment Method) certification. The explanation of the heating degree day (HDD) and its utilization in the thesis project are also presented.

2.1 Regulations and directives

The EED highlights the positive effect of utilizing the potential for energy savings. Directive 2018/2002, amending the original Directive 2012/27, establishes a set of binding measures to help the EU reach its minimum 32,5% energy efficiency target by 2030 [7]. All EU countries are required to use energy more efficiently at all stages of the energy life cycle.

Relating to the scope of this project, the directive requires, among other things, that:

1. Energy requirements must be included in certain public procurement.
2. There must be a strategy for energy-efficient renovations for the building stock in the country.
3. Large companies must do an energy survey.
4. Potential for the use of district heating / cooling, as well as residual heat must be mapped.
5. There must be information about and availability of energy services [8]).

Swedish law 2014:266 involves requirements for energy mapping in large companies and is an aid in meeting the mandatory requirements of the EED. In Swedish, the term used would be 'Energikartläggning', abbreviated as EKL. According to the law, large companies have an obligation to carry out quality-assured EKLs every four years, at minimum. Large companies, by their definition, are those that employ at least 250 persons and have an annual turnover of at least 50 million euro or a net worth over 43 million euro per year. Law 2014:266 also states that the EKL should include a thorough review of the energy usage in the company as well as include proposals for cost-effective measures to save energy and make the current energy usage more efficient [9].

2.2 District heating systems

District heating systems distribute generated heat from a centralized location through a system of pipes for both residential and commercial heating requirements. DH systems consist of three major components: the heating plant, the transmission and distribution network, and the consumer building (Figure 2.1).

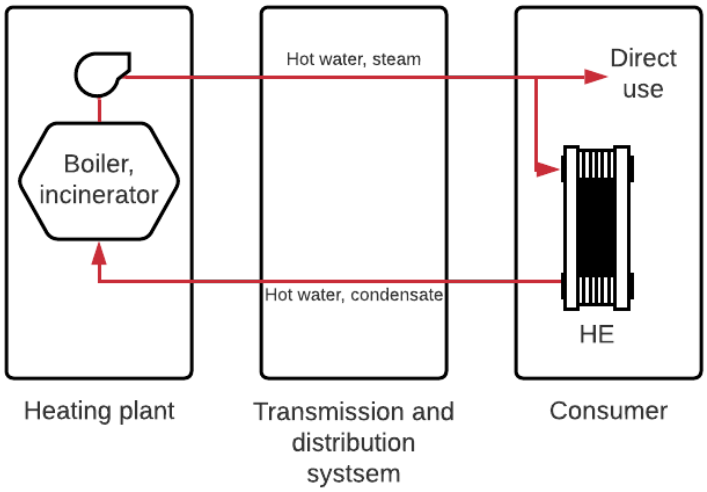

Figure 2.1: General schematic of the primary components within a DH system.

The central heating plant may be made up of boilers, solar energy, geothermal sources or thermal energy obtained as a by-product of electrical generation [10]. The source of fuel burned can be very resource-advantageous and can consist of various forms of residues: residual waste from households or businesses, wood waste from industries, or residues from deforestation. It is also possible to utilize surplus heat from local industries or data halls [11].

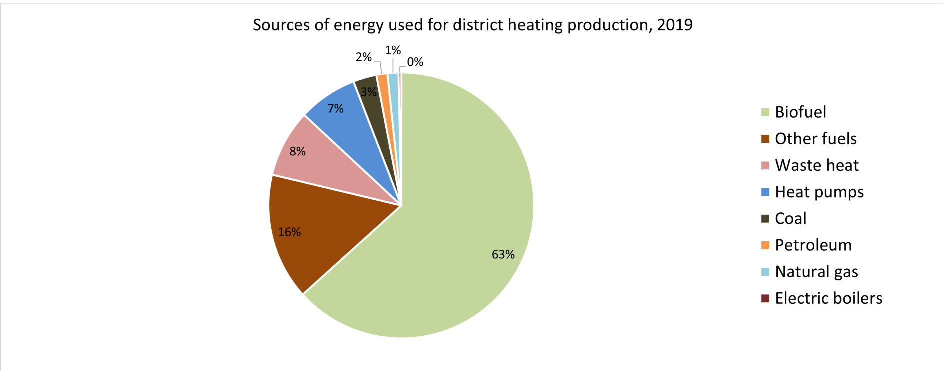

Figure 2.2: Diagram of the ratio between the sources of energy used for district heating production in Sweden in 2019 [12].

Domestic hot water or steam act as distribution mediums depending on the source of heat or the preference of the consumer system. The medium is pumped out into a network of isolated, underground pipes under high pressure, which constitute the transmission and distribution system. This pipe network constitutes between 50 to 75 percent of the total cost for the district heating system [10]. The high capital investment emphasizes the importance of optimizing the end-use of the distributed heating medium. When domestic hot water is used as the medium, it may be used directly by the building's HVAC-system or passed by a heat exchanger. When steam is supplied, it may be (1) used directly for heating, (2) reduced in pressure for space heating and water heating, or (3) passed through a heat exchanger [10].

Once the distribution medium has circulated through the consumer system, it has cooled down and is then led back to the heating plant. During its return, the medium can be of use for other heating purposes i.e., heating sidewalks and football fields. At the heating plant, the medium can then be reheated and redistributed into the DH network [11].

2.3 Heat recovery utilization

Major energy users in industrial processes require a vast amount of energy, where much of it is emitted again into the environment in the form of heat. For those users that emit in the form of hot gases and liquids, technologies exist in order to recover some of that heat.

A classification of heat recovery technologies can be done into the following groups [13]:

- Technologies that recover heat from a primary flow and provide a lower quality source of heat in a secondary flow. Some examples are heat exchangers, recuperators and regenerating furnaces.

- Technologies that recover heat from a primary flow and instead upgrade it to an energy form of higher quality by using another source of energy as input. Common examples are heat pumps, absorption chillers and organic Rankine cycles. Heat pumps bring the temperature of heat flow to a higher level. Absorption chillers transform the source of heat into cold. Organic Rankine cycles are able to transform the heat, if at a high enough temperature, into electricity.

- Technologies that transport the recovered heat from the primary flow to another unit with aid from domestic hot water pipes or steam distribution systems.

- Technologies that store the heat for use at another time. This could entail either seasonal storage or day/night storage.

Combining the technologies listed above is often required in a heat recovery system, as shown in several studies regarding the investigation of industrial excess heat (i.e. [14, 15]). The system's characteristics largely depend on the source of energy emitted from major energy users. Many industries develop specific technologies for integration of actors that suit both the production facility as well as their energy needs.

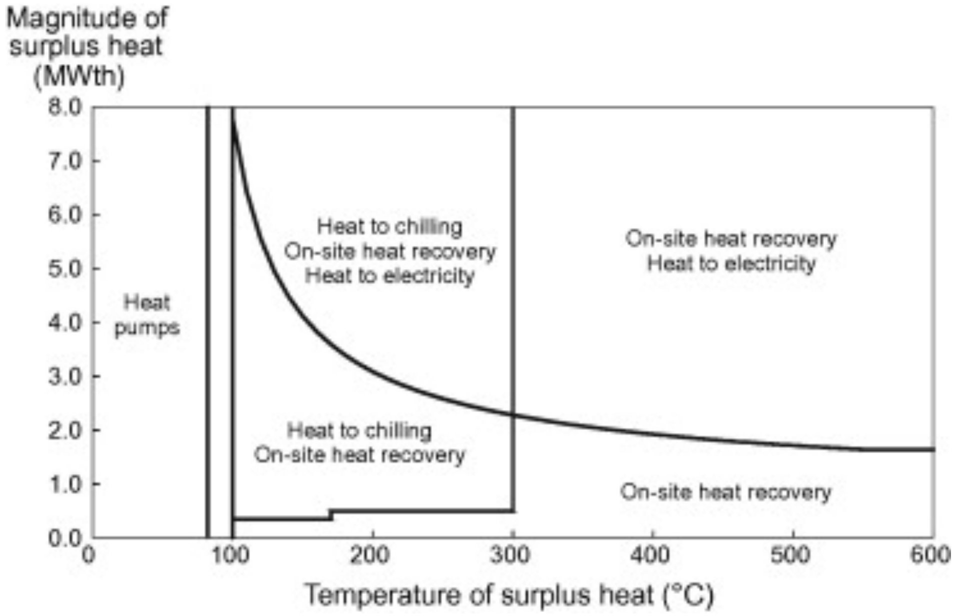

Figure 2.3: Surplus heat source characteristics required for use by different technologies [16].

