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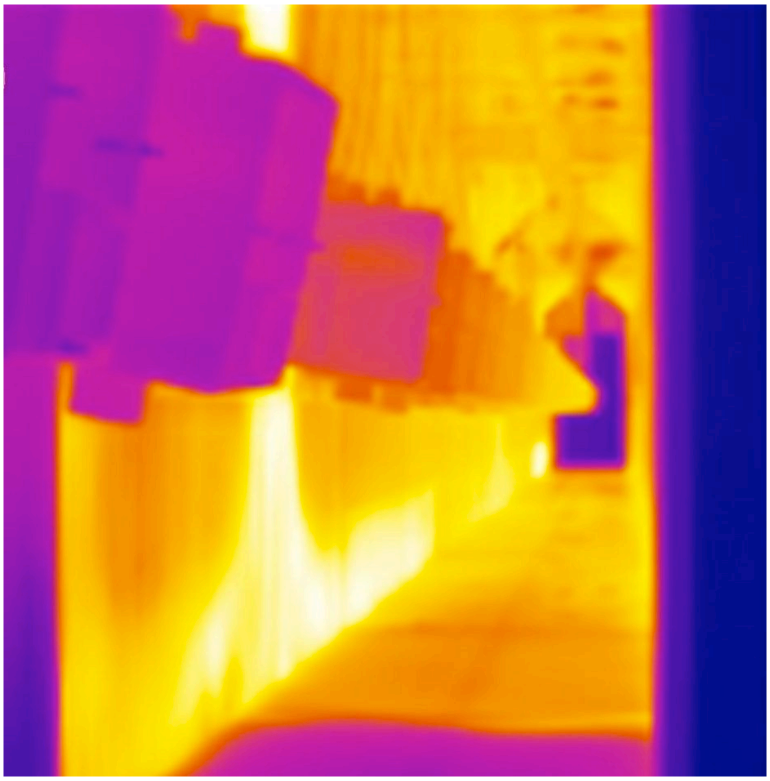

Energy efficiency opportunities within the powder coating industry

Energy audit and pinch analysis

Master's Thesis within the Sustainable Energy Systems programme

CHARLOTTE BERGEK

Department of Energy and Environment
Division of Heat and Power Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2011

MASTER'S THESIS

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Cover:
A thermo camera picture showing the cure oven and the powder coated parts that are coming out from it.

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ABSTRACT

The powder coating industries in Sweden use about 525 GWh of energy every year. The need to reduce the energy use is increasing due to increasing energy prices but also due to demands from customers. Most plants uses LPG and electricity, which has an energy price that is expected to increase by 50-60 % until 2020 compared with the prices in 2010. This type of industry has had focus on environmental issues concerning hazardous chemicals and powder types. However, focus has not been on energy efficiency measures.

In this project the powder coating company Quality Powder Coating AB was investigated. At the same time Sofie Osbeck from Linköping University conducted a parallel project at LaRay AB. The objective of the projects was to perform energy audits and calculate possible energy efficiency measures to see the energy efficiency potential within this type of industry.

The project was separated into four main parts. These parts were fact and data collection, energy audit, calculations of energy efficiency opportunities and benchmarking with the project at LaRay AB. The energy audit showed that QPC AB uses approximately two GWh of energy each year distributed on LPG, electricity and district heating. The biggest consumers of energy within the plant are the cure oven, drying oven and pre-treatment unit. The largest consumer of electricity is the powder box due to its high ventilation.

The heat exchange possibilities were investigated by the use of pinch analysis and three possible networks for heat exchange were compiled. These networks are either based on heat exchange for the ovens or with an additional cooling zone.

In this project it was showed that the energy usage for QPC AB can be reduced with 420 MWh of energy per year which equals 21% of their total energy consumption. This energy reduction will also lead to cost savings of 24% compared with 2010 or 330 000 SEK per year and savings of carbon dioxide emissions of 157 tonne or 25%. The results for the project at LaRay AB were that the energy use can be decreased by 30%.

Since powder coating industries is quite homogeneous the conclusion of these two projects is that the energy use within powder coating industries can be reduced by at least 20%, which responds to 105 GWh per year. Benchmarking between the two projects showed that heat exchange should be conducted within the same unit in the process.

Key words: Powder coating, varnishing, energy audit, pinch analysis, energy efficiency, energy audit

Energieffektiviseringsmöjligheter i pulverlackeringsindustrin
En energikartläggning och pinchanalys
Examensarbete inom masterprogrammet *Sustainable Energy Systems*
CHARLOTTE BERGEK
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SAMMANFATTNING

I nuläget står den pulverlacktekniska industrin för en energianvändning på cirka 525 GWh per år. De flesta anläggningarna drivs av gasol och elektricitet vilket är energikällor vars energipris förutspås öka med 50 – 60 % från 2010 till 2020. Detta samt påtryckningar från kunder ökar drivkraften för energieffektiviseringar. Denna typ av industri har tidigare haft fokus på miljötekniska lösningar medan åtgärder för energieffektiviseringar har blivit nedprioriterat.

Detta projekt är en undersökning av Quality Powder Coating AB som är ett pulverlacktekniskt ytbehandlingsföretag. Ett parallellt projekt har genomförts för LaRay AB av Sofie Osbeck från Linköpings Universitet. Målet med studierna var att utföra energikartläggningar och ta fram möjliga åtgärdsförslag för energieffektivisering för att kunna undersöka den möjliga energibesparingspotentialen av denna typ av industri.

Projektet var uppdelat i fyra delar, vilka var fakta- och datainsamling, energikartläggning, framtagning av energieffektiviseringsåtgärder samt benchmarking mot resultaten för LaRay AB. Energikartläggningen visade att QPC AB använder ungefär två GWh energi som är fördelat på gasol, elektricitet och fjärrvärme. De delar i processen som använder mest energi är härdugnen, torkugnen och förbehandlingen. Den största förbrukaren av elektricitet är pulverboxen på grund av den stora ventilationsmängd som behövs.

