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Energy Consumption and Potential Savings in the Automotive Body Shop

Bachelor's Thesis within the Industrial and materials science programme

RAFID KADHIM
ALBERT NORIN

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
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Rafid Kadhim
Albert Norin

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Supervisor: Göran Kollback, Volvo Cars
Examiner: Dag Henrik Bergsjö, Department of Industrial and Materials Science

Bachelor's Thesis 2021
Department of industrial and material science
Chalmers University of Technology
SE-417 56 Gothenburg
Telephone +46 31 772 1000

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Abstract

Extensive effort has been put into measuring sustainability efficiency within the manufacturing over the last few years. This study presents a comprehensive look at sustainability solutions within the industry and further development of an existing energy map. It is vital that existing buildings operate more efficiently while providing a lower impact on the environment, and it is essential that new structures maximize their energy efficiency. The ventilation system of a building accounts for a significant portion of its energy consumption, and there is frequently significant potential for the system to be optimized and streamlined. This report consists of the end result of an evaluation of the usage of sustainability evaluation techniques inside the industry. This through a literature study and meetings with experienced individuals from each relevant sector. Based on our analysis, a conclusion could be drawn that the possibilities for a more environmentally friendly and efficient system were possible and profitable for the case company when making changes to their lighting situation such as changing to LED lights and also making the heat exchangers more effective by establish a regular maintenance schedule against the so called "Fouling effect". Furthermore, when working with the effectiveness of the heat exchangers calculations were made to obtain a value, this value showed the potential amount of heat that could be recovered from the given system. Some suggestions were proposed to the case company on where this obtained value could be used in future research. In order to promote sustainable production, industry and academia must collaborate on method creation and implementation. Also, collaboration between industries must be implemented, because the case company must show a sense of responsibility and understand that sustainability is not a competition-oriented topic.

Keywords: Sustainable energy systems, energy research, energy optimization, heating, lights.

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Rafid Kadhim
Albert Norin

Gothenburg, May 2021

Abbrivations

VCT - Volvo Cars Torslanda.

CTH - Chalmers University of Technology.

CL90 - Cluster 90, the car models in the 90-series.

CL60 - Cluster 60, the car models in the 60-series.

TA - A VCT body shop.

TA3 - A VCT body shop, housing most of the CL90 production lines.

TAÖ - A VCT body shop, housing both CL60 and CL90 production lines.

LCC - Life cycle cost analysis.

PLC - Programable logic controller, used to communicate and control systems.

Keytalk - Holistic control system used by the case company for controlling lighting and ventilation.

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1
Introduction

This chapter presents the background to the subject of sustainability and how energy consumption is defined today and and why reducing the energy consumption in the automotive body shop is important. It also presents the aim of the report, broken down in Research Questions (RQ)s which will be answered during the project. A presentation of the limitations that could emerge is also included. Lastly the chapter ends with a brief introduction about the methodologies used in the project.

1.1 Background

Our and future generations face a huge challenge. Since the birth of industrialism, humans have been constantly looking for new ways to streamline manufacturing processes and this has led to more products at lower prices. However, this improved existence has come at a very high price. We see today that the sea temperature is rising in everything as the great ice melts, that our lakes and seas are becoming more acidic, that extreme weather and other natural disasters are happening more and more frequently.[1] All data show that these effects are due to global warming due to our use of fossil fuels.[2]

Breaking humanity's dependence on fossil fuels is therefore of high interest.

In Sweden, industry used 142 TWh in 2019, this corresponded to around 38 percent of Sweden's total energy use.[3]

1.2 Aim

In this report, we intend to examine the factors that contribute to energy consumption in a body factory for the automotive industry. We expect to present the distribution of energy consumption in industry as well as potential improvement proposals. In order to determine how the case company Volvo Cars can develop their work for sustainability, the following research questions will be answered;

- What factors contribute to the energy consumption in an Automotive Body shop?
- How is the energy consumption distributed in the factory?
- What potential energy savings can reduce energy consumption?

1.3 Limitations

The project will only examine the energy consumption in the body factory, this means that the painting factory, assembly plant and other premises are not handled in this project.
The project aims to present an overview of energy consumption in the body factory and present new methods that have the opportunity to reduce energy consumption. This means that the large part of the project will consist of information gathering of scientific methods and presentation of this as well as overall calculations, not in-depth analysis and calculations.
Due to the prevailing pandemic, most things will happen at a distance. This is seen as a demarcation as our ideas will not be able to be discussed immediately with individuals in the area.
The project is planned to be carried out in the spring of 2021, starting in January and final presentation in May. Due to the time constraint, we will need to prioritize the factors that have the greatest impact, thus certain factors may not be presented in the project.

1.4 Methodology

The methodology described in this chapter is a run-through of how the analysis was carried out. It begins by describing the literature review process and then the process of the conducted meetings. Furthermore, demonstrating how the data from these sources was used as material in order to achieve our results.
Meetings will be carried out during the project and the goal is to do them with relevant individuals from the case company and Chalmers to give us various input data. The meeting would be constructed in a way that they will include insight on what is actually implemented or not and why. Also the meetings will be kept with high quality output.
The literature review will cover what kind of methods that will be implemented within manufacturing companies and what academia believes can be implemented. Also previous thesis work was reviewed to get an idea on what approach and various layout could be implemented for the project. A tour on the facility was done in the early phase to get an idea and an understanding of how the ventilation system, cooling system and heating system were constructed.
Furthermore, Meeting routines for reconciliation played an important role to set the project into the right course. This was done once a week and became the foundation of the thesis.

2
Theory

In this chapter, a theoretical framework was developed to serve as the study's foundation. A mindmap was produced to identify areas related to energy savings within the automotive body shop. Theory for how to work with these areas will be described, see Appendix A.

2.1 Facility

2.1.1 Heating

The heating of the facility mainly consists of heated water that is bought and distributed to areas that needs to be heated. Passive heating also exists, in form of workers that emits heat to the premises as well as robots/machines that emits heat during operations.

2.1.2 Insulation/leakage

Heat losses due to air leakage occur in buildings when it's shell is not intact. Leaks can consist of holes, cracks or openings in the facade and can, for example be found around doors and windows.

2.1.3 Ventilation

The movement and exchange of air in buildings is referred to as ventilation. There are many reasons for using ventilation, the most common is to maintain a pleasant indoor environment. The ventilation system removes moisture, toxins, and other contaminants from the space and replaces them with fresh air.
To enable fresh air to replace the used air, the air needs to be moved. This can be done in two general ways, by natural ventilation and by mechanical ventilation.

2.1.3.1 Natural ventilation

Natural ventilation is triggered by natural forces (e.g. winds and thermal buoyancy force due to indoor and outdoor air density differences) drive outdoor air through purpose-built, building envelope openings. Purpose-built openings include windows, doors, solar chimneys, wind towers and trickle ventilators. This natural ventilation of buildings depends on climate, building design and human behaviour.[4]

2.1.3.2 Mechanical ventilation

Mechanical ventilation uses mechanical fans to drive the air flow. In facilities where a large air flow is needed or precise control is required, this solution is used. These fans are often installed in air ducts for supplying air into, or exhausting air from, a room. [4].

2.1.3.3 Heat recovery

Heat recovery, which uses the heat content of the exhaust air to mitigate energy use and heating costs for heating the ventilation supply air, is most often used to minimize energy use and heating costs for heating the ventilation supply air. A strong heat recovery of exhaust air adds to cost savings while also lowering total energy consumption. The quality of the indoor environment is maintained and can even be enhanced with the addition of heat recovery. FTX ventilation, which stands for exhaust and supply air ventilation, is another heat recovery technique.

Heat recovery accounts for between 50 and 80 percent of the heat required to sustain a comfortable indoor environment. The property's environment shell must be airtight in order for FTX equipment to work as effectively as possible. Because of this, transmission losses through the climate shell of the house are reduced, allowing for optimum heat recovery [6]. The temperature efficiency of heat recovery units can be conveniently calculated using the formula below based on three temperatures.

$$n_t = \frac{T_2 - T_1}{T_3 - T_1} \tag{2.1}$$

2.1.3.4 Introduction to heat exchangers

Heat exchangers are devices that transfer heat between two or more liquids of varying temperatures, such as liquids, vapors, or gases. Heat transfer may occur from gas to gas, liquid to gas, or liquid to liquid. Depending on the form of heat exchanger used, this can be accomplished by the use of a solids separator, which prevents liquids from mixing or coming into close contact with liquids. Other design elements, such as materials and parts, heat exchangers with transfer mechanisms, and flow configurations, aid in the classification and categorization of heat exchangers. A variety of heat exchange devices have been developed and manufactured for use in heating and cooling processes, and they are used in a variety of industries.[8]
A heat exchanger's architecture is an exercise in thermodynamics, a science that studies the distribution of thermal energy, temperature, and their relationships with other forms of energy. It is a good idea to understand the three types of heat transfer (conduction, convection, and radiation). A starting point for learning about heat exchanger thermodynamics.

Each of these heat transfer modes is addressed in depth in the sections that follow. Boilers, condensers, and radiators all have heat exchangers. Let's consider some examples of heat exchangers. Hot:

I. Preheaters and Intercoolers
II. Condensers and boilers in steam plant
III. Regenerators
IV. Radiators used in automobile
V. Boiler

The most popular types of heat exchangers used in almost all energy applications are shell and tube heat exchangers. Their applications include air conditioning, chemical and process industries, power generation, and medical applications. The sheath is made of polyvinyl chloride (PVC), and the pipes are fin-type and made of copper. Another one flows through the tubes of a shell and tube heat exchanger, while a liquid flows through the tube banks. It's expected to flow through the finned copper pipes, losing heat to the cold water in the PVC jacket as it goes. Heat is transferred between the shell and the liquids on the tube side. It is made up of housing, tubes, baffles, a front head, a back head, tube plates, and nozzles. The hot and cold water inlets and outlets are divided by two circular baffles, one between the two inlets and one between the two outlets.