Figure 2.3 visualizes the temperature barriers for various heat recovery methods. In terms of low-grade waste heat, which can be seen as a by-product of both thermal power production as well as intensive industrial processes, it is possible to recover the excess heat directly into the building's ventilation system. Temperatures as low as 40°C can easily be used for heating purposes via ventilation [17]. If combined with technologies capable of upgrading the heat into a higher quality, such as a heat pump, even lower temperatures are advantageous. As an example, a source at 0–50°C can be raised to 50–90°C [18]. Therefore, the utilization of waste heat in a wide range of temperatures can be seen as beneficial in terms of energy efficiency. There is, as well, an economic dimension that comes into play in terms of how valuable the lower and higher quality heats are. This can be, for example, dependent on whether or not the lower quality heat can be used directly or if the investment in a heat pump is economically profitable in the long-run.

2.4 BREEAM SE certification

BREEAM, developed by the Building Research Establishment (BRE), is an environmental certification system. BREEAM is one of the oldest, most widespread systems of all the international systems and has been used in the certification of over 500,000 buildings. In 2013, the Swedish Green Building Council adapted BREEAM to BREEAM-SE in order to better suit Swedish conditions [19].

A building's environmental performance is assessed in a number of different areas e.g., energy use, indoor climate and water management. A score for each area is calculated according to certain criteria and then summed to deliver the total score as well as the certification grade level achieved. Extra points can be achieved for innovation in regards to technical solutions [19].

There are several energy aspects in BREEAM-SE's Environmental Control Plan that must be fulfilled to achieve BREEAM-SE Excellent certification. Summarized below are some of the most relevant major points. These points were chosen on the basis of their relevance to the thesis project and contributed to the comprehension of energy efficient buildings in comparison to the current condition of all three AL sites. The degree to which these points were implemented at each AL site assisted in outlining where the sites are lacking in terms of energy savings and provided key focus areas. These areas are further discussed in Chapter 4.4. Access to the BREEAM-SE Excellent Control Plan was in account of Fabege [20], who will certify Alfa Laval's newest office in Flemingsberg. In order to simplify the summary of the major points, they are presented in the subsections below as requirements.

2.4.1 Minimised energy consumption

The maximum permitted primary energy and information on how the external air flow (q-value) has been determined must be presented. In addition, simulation results for primary energy, divided into different energy sources, must be shown. The various calculation zones in all buildings must be visually represented as well as ventilation data for different zones and operating times. A_{temp} and as U-values for different parts of the building and area must be presented in addition to information about cold bridges and air leakages. The heat loads from people and equipment indoors, as well as time schedules for such loads, must be taken into account for heating purposes. Furthermore, calculations must be done in order to certify energy needs for heating, ventilation and lighting. Efficiency figures for installed equipment in the building envelope (e.g efficiencies for pumps, heat recovery systems and specific fan power (SFP)) must be presented. An analysis of the possibilities for local energy production must also be taken into account.

2.4.2 Energy monitoring

Installed energy measurement systems are required, e.g. a Building management system (BMS), that make it possible to derive at least 90% of the estimated annual energy consumption per energy source to the different end-use categories of energy-using systems. All energy-using systems in buildings with an indoor area greater than 1,000m^2 should be measured with a monitoring system. Systems in smaller buildings should either be available on a monitoring system or equipped with accessible sub-meters. The end use of the energy must be able to be traced back to the building's users e.g., by means of marking or data output.

2.4.3 Energy efficient lighting solutions

The building should been designed to function without outdoor lighting (which includes lighting on the building, signs and at entrances). If the building has outdoor lighting, the average initial light output for outdoor lighting fixtures in the project area should not be less than 70 lumens per watt. For signs with a power of < 25 W, 60 lumens per Watt is acceptable. All outdoor lighting fixtures should be automatically controlled to prevent lighting during the day. Presence detection should also be installed in areas with irregular pedestrian traffic. For indoor lighting, the installed lighting effect must be less than or equal to the recommended "setpoints" specified on the basis of Swedish standards in 'Ljus och Rum, 2013' (Light and Room, 2013). All permanent installed lighting solutions must meet the requirements.

2.4.4 Energy efficient cold storage

With regard to the cooling system, its control and its components, a strategy for design and installation should be established and implemented by a specialist. The strategy should contain both an objective and a method for obtaining the lowest possible environmental impact from energy use, carbon dioxide emissions and refrigerants. The design should show that both the cold storage and the building have been designed to minimize heat loads through good insulation, reduced air infiltration and the minimization of extra heat loads (such as fans, pumps, machines, etc.). Both control systems and sub-meters should be installed in order to minimize temperature rises as well as provide adequate central monitoring of operating parameters.

2.4.5 Energy efficient equipment

It is necessary to identify the building's manufacturing energy consumption and estimate its contribution to the building's total annual use of operating energy. In addition, systems and processes that account for a significant proportion of the building's and operations' total annual energy usage must be presented. A proposal for a significant reduction of that usage must be carried out.

2.4.6 Water measurement

Water meters on the main line for incoming water to each building must be installed. Water-consuming installations that consume at least 10 percent of the building's total water requirements must either be equipped with separate submeters or have monitoring equipment integrated. Each meter must be connected to a monitoring system.

2.4.7 Water efficient equipment

All tap water used for purposes other than drinking and sanitary use should be identified. Measures should be taken to reduce the tap water usage for efficiency purposes.

2.5 Heating Degree Day

One of the main factors to consider when designing a building is the climate. The climate influences the dynamic behavior of the building, which in turn determines the fluctuations in energy consumption. There are several areas that are affected by the climate: the building structure, the degree of insulation and the heating and cooling systems. An energy evaluation of the heating consumption was assessed through the use of the degree day.

A Heating Degree Day (HDD) measures the average number of days that the outdoor temperature falls below a certain base temperature and is designed to quantify the demand for energy needed to heat a building. A base temperature is used to indicate the point at which a building turns on its heating systems. The HDD makes it possible to relate the outdoor temperature to a building's demand for fuel or energy to heat them. 18°C is typically used as the reference temperature since this is the temperature at which most buildings turn on their heating systems [22].

The HDD value gives a range of information to analysts. As an example, if a production site has abnormally high heating consumption for a certain month, then certain questions should be asked to find out why this occurred. Was there a rapid fall in temperature? Were the HVAC-system's set points unreasonable? Was a door or window open that affected the the HVAC-system's cycles? These are just some examples of how the HDD can contribute to optimising energy consumption.

The daily HDD can be calculated with the following equation:

$$HDD = 18 - temp_{avg} \tag{2.1}$$

where $temp_{avg}$ is the daily temperature average. If the HDD has a negative value, it is instead set to zero [22].

However, if only weekly or monthly values are available, the HDD can be instead calculated with the following equation:

$$HDD = (18 - temp_{avg}) * days \tag{2.2}$$

where $temp_{avg}$ is the weekly/monthly temperature average and $days$ is the number of days in each week or respective month. The HDD is also set to zero if a negative value is calculated [22].

2.5.1 Simple regression analysis

Regression analysis is a method used to mathematically sort out the relationship between variables in order to make predictions or find trends in data sets. One dependent variable and one independent variable is used to define the relationship [23]. In order to conduct a regression analysis, data on the variables in question must be gathered.

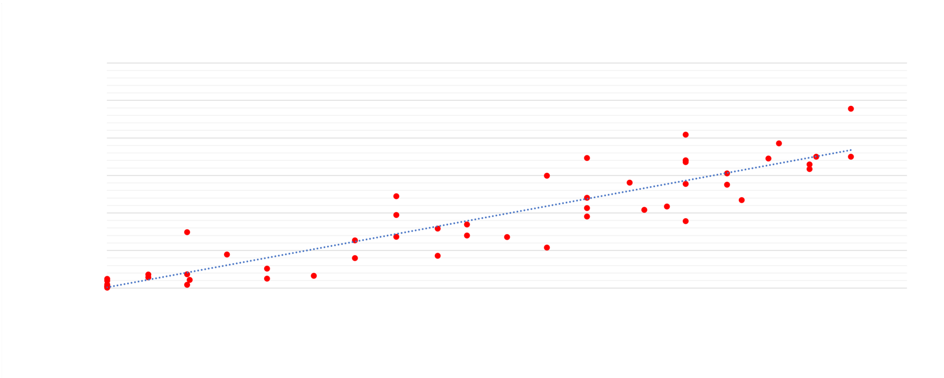

Figure 2.4: An example of a simple regression analysis between two variables.

The regression analysis can be calculated for data sets of all different sizes. It is important, however, to ensure that the data sets refer to the same time period. The equations used to execute a simple regression analysis are shown below.

$$y = ax + b. \tag{2.3}$$

$$R^2 = c. \tag{2.4}$$

- The y in Equation 2.3 represents the dependent variable.
- The x in Equation 2.3 represents the independent variable.
- The figure that is multiplied by the x (a) in Equation 2.3 stands for the "regression coefficient" that represents the **gradient of the regression line**.
- The constant at the end of the formula (b) in Equation 2.3 stands for the regression coefficient that represents the **intercept**.
- In Equation 2.4, R^2, the coefficient of determination, is a measure of how well the regression line fits the source data. The number ranges between 0 and 1, and the closer it is to 1, the better the fit. The higher the R^2, the better.