Pinchanalys användes för att beräkna möjligheterna att införa värmeväxling i processen. I rapporten presenteras tre möjliga fall för värmeåtervinningen där två är baserade på värmeväxling för ugnarnas till- och frånluft och en inkluderar införandet av en kylzon efter härdugnen.

Under projektets gång har det visat sig att QPC AB kan minska sin energianvändning med 420 MWh per år vilket motsvarar 21 % av deras totala energikonsumtion. Energiminskning kommer även leda till 330 000 SEK i minskade energikostnader och 157 ton mindre koldioxidutsläpp, vilket motsvarar 24 respektive 25 %. Resultaten för LaRay AB antyder att energianvändningen kan minskas med 30 %.

Eftersom den pulverlacktekniska industrin är en relativt homogen bransch är slutsatsen från studierna att denna typ av industri kan minska sin energianvändning med minst 20 % vilket motsvarar 105 GWh per år. Jämförelsen mellan de båda företagen har visat att värmeväxling bör införas inom samma enhet i processen för att hålla processen flexibel.

Nyckelord: pulverlackering, energikartläggning, pinchanalys, energieffektivisering

Contents

Preface

In this study, an energy audit and calculations for energy efficiency opportunities was performed for QPC AB. The project was conducted from September 2010 to February 2011. This master thesis was a part of the ENIG – project and it was carried out at Swerea IVF in Mölndal, Sweden. The thesis was conducted by Charlotte Bergek from Chalmers University of Technology with Anders Klässbo at Swerea IVF and Simon Harvey at Chalmers University of Technology as supervisors. The project was performed in parallel with another similar project conducted by Sofie Osbeck from Linköping University.

My supervisors, Anders Klässbo and Simon Harvey are highly appreciated for all help during the project. Also, Sofie Osbeck has provided a lot of knowledge, help and support during this period. The manager and production manager of QPC AB, Roger Fröjdh and Jonas Eriksson, were really helpful with providing data and information on short notice.

Anders Jansson, Technical manager at SCS finishing AB has provided knowledge about powder coating plants as well as parameters that could not be measured. Patrik Thollander, research assistant for Energy systems at Linköping University have provided useful information and support.

Finally, Jerry Börjesson and Jakob Rosenqvist have been really helpful during the electricity measurements and concerning theory about electricity calculations.

Göteborg, February 2011

Charlotte Bergek

Notations

Roman upper case letters

A	Area [m^2]
Cp	Specific heat capacity [$J/(kg \cdot °C)$]
Cp_{parts}	Specific heat capacity for the parts [$J/(kg \cdot °C)$]
I	Initial investment [SEK]
I_f	Effective value for the phase current [A]
I_L	Effective value for the line current [A]
NPQ	Net present value ratio
NPV	Net present value [SEK]
O	Operating cost [SEK]
P	Active power load [W]
Q	Reactive power load [W]
Q_{air}	Energy to heat the air [kW]
$Q_{C,min}$	Minimum cooling demand [kW]
$Q_{conduciton}$	Conduction losses [kW]
Q_{heat}	Heat added [kW]
$Q_{H,min}$	Minimum heat demand [kW]
Q_{HX}	Heat exchange load [kW]
Q_{losses}	Heat losses [kW]
Q_{parts}	Energy to heat the parts [kW]
$Q_{radiation}$	Radiation losses [kW]
R_{si}	Inner heat transfer resistance [$m^2 \cdot K/W$]
R_{sy}	Outer heat transfer resistance [$m^2 \cdot K/W$]
S	Apparent power load [VA]
S_i	Savings [SEK]
T	Temperature [°C]
T_{parts}	Temperature of the parts [°C]
T_{in}	Temperature inside [°C]
$T_{ingoing\ air}$	Temperature of the ingoing air to the ovens [°C]
T_{int}	Interval temperature [°C]
T_{lid}	Lid temperature [°C]
T_{min}	Minimum temperature [°C]

$T_{surrounding}$	Surrounding temperature [°C]
U_f	Effective value for the phase voltage [V]
U_H	Principal voltage [V]
U_h	Heat transfer coefficient $[W/(m^2 \cdot K)]$
V	Volume flow $[m^3/h]$

Roman lower case letters

a_i	Net payment [SEK]
a_0	Initial investment [SEK]
i	Period i
$\dot{m}$	Mass flow [kg/s]
m_{parts}	Mass flow for the parts [kg/s]
r	Interest rate

Greek letters

ρ	Density [kg/m^3]
ε	Absorption coefficient
λ	Heat conductivity $[W/(m \cdot K)]$
σ	Stefan Boltzmann's constant $[W/(m^2 \cdot K^4)]$
$\cos{(\varphi)}$	Power factor

1 Introduction

In this chapter the background for the masters thesis project is described as well as the energy policy instruments for industries. Also, there is a short description of a powder coating plant and the goal and scope, problem formulation and limitations are defined. At the end of the chapter the outline for the rest of the report is given.

1.1 Background

It is a common fact nowadays that the use of fossil fuels has to be reduced. 85 percent of the world's energy supply comes from fossil fuels leading to a non-sustainable situation with high emissions of carbon dioxide. One solution for a more sustainable future is to make industry processes more energy efficient, which includes reducing the carbon dioxide emissions (Brandt, Gröndahl, 2005). Energy efficiency is important on a global scale, a national scale and on a company scale. In a global perspective energy efficiency contributes to less global warming, on a national scale it contributes to less import of energy from fossil fuels and on a company scale to cost-savings (Klingspor, 2007).