2.1.3.4.1 Rotary heat exchanger The exhaust air from the ventilation system passes through a revolving filter made up of narrow sheet metal ducts in a rotary heat exchanger. A rotary heat exchanger requires the use of a generator, which consumes a limited amount of energy. The filter has strong thermal conductivity, and the plate is ruffled in several layers to have a large heat dissipating surface. The heat from the exhaust air is contained in the plate, which rotates to the supply air vent and releases the heat to the outside air [5]. Low pressure drops characterize the rotary heat exchanger, resulting in low fan power requirements and, as a result, low electrical energy consumption during fan service. It's relatively simple to clean and has a high productivity of about 80%. Disadvantages of using a rotary heat exchanger is that the temperature efficiency is severely harmed by even the tiniest dust or dirt on their structure. See Appendix A.X for an illustration of a rotary heat exchanger.[6]

2.1.3.4.2 Plate heat exchanger A plate heat exchanger is a type of heat exchanger that transfers heat between two fluids using metal plates. Since the fluids are spread out over the plates, this has a significant advantage over a traditional heat exchanger in that the fluids are exposed to a much greater surface area.There are no moving parts which doesn't consume any energy [5]. Plate heat exchangers have efficiencies of 60-90 percent, with countercurrent heat exchangers having the best efficiency. Disadvantages of using plate heat exchangers are their structure, plate heat exchangers can be perceived as difficult to clean. See Appendix A.X for an illustration of a plate heat exchanger. [6]

2.1.3.5 Conduction

Conduction is the transfer of thermal energy between materials in contact. Temperature is used to calculate the overall kinetic energy of molecules in a substance; colder structures (those with a higher temperature) have more molecular motion. When a warmer object collides with a colder object (one that is at a lower temperature), the cooler object becomes more energized, and the warmer object becomes less energized. This process will continue to operate until the temperature reaches thermal equilibrium.[7]

The following expression expresses the rate at which heat energy is transferred in a material through thermal conduction:

$$\frac{Q}{t} = \frac{kA\Delta T}{d} \tag{2.2}$$

2.1.3.6 Convection

Convection is the conversion of thermal energy from a surface to a substance that has been heated, such as air or water. When a fluid is heated, it expands, becoming less compact and rising in comparison to other areas of the fluid that are colder. As a result, when a room's air is heated, it rises to the ceiling when it is colder and less compact, transfers heat energy when it collides with the room's cooler air, then becomes denser and falls to the surface. A normal or free convection current is created as a result of this process. Forced or aided convection occurs as hot water is pumped into a nozzle, such as in a hydronic heating system.[7]

For free convection, the rate of transfer of heat is expressed by Newton's law of cooling:

$$\dot{Q} = h_c A \Delta T \tag{2.3}$$

2.1.3.7 Radiation

Thermal radiation is a form of heat energy transfer that occurs when a hot surface or substance emits electromagnetic waves. Unlike conduction and convection, thermal radiation does not require an intermediate medium to transmit wave energy. Thermal radiation is released in a wide spectral range from all surfaces with a temperature greater than absolute zero (-273.15°C).[7]

The Stefan-Boltzmann Law can be used to express the net rate of radiation heat loss as follows:

$$Q = \epsilon\sigma\left(T_h^4 - T_c^4\right)A^h \tag{2.4}$$

2.1.4 Lights

2.1.4.1 Light source

There have been many types of light sources in the market since the making of the incandescent bulb, and ever since then research for better, more efficient technology have been done. Today the dominant technology for creating light is light emitting diodes (LEDs) due to it's many upsides, mostly being luminous efficacy and long lifespan. The downside of LEDs is the increased purchase price compared to fluorescent tubes/CFL, this increased cost can however be payed of over time due to it's lower running costs and lifespan.

2.1.4.2 Control system

The light sources can be controlled in different ways. They can be controlled by the press of a button, different types of sensors and they can be connected to a smart control system with online access. In a large facility like an automotive plant, large amounts of energy could be saved if the light stays off when it's not needed, therefore control systems can have a great impact on the energy usage of the facility.

2.1.4.3 Comparison of light sources

To be able to compare different light sources, we need to introduce the measure luminous efficacy. This is a measure of how efficient a light source is at emitting visible light. It is the ratio of luminous flux to power, measured in lumens per watt in the International System of Units (SI).

$$K = \frac{\Phi_v}{\Phi_e} = \frac{\int_0^\infty K(\lambda)\Phi_{e,\lambda}\, \delta\lambda}{\int_0^\infty \Phi_{e,\lambda}\, \delta\lambda},$$

where,

ϕ_v is the luminous flux
ϕ_e is the radiant flux
$\phi_{v,\lambda}$ is the spectral radiant flux
ϕ_v is the luminous flux
$K(\lambda) = K_m V(\lambda)$ is the spectral luminous efficacy

2.1.4.4 Phasing out of dated light sources

According to energimyndigheten [9], (EU 2019/2015) will take effect and a roadmap for phasing out dated lighting sources were published. See table 2.1
Allowed - Lamps allowed to be placed on the market
Outdated - Lamps phased out, can not be placed on the market

Date	1 sept 2018	1 sept 2021	1 sept 2023
Halogen lamps 230 V (except R7s and G9)	Outdated	Outdated	Outdated
Halogen lamps G9 (230 V)	Allowed	Outdated	Outdated
Low voltage halogen lamps G4 and GY6.35	Allowed	Allowed	Outdated
Other low voltage halogen lamps	Allowed	Outdated	Outdated
Halogen lamps R7s (230 V), $\leq 2700lm$	Allowed	Allowed	Allowed
Halogen lamps R7s (230 V), $\geq 2700lm$	Allowed	Outdated	Outdated
Low energy light bulbs (CFLi)	Allowed	Outdated	Outdated
Fluorescent T8 (2.4 and 5 feet)	Allowed	Allowed	Outdated
Fluorescent lamp T2	Allowed	Outdated	Outdated
Fluorescent lamp T12 with outer ignition strip	Allowed	Outdated	Outdated
Fluorescent lamp T12 without outer ignition strip	Outdated	Outdated	Outdated

Table 2.1: Exemptions from requirements exist for certain applications according to Appendix III in the EU 2019/2020

3
Methods

This chapter goes through a step-by-step approach to how the research was conducted. Firstly defining the process the literature review, then the benefits that were drawn from the meetings with relevant individuals and lastly the site visits that were carried out during the project. The report concludes by showing how this knowledge was put to use in the rest of the study, addressing the research questions that were outlined in the previous chapter.

3.1 Data collection

In order to capture, analyze and summarize material of the literature, a systemic approach was adopted during the review process suggested [17]. The journal of cleaner production database was suitable since all publications would comply with the appropriate criteria for publishing but not too strictly to exclude essential articles.
The case company gave access to their database with all the necessary data to achieve the result needed for this project. Data were gathered mainly through meetings with key employees in the relevant department, and the energy mapping report provided by the case company. Lastly, knowledge has been acquired by publications and manuals of various sorts. The literature used has primarily consisted of publications on Volvo's intranet or that were otherwise accessible at the company, as well as research literature. This has been done in consultation with competent specialists in the industry or sector.

3.1.1 Secondary data

Selected data is supplemented by secondary sources, since it helps to confirm the ongoing research questions and is useful to others as well as distributing it to the public. Secondary data help analysis that has already been done to advance the study of research. However, it is important to recognize that their motivation might have been other than what they had anticipated.[11] The gathering of secondary data has mostly been done from Chalmers University library, DiVA and the database provided by our supervisor, A journal of cleaner production.

3.1.2 Reviewing material

All documents collected from A journal of cleaner production and DiVA were evenly divided between the two of us in the project group. In order to assess the contributions of the documents, they were first reviewed. When evaluating the document, it was first established whether or not the document could help in supporting the case. Most relevant papers were noted. The articles where the individual project members could not decide the level of relevance, they were taken to a discussion within the project group where a decision could be made together.

3.2 Meetings

Four important meetings with relevant individuals from the case company and Chalmers were carried out. They were conducted to collect data and information about how the project would proceed and what type of material that were available for the project. But also to understand how the system and facility looks today. To gather energy usage data, energy and sustainability experts at the case company were contacted. From them we could collect energy invoices that showed energy usage for the specified facilities. The case company uses a energy measurement system called esight. Electricity measurements are available at the transformer level, with logged values for energy consumption in esight.

3.2.1 Maintenance engineer

Several meetings with a maintenance engineer with knowledge about the production and lighting configurations happened during the study. The engineer provided us with knowledge of the current situation and problems that existed, as well as some ideas of how to proceed during the project.

3.2.2 Veolia energy optimizer

Several meetings with an energy optimizer with knowledge of the ventilation and lighting configurations happened during the study. We collected information of how the ventilation and lighting were controlled in the different factories. We also got information that one of the factories within the scope of our project the TA factory, were undergoing a renovation. During this renovation the roof will be rebuilt and new up to date lights and ventilation solutions will be acquired. We will therefore not focus on this part of the plant.

3.2.3 CTH professor

To get an idea of how we would proceed with the heat exchangers, we had a meeting with a professor from Chalmers who had previous knowledge in the field. This became the turning point for the project because it gave the project new ideas that were not thought of earlier. It was also here the project knew how to look for specific literature studies that would help support the results later. The meeting was overall short but really beneficial.

3.2.4 Electric specialist

To collect data needed to do a Life cycle cost analysis for the change to LED lightning in TA3 and TAÖ, we got in contact with a Senior electrical specialist that had good knowledge of the lighting situation. The electrical specialist provided us with data needed for the LCC such as, estimated costs for, lighting solutions, installation of hardware and software, planned and unplanned repairs.

3.3 Site visits

Site visits were carried out to get a better understanding of their systems today. Due to the current situation of the COVID-19 pandemic we were only given two site visits. During these site visits we were introduced to their current system to give a better understanding to proceed with our project.

3.3.1 First visit

The first site visit was carried out at the TA factory. During this meeting, we were shown the factories control system for ventilation and lighting from their office by one of the case company´s energy optimizers. In this system, they have the ability to monitor ventilation and lighting systems, as well as control the systems to a certain degree.
Later we went on a tour up to the roof of the factory, where we went into the various cooling towers that exist, these vary in modernity and only some of the cooling towers have been modernized since the 90s.
We noticed that cooling towers 110 and 120 are of the old model and do not take advantage of process heat that is currently ventilated out on the roof freely through a couple of fans. We also visited cooling tower 170 and 180. Cooling tower 170 is also of an older model, but here the process heat is used and is used to heat the new air that is ventilated into the facility.