There are many benefits for companies to implement such analyses and reasons for why it's important that the model-predicted values are valid. Many companies use this form of analysis to explain previously occurred phenomenon, make predictions about the future or provide information in order to execute decisions [23]. The utilization of the regression analysis for this thesis project is explained further in Chapter 3.

Chapter 3

Methodology

For this thesis, several methods were used to undertake the research question and its underlying components. The research methodology incorporates a background study, benchmarking with similar industries and observations and calculations based on existing data.

Alfa Laval has decided to build a new production site with BREEAM-SE Excellent classification in Flemingsberg, Sweden. The classification's standards were investigated in order to provide a reference point as well as correlate current levels of efficiency and standards with desired standards for the future. The background study was enacted by researching published articles relating to HVAC, building management and HRV-systems in the industry sector on Google Scholar.

Benchmarking was also done with Sandvik, Ovako and Schneider Electric to provide further groundwork on existing initiatives and solutions for optimizing energy consumption. Since all three production layouts and processes varied from one another, the specificity of the questions asked to each of them varied. However, the benchmarking interviews all had their ground in the following questions:

- Do the production facilities have a heat recovery system? If so, which major energy users are being utilized and how long ago was the system implemented?
- What is the quality of the current HVAC-system in terms of age, efficiency and compatibility with BMSs?
- Have their been any changes to the building structure since its initial construction?

All three interviews took place digitally on Microsoft Teams with the Factory Manager or the Central Energy Coordinator, all of which are previous colleagues to the ALEM team at Alfa Laval. The interviews ranged between two to three hours for each company and were not recorded for confidentiality reasons; rather, notes were taken instead. Information gained from these interviews could not be published due to sensitive information but instead contributed to the general findings in Chapter 4 as well as the discussion in Chapter 5.

To map out the HVAC-system structure, trips were carried out to the production facilities in both Ronneby and Lund during October and November of 2021 and took place over the matter of three to four days. Once there, tours were given by the property manager where ventilation systems, heating systems and major energy users were presented and explained. Due to last-minute COVID-19 restrictions enforced in Denmark, the trip to Kolding was cancelled, hindering a deep analysis of their production facilities from this project.

Moreover, the research methodology involves analyses of existing data on current energy consumption to thereby understand the HVAC-system and asses where all three sites can undergo energy savings. All of the production facilities have submetering data available on current energy consumption that has been uploaded to a cloud-based platform, Resource Advisor, making it easy to analyze and compare metrics, energy supply data and facility information (see Chapter 4).

Calculations to find the HDD were done by using Equation 2.2. District heating values retrieved from Resource Advisor or company invoices displayed monthly values instead of daily or weekly. This is due to the digitalization shift for data on energy consumption for Alfa Laval having started circa one year ago. As a result, the HDD values were measured using monthly temperature averages in order to match the monthly consumption values. The consumption values were both consistent and credible, and can therefore be deemed to be of high quality. The monthly temperature averages were retrieved from www.worldweatheronline.com.

By matching the measured time periods for the HDD values and the energy consumption values, these two data sets made it possible to apply a simple linear regression to obtain rough estimate of seasonal heating requirements. Equations 2.3 and 2.4 as well as the linear regression functionality in Microsoft Excel were utilized to do so. In terms of the base temperature in the calculation, it is generally decided subjectively and through statistical reasoning. However, the base temperature was decided to be 18°C after careful review of other studies and documentation ([24], [25]) and can be, if desired, adjusted for future works.

For this project, Equation 2.3 was rewritten to the following equation to relate the monthly HDD values to the energy consumption values:

$$E = a * HDD + b. \tag{3.1}$$

- The E signifies "Energy" and corresponds to kWh for a specific month.
- HDD corresponds to the degree days for a period of a month.
- The constant at the end of the formula (b) represents the baseload energy consumption when $temp_{avg}$ is 18°C for the timescale analyzed. Since the regression is calculated using monthly data, it represents the baseload energy consumption in a month.

This analysis method aims to find an expressible model between energy data and heating degree days. For both this project and future projects, the method makes energy savings possible in a variety of ways, some of which include:

- Comparing the expected baseload energy consumption to the actual energy consumption to evaluate whether energy efficiency has improved or declined.
- Continuously assess ongoing energy performance by making comparisons of energy consumption with model-predicted consumption.
- Compare normalized regressions vs. surface area for production sites with similar production processes.

Chapter 4

Results

This chapter presents the results on both data analysis from Resource Advisor and factory visits to each site. For each site, a summary of the building envelope, heating system and ventilation system is presented. Major energy users for Ronneby are described due to their potential contribution for an HRV-system. Each heating system summary consists of consumption values over specific time periods and an HDD regression analysis. Consumption values for each ventilation system are also presented for each site. Discussions and further analyses on these topics can be found in Chapter 5. This chapter also includes general findings that relate to all three production sites, where analyses and comparisons to BREEAM-SE Excellent were made, as well.

The results from this thesis project will be used to aide Alfa Laval in several aspects, some of which are the following:

- Set groundwork for upcoming energy efficiency projects, whether or not they relate to the company's Carbon Neutral goal for 2030.
- Provide a better understanding of where internal investments should be expended.
- Establish a centralized understanding of energy awareness within global AL sites.

4.1 Lund

The production facilities in Lund consist of three buildings: GP, GQ and the lab. In total, the facilities can be estimated to occupy 35,000 m^2. The facilities vary in production hours which entails that some departments work 5-shifts whereas others only work day-time shifts. Lighting solutions have been divided into a few separate units per production building in order to detect possible timings for energy savings. The amount of LED solutions can be estimated to 80% in GP and the remaining buildings 20%. The building envelope can be described as "unchanged" since the initial construction in 1979. The insulation material for both the ceiling and walls are unknown to AL Lund's property managers.

4.1.1 Heating system

The central heating is located in the largest production facility, GP, where hot water from district heating flows in to heat the facility's hot water circuit. The internal circuit is then sent out to sub-stations in the remaining buildings; both production and offices. Each sub-station is equipped with three heat exchangers to further distribute heat into other units: ventilation, domestic hot water and radiators. For a better understanding of the heating system, see Figure 4.1.

Connected to the individual hot water circuits is a heat recovery system. The major energy users that are connected to the heat recovery system include presses, air compressors, drying furnaces, welding machines and washing machines. The presses, all of which are mostly hydraulic, are the biggest energy users.

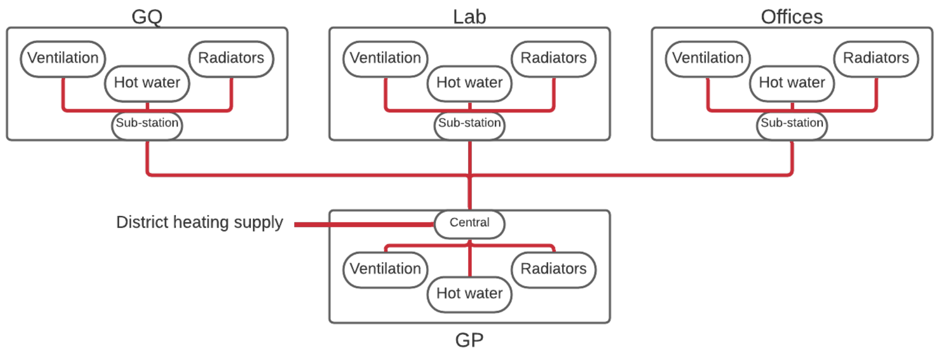

Figure 4.1: Simplified schematic of the district heating system at AL Lund.

The heat recovery system consists of a heat exchanger, heat pump and accumulator tank. The heat pump, according to a monitoring system, has an average coefficient of performance (COP) of 2.9. This entails that 2.9 kW of heating power is achieved for each kW of power consumed by the pump's compressor. In order to function as the primary heating system, the incoming water requires a temperature around 25°C.

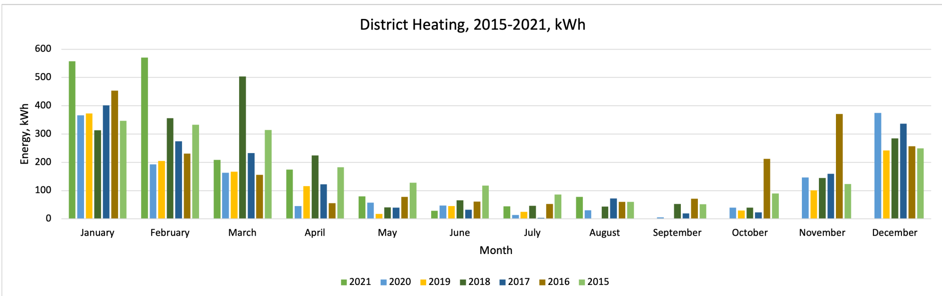

Figure 4.2: District heating for AL Lund between January 2015 and September 2021.