Within the powder coating industry much work has been performed with the goal of reducing environmental impact. Pre-treatment baths with chemicals that are hazardous for the environment have been replaced with less harmful options and the paint and powders that are used are under constant improvement from an environmental point of view. However, the coating industry produces a lot of excess heat that cannot be used in the plants today. Reusing the excess heat will lead to energy and cost savings for the powder coating industry.

Energy efficiency measures are usually performed by larger industries since policy instruments have been focused on where the highest energy reduction can be reached. However, the need for doing this type of measures on smaller industries is increasing. The customers as well as increasing energy prices force the industries to become more energy efficient (Klässbo, 2010-09-08).

1.2 Energy policy instruments in the industry

The chemical plants in Sweden stand for about eight percent of the total energy use in the industrial sector. The energy use in this sector is expected to increase both in a short-term and in a long-term perspective (Energimyndigheten, 2008 and 2010) Industries need to be more energy efficient in a sustainable society. The European goal for 2020 is that the energy intensity shall be decreased by 20% with regard to all sectors in comparison with the levels of 1990. Also, in 2020 the emissions of greenhouse gases shall be reduced by 20% and 20% of the total energy use shall come from renewable energy sources (Energimyndigheten, 2009).

In Sweden, the goals for 2020 are stricter than for Europe. The energy supplied from renewable resources shall amount to at least 50% of the total energy and 10% of the energy used for the transport sector. This is only a part goal; the transport sector should be independent of fossil fuels by 2030. Also, the energy intensity shall be decreased by 20% with regard to all sectors between 2008-2020 (Energimyndigheten, 2009).

To be able to reach these goals energy policy instruments must be implemented. These can include for example energy taxes, green electricity certificates, programme for energy efficiency improvements (PFE), emission rights trading, energy audit checks and energy programmes.

1.2.1 Energy taxes

Energy taxes are used to lead the use and production of energy towards specific energy and environmental goals. Today, energy taxes are aimed at improving the efficiency of energy use, favour the use of bio fuels, to ensure incentives towards less environmental impact from the industry and to create conditions supporting indigenous production of electricity.

In Sweden there are taxes on electricity and fuels, on carbon dioxide and sulphur emissions, and there is a levy system on emissions of nitrogen oxide. The taxes are varying and are dependent on whether the fuel is being used for heating or as motor fuel, and whether it is used for households, industry or the energy conversion sector. The taxes on electricity also vary and are dependent on what the electricity is used for and where in Sweden it is consumed (Energimyndigheten, 2010).

1.2.2 Green electricity certificate scheme

The green electricity certificate scheme is a market-based support system to increase electricity production from renewable resources in Sweden. The certificates will contribute to transition towards a more sustainable energy system in Sweden and the goal is to increase the electricity production from renewable resources and peat by 25 TWh from 2002 to 2020. One green certificate unit is issued for each produced MWh of renewable electricity, which contributes to an incentive to expand the renewable electricity production.

Electricity suppliers and certain electricity users are required to buy green electricity certificates equal to a certain proportion of their electricity sales or use. The market for the certificates is increasing since the amount of electricity certificates that must be purchased each year is changed (Energimyndigheten, 2010).

1.2.3 Programme for energy efficiency improvement, PFE

The programme for energy efficiency improvement is a programme for energy intensive industry and the objective is to support efficient use of energy. The companies participating in the five-year programme do not need to pay the energy tax for electricity. In return, they have to introduce an energy management system and perform an energy audit within the first two years of the programme. The energy audit is performed to determine the potential for energy savings. The next step is to implement all energy efficiency measures that have been identified and that have a pay back period of less than three years. The cost for these measures will be more or less equivalent to what the electricity tax would have raised (Energimyndigheten, 2010).

1.2.4 Emission rights trading

The objective with emission rights trading is to reach the commitment in respect of reduced emissions set by the European Union in the Kyoto protocol. The aim is to reduce the emissions of greenhouse gases at the lowest possible cost by letting companies create a market for the allowances of carbon dioxide emissions given a limited ceiling. The right to use the trading system include a limited amount of sectors within the energy intense industry as well as electricity and heat producers.

One emission allowance gives a company the right to emit one tonne of carbon dioxide over a certain time interval. Due to that the companies can sell their emission allowances the emission reduction will occur for the companies and countries where it is cheapest (Energimyndigheten, 2010).

1.2.5 Energy audit checks

Companies that use more than 500 MWh of energy each year can until 2014 apply for economical support to perform an energy audit. The economical support covers 50%, maximum 30 000 SEK, of the energy audit cost. Farmers can receive the support even though they use less than 500 MWh of energy. The aim of the support is to find new ways to reduce the total energy use in Sweden (Energimyndigheten, 2011).

1.2.6 Energy programmes and the ENIG-project

According to government decision, Energimyndigheten will perform a five-year project between 2010 and 2014 concerning energy efficiency. The objective of this project is to improve the energy and climate work on a local and regional level (Energimyndigheten, 2009).

This master thesis is a part of the ENIG-project, which is a network to improve energy efficiency for small and medium sized Swedish industries. ENIG stands for "Energieffektivisering I Grupp" (Energy efficiency In Group). The organisations behind ENIG are Swerea SWECAST, Swerea IVF and FSEK (Föreningen Sveriges Regionala Energikontor). Energimyndigheten is funding the project. ENIG is a tool to compare the energy use between different small companies based on specific energy usage indicators and it also works as support for the companies when questions concerning energy efficiency arise. Companies can use the web site and create their own profile. In the profile they add all information they have about the companies energy use. They will receive more indicators and information the more input data they have. The results show how good the company is at using their energy based on the specific energy usage indicators (ENIG, 2010).