3.3.2 Second visit

The second site visit was carried out at the TA factories. During this meeting, a tour was conducted with two maintenance engineers. In TA3, One of them described the problem of controlling the lighting in the TA3 factory and the CL-90 line in TAÖ. The problem is due to the supplier of the control system not carrying out qualitative work and not making the system work properly. The supplier's system is used here as an intermediary between the case company's HMI system and the holistic control system. This has created problems that do not exist in the 60 line in TAÖ, as the control there takes place without intermediaries. The problem that has been created is that the lighting is sometimes dimmed to about 30% and cannot be adjusted as input signals are not communicated correctly via the intermediary. The control has therefore been corrected to a manual control in order to be able to keep production going.

The lighting in TA3 and TAÖ - 90 line also consists of fluorescent lighting, however, it is considered that there is no value in switching to LED lighting here without solving the problem with the control first, because only changing to led lights wont remove the problem of insufficient light and might resolute in double work. The improvement proposal here consists primarily of changing the control to a robust control system that is compatible with the case company´s overhaul / control system. In this way, we can reduce the operating hours of the lighting, as well as smartly control and dim lighting at the right times to reduce energy consumption. The second step consists of replacing existing fluorescent lighting with LED, this reduces energy consumption with the added benefit of decreases losses of energy for the lighting in form of heat losses. More on this in 4.3.1 and 4.3.2.

Compressed air sensors in different robot flows were also shown, these compressed air sensors today only have the function of showing a value of the flow in the compressed air pipe to the line. They described that the sensor has the function of visualizing the instantaneous volume flow and pressure in the systems. When the line were stationary we could see that most often a value for volume flow could be observed. This means that energy is lost in form of leaking compressed air, which apart from energy losses also can lead to breakdowns as well as increase the cycle time for lines, due to pressure drops. The improvement proposal here was to connect these sensors to the case company's inspection system and the Status Boards at the lines, this could give line mechanics and team leaders new visual information about the status of the compressed air sensors at standstill. This would give line mechanics and team leaders up-to-date information on where problems are and the opportunity to troubleshoot simpler problems such as non-clogged quick couplings or valves in the wrong position. If the problem cannot be solved, maintenance could be planned and called in. This would have led to better opportunities for preventive maintenance for the pressure systems in the lines, simple visualized information for line mechanics to work with to prevent downtime and energy losses.

4

Results

4.1 What factors contribute to the energy consumption in an Automotive Body shop

Here we will list some factors we have considered to have an impact on the energy consumption.

• Continuous collaboration between organizations working with similar and adjacent products/services.
High impact. To have organizations collaborating, sharing their progress and status in its work of improving energy consumption is a great way of sharing knowledge. Organizations should share their knowledge of what improvement ideas they've tested, which ones that worked and which ones that did not. By doing this other organizations will be able to collect already proven improvements. Making decision making easier.
• Operating times
Medium impact. By planning and optimizing the operating times for production and supporting systems, the systems can be active when they are required and inactive when not required. By doing this much energy can be saved from being consumed unnecessarily.
• Workforce awareness
Medium impact. People working in or for the organization can have a big positive impact on the energy usage, it is therefore important to raise the awareness of what they can do to decrease the energy usage. It could be people working in the facilities with access to equipment that can be turned off during breaks etc.
• Equipment status/ need of maintenance
Medium impact. Its important to keep the production systems and supporting systems in good shape to have them perform as energy efficient as possible. This applies to both robot systems as well as ventilation and compressed air systems.
• Production rate/production mix
Lesser impact. The production lines are automated and flexible for the current product mix.
• Weather conditions
Lesser impact. The weather has an impact on the energy usage in forms of need for heating/cooling.

4.2 How is the energy consumption distributed in the factory

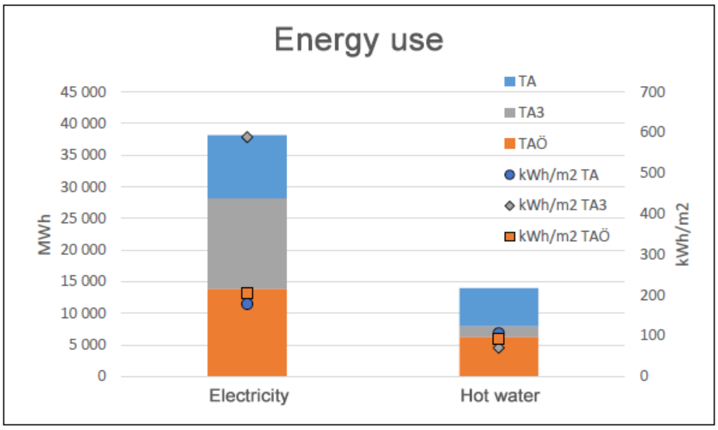

Figure 4.1: Total energy use 2018

Figure 4.1 illustrates the overall energy usage of different types for each factory section in 2018, both in total and per square meter. It is clear that the consumption of hot water per square meter for the various parts is relatively equal, while the consumption of electricity per square meter in TA3 is substantially higher than in the other parts. This is most likely due to the fact that, in comparison to TA and TA, TA3 had no demolished areas without operations in 2018.

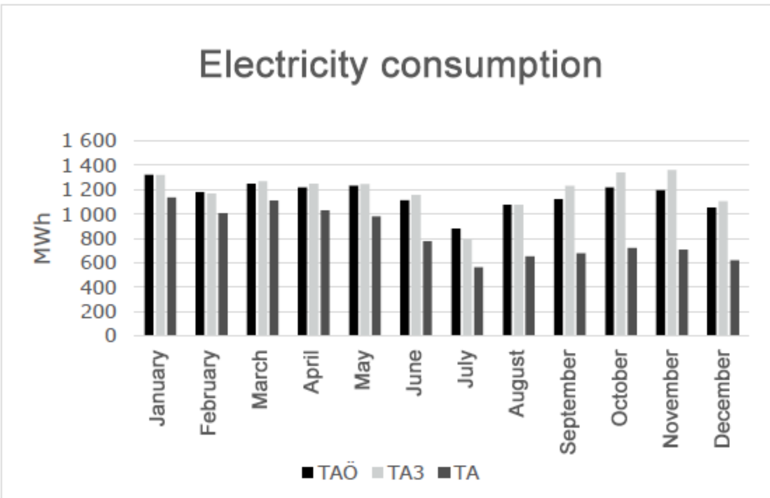

Figure 4.2: Electricity consumption for each factory part in 2018

Figure 4.2 illustrates a more comprehensive look back at the years 2016-2018 in terms of electricity consumption. The most noticeable difference in a calendar year is the holiday leave in July. In other words, consumption varies equally well over the year, with the lowest and highest consumption occurring in different years. This supports the hypothesis that variations in occupancy rate are primarily responsible for variations in electricity consumption.

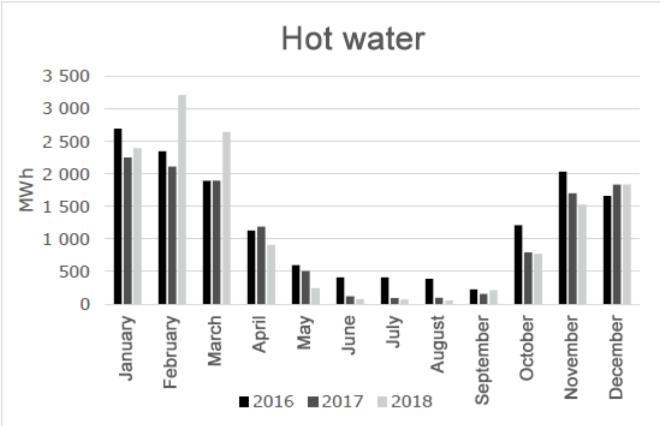

Figure 4.3: Hot water consumption on a monthly basis for the years 2016-2018

Hot water serves as TA's heat source. Figure 4.3 contains information on purchased hot water over the last three years. As previously stated, hot water consumption is primarily determined by outdoor weather, as shown by the 2018 consumption, which reflects the exceptionally cold late winter during February and March, as well as the hot summer. It can be seen that in the last two years, the use of hot water during the summer months has been limited, which mostly consists of hot water for changing rooms and restaurants.

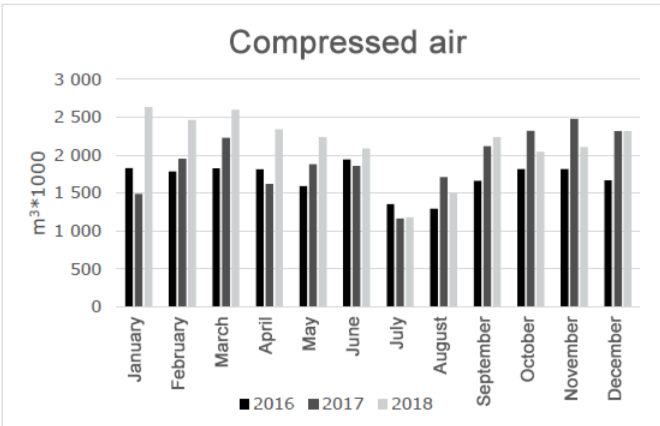

Figure 4.4: Compressed air consumption per month 2016-2018

At TA, compressed air is used extensively, primarily to transfer information in the robot cells with vacuum suctions. Figure 4.4 summarizes the compressed air intake per month for the years between 2016-2018. It's amazing how little use of compressed air decreases during the month of July, when most of the facility is on holiday. It can be seen that compressed air usage was higher in most months in 2018.

Figure 8 depicts how compressed air use has risen over the last three years. This is because of increased compressed air leakage and the addition of a new line in 2018.