The data analysis for district heating in Figure 4.2 shows a seasonal trend. The consumption varies between 2015 and 2021, reflecting no distinct pattern in an increase or decrease of consumption as the years progress. Though there are some outliers in Figure 4.2, these were assumed to be due to differences in the climate and can be seen in the DH values in Figure 4.3. In order to reflect the efficiency of the heat pump's contribution in relation to the district heating consumption, the following figure was developed.

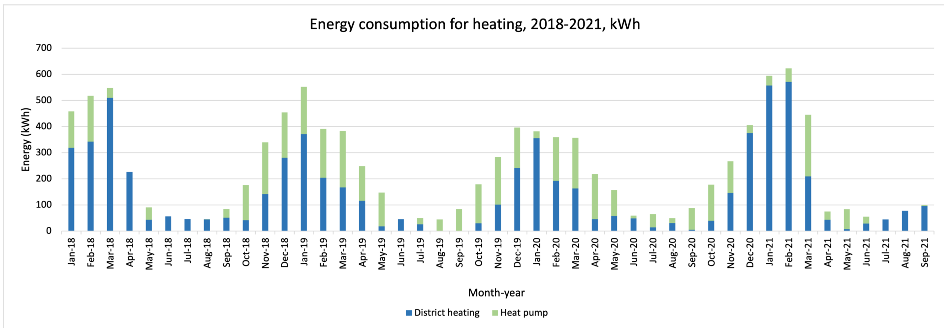

Figure 4.3: Total energy consumption for both district heating and heat pump between January 2018 and September 2021.

Figure 4.3 includes both district heating and heat pump consumption values. A greater contribution from the heat pump between 2018 and 2021 can be seen during the following time periods:

- Q1 and Q4 of 2018
- Q1-Q4 of 2019
- Q1, Q2 and Q3 of 2020.

The total energy consumption for heating follows a yearly pattern. However, variations have been identified, particularly between Q4 of 2019 through Q2 of 2020. In regards to the ratio of energy consumed between district heating and the heat pump over the course of three years, no distinct correlation can be seen. In April of 2018, June of 2018, July of 2018 and June of 2019, the sub-meter on the heat pump represented negative values. This has been corrected to a value of 0 in Figure 4.3 after the analysis and concluded that these values were incorrect, though no clarification can be presented.

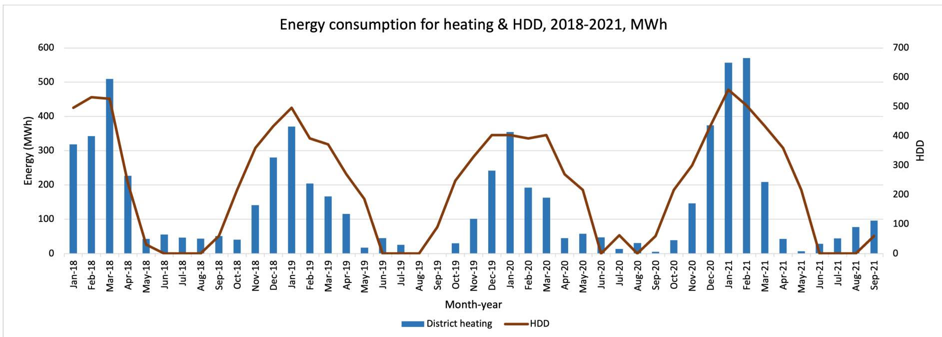

Figure 4.4: Total energy consumption for heating and HDD between January 2018 and September 2021.
Temperature source: www.worldweatheronline.com

The HDD regression model calculated in Excel can be seen below. The model represents the data solely from district heating for each month throughout the period of 2018 and September of 2021. Values that the HRV-system has contributed could not be obtained from the data sets in Resource Advisor, therefore affecting how well HDD correlates to the total energy consumption for heating. This can be seen in both Figure 4.4 and 4.5, where the absence of the HRV-system's heat contributions are visible. The baseload consumption per month, according to the regression model in Figure 4.5, is predicted to be -9.5 MWh. This indicates a generation of energy which is statistically incorrect in this case. R^2, valued at 0.66, also indicates a poor fit of the linear regression to the data set An analysis and explanation of these results can be found in Chapter 6.3.

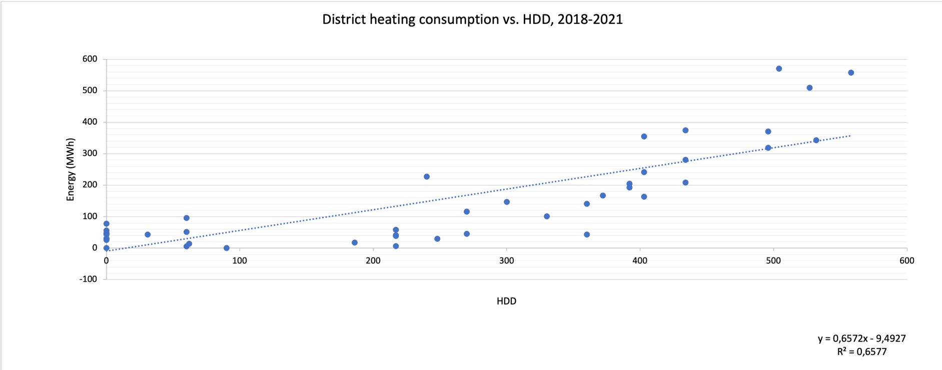

Figure 4.5: Regression analysis of the monthly total heating consumption vs HDD between 2018 to 2021.

Figure 4.5 displays a linear connection between heating consumption and HDD values to some degree, though an important data set needs to be regarded to fully visualize AL Lund's total energy consumption for heating: the heat generation from the heat pump. The figures are not precise, however, but an estimation of the feasible values for AL Lund's heat generation were calculated using the heat pump's COP, 2.9, multiplied by the electricity consumption of the heat pump. Although the COP value represents an average during a certain period of evaluation, the analysis improved the comprehension of the site's heating system as well as contributed to a more realistic correlation between heating and HDD values.

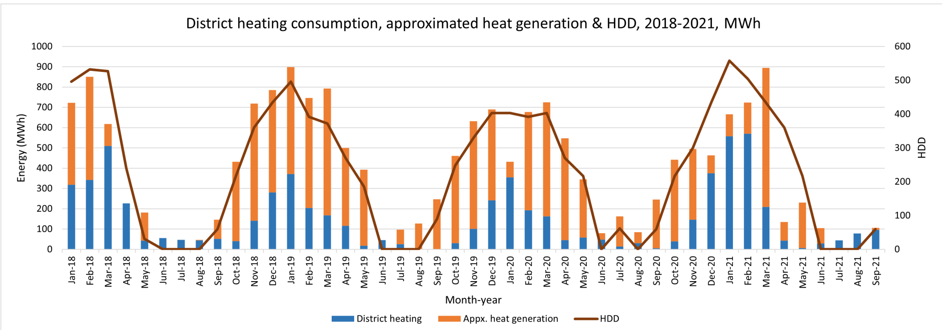

Figure 4.6: Total energy consumption for heating, approximated heating generation and HDD between January 2018 and September 2021.
Temperature source: www.worldweatheronline.com

The energy contribution from the HRV-system acted as the primary source of heating during the turn of the year for 2018/2019 and 2019/2020. However, Figure 4.6 reveals a reduction of the HRV-system's contribution during the winter months between 2020 and 2021, demonstrating that district heating was the primary source of heating. The HDD values between 2018 and 2021 coincide more prominently with the combined values for district heating consumption and heat generation in comparison to 4.4. This improved correlation is also reflected in the regression analysis in Figure 4.7. The baseload energy consumption at 18 °C is instead predicted to be 87 MWh as opposed to -9.5 MWh, with an increase of 1.3 MWh per HDD. The R^2-value, with a value of 0.82, also indicated a better fit of the regression model.

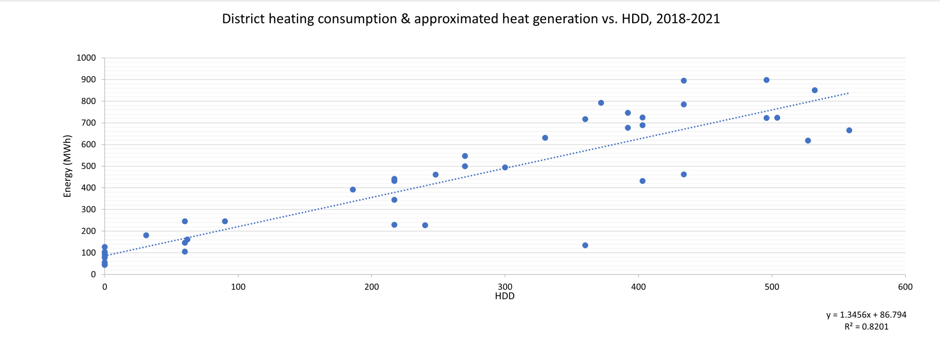

Figure 4.7: Regression analysis of the monthly total heating consumption and approximated heat generation vs HDD between 2018 to 2021.