1.3 Powder coating industry

In the varnish industry liquid finish has been the most commonly used. However, regulations on air and water emissions have increased the use of powder finishing. Liquid finishing includes solvents to make the paint stick and this leads to a highly controlled system including venting, filtering and recovery systems for the volatile organic compounds (VOC). These solvents are not necessary for powder finish. There are also economic considerations that lead to increased use of powder coating. Since the liquid finish contains VOC a lot of venting is needed in the cure oven and this leads to a large amount of exhaust air. The high volume of exhaust air prevents the solvent fumes to reach such high levels that there is a risk of explosion. For powder coating the cure oven has to have a higher temperature than for liquid coating, but the reduced demand of exhaust air leads to energy and cost savings (Liberto, 2003).

A powder coating plant usually has the following processes; pre-treatment, drying oven, powder box and cure oven. There is also a possibility to include a primer box, primer oven and cooling zone between the drying oven and powder box as well as a cooling zone after the cure oven. A plant is illustrated in Figure 1.1. In the figure red zones represents areas that need heating, blue zones represents areas that need cooling and green zones are areas that are neutral from a temperature perspective. It has been seen that the powder coating industry is quite homogeneous and that the processes are similar for different companies.

In the pre-treatment unit the parts that is to be powder coated is washed in a degreasing step with water of around 60°C. The pre-treatment also includes a number of rinsing steps. After this the parts goes through a drying oven that has a temperature of about 120 – 140°C.

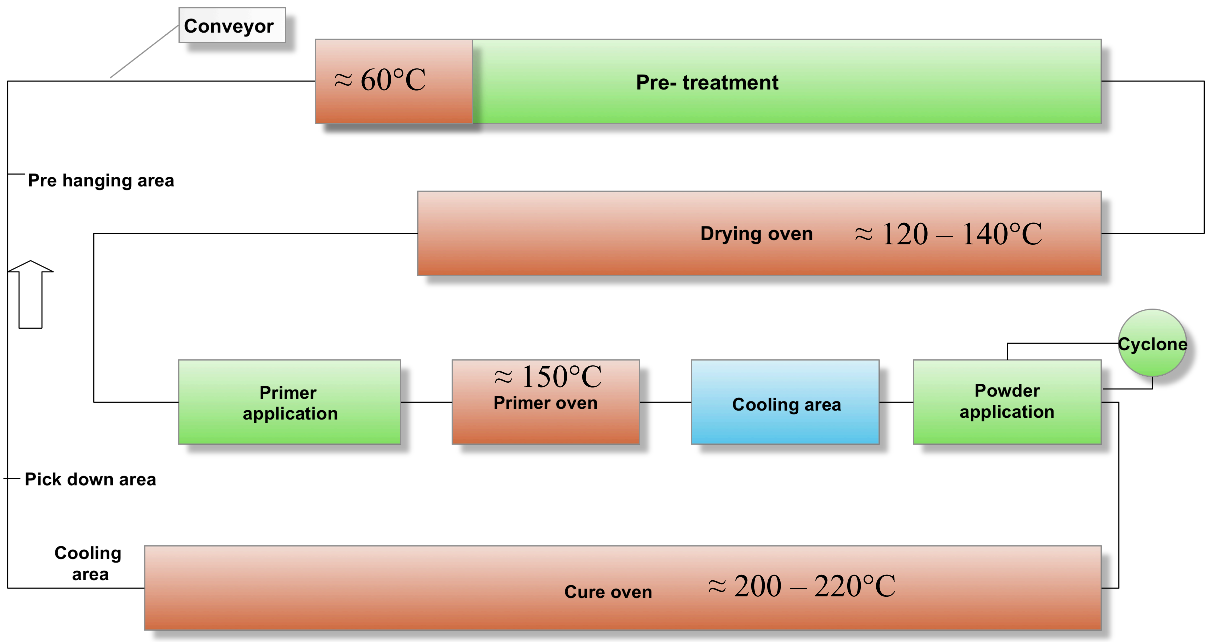

Figure 1.1: Overview of a powder coating plant

After the drying oven the plant can either have a primer box or the parts can go directly to the powder box. The primer box makes it possible to apply two layers of powder on the product. A first layer of powder is applied in the primer box and the powder is thereafter cured in the primer oven. Another layer of powder, or the first layer if the plant does not have a primer box, is applied in the powder box and in the end of the conveyor the parts goes through a cure oven that has a temperature of about 200°C. After the cure oven some plants have a cooling zone where cold air is blown over the parts to make them cool faster (Liberto, 2003).

In Sweden there are approximately 350 powder coating plants using more than one metric tonne of coating powder per year. Each plant can be estimated to use 1.5 GWh of energy each year, which make a total combined energy usage of about 525

GWh/year for the powder coating industry. Most of the energy is used for heating of the ovens and the pre-treatment bath. But there is also a large need for venting in the powder box, which contributes to a high use of electricity (Österberg, 2010-09-07).

1.4 Goal and Scope

This master's thesis is part of a larger project concerning energy efficiency in powder coating industries in Sweden performed at Swerea IVF. The goal of this thesis is to show that the energy use for the Swedish powder coating industry can be reduced by at least 20% by adopting energy efficient solutions. Technical solutions for the energy efficiency measures are to be suggested. The objective is also to compare this project with a similar project based on another varnish plant to be able to make general conclusions about energy efficiency measures for this type of industry. Both the plants use powder coating but the other has liquid finish as well. The company investigated in this thesis, Quality Powder Coating AB, has a primer box, primer oven and cooling zone while for the other company, LaRay AB, this part is left out and instead they have two additional boxes for liquid finishing. Besides this the processes are similar.

1.5 Presentation of problem

In this section the task and problem formulation are presented. The problem formulation includes questions that were used as guidelines during the thesis project.