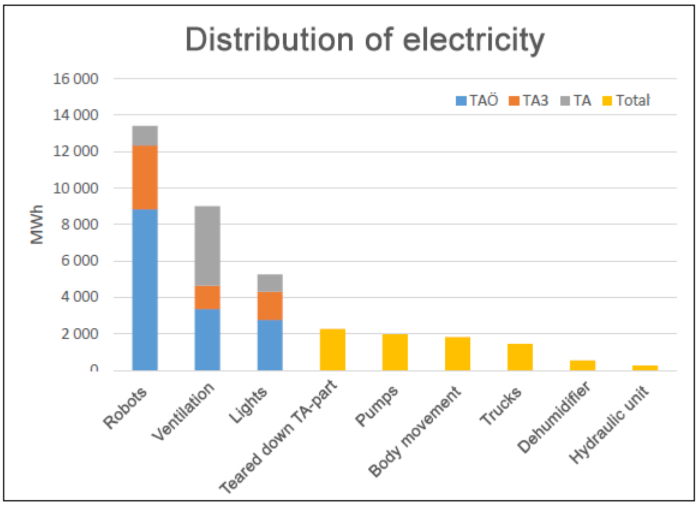

Figure 4.5: Distribution of electricity consumption

Electricity consumption is divided by various consumers. The three factory pieces are also used to separate the main customers. Figure 4.5 also includes percentages and comments for each section.
TA receives heat from hot water provided in a boiler plant. The hot water is then

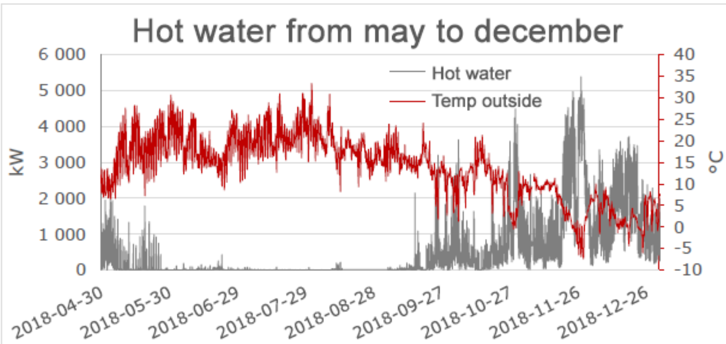

Figure 4.6: Consumption of hot water per hour from May to December 2018

delivered to TA via pipe systems and exchanged in heat exchangers. The water on the secondary side is transferred and used to heat tap water, radiator circuits, and air heaters and other air handling units. When it is cold outside, the need for heat is highest. When the hot water meters were replaced in the spring of 2018, there was no hot water calculation for TA3, so there is only revised hourly data for this consumption from May onward. Figure 4.6 illustrates this information. It should be noted that this data includes the hot water delivered to TP's storage tent via TA.

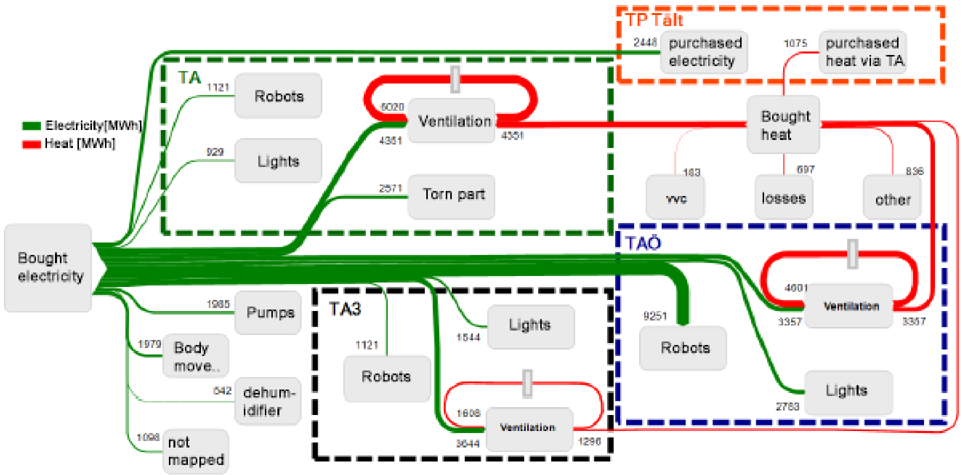

Figure 4.7: Sankey diagram showing the distribution of energy use. The thickness of the arrows corresponds to the size of the energy use over a year.

The sankeydiagram in Figure 4.7 shows in a more systematic way how the energy purchased is divided into different consumers

4.3 What potential energy savings can reduce energy consumption

4.3.1 Lighting control system in TA3

The lighting in parts of the TA factories is lacking in how they are controlled. Today, a large part in the TA3 factory the existing control system does not work properly and is therefore controlled manually. This leads to all lighting often being on around the clock every day and that the lighting does not dim correctly, in this way the lighting is on unnecessary hours and the workers sometimes get insufficient light. A lot of extra manual work is required to compensate for this which is both costly and time consuming. The recommendation is therefore to replace the current non functional control system to reduce the lighting's operating time and at the same time increase operational reliability as there is a great potential for savings and an improved working environment.

Factory part	Current situation	Measure
TA3	General lighting	00-24 Every day (168h)
	Low process	m-f 00-24, Sat 00-01, sun 18-24
	High process	Manual +4h/day

Table 4.1: Operating times according to the report

4.3.1.1 In-depth measures

The control system in the different factory parts varies. In TAÖ CL60, the production PLC communicates directly with the overview control system Keytalk. This communication works as intended and the operating times for the lighting can be seen in Table 4.1.
In TAÖ CL90 and TA3 however, another control system called Teamster was purchased to handle the communication between production PLC and Keytalk. As said, this communication setup does not work as intended, therefore it is recommended that the control system is redesigned so that the control is to be handled in a similar way as in CL60. In this way, the lighting can be controlled in the same way as the ventilation is controlled today. That the operating time is set on time channels according to the regular operating hours that can be updated when overtime is called for. This would reduce the operating time of low process lighting from 168 hours to 127 and from 168 hours to 77 hours for general lighting in a normal week. With this as a background, it is proposed that the operating times for the lighting in TA3 and TAÖ CL90 be changed according to Table 4.1.

4.3.1.2 Energy savings

The energy savings are calculated based on all production lighting having the proposed operating times.

Electricity cost: 0.54 sek/KWh
Electricity: 595 MWh Total/year
Cost savings: 321 533 kr/year

4.3.1.3 Complexity and risk

As the operating hours in most parts of the factory are around the clock on weekdays and daytime on weekends, some changes will need to be made during operation, which increases the complexity somewhat. However, good planning can minimize this complication. There is some maintenance work outside the normal operating hours that would also need lighting, which can be disadvantaged by controlling the lighting in the proposed way. Therefore it is important to make it possible for maintenance personnel to have access to local buttons that gives them the required lighting.

4.3.1.4 Side values

The fact that the lighting is on less time, it will increase the service life of the lighting and reduces the need for maintenance. During the summer, the excess heat in the factory premises decreases when the heat dissipation from the lighting decreases. However, for the same reason you might buy more heat in the winter.

4.3.2 Change to LED lights in TA3 and TAÖ

In the TA factories the distribution of light sources differs. In TAÖ about 45% of the armatures are LEDs, in TA3 only 3% of the armatures are LEDs. The rest of the armatures are still fluorescent tubes with a mix of T8 and T5 tubes. The remaining 3673 Fluorescent armatures in TAÖ and TA3 should be changed to LEDs to lower the energy usage from lighting. By changing to LED lights mainly two positive effects will happen. The first thing is much lower energy usage, due to the improved luminous efficacy from the LEDs. The second improvement will be lower maintenance cost over time, hence the much longer service time. These effects will therefore not only lower the energy usage and cost but also lower the cost for maintenance. As can be seen in 2.1.4.4, older light sources such as T8 fluorescent lamps are being phased out and will not be available on the market in the near future and will therefore need to be replaced. Therefore it can be a good opportunity to change to LEDs.

4.3.2.1 In-depth measures

The measure for replacement of the lighting fixtures for each location within the factories can be seen in Table 4.2. The number of LEDs that are needed to replace the old lighting fixtures were calculated by comparing the total luminous flux of the current situation to one with the specified LED alternative. By doing this, the total light emitted i lumens should therefore be the same.

Location	Current situation		Measure	
	Type	Quantity	Type	Quantity
TAÖ general	T8 2x58W	733	LED 383W	191
TAÖ general	T5 2x48W	111	LED 383W	24
TAÖ low process	T5 2x48W	663	LED 383W	145
TAÖ high process	T5 2x48W	218	LED 383W	48
TA3 general	T5 2x80W	492	LED 383W	160
TA3 low process	T5 2x48W	937	LED 383W	205
TA3 high process	T5 2x48W	519	LED 383W	114
Total		**3 673**		**886**

Table 4.2: Compiled proposals for the replacement of lighting

4.3.2.2 Savings

The energy savings are calculated based on all production lighting having the proposed operating times which can be seen in table 4.1. This is done to avoid the savings from 4.3.1 to be calculated twice.

Electricity cost: 0.54 sek/KWh
Electricity: 1083 MWh Total/year
Cost savings: 585 197 Kr/year

As mentioned earlier the change to LEDs will lower the need for maintenance, this also leads to some savings. These costs are calculated from the service time of the light source.

Maintenance TAÖ: 109 260 kr/year
Maintenance TA3: 120 720 kr/year
Total: 229980 kr/year

Total savings from energy.
TAÖ: 266 848kr/year
TA3: 318 350 kr/year
Total: 585 197 kr/year

4.3.2.3 Project costs

The costs for the project/installation costs are presented in table 4.3, below.

	For each luminaire	Total
Luminaire cost	8 000,00 kr	7 096 000,00 kr
Installation cost	600,00 kr	532 200,00 kr
Automation HW		975 700,00 kr
Automation SW		487 850,00 kr
Sum		**9 091 750,00 kr**

Table 4.3: Calculated costs for the project

4.3.2.4 Result

An assessment of the total life cycle costs (LCC), were carried out. See Figure A.7-9 in appendix A. The LCC provided a estimate for the payback time and is presented below.