4.1.2 Ventilation

The ventilation system, installed in 1979 in conjunction with the initial construction, has not been updated since. The ventilation units run 100% in all production buildings and are controlled manually. However, as heat waves during the summertime lead to higher indoor temperatures, employees are known to open fire hatches to try and create wind drag.

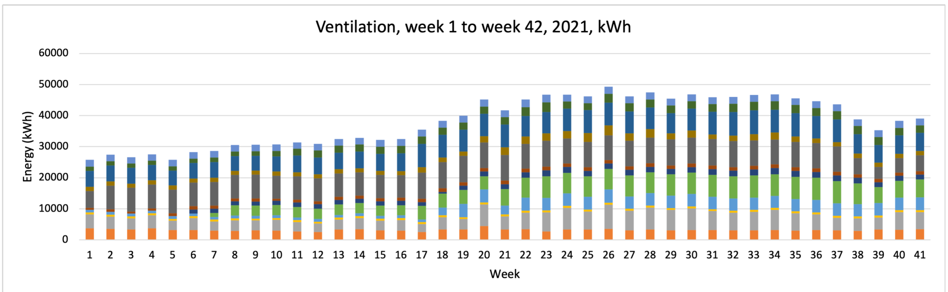

Figure 4.8: Weekly energy consumption for the ventilation system in Lund between week 1 to week 42 of 2021(one separate ventilation unit for each data set color).

The energy consumption from the ventilation units in all three production buildings in AL Lund is shown in Figure 4.8. The sub-metering of the ventilation units has been an on-going process, as can be seen with the addition of several submeters between week 7 and 17. Therefore, a yearly analysis cannot be presented but instead assumed. The weekly consumption can be assumed to be between 40,000 kWh and 50,000 kWh.

4.2 Ronneby

Work in the production facility is running continuously throughout the day. Many of the shifts are 2-shifts or 5-shifts, and half of the employees work on weekends. Motion-detection sensors have been installed both inside and outside of the production facility for lighting purposes. Since the production continues outside of normal working hours, lighting remains turned on in most sections. Circa 15 percent of the lighting solutions are LED. The walls and the ceiling are built of Siporex, an aerated concrete.

4.2.1 Major energy users

There are around 20 furnaces on-site in Ronneby, varying from 800A to 1600A (600kW to 1200kW during maximum load). These furnaces do not run simultaneously but instead five to six at once. All of the furnaces are vacuum furnaces and are able to heat up to an inner temperature of approximately 1600°C. The inlet temperature for water is between 15-20°C and the outlet temperature is between 50-60°C, as requested from the furnace manufacturer.

The majority of the energy is lost during the cooling process, during which the plates are quenched to approximately 80 degrees to ensure proper quality. Two cooling tanks, 10 m^3 each, are used to supply and receive the varying water temperatures during the quenching process where the energy loss is predominant. Both tanks are emptied and refilled completely once or twice a year.

The secondary cooling tank cools the water used in the furnaces via a heat exchanger. The primary cooling tower is used to regulate the secondary tank's water temperature, also via a heat exchanger, and pumps water to the cooling tower where it is then released into the air. In total, there are seven cooling towers on the roof of the facility. A schematic of the cooling process is shown in Figure 4.9.

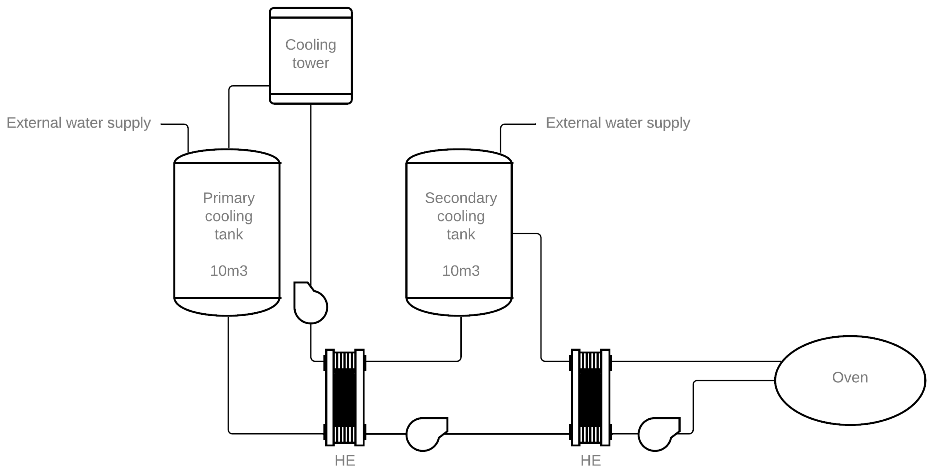

Figure 4.9: Cooling process schematic from furnace to cooling towers in Ronneby.

After the quenching process in the furnaces is complete, the plates are then removed from the furnaces and placed in the facility to cool down to room temperature, where the remaining energy losses take place.

4.2.2 Use of heat

The district heating data for AL Ronneby in Resource Advisor supplies both the production facility and the main building office. There is currently no heat recovery system in-place which entails that all of the heating is supplied through district heating pipes. The supplied domestic hot water from the district heating is transferred via heat exchangers in order to provide hot water for bathrooms, radiators and the ventilation system. Monthly values for district heating are shown in Figure 4.10.

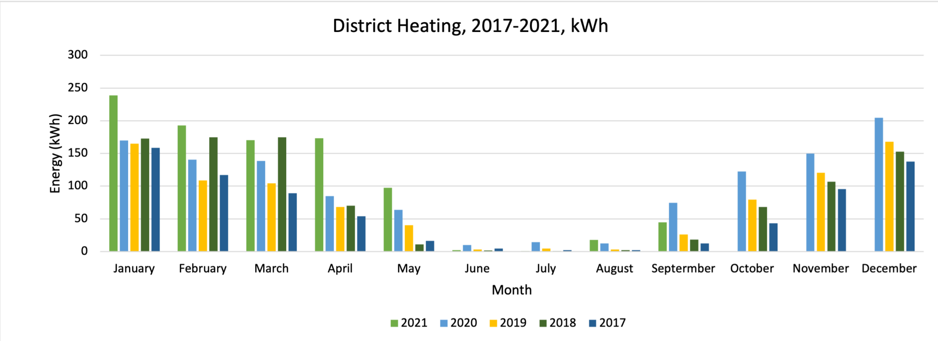

Figure 4.10: District heating for Ronneby between January 2017 and September 2021.

The trend analysis shows an increase in district heating consumption for the first few months in 2021 from previous years. Throughout the year, the total energy consumption ranges between 1,000 kWh and 250,000 kWh per month.

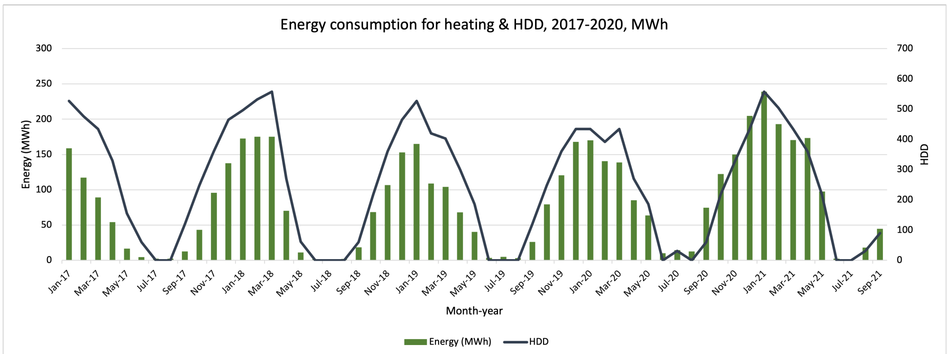

Figure 4.11: Total energy consumption for heating and HDD between 2017 and September 2021.
Temperature source: www.worldweatheronline.com

Figure 4.11 presents the district heating consumption in a continuous manner alongside HDD values for each month. In order to gain a better understanding of how the HDD values correlate to AL Ronneby's heating consumption, a regression analysis was performed.

In Figure 4.12, a regression analysis for the total heating consumption was brought forth. The model included monthly data between 2017 and 2021. From the model, it can be understood that the baseload monthly energy consumption at 18°C is 1 MWh. For each increase in HDD, an additional 0.33 MWh can be added.

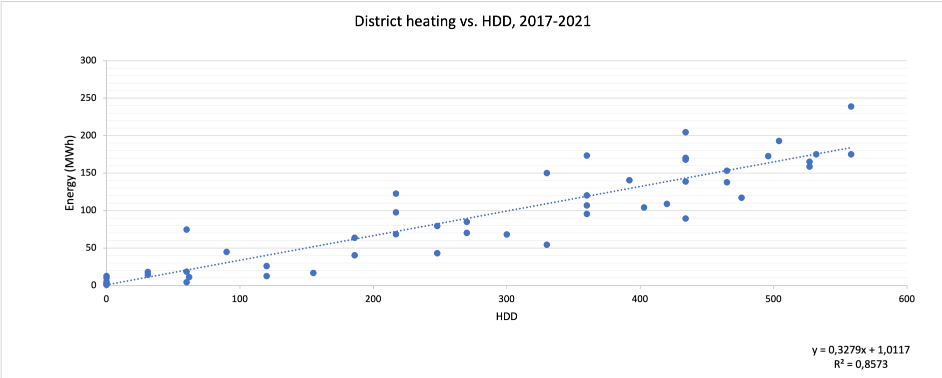

Figure 4.12: Regression analysis of the monthly total heating consumption vs HDD between 2017 to 2021.