1.5.1 Task

The coating industry consumes a lot of energy and few measures have been done to decrease the energy usage, mainly driven by problems with particles and air pollutions. The task of this thesis is to perform an energy audit of a powder coating company, Quality Powder Coating AB, another objective is to use pinch analysis tools to estimate the theoretical potential for energy savings by thermal heat exchange and also to suggest possible technical solutions to make the plant more energy efficient. The possible measures are to be connected to an economic assessment. Also, a similar master thesis was conducted in parallel on another coating company, LaRay AB, and the technical solutions for these two industries are to be compared to see if it is possible to formulate general measures that can be implemented.

1.5.2 Problem formulation

These questions were intended to work as a guide through the literature study and the search for increased energy efficiency measures.

- How high is the energy use within the constituting units of the plant?
- Which processes use the most energy and where will it be most cost-efficient to reduce the energy demand?
- Are there techniques to achieve energy saving measures for the hot and contaminated air from the cure oven?

- Are there techniques that enable use of excess heat from the drying oven and cure oven to heat the water used in the pre-treatment or to heat the ingoing air to the ovens?
- Is it possible to reduce particles and pollutant concentration in the flue gases leaving the cure oven with filters so that the heat content of these gases can be efficiently used for heat exchange?
- Are there any heat exchangers that are economically feasible to use?
- Which type of heat exchanger should be used?
- Is it possible to decrease the need for ventilation in the plant without reducing the security within the plant?

1.6 Limitations

In this master thesis the focus will be on the production process and measures to decrease the energy use within the process. However, some smaller measures for the support processes will be suggested as well but the calculations supporting these will be limited.

The data will be collected during one week. This means that variations due to market fluctuations and seasons will not be regarded. The energy demand for the process is quite similar during winter and summer. The difference is that there might be some need for heating of the facility during winter.

1.7 Outline of the report

In the next chapter the companies of interest for this thesis are introduced. The work procedure is described in the chapter called method. In chapter four the theory behind energy audit, pinch analysis and economic assessment is presented. Chapter five describes the current status of the plant that has been investigated. The report continues with presentation of results, discussion, conclusions and future work.

2 Company presentations

In this chapter there is a short description of the three companies that are involved within this master's thesis. The master's thesis have been conducted at Swerea IVF, Quality Powder Coating AB is the company that was investigated in this master's thesis while LaRay AB was investigated in a parallel study.

2.1 Swerea

Swerea is a research company with focus on material-, process-, product-, and production technologies. The corporate group includes the parent company Swerea as well as five research institutes: Swerea IVF, Swerea KIMAB, Swerea MEFOS, Swerea SICOMP and Swerea SWECAST. 53 percent of Swerea is owned by six different owner coalitions representing about 450 different industry companies. RISE Holding AB, which is the states holding company, owns the other 47 percent.

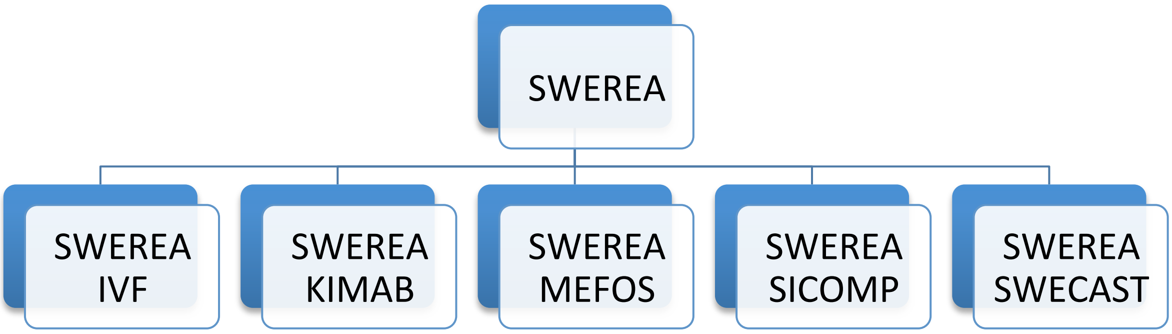

Figure 2.1: Picture of the Swerea group

Swerea IVF offers research and consultant services with focus on production and product development industries. The main target for the company is to develop and implement new technologies rapidly within client industries. This offers competitive advantages for the company's customers. The company develops products and processes as well as materials.

2.2 Quality Powder Coating AB

QPC AB is the company that was considered in this master's thesis. An energy audit of the company was conducted and measures for energy optimisation were investigated.

Quality Powder Coating AB is situated in Nässjö, Sweden. Roger Fröjdh is the director of the company and he started the company in 1999. The process has a pre-treatment unit, drying oven, primer box, primer oven, cooling zone, powder box and cure oven. The plant uses about two GWh of energy each year and the energy supply is distributed between LPG, electricity and district heating. The first bath in the pre-treatment unit is heated with district heating and all the ovens use LPG. All other energy use within the process is electricity.

The building has an area of 2500 square meters with an additional cold tent/layer of 1300 square meters and the company has a turnover of 20 million per year. Today the company has 16 employees that usually work in one and a half shifts, ten hours, each day. Each year the process is operating for about 2200 hours.

The maximum dimension for the powder coated parts is a length of eight meters, a height of 2.2 meters and a width of one meter. By pre-hanging the powder coated parts to make it cost and energy efficient there is a possibility to varnish very small parts as well. The majority of the plant is designed by SCS finishing AB but Crescocito has distributed a smaller part of the plant.

2.3 LaRay AB

LaRay AB is a powder coating industry that uses both powder coating and liquid finish. The energy audit and efficiency calculations for LaRay AB have been conducted in a parallel master thesis project to this one by Sofie Osbeck at Linköpings University. Benchmarking has been performed between QPC AB and LaRay AB.

LaRay's process has a pre-treatment unit, drying oven, liquid finish box, powder finish box and cure oven. They have about 65 percent liquid finishing and 35 percent powder coating. When they use powder coating the whole plant is running and when they use liquid finish it is only the liquid finish box and the cure oven that are used. The energy use within the plant is one GWh consisting of electricity and LPG. The first bath in the pre-treatment unit and the drying oven use LPG for heating while the cure oven uses electricity.