TAÖ: 11,1 years
TA3: 11,2 years
The long payback time is due to the high investment cost. However a lot of energy and money can be saved in the long term.

To get a good holistic view of what effects the measure of replacing the current lighting situation with one with only LEDs could have, data where analysed in terms of economical, ecological and social perspectives.
Seen to the economical perspective a Life Cycle Cost analysis (LCC) were conducted. In the LCC, projecting costs, maintenance costs and running costs were put together. The result can be seen in Figure A.7-9 in appendix A.

In the Figures we can see that for TAÖ there will be a investment of about 4 000 000 Kr which means that the measure will be payed off in 11.2 years. For TA3 the investment will be around 5 000 000 Kr which means a payback time of 11,1 years. After the payback point running costs will decrease by 376 108 Kr/year for TAÖ and 439 070 Kr/year for TA3.

For the ecological perspective, energy savings were calculated and converted to CO2e emissions by using the conversion table from Energimyndigheten. [20] In Figure A.10-12. the expected CO2e emissions for each factory can be seen. The conclusions that can be drawn from this diagram is that from day one CO2e emissions will be decreased, due to the reduction of energy usage. However production emissions for the LEDs have not been added to the calculation here. For TAÖ and TA3 combined this would lead to a reduction of about 4 Tons CO2/year.

Seen to the social perspective, we think it would have an immediate positive effect. We think that due to the expected lowered need for maintenance, maintenance personnel will work less with fixing and repairing the lighting. This also means that the production workers and other personnel in the factory will get a better guarantee for correct and sufficient light.

4.3.2.5 Complexity and risk

Dismantling just over 3,500 fluorescent lamps and fitting new LEDs is an extensive task, which needs a lot of planning. As the operating hours in most parts of the factory are around the clock on weekdays and daytime on weekends, some changes will need to be made during operation, which increases the complexity somewhat. It might be a good idea to use the semester or other natural idle scenarios for the plant.

4.3.2.6 Side values

The change to LEDs will not only lower the energy usage heavily, but also have several positive effects as mentioned earlier.The longer service life of the lighting will reduce the need for maintenance. The LEDs are much more efficient and therefore have lower heat losses. During the summer, the excess heat in the factory premises will therefore decreases when the heat dissipation from the lighting decreases. However, for the same reason you might buy more heat in the winter. The LEDs also have improved functionality when it comes to communication with the control system and can give notice when its health gets low. This means that the maintenance for the lighting can be planned more efficiently.

4.3.3 Heat recovery

There are three separate cooling systems that serve the factory and the processes that generate heat during processing. A system for TA3 and TAÖ, one for laser and one for the old part of the factory located in TAV. description of the system goes as follow, which is the one we got to inspect during our site visit. This cooling system serves the factory parts TA3 and TAÖ. The system emits its heat via three modular coolant coolers of the type AIA VX3 which are located on the ground floor outside the TA3 sub-factory. The cooling system is switched in steps, this means that there is a cooling circuit between the coolant coolers which are then switched to 8 cooling circuits which are located in three substations (pump rooms), these cooling circuits are then switched to the end users. There are three circulation pumps between the heat exchangers and the coolant coolers (301-GL01, GL02 and GL03), these pumps are speed controlled on the temperature sensor 201-BT01 at a set value. the pumps and, if necessary, the other pumps are also started. The fans on the three KMK are regulated by the sensors 301-BT03, 4,7,8,11 and 12. In the circuit between the coolant coolers and the cooling circuit towards the factory are two pumps (201-P1 and 201-P2) which circulate the cooling water which is exchanged between the cooling towers and the other three substations. We have measured the flow through 201-P1 and P2, we got 302 cubic meters per hour and as seen in the image,(See Appendix A.4) right there we have ΔT at 1.3 degrees. Now we attend to investigate where this energy can be used.

As per given data, we have 302 m^3/hr. (Volumetric Flow) and Temperature Gradient of 1.3 degrees, and we need to use this energy against something else in the system to make existing system more energy efficient.

Let's consider about the parts in given system, they are as follows:

Heat Exchangers (301-EM01, 301-EM02, 301-EM03), Coolant Coolers (301-GL01, GL02 and GL03), Three Circulation Pumps 301- VC 31, 32, 33), Set Point Fans (Börv. Fläktar), EC Fans Electronically Commutated Fans (EC Fläktar), the temperature sensor 201-BT01, Fan regulating sensors the sensors 301-BT03, 4, 7, 8, 11 and 12, Pumps to measure flow rates (201-P1 and P2), three modular coolant coolers of the type AIA VX3, Cooling Towers etc

4.3.4 Calculations

We have given that, 302 cubic meters per hour of cooling water is available. This is nothing but Volume Flow Rate (m^3/hr.). In fluid dynamics, volumetric flow rate is the volume of fluid which passes per unit time, and is denoted by (Q or $\dot{V}$). The SI unit is m^3/s. So, first we will convert the unit,

$$\dot{V} = 302m^3/hr. = 302/3600(m^3/s) \tag{4.1}$$

Hence, $\dot{V}$ = 0.08388 (m^3/s)

Now, we know that mass flow rate $\dot{m}$ is the mass of the substance which passes per unit time. Unit is kg/s.

As per given data, fluid is the cooling water. We know that water has density of 1000 kg/m^3.

$$\dot{m} = \rho \cdot \dot{V} \tag{4.2}$$

$$\dot{m} = 1000 \cdot 0.08388 = 83.88kg/s \tag{4.3}$$

Mass flow rate available is 83.88 kg/s.

Heat transfer is the fundamental energy engineering operation. Here we will try to find out, Heat Loss or Heat Gain (i.e. Amount of Heat Energy Transferred). **Heat Energy Transferred** is calculated from following formula:

$$Q = m \cdot C_p \cdot \mathrm{T}_{\mathrm{diff.}} \tag{4.4}$$

Where, the specific heat capacity C_p [$J/_{\mathrm{kg.}}$ K] is a thermodynamic property specific of the fluid used to transfer heat. For water, specific heat capacity at constant pressure is given below. The heat energy required to raise the temperature of 1 kg of water by 1 K is **4184 joules** so the specific heat capacity of water is
4184 $J \cdot kg^{-1} \cdot K^{-1}$

$$Q = 83.88(kg/s) \cdot 4.184(KJ/kgK) \cdot 1.3(degrees) \tag{4.5}$$

$$Q = 83.88(kg/s) \cdot 4.184(KJ/kgK) \cdot (294.95K - 293.65K) \qquad (4.6)$$

Calculating above equation we get,

$$Q = 456.24(KJ/s) \qquad (4.7)$$

We have to use this available energy, **456.24 KJ/s** of heat energy to something else in our system to make our system more energy efficient.

4.3.5 Suggestions for improving Efficiency of plant

The available water (measured by Temperature Sensor BT 01) (of approx. heat energy 456.24 KJ/s) can be used in heat exchangers (301-EM01, 301-EM02, 301-EM03), this may increase efficiency of plant.

4.3.5.1 More about heat exchanger study

The efficiency of the heat exchanger is determined by the temperature difference between the two liquids. If all other factors remain constant, a heat exchanger with a greater temperature difference can transfer more heat. Any cooler has a temperature gradient running through it. We may also investigate what happens when they are linked in sequence. First, you can read more about the theory of heat exchanger series and parallel connections.

4.3.5.2 Series benefits

The key benefit of series radiators is that they can maintain consistent flow through each radiator. This is required for maximum production. You can make all hose lengths the same and have the same accessories (minor losses) for each route in a parallel system, but there is no guarantee.
The second benefit of the sequence is that as the flow velocity increases, so does the turbulence in the cooler. If the liquid is not as strong a heat conductor as gasoline, it can result in a measurable increase in total heat transfer. Connecting radiators in series necessitates less accessories. This means less installation time and less leak points. In the series, the flow rate is higher. The configuration also increases the pressure drop, pump power demand, and heat added to the liquid by the pump power draw (everything must go somewhere). [8]

4.3.5.3 Parallel benefits

The second benefit of the sequence is that as the flow velocity increases, so does the turbulence in the cooler. If the liquid is not as strong a heat conductor as gasoline, it can result in a measurable increase in total heat transfer. Connecting radiators

in series necessitates less accessories. This means less installation time and less leak points. In the series, the flow rate is higher. The configuration also increases the pressure drop, pump power demand, and heat added to the liquid by the pump power draw (everything must go somewhere).
In parallel, a cooler can be separated for operation when it is running. This is a slight advantage, as the series can be isolated and fixed when running with a few extra installation add-ons. When the coolers are run in parallel, it is easier to compare their performance. If a radiator becomes dirty from the inside or the outside, if there is outside pollution, it is easy to see that one differential is less than the other without having to do the calculations.[8]

4.3.6 Suggestions

Suggestions improve efficiency or performance of Heat Exchangers:
Fouling effect, Heat transfer coefficient, pressure drop, baffles etc. are responsible for the efficiency of the heat exchanger. By increasing the flow resistance the heat transfer rate can be increased by creating the turbulence in the shell side of the heat exchanger.
The material which is depositing on the inner sides of the tube is responsible for the formation of fouling; the fouling rate can be reduced by pre- treatment of fluid (water). The proper cleaning of the heat exchanger can minimize the effect of fouling. Passing the higher temperature over the shell side will reduce the fouling rate.
Now let's consider about baffles plates used in Heat Exchangers. Efficiency can be improved by using helical baffles. The baffles are used to increase the heat transfer coefficient by diverting the fluid. The perfect baffle spacing should be done for the better heat transfer rate. According to some researchers, it is found that, the helical baffles at 400 inclinations will gives the higher heat transfer rate. Helical baffles with inclination angles of 40 degree have maximum efficiency in heat transfer and minimal pressure drop. It offers following advantages:[16]

- Increased heat transfer rates /pressure drop ratio.
- reduced bypass effect
- Reduced maintenance of equipment and prevention of flow induced vibrations.
- Reduced shell-side fouling.

CFD (Computational Fluid Dynamics) software can be used to study such thermal design analysis. The factors which are responsible for affecting the efficiency of the heat exchanger is the temperature, heat transfer coefficient and surface area. This is according to Newton's Law of Cooling.