4.2.3 Ventilation

Ronneby has an exhaust and supply air ventilation system, consisting of many separate ventilation units spread out across the entire production facility. A majority of the ventilation units have not been updated since the 1960's. The fans to each separate ventilation unit are controlled manually with an ON-OFF functionality and are adjusted throughout the year. The air travels in and out through circa 20 hatches on the roof inside which fans are installed directly. The independent exhaust air fans do not have dampers that close when the fans are not in operation, providing susceptibility for air leakages.

The fans are not currently being sub-metered, so a yearly or weekly trend analysis cannot be shown. However, the yearly total energy consumption for the ventilation system was approximated to 2,306 MWh in the previous EKL in 2016.

4.3 Kolding

As briefly mentioned in the *Methodology* chapter, COVID-19 restrictions were implemented on the same day as the trip to the production facility was supposed to take place. Because of this, a deep analysis of their production facilities was not possible. However, data from Resource Advisor was taken forth in order to provide a brief overview of the site's consumption. Information on major energy users, for the purpose of evaluating possible heat recovery systems, was unable to be retrieved.

4.3.1 District heating

An energy survey that was sent out in the beginning of 2021 indicated that Kolding had neither an HRV-system nor a BMS. It can be assumed that all heating consumption is provided by district heating. Values for the site's district heating consumption were retrieved from Resource Advisor as well as company invoices.

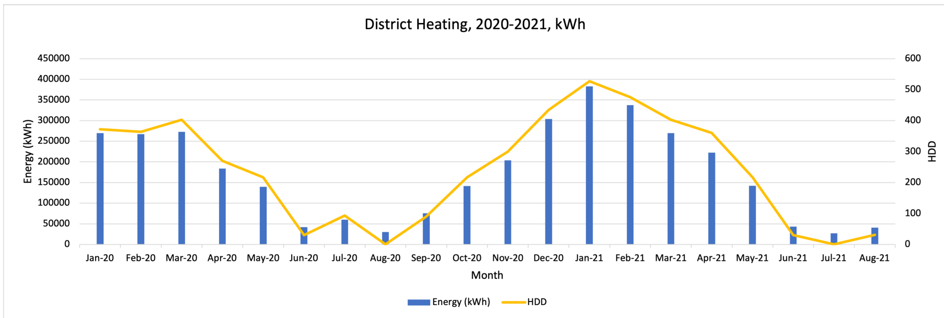

Figure 4.13: District heating for Kolding for 2020 through August of 2021.
Temperature source: www.worldweatheronline.com

The district heating consumption for January 2020 until August 2021 can be seen in Figure 4.13. The values range from 25,000 kWh and 400,000 kWh per month during the span of 20 months. As expected, the values coincide with annual temperature fluctuations, as shown by the HDD curve on the secondary, vertical axis.

A linear regression of the monthly district heating values was taken forth in Figure 4.14 using the same values from Figure 4.13. The R^2-value was the highest of all three sites studied, 0.9856, indicating a very good fit for the linear model. 15 MWh is predicted to be the baseload energy consumption for the site, with an increase of 0.65 MWh per HDD.

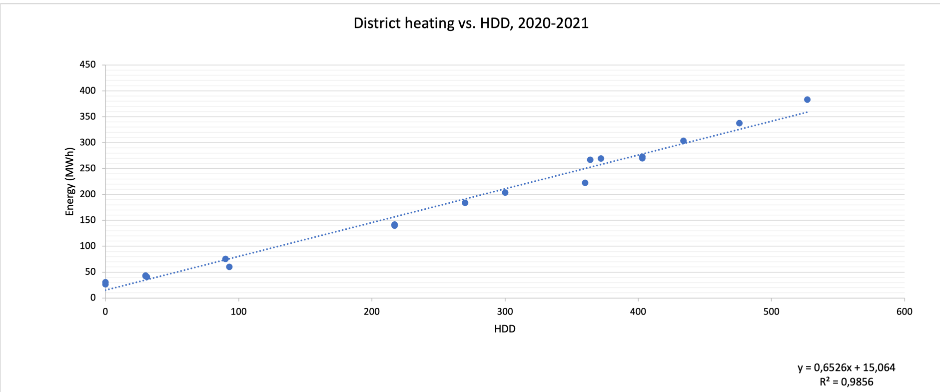

Figure 4.14: Regression analysis of the monthly total heating consumption vs HDD between 2020 to August of 2021.

4.3.2 Ventilation

Energy consumption from seven ventilation units were brought forth and analyzed from both a daily and weekly perspective. Although verbal confirmation was not possible, several conclusions were made from the data analyzed. However, the age and quality of the ventilation system is unknown by the author.

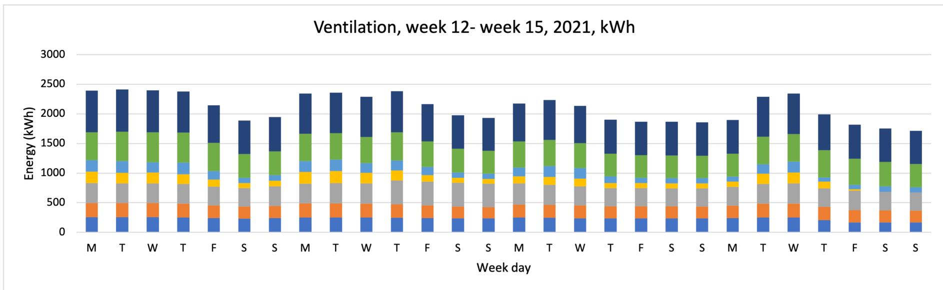

Figure 4.15: Daily energy consumption for the ventilation system in Kolding between week 12 through week 15, 2021.

It can be concluded that the ventilation systems in Kolding are variable controlled due to the minimized consumption of each unit on certain days without switching off the unit. Whether or not this is done manually is unknown. A weekly pattern cannot be seen from the data, though assumptions can be made that the AL Kolding site controls the ventilation in proportion to production facility needs. This can be seen in Figure 4.15.

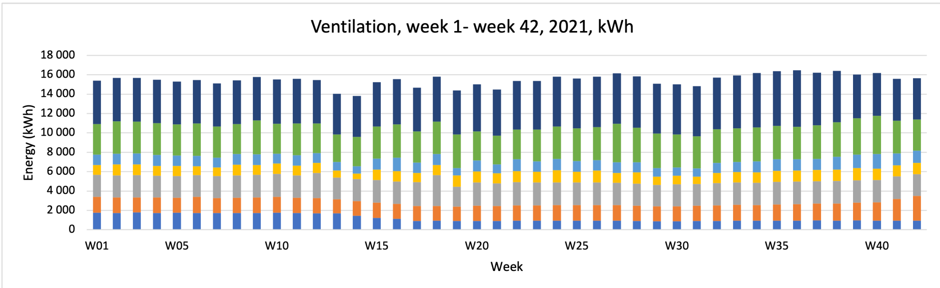

Figure 4.16: Weekly energy consumption for the ventilation system in Kolding between week 1- week 42 of 2021.

The weekly energy consumption analysis started in January of 2021 due to lack of data measurements in Resource Advisor. Figure 4.16 does not display any visible trends for the ventilation system throughout the year. However, consumption dips around week 12 and week 30 are visible and can be concluded to correlate with Easter and summer holidays when there are limited production capabilities.

4.4 General findings

The potential for heat recovery is site-dependent and governed by multiple factors. These include the source of waste heat, its compatibility with heat sinks, and the available heat recovery technologies. The compatibility is constituted by the inlet and outlet temperatures, capacity, time of day as well as location in the facility itself. The outlet temperatures for the major energy users at each production site are too low for conversion to electricity, as shown in Figure 2.3. Ideally, the sources of waste heat should, in combination, be able to deliver continuously into the HRV-system and act as the primary heating system when needed. However, this is typically not the case at all three sites due to the dynamic work flow, which suggests the need of a stable secondary system. District heating should come into act in the event of insufficient waste heat energy from major energy users. This solution, discussed during the benchmarking phase with Sandvik and Ovako, is also highly favorable at their production facilities due to ensuring energy efficiency in energy-intensive industries. Ensuring that the primary and secondary systems work as designed should be important in order to prioritize the recovery of energy and minimize consumption from external sources when possible. This statement can also be supported by BREEAM-SE's Excellent guidelines for minimized energy consumption. As summarized in Section 2.5.1, the heat loads from people and equipment indoors, as well as time schedules for such loads, must be taken into account for heating purposes. The utilization of the heat loads must be prioritized and the timing schedules for the loads must be clearly defined.