The company has 23 employees and they have a turnover of 21 million per year. The production building has an area of 2500 square meters. A Danish company called Ideal Line has designed the process.

3 Method

This part describes how the master thesis project was conducted. Also, the fact collection, the data collection, analysis and assumptions are described in more detail.

3.1 Implementation

The project was separated into four main steps. The first step was fact collection. In this part both a literature study about powder coating processes as well as collection of general information for QPC AB was included.

The second step was the energy audit. The data collection is further described in Section 3.3. During the energy audit all relevant data concerning electricity, use of LPG and district heating was organised. The results are presented in graphs showing the electricity use per hour during one average day, the power load and energy balances for the plant, the energy distribution, the total energy use and the cost for the different energy sources. The energy audit is also illustrated in a fish bone diagram.

The third part of the project was to identify energy efficiency opportunities within the plant. Pinch analysis was used to investigate thermal heat exchange opportunities. Economical calculations for the suggested energy efficiency measures were conducted.

The fourth part of the project was benchmarking by comparing the energy audit and the energy efficiency calculations for QPC AB with the results from the parallel study made at LaRay AB. From the results general energy efficiency solutions for the powder coating industry was formulated.

The work was conducted in parallel with Sofie Osbeck's master's thesis project at LaRay AB and with Anders Klässbo at Swerea IVF and Simon Harvey at Chalmers University of Technology as supervisor.

3.2 Fact collection

The master's thesis started with a literature study about powder coating process technology and continued with fact collection for QPC AB.

3.2.1 Literature

In the beginning of the project a basic literature study was conducted to learn about powder coating process technology. Literature was mostly available from Svensk Pulverteknisk Förening, Swerea IVF, Chalmers Tekniska Högskola, Linköpings University, Energimyndigheten and articles about powder coating.

3.2.2 Case study

Information about QPC AB was collected through their webpage and through interviews with the manager and the head of production. Detailed information about different parts within the process was collected from the designers of the process. Several visits were made to the plant to collect data and photograph the process.

3.3 Data collection

Data was collected by electricity measurements, flow measurements, temperature measurements and by the use of a thermo camera. Also, some flows that could not be measured were estimated, based on engineering judgement or mass and energy balances, if possible.

3.3.1 Plant data

Information about the plant was provided by the designer of the plant, Anders Jansson, and the manager of QPC AB, Roger Fröjdh, as well as by other company employees.

During the efficiency calculations, data for specifications and costs concerning heat exchangers, compressors and cooling zones was provided by different actors. The alternatives for energy efficiency were discussed with the designer of the plant, Anders Jansson at SCS finishing AB.

3.3.2 Electricity usage measurements

To be able to collect all relevant data for the energy audit both instantaneous measurements and logging for a period of six days was conducted. Instantaneous measurements were done on all the equipment within the plant to be able to see if all three phases had the same current, to see the active power load and cos φ. The data from the instantaneous measurements was used to decide where to place the loggers and which settings that should be used as well as to provide useful data for the energy audit, see also Section 4.1. The principal voltage within the plant was also measured.

The logging was made with electricity tongs that measured the current in one phase and they were connected to data loggers. This data collection was performed from 21st of September to 27th of September 2010. The program EasyView 5.0 was used to collect and handle the data. Eight electricity tongs were used, six of them took new values every one and a half minute and two of them measured every 15 seconds.

The period chosen for the measurements can be seen as a representative week for the plant. One week was chosen to be able to see variations during the weekend as well as to see if the units are using electricity during the time when the plant is turned off. During drive time the process is homogeneous from day to day. There are small variations during winter and summer time. The difference is that some district heating might be needed for space heating during the winter.

3.3.3 Flow and temperature measurement

The flows from the ovens have been measured by ABB in 1999. No changes have been implemented to the drying oven and cure oven since then so these measurements were used in the calculations. The operating conditions in 1999 were the same as for today and the measured values corresponds well with data given from the designer. For the primer oven the distributor of the oven, Christer Johansson from Crescocito, provided flow data. This part of the plant is quite new so the provided data is probably accurate. However, the flows have never been measured for QPC AB's conditions leading to that there is an uncertainty with these flows. The cold flow in the pre-treatment was calculated from the values given for the district heating's hot flow and energy use. The flows into the ovens cannot be measured and were therefore calculated using mass balances.

Temperatures for the oven flows were measured with a temperature meter from Testo with a margin of error of one percent. For temperature of the pre-treatment flow were measured with a thermometer on the outside of the pipe. Also temperatures within the plant and thermal bridges in the ovens were identified with a thermo camera from Testo. The temperature changes throughout the ovens for the parts that were to be powder coated have also been measured.

3.3.4 Source of error

The electricity data for this master thesis has been collected during one week, as a result the cost and energy consumption for longer periods such as a month and a year are only estimations. However, the calculations have been compared to the invoices leading to a good estimation. Also, the data loggers that were used for the electricity measurements had a margin of error of 2.5 percent. Logging has not been possible for the use of LPG and district heating. Therefore the values used in the energy audit are based on the invoices during one year.

The device that was used for the flow measurements had a higher uncertainty the closer to 100°C the flow was. It did not work at all for flows above this temperature. Therefore the flows have been estimated based on measurements that were made by ABB when the plant was built in 1999. No changes have been made for these flows since then and the measurements from ABB correspond well with the values from the designer of the plant.

Temperatures in the pipes were measured by new Testo equipment with a margin of error of one percent and the values also corresponded well with the control system in the plant.

In the pinch analysis ΔT_{min} has been assumed to be 10°C. This might result in higher efficiency of the heat exchangers than is possible.

3.4 Analysis

The analysis for identifying energy efficiency measures was performed by the use of pinch analysis and by analysing other energy consumers that are not related to heat demand, such as production planning.