The baffles and the flow breakers will definitely increases the surface area, the wave strip type flow breaker has a less pressure drop, with increased temperature range and hence the efficiency of the heat transfer (Q) is improved.
(Note: The scope of improvement of plant efficiency is by improving Existing Heat Exchanger Design and utilizing available heat energy (due to temperature gradient of 1.3 degrees) in the Heat Exchanger with proper thermal study.)

Improvement in design of heat exchanger by using Rough Surfaces, Fins and Inserts:

According to a study of shell and tube type heat exchangers[13], Copper already being good conductor of heat it accelerates heat transfer (study of Copper tubes in shell and tube heat exchangers). Copper's many properties, including rustproofing, antifouling, and corrosion resistance, as well as its low cost and ease of availability, make it an excellent choice for heat exchangers. Copper pipes are fitted with the inserts. The inserts are bent in a spiral so that the water flowing through the pipes twists in a spiral and the inserts press it against the wall of the copper pipes, assisting in heat transfer. The inserts also raise the turbulence in the pipes' water. The contact area (surface) for convection heat transfer is increased by copper pipe fins.

Use of rough surfaces also improves efficiency of heat exchangers. Some researchers suggest that surface roughness up to some value increases efficiency of heat exchanger after that effect becomes useless.[16]

Available excess energy calculated (456.24 KJ/s of heat energy as per above calculations) can be used more effectively in Heat Exchangers (301-EM01, 301-EM02, 301-EM03) by improving its designing.

Another suggestion is changing specifications of coolant pumps. We have used three Circulation Pumps 301- VC 31, 32, 33 in our layout, try to check its specifications and add pump of more capacity. It may increase the efficiency of existing plant.

4.3.7 Increase effectiveness of plate heat exchangers

Heat exchangers that are properly designed, operated, and maintained can make the process more energy efficient and, as a result, reduce energy losses. Heat exchanger efficiency will degrade over time due to off-design operations and other factors such as fouling, scaling, and so on. We will also look at 'Waste Heat Recovery' here. Waste heat is described as heat produced in a process by fuel combustion or chemical reaction that is then "dumped" into the atmosphere rather than being reused for useful and economical purposes. We must use waste heat correctly in order to increase effectiveness and performance.[18]

4.3.7.1 Suggestions

The radiant and convection heat loss from outside the plate heat exchanger must be measured. The heat loss quality is "poor" in this case. When this energy is obtained, it can be used in a variety of ways, including: It can be used to heat a room or to pre-heat the air. Heating rooms exclusively for human comfort is referred to as space heating. Space heating systems are intended to meet the thermal comfort needs of the building's occupants.

We can also see whether heat loss in the cooling water is a residual heat source.

The heat loss quality in this case is "Low Grade." We can use this energy if the heat is exchanged with the incoming fresh water.

To improve system efficiency, fouling in the plate heat exchanger must be minimized or eliminated. Fouling is the creation and growth of scale and debris on the heat transfer surface, which reduces heat flow. Pressure drop. Fouling is defined by 'Fouling Factor'. It is nothing more than the reciprocal of the dirt's heat transfer coefficient during the heat exchange process. The greater the value, the lower the overall heat transfer coefficient. We need more heat transfer coefficients to improve system performance (h). We need a lower emission factor for that, which means less pollution. **The solution to the fouling effect is regular heat exchanger maintenance.**

The use of insulating jackets on plate heat exchangers increases device efficiency by reducing thermal energy leakage from the heat exchangers to the atmosphere. We can cover the heat exchangers with easily removable insulating jackets, which not only avoids heat loss but also allows for easy maintenance of the heat exchanger.

Given Data:
The Heat Exchanger used is Plate type Heat exchanger with stand of Brand 'Alfa Laval'.

Data:	Hot side	Cold side
Medium	Water	EG 35% (weight)
Effect	755 kW	755 kW
Temp in	30.5°C	24°C
Temp out	25°	30°
Flow	33 l/s	33 l/s
Pressure drop	70kPa	80kPa

Table 4.4: Data specifications on the plate heat exchanger.

Firstly, we will determine the amount of recoverable heat from the given system. For this, we can use following formula:

$$Q = V \cdot \rho \cdot C_p \cdot \Delta T \tag{4.8}$$

Where,
'Q' is the heat content in kcal,
'V' is the flow rate of the substance in m^3/hr.
'ρ' is density of the flue gas in kg/m^3
'C_p' is the specific heat of the substance in kCal/kg °C
'ΔT' is the temperature difference in °C.
Putting the values as per the given data available in above equation,

$$Q = 302 \cdot 1000 \cdot 4.187 \cdot 1.3$$

$$Q = 1.643 \cdot 10^6 kCal$$

The amount of recoverable heat from the given system is $1.643 \cdot 10^6$ kCal.

5
Conclusion

In chapter 4.3.1, the research of the problem discovered that the control system did not function as it should. This were because the intermediary between the case company's HMI system and the holistic control system created problems with the control functionality. That led to increased energy usage and a lot of maintenance. The improvement presented were to redesign the control system to work in a similar way to the TAÖ factory.
In chapter 4.3.2, an assessment of the effects the measure would have, were carried out. The assessment, which involved an economical, ecological and social perspective showed that the measure consisted of a large investment and had therefore a long payback time, but had the possibility to be very cost efficient in the long term. For the ecological and social aspect, positive effects from day 1 are expected. To further simplify the expected effects an multi-criteria analysis were conducted and can be seen in Figure A.13 in appendix A. However before applying this measure it's necessary to solve the current problem with the control system.

In the heat recovery chapter, When the calculations were completed, you could utilize the data to generate proposals that you could subsequently use on future projects. The majority are theoretical methods that might only work in theory. The proposal on the pollution effect is something that can be further developed and tested in practice. Regular maintenance is the solution, but you can dive into this issue to learn more specifically what may be done.

In chapter 4.4.5 Increase effectiveness of plate heat exchanger, the retrieved data from the case company was utilized to obtain a value. This value showed the potential amount of heat that could be recovered from the given system. However, there are more factors that play a substantial role in the heat recovery process but are not included in the calculation. Therefore, the obtained value will only act as a reference in a pre-study where more data and time, not available in the given timeframe for this project, is required to obtain a more accurate representation of the amount of potential heat that is recoverable.

6
Discussion

The method of this work has been to approach the questions at issue using two approaches; Meeting with individuals who are active in the respective field and conducting a literature review that would support further ideas of the measured data.

Some of the data used in this project were collected from an earlier conducted energy mapping. Some of the estimates from that report were very rough. Such as the energy data for "Robots" in the factory, which can be seen in Figure 4.5. This value were estimated by mapping the energy usage from a single production line in a factory and then multiplied by the number of production lines in each factory. Due to the fact that most production lines have very different layouts and work tasks, this data most likely is very off from the real energy usage. Therefore it's important that it's done more accurately for the next energy mapping.
It is important that the case company shows a sense of responsibility that is not only beneficial from an economic point of view. For example, corporate sustainability means that you understand how the external environment works [19]. Volvo has now recently made collaborations with different industries around the Gothenburg area to discuss the environmental impact and how they can come up with ideas to help each other and in order to accomplish this, we will have to work together in order to make it work, and we will have to work together in order to advance as this is not a competition-oriented topic.

We had to operate from home due to the Covid-19 pandemic. As a consequence, if we needed to collect additional data, the next time window could take up to a week. The data collection process was time-consuming, and sadly, due to time constraints, some kind of compilation setting was used, which may be one of the causes of some measurement errors. Furthermore, The energy map data we received from the case company used in this project was last updated in 2019. The situation may have changed since this data was collected and therefore some measurements may not be correct.

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A

Appendix 1

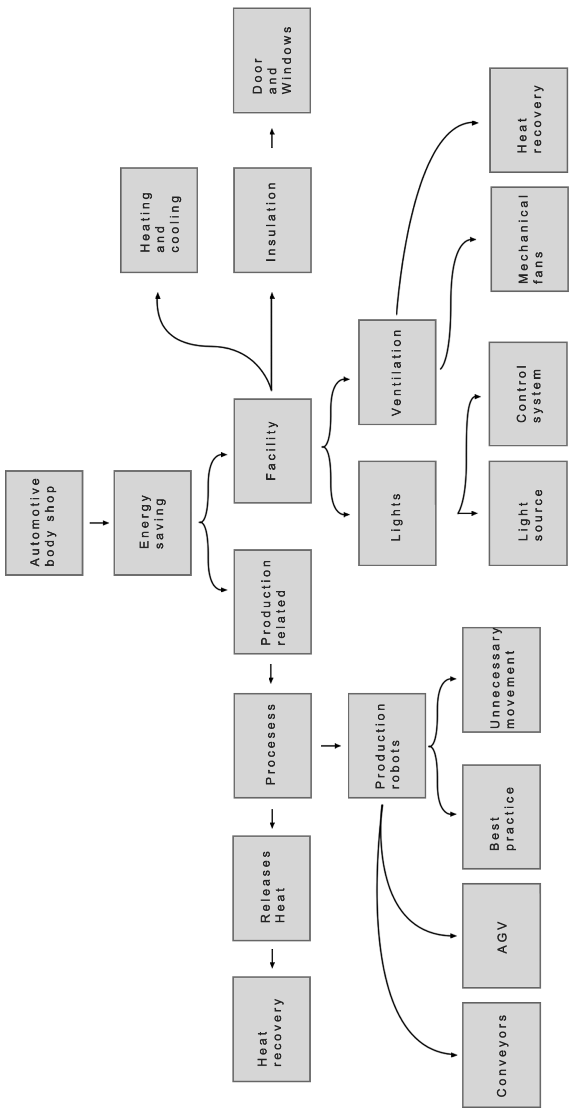

Figure A.1: A theoretical mindmap was created to get a view of areas that could affect the energy usage.