Retrieving figures for the ventilation units, their q-values, as well as efficiency levels (e.g. SFP for fans) proved rather difficult for this project. This was due to the lack of documentation about the systems, which haven't been upgraded since the initial build, and the lack of research about the current state. This resulted in creating assumptions in order to gain a better understanding of the possible gains in energy efficiency when compared to newer ventilation systems. It is known, however, that the ventilation systems for all three production facilities run 100 percent throughout the year unless manually turned off, as stated in *Results*. These, too, can be seen as major factors that need to be mended; not only to significantly reduce each facility's daily operational energy consumption but also in order to comply with BREEAM-SE Excellent standards on "Minimized energy consumption" and "Energy efficient equipment". These state requirements on the presentation of several important values:

- The external air flow.
- The ventilation data for various zones and their operating times
- The efficiency figures for installed equipment in the building envelope
- The consumption of systems and processes that account for a significant proportion of the building's and operations' total annual energy usage.

Energy efficient lighting solutions are currently being installed at all three production facilities. According to an internal energy survey sent out in the beginning of 2021, LED stood for less than 10 percent of the total facilities' lighting solutions in both AL Lund and AL Ronneby and between 20-30 percent in AL Kolding. Today, that value has seen an increase at all sites though vast improvements are possible. With a decrease of up to 50 percent in energy usage in the conversion from fluorescent to LED, each site has the potential to reduce their energy consumption with that same amount once fully converted ([21]). The output required should be set accordingly to BREEAM-SE standards, as summarized in Section 2.5.3.

Energy monitoring, such as a BMS, is an aspect defined as mandatory for BREEAM-SE's Excellent (see Section 2.5.2) and would greatly benefit all three production facilities. A multi-discipline platform is able to incorporate many systems i.e., HVAC, lighting and power. For HVAC control, the BMS can correlate data coming from many devices inside each building. By merging the installed sensors with the possibilities of the HVAC system, the indoor environment can adapt automatically to any change in conditions (e.g., time schedules for production, occupancy and climate forecasts). A control system for lighting solutions can extend energy-savings possibilities by adjusting illumination based on the time of day, the season and the location of each room. Incorporating a multi-discipline BMS is highly recommended. According to Ovako, their BMS enables smart building infrastructure on three system levels: ventilation, district heating and cooling fans. Accessibility to their BMS system from both work and home increase comfort, efficiency and resilience. A strong proposal is to investigate BMS options for all three sites in this study.

As for the HDD regression analysis, it intended to find an expressible model between energy data and heating degree days for part of the heating consumption analyses. What comes afterwards, i.e. applying that regression model to estimate future energy consumption for degree days, can be even more interesting. By taking the regression model for a certain time period (i.e. 2020), we can predict the energy consumption for the following year as if it had operated as it previously did. What can one do with this information, though? Well, by comparing the expected consumption to the actual consumption, you can see whether energy efficiency has improved or declined, and to what degree. This can be beneficial when monitoring the quality of a system or following up on currently implemented energy-savings projects. Another option is to monitor ongoing energy performance by continuously making comparisons of recent energy consumption with model-predicted consumption on a daily, weekly or monthly level. For production sites with similar production processes, it could be useful to compare their normalized regressions vs. surface area. This can be established in the form of KPIs, which should be site-dependent due to the variance in products and services which affects the baseload energy consumption. Because of the benefits of assessing current consumption or predicting expected consumption, securing a stable regression model with accurate data should be a priority in order to act as an additional tool in energy analysis.

Chapter 5

Discussion

The *Method discussion*, found in Chapter 5.1 below, analyzes the chosen procedure used to bring forth the results. A discussion on the general findings from each production site, as well as broad comparisons to BREEAM-SE Excellent's requirements, succeed the *Method discussion.* Thereafter, an analysis of each separate production site is conferred alongside recommendations for energy-savings solutions.

5.1 Method discussion

Interviews with Sandvik, Ovako and Schneider Electric for benchmarking purposes provided knowledge and insights that contributed to both a better understanding of the results as well as insights for the discussion that follows. Sandvik and Ovako were selected due to their similarity in being energy-intensive industries in Sweden. Schneider Electric, as previously stated, has been hired to do consultancy work regarding energy efficiency for Alfa Laval. Therefore, based on the company's experience in providing energy-savings solutions to other companies, it was deemed beneficial to include them in the benchmarking phase.

The digitalization shift for data on energy consumption for Alfa Laval started circa one year ago. This entails that there was not a possibility of comparing yearly consumption data without the aid of invoices in some cases. However, the data that was uploaded to Resource Advisor for each site was easy to navigate and export to Excel for analysis purposes. In addition, the quality of the data was adequate enough for the extent to which it was used.

Travelling to Ronneby and Lund along with partaking in the sites' Energy Mapping contributed a large amount to the understanding of the site's production methods, manner of working, major energy users as well as their HVAC-systems and HRV-systems. The in-person visits delivered better information exchanges in terms of solutions, current energy-savings initiatives and site limitations. There is no doubt that a visit to Kolding would have provided more information on these fronts.

As for the regression analysis for the monthly HDD, there are several adjustments that could be made to better understand heating demands. Most buildings follow a weekly routine, which means that solely having access to monthly data was not optimal. There are several reasons why the absence of supplementary data is not optimal. Although the occupancy of a building, along with it's heating patterns, may vary throughout the week, the patterns are usually consistent from one week to another. In most cases, the days of the week do not line up with calendar months which causes inaccuracies in the data analysis. This is due to the variance in the number of week days and weekends in each month. In addition, the calculation method for energy usage per HDD used assumes that the baseload is a constant number. This, too, requires periods of consumption that are all the same length due to the fact that the baseload energy consumption depends on the length in question. By providing data for heating consumption on a weekly basis (or summing daily data into weekly totals) and ensuring equally sized data sets, the regression analysis can be more accurate. Furthermore, using the highest R^2 value to indicate the best fit for the linear equation, and therefore base temperature, is optimal in theory. In reality, however, there are various imprecisions in degree-day analysis which can cause misleading figures. In the case for AL Ronneby and AL Kolding, the monthly district heating consumption values included both the production facility and offices. Additional analyses with different base temperatures were therefore not executed due to the varied structure of data available.

At an early stage of the work, the possibility of using a static simulation model provided by LTH for assessing heating system performance and forecasting energy needs with and without an HRV-system was investigated. However, this was rejected on the grounds that it was not practicable with the available data for each site.

5.2 Site-specific: Lund

Regarding AL Lund, a few site specific solutions have been identified for the building and heating system. In terms of building solutions, it is recommended that the site implements additional lighting zones as well as installs LED lighting solutions, starting with upgrading the largest zones. The addition of zones would benefit the production departments that are not in use during off-peak hours. One recommendation would be to carry out tours throughout the facilities during the off-peak hours in order to identify possible additional zones. Accommodation to renovations and/or placement changes for production departments would also be easier with more zones in place. As for the building envelope, no information was gathered on materials or insulation values. Further research should be conducted on this front in order to evaluate possible strategies for minimizing heat losses through all barriers as well as leakages.

As for heat recovery solutions, the Lund site has developed a beneficial system by combining three technologies: a heat exchanger, a heat pump and an accumulator tank. Although the exact values of its energy contributions are unknown, it was possible to speculate. Examining the monthly heating consumption without the addition of the approximated heat generation, as represented in Figure 4.6 and 4.5, the value for the baseload energy consumption was negative and the coefficient of determination was 0.66. These values imply an incorrect fit of the linear regression to the data set, which is very logical in several aspects. The HRV-system, as designed, is the primary source of heating for the production facilities. At high outdoor temperatures (when HDD is low) and when the need for heating in minimal, DH consumption are at its lowest. When the HRV-system's contributions aren't sustainable to the facilities' heating demands, DH is turned on and increases as temperatures rise. In order to better explain, a line graph on this matter is presented in Figure 5.1.

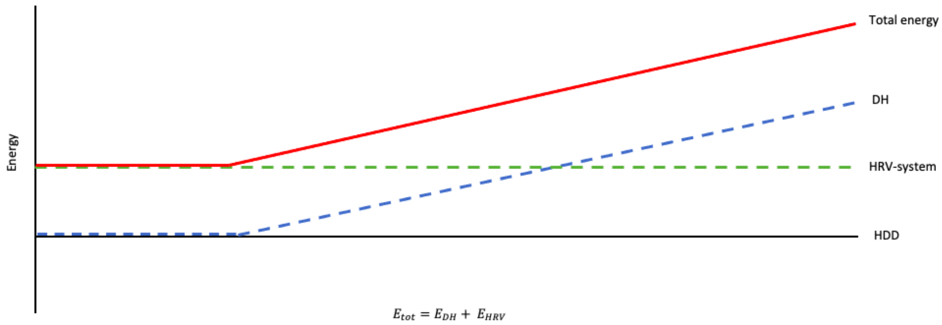

Figure 5.1: Simple graph visualizing how the linear regression will shift when the HRV-system is taken into account.