3.4.1 Pinch analysis

In this project the heat content in the different streams was estimated based on process data and after this different possible options for heat exchange were investigated. How the heat can be used depends on when different processes are used, for how long time they are on and the distance between them, see also Appendix 1. In the end the options are weighed against each other based on savings of energy and capital. The theory behind pinch analysis is further described in Chapter 4 and in particular Section 4.2.2.

3.4.2 Other energy efficiency measures

There are some energy efficiency measures that do not require heat exchanging. All process units were checked to see if there are possibilities to reduce the energy demand.

3.4.3 Economic assessment

The economic performance for the suggested measures was assessed using the payoff period and the net present value methods. The theory behind these two methods is presented in Section 4.3. Also, a sensitivity analysis was conducted based on the expected price increase for energy during the next ten years.

3.4.4 Benchmarking

Benchmarking is defined as measuring how a company, industry or country performs in comparison with other companies, industries or countries (Nationalencyklopedin). Originally, the expression comes from business administration where the business could be internally or externally compared with similar competitors. The business could also be compared with consideration of the function, against other competitors that were considered to be the best within the category (Anderson, Pettersen, 1997).

Internally the comparison is based on the energy audit that was made for QPC AB. Also, Swerea IVF has a small powder coating plant that was used to increase the understanding about powder coating. The external comparison was made continuously by comparing the energy use and efficiency calculations for QPC AB with LaRay AB. Several visits to LaRay AB were made to increase the understanding for the production, energy use and possible energy efficiency measures.

Also, participation at the Svensk Pulverlackteknisk Förenings (SPF) conference in Vadstena 3-4 November 2010 provided useful input to this project. In connection with the conference a study visit was made at BT Powered Trucks (Toyota Material Handling Sweden) powder coating plant in Mjölby. This powder coating plant is a top modern plant that has implemented some energy efficiency measures already. The visit provided a function-based benchmarking-opportunity.

3.5 Assumptions

In this section all assumptions that was made during the thesis is presented. The assumptions are divided into production assumptions, assumptions for the energy audit and assumptions for the energy efficiency calculations and pinch analysis.

3.5.1 Production

According to the manager of QPC AB one average production day is ten hours. It was assumed that each month contains 20 working days and that the plant is running during eleven months each year. This gives a running time of 2200 hours per year.

All energy use for the processes was split over eleven months per year except the district heating. The district heating is assumed to be running all twelve months since it is used to heat the facility during the vacations in winter.

3.5.2 Energy audit

The logged week was assumed to represent a standard week and the periods when the process units are running were based on this week. The average values from the logging were used as much as possible but when there was a lack of data, the instantaneous measurements were used instead.

The primer oven and the cooling zone was not logged but is assumed to be running at the same times as the primer box. The power factor, cos(φ), was not measured for these two processes. Since this part is quite new the power factor for the different units is assumed to be 0.8.

Different units such as fans and pumps were assumed to use the same amount of energy as during the instantaneous measurements.

Due to that the signal box was connected so that some of the neighbours electricity was taken from the same signal box, the power load that was taken from other sources than the process had to be estimated. This assumption was based on the statements from the electrician that investigated the signal box. The background current was therefore set to 15 ampere instead of the measured value of 105 ampere.

3.5.3 Energy efficiency calculations and pinch analysis

Average densities and specific heat capacities over the temperature intervals were used for the thermodynamic calculations of the different streams.

The airflows that were measured by ABB in 1999 were assumed to be correct today as well. The airflows for the primer oven and cooling zone were estimated from theoretical values and the fact that the dampers are fully open. The outdoor temperature is assumed to have an average value of 15°C throughout the year. This is the temperature that was used as inflow temperature to the cooling zone.

The heat loss in the ovens airlocks was estimated to be 30%, meaning that 30% of the air through the locks is taken from inside the ovens and 70% is taken from outside the ovens. This was based on the temperatures in the flows.

The thickness of the steel in the walls and roof of the ovens was estimated while the thickness of the isolation was known. This was estimated for the calculations of the heat losses through the walls and roof of the ovens. It was assumed that there are no heat losses through the walls and roof in the cooling zone since the temperature is low. The inner and outer heat transfer resistance was neglected for the calculations of these losses.

The mass flow for the powder coated parts was assumed to be 50% of the maximum capacity for the conveyor. The conveyor was estimated to have an average speed of 1.5 meters per minute.

The powder box is known to use 6600 litres of compressed air each minute. The primer box was assumed to use 4000 litres each minute and the zone after the pre-treatment was estimated to use 1000 litres per minute.

The energy use for lighting were assumed to be reduced by 50% by changing to low energy lighting where it is possible and by switching off the lights when there is no need for them. The electricity use for the fans connected to the drying oven and cure oven was estimated to decrease by 30% when changing the fans.

4 Theory

In this chapter a theoretical description of the electricity measurements, heat demand and heat content, pinch analysis, economic assessment methods and sensitivity analysis is presented.

4.1 Electricity measurements

In this project the electricity was measured both instantaneous and logged during one week. The instantaneous measurements were made to receive the active power load, the current and the power factor (cos φ). Which settings that was to be used for the data loggers as well as where to place them was based on the values from the instantaneous measurements. The goal of the logging was to collect data for the active power load for the component that is measured during a certain time interval. Since the loggers only measure the current, calculations had to be conducted. In these calculations it was important to take into account whether the component has a one-phase system or a three-phase system. For a one-phase system the active power load is calculated by multiplying the line current, phase voltage and power factor. For a three-phase system the principal voltage is used instead, see Figure 4.1 and Equation 4.1 (Börjesson and Rosenqvist, 2010-10-01).

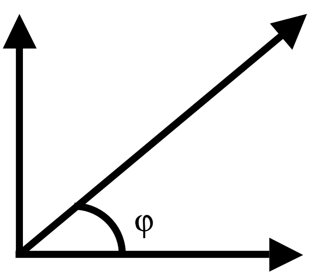

Figure 4.1: Power load triangle

In Figure 4.1, P is the active power load, Q the reactive power load and S the apparent power load. φ is the angle between the active power load and the apparent power load which makes the reactive power load dependent on this factor. This relationship gives that the apparent power load for a three–phase system is:

$$S = 3 \cdot U_f \cdot I_f = \sqrt{3} \cdot U_H \cdot I_L \tag{4.1}$$

where U_f is the effective value for the phase power load, I_f is the effective value for the phase current, U_H is the principal voltage and I_L is the line currents effective value.

The active power load is given by multiplying the apparent power load by the power factor:

$$P = \sqrt{3} \cdot U_H \cdot I_L \cdot cos\varphi \tag{4.2}$$

4.2 Energy optimisation

The energy optimisation section presents the theory about heat demand and heat content as well as pinch analysis.

4.2.1 Heat demand and heat content

The heat demand and heat content for the streams have been calculated by using the first law of thermodynamics.

The added energy to heat the ingoing airflow to the ovens is given by the mass flow ($\dot{m}$), the specific heat capacity (Cp) and the temperature difference ($T_{in} - T_{surrounding}$), see Equation 4.3 (Elliot, Lira, 2001). T_{in} is the temperature inside the oven and $T_{surrounding}$ is the temperature of the surrounding air.

$$Q_{air} = \dot{m} \cdot Cp \cdot (T_{in} - T_{surrounding}) \tag{4.3}$$

Equation 4.4 defines the conduction losses through the walls and roof of the ovens as well as from the lid to the pre-treatment bath.

$$Q_{conduction} = \sum_{n=i}^{j} (A_i \cdot U_{h,i}) \cdot \Delta T = \sum_{n=i}^{j} A_i \cdot \frac{(T_{in} - T_{surrounding})}{R_{si} + \frac{d_i}{\lambda_i} + \cdots + \frac{d_j}{\lambda_j} + R_{sy}} \tag{4.4}$$

In Equation 4.4, A is the area, U_h is the heat transfer coefficient over layer i, T_{in} is the temperature inside the oven or for the surface of the lid of the first pre-treatment bath, $T_{surrounding}$ is the temperature of the outside air, d is the thickness of each layer, R_{si} is the inner heat transfer resistance, R_{sy} is the outer heat transfer resistance and λ is the heat conductivity (Welty, Wicks, Wilson, Rorrer, 2001).

The energy demand to heat the powder coated parts within the ovens is given by the mass flow ($\dot{m}$), the specific heat capacity (Cp) for the parts and the temperature difference of the parts at the entrance to the oven and at the end of the oven ($T_{parts,out} - T_{parts,in}$), see Equation 4.5.

$$Q_{parts} = \dot{m}_{parts} \cdot Cp_{parts} \cdot (T_{parts,out} - T_{parts,in}) \tag{4.5}$$

The heat added to the oven equals the sum of the energy added to heat the incoming air, Q_{air}, the energy added to heat the parts to the specified temperature according to the powder type, Q_{parts}, and the heat added to cover the conduction losses, $Q_{conduction}$, see Equation 4.6 and Figure 4.3.

$$Q_{heat} = Q_{air} + Q_{parts} + Q_{conduction} \tag{4.6}$$

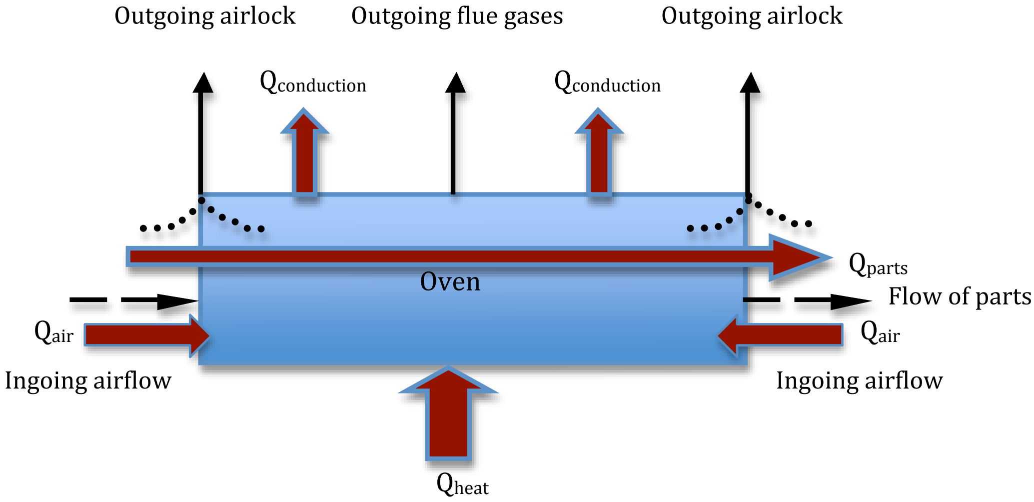

Figure 4.3: Illustration of equation 4.6

For the pre-treatment bath the total heat loss out from the lid covering the bath is given by calculating the radiation and conduction losses. The radiation losses are included for the bath due to that heat loss from the bath has been a concern within the powder coating industries. The radiation losses are calculated using equation 4.7. The conduction losses are calculated by using Equation 4.4.

$$Q_{radiation} = \sigma \cdot \varepsilon \cdot A \cdot \left(T_{lid}^4 - T_{surrounding}^4\right) \qquad (4.7)$$

where σ is Stefan Boltzmanns constant, ε is the absorption coefficient, A is the area of the lid, T_{lid} is the temperature on the surface of the lid and $T_{surrounding}$ is the temperature of the surrounding surfaces (Welty,Wicks