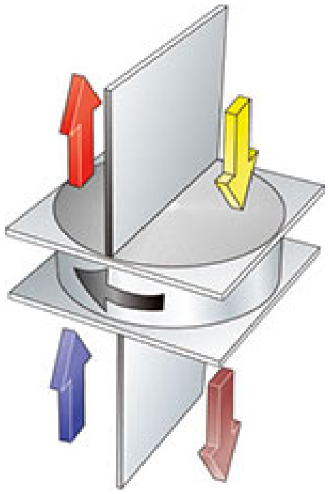

Figure A.2: The technicality of a rotary heat exchanger. Red arrow as supply air, blue as outdoor air, yellow as exhaust air, brown as waste air[6]

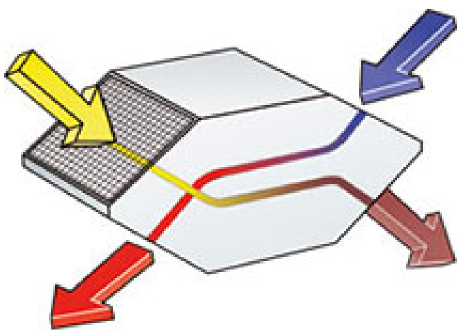

Figure A.3: The technicality of a plate heat exchanger. Red arrow as supply air, blue as outdoor air, yellow as exhaust air, brown as waste air[6]

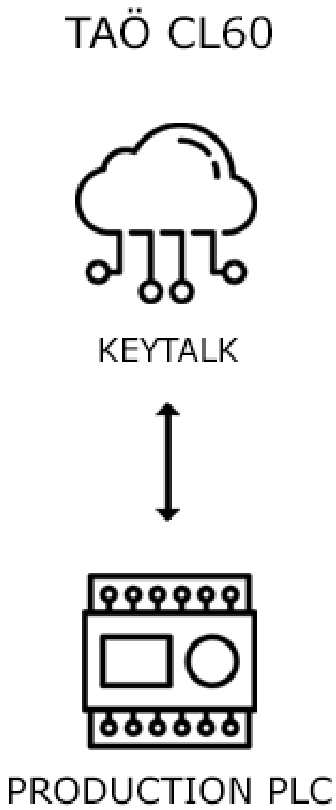

Figure A.4: A view of how the control system in Cluster 60 looks like.

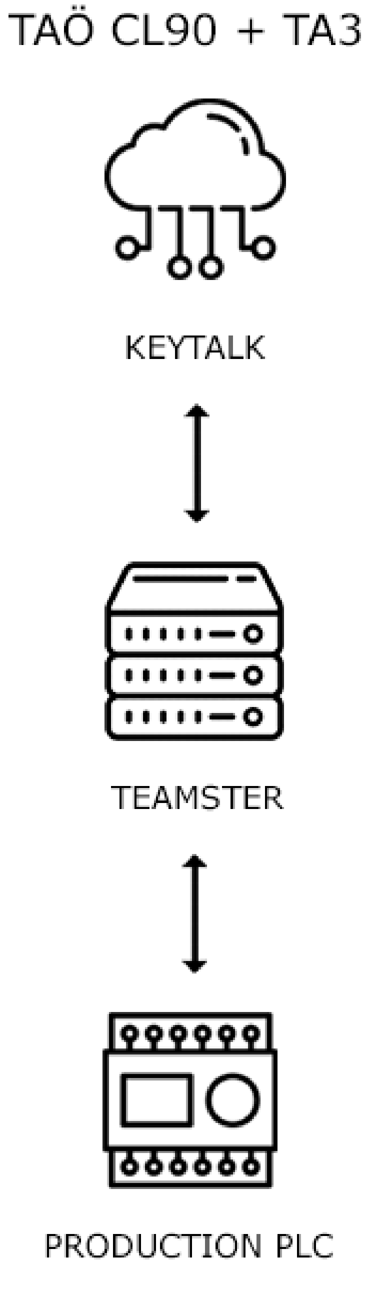

Figure A.5: A view of how the control system in Cluster 90 looks like.

Lighting source	Product name	Ammount	Effect(W)	Dimmed	Total effect	Unit
General "saucer"	Haloprism 371W (305W)	43	13115	90%	11803,5	Watt
General dubble led	Prismaspace 87W (69W)	12	780	80%	624	Watt
General T5 fluorescent lamp	Dubble T5 fluorescent lamps. 2*80W	492	78720	85%	66912	Watt
General sum					79,3395	KW
Low process T5 fluorescent lamp	Dubble T5 fluorescent lamp. 2*49W	937	91826	90%	82643,4	Watt
Low process sum					82,6434	KW
High process T5 fluorescent lamp	Dubble T5 fluorescent lamp. 2*49W	519	50862	90%	45775,8	Watt
High process sum					45,7758	KW
Total sum					**208**	KW

Table A.1: General lighting TA3 + TA3 CL90

Column1	Description	Value	Unit
Overtime in current situation	6 hours*46 weeks/year	57341,4	Totalt KWh/year
Working weeks/year	46	805937,0	Totalt KWh/year
operating times vacation	06:00-20:00	1460,0	KWh/vacation day
Days vacation	42	61321,3	Total KWh/year
Energy consumption with new operating times		867258,3	KWh/year
Cost lighting/year		468319,5	sek/year
Energy savings with new operating times		**595431,1661**	KWh/year
Cost savings with new operating times		**321532,8297**	sek/year

Table A.2: Cost- and energy savings with new operating times.

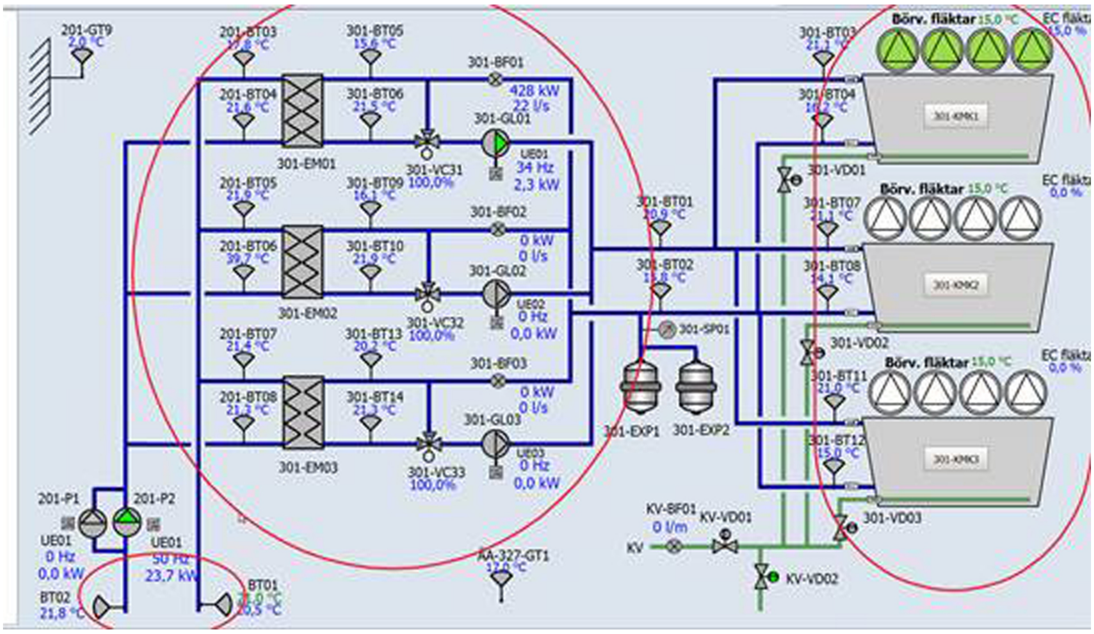

Figure A.6: Existing cooling circuit system

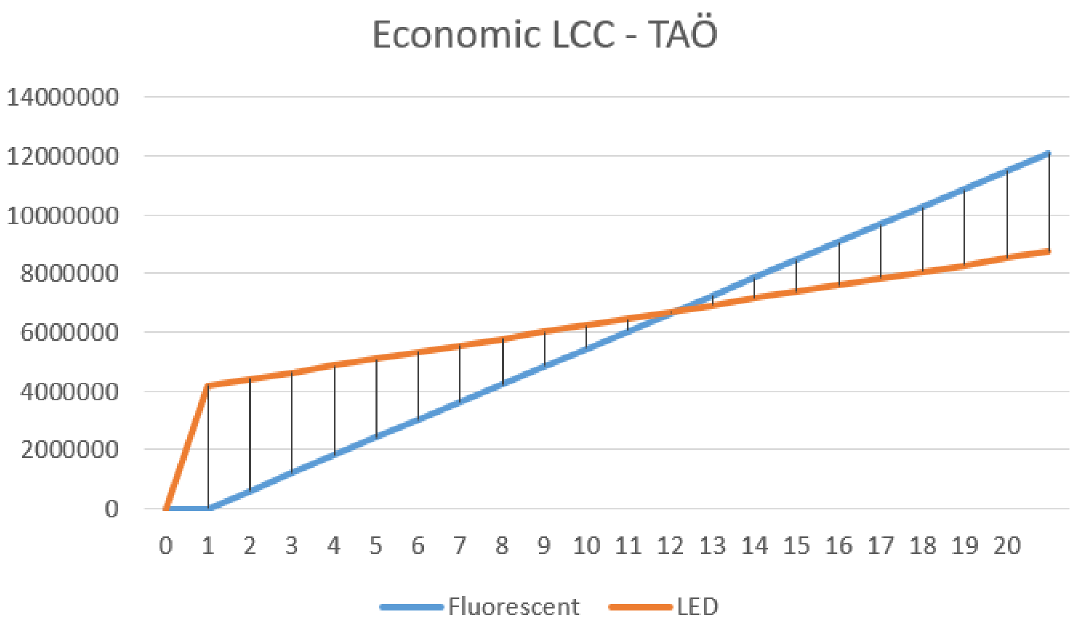

Figure A.7: LCC diagram that shows the investment cost and savings for TAÖ, the payback time is visualised as the intersection of the lines.

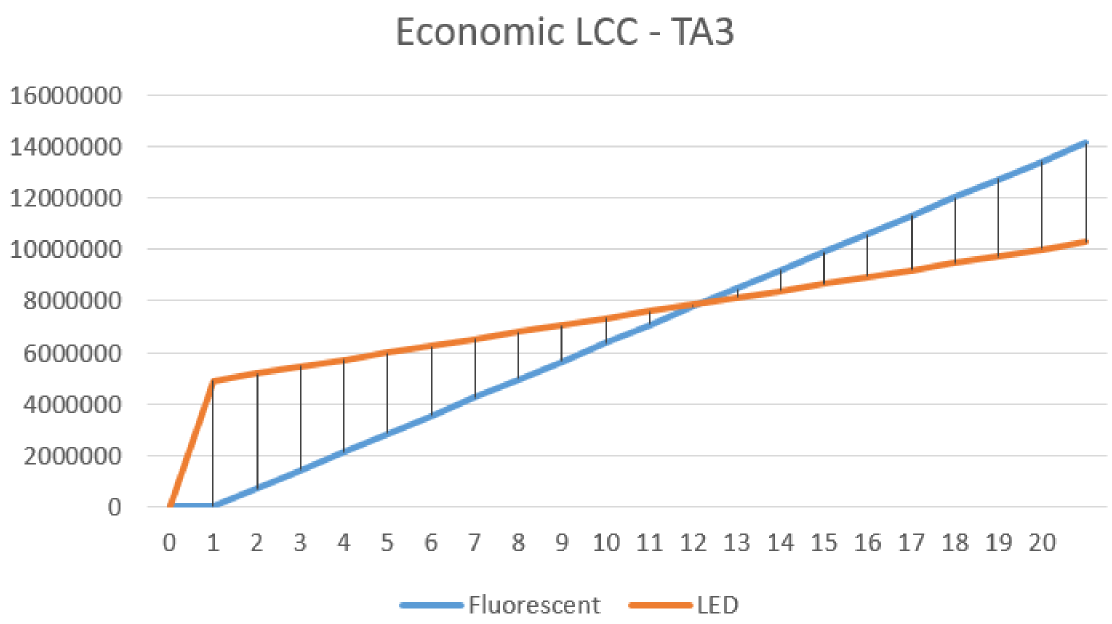

Figure A.8: LCC diagram that shows the investment cost and savings for TA3, the payback time is visualised as the intersection of the lines.

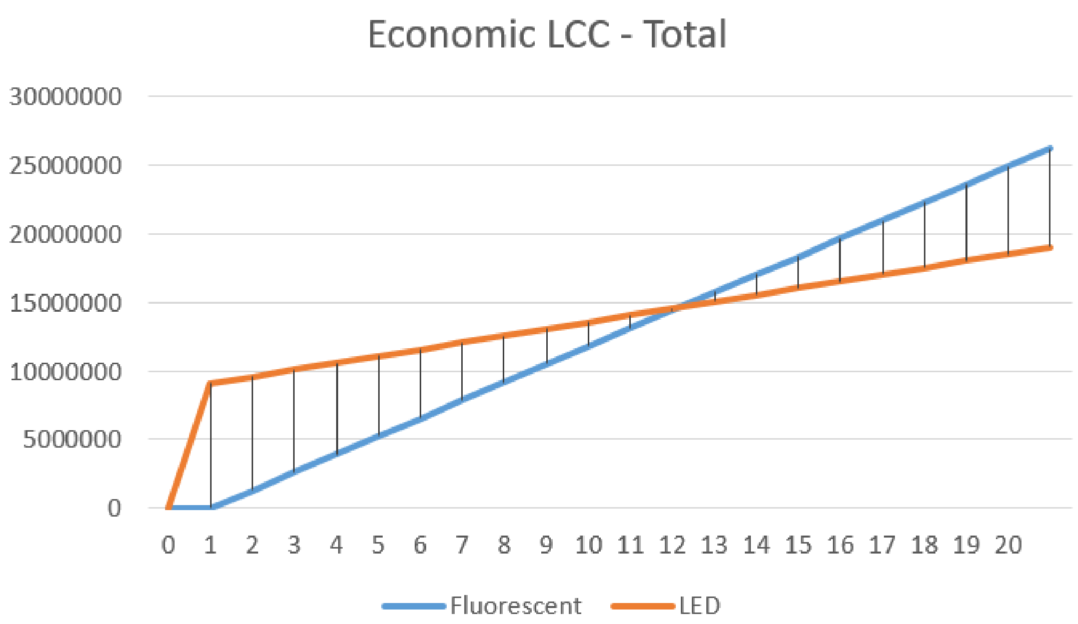

Figure A.9: LCC diagram that shows the investment cost and savings for TA3 and TAÖ combined, the payback time is visualised as the intersection of the lines.

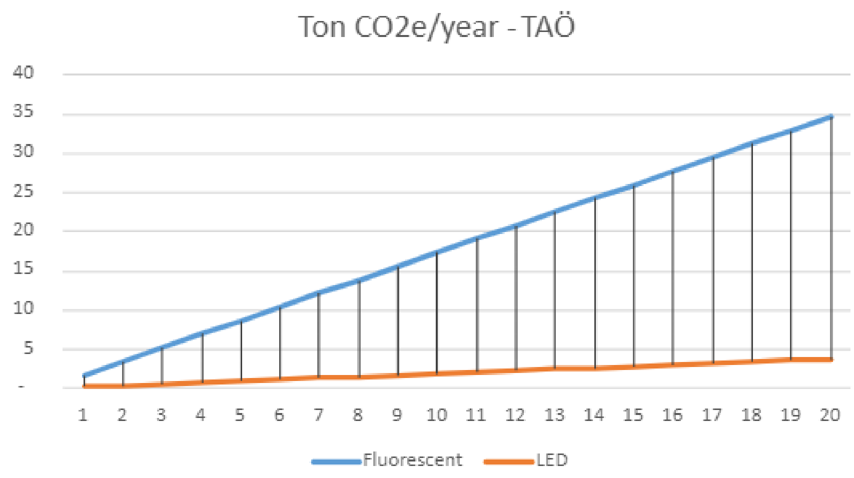

Figure A.10: Diagram that shows the CO2e emissions from the energy usage for TAÖ.

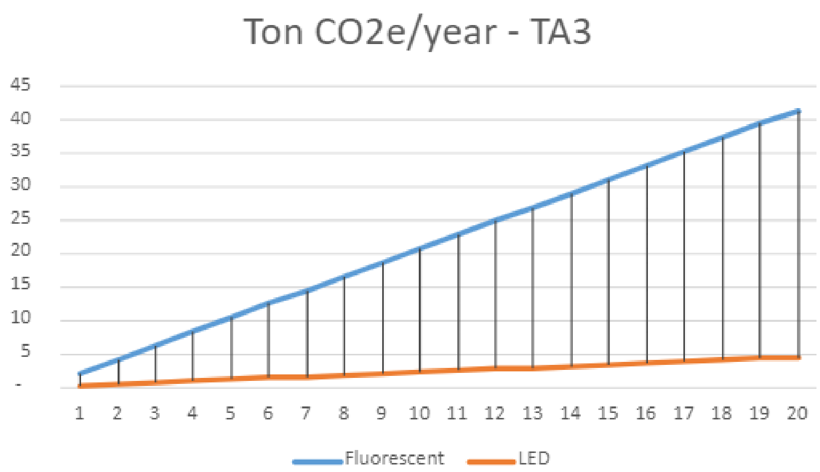

Figure A.11: Diagram that shows the CO2e emissions from the energy usage for TA3.

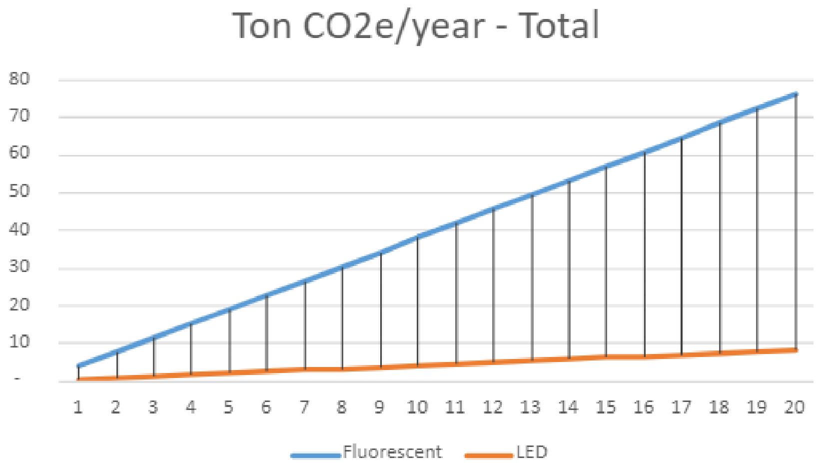

Figure A.12: Diagram that shows the CO2e emissions from the energy usage for TA3 and TAÖ.

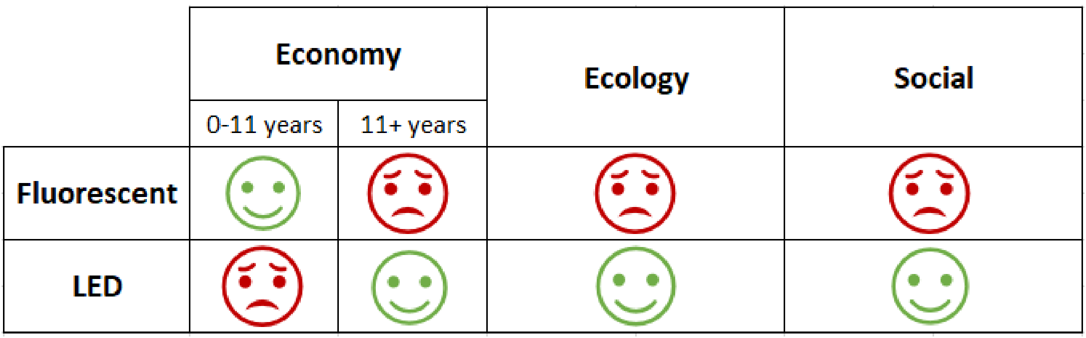

Figure A.13: Multi-criteria analysis that in a simple way, shows the expected effects for the perspectives.