The scenario represents a stable contribution throughout the year from the HRV-system and where the DH is actuated once the HDD reaches a certain value. The total energy consumption for heating, as shown with the *red* line, is the sum of the two. Implementing a linear regression on the total consumption will shift the intercept upwards on the y-axis and result in a more realistic baseload energy consumption. Although this scenario is not representational of AL Lund's HRV-system due to discontinuous production patterns, it aims to explain the negative intercept to the reader and why its value is irrational. Moreover, it is possible that the sum of DH and the HRV-system's contributions includes less noise in the regression analysis than what is shown in Figure 4.5.

The addition of the HRV-system's estimated contribution included less noise than what is shown in Figure 4.5, as suspected. This is represented in Figure 4.7 where both the R^2-value and baseload energy consumption increased, signifying an improved linear relationship. By utilizing the averaged COP for the heat pump, it was concluded that the HRV-system acts largely as designed: as the primary source of heating for AL Lund. This is, however, with the exception of the winter months between 2020 and 2021. Access to the updated COP values for the heat pump, or values for its energy contribution, would be ideal in order to evaluate the system's effectiveness as well as identify issues. These issues include, but are not limited to, the negative values from the heat pump and the HRV-system's failure to act as the primary source of heating. This is another key example of how more efficient energy monitoring can be beneficial.

To summarize, a few key initiatives that AL Lund can implement or further investigate are shown in Table 5.1 below.

AL Lund	
Building	Implement additional lighting zones to minimise unnecessary energy losses.
	Continue with upgrading to LED lighting solutions.
	Investigate the building envelope regarding insulation, heat losses through barriers and leakages.
HVAC-system	Evaluate real-time contributions from the existing HRV-system to assess energy efficiency.
	Ensure that the HRV-system serves as the primary system when sufficient waste heat energy is available.
	Follow-up on negative values from the heat pump.
	Investigate current figures for the ventilation units for upgrading purposes.
	Invest in a BMS for monitoring and regulatory purposes.

Table 5.1: Key site-specific proposals for AL Lund to investigate.

5.3 Site-specific: Ronneby

One major solution for minimizing energy consumption would be to implement a heat recovery system, similar to that of the production site in Lund. With five to six furnaces running at once, and the majority of their energy released from the cooling towers, one can enable an extreme amount of heat recovery that can be utilized for heating purposes. With a water outlet temperature between 50 and 60 degrees, either direct recovery or a heat pump technology would be suitable, as shown in Figure 2.3. Although the furnaces do not run continuously, utilizing the outlet temperatures from the furnaces as the primary source for heating would minimize the district heating consumption or even remove the need in its entirety. The consumption of district heating can be set into motion as a secondary unit when heat recovery from the site's major energy users is not possible. The transition from older furnaces to newer will strengthen the stability of using heat recovery from major energy users as a primary source of heating. Further investigating this transition is considered to be highly recommended.

Ventilation is another area within the HVAC-system where vast amounts of savings can be seen. Though some of the neglected units have been replaced with newer ones, they are still equipped with the outdated control systems that solely include ON-OFF functionality. Due to the age of the current units, it is not possible to control them with variable air flow if an advanced control system were to be implemented. The production site has begun upgrading its ventilation units at a slow pace due to the shortage of investments. By starting with upgrading the largest units in the production facility, a greater profitability can be obtained from both an energy and financial perspective. Thereafter, continuing with the smaller units will create modernization for the entire ventilation system in the long run. It is recommended to install a centralized control system (i.e. BMS) for the ventilation system in order to maximize energy efficiency from the newer ventilation units during the entire transition process and from there on.

The regression analysis showed the lowest regression coefficient values. This can be due to the size of the production site or the excess of waste heat coming from major energy users. The implementation of an HRV-system would bring value-add data on how HRV-systems contribute to energy efficiency with linear regressions.

A list of a few summarized, key site-specific proposals for AL Ronneby are explained in Table 5.2.

AL Ronneby	
Building	Continue with upgrading to LED lighting solutions. Investigate thermal variability from insulation and possible leakages.
HVAC-system	Apply heat recovery solutions for current major energy users, replacing out-dated cooling towers. Identify heat recovery solutions for the site's upcoming major energy users. Continue upgrading ventilation systems by starting with the largest units to maximize profitability. Invest in a BMS for monitoring and regulatory purposes.

Table 5.2: Key site-specific proposals for AL Ronneby to investigate.

5.4 Site-specific: Kolding

The analysis of AL Kolding, though meant to be expanded, still provided valuable insights on consumption patterns. The site is able to control the capacity at which the ventilation units are running, though it is unknown to the author whether or not this is done manually. However, seeing that the daily values fluctuate gives insight that the site is aiming to make energy consumption effective during off-peak hours. Conclusions on the age and quality of the ventilation system could not be made from the data retrieved.

District heating consumption values correlated well with HDD values, as shown in Figure 4.13 and 4.14. However, the effectiveness of the DH system cannot be interpreted solely from the data. The size of the AL Kolding facility can be assumed from the regression analysis since the gradient and interception values were between those of AL Lund and AL Ronneby. The coefficient of determination was the highest out of all three sites studied, but this can be due to the smaller scale of data points included in the model. However, it is still a clear indication that AL Kolding has the most linear correlated DH consumption to HDD. Verbal communication with employees on-site would be needed to determine if there is unnecessary heating during the summer months. In that case, either DH needs or insulation in the building envelope should be revised. Lastly, the contribution of waste heat to act as a primary source of heating should be investigated, as this was not possible for this project. The right technologies for an HRV-system would need to be implemented to suit the characteristics of AL Kolding's major energy users where inspiration from the HRV-system in AL Lund can be taken.

Although the analysis of AL Kolding was shortcoming in comparison to those of AL Lund and Ronneby, Table 5.3 summarizes a few key areas that the site can further investigate to undergo energy savings.

AL Kolding	
Building	Persist in upgrading to LED lighting solutions.
HVAC-system	Investigate the implementation of an HRV-system. Evaluate possibilities of implementing a BMS for ventilation, lighting and heating purposes.

Table 5.3: Key site-specific proposals for AL Kolding to investigate.

Chapter 6

Conclusions and Future Work

6.1 Conclusions

Energy efficiency has been one of the most discussed topics across the globe the past decade. As the EU pushes energy efficiency with Directive 2018/2002, many industries have focused their attention on minimizing both emissions and energy consumption. Alfa Laval has established many internal initiatives, one of which is investigating how production sites can minimize their energy consumption regarding their building and HVAC-systems.

In this thesis, I have investigated this initiative for three AL production sites: Lund, Ronneby and Kolding. In this work, an overall attempt was made to examine different energy-savings solutions from both a general and site-specific perspective. As realized during the thesis project, there is insufficient information and comparisons about the scale of how beneficial upgrading older equipment could be. Information has been obtained from various literature sources in order to supplement this and give some perspective on what scale these solutions can provide energy savings. The biggest theoretical insights came from comparing each site's current status to BREEAM-SE Excellent's requirements. In addition, the HDD regression models can be seen as an introduction to the possibilities of improving performance from both past and current data sets.

In conclusion, it has been shown that these three AL sites are in vast need of both building and equipment upgrades. However, the magnitude at which upgrades and/or implementations to the HVAC-system could contribute to energy savings can only be fully specified with access to more data on the existing systems e.g., q-values, SFP. In addition, the current outdated systems prohibit the possibility of automatically regulating the HVAC-systems. The utilization of waste heat from major energy users should also be implemented at all sites in order to enhance efficiency and repurpose instead of discard.

With the help of Schneider and Resource Advisor, all three sites have commenced measuring their energy consumption on many levels. Without the possibility of controlling and regulating this consumption with smart technology, however, energy savings can be very limited. Advanced BMSs would be able to control HVAC-systems by learning and recognizing patterns of activity and temperature in both the internal environment and external environment as well as the climate outside the industrial premises. In regards to regression modelling, it can also be further investigated for understanding current energy needs as well as calculating future energy savings. Collaboration and further benchmarking with other production firms would aide in expanding knowledge and generating additional energy-savings solutions. Advancements on all of these fronts need to be prioritized if a 50 percent reduction in energy consumption is an important goal for Alfa

Laval. Guidelines and standards can then be fully implemented with the intention of creating Alfa Laval's factory of the future.

6.2 Perspectives for future work

To give a few examples on how one could build upon the results of this thesis, a few suggestions are mentioned below:

- Cost-benefit analysis for upgrading purposes, taking into account energy savings from heat recovery.
- Investigate outdoor lighting efficiency on each production facility.
- Analyze energy efficiency for heating by using linear regression models. Can also compare sites by production surface area.
- Study heat losses via all barriers as well as leakages with the aid of IR-technologies and data analysis.
- Execute an advanced thermal balance simulation and examine results to further investigate effectiveness of insulation and HVAC-systems.
- Investigate future energy-efficiency requirements from relevant stakeholders for Alfa Laval.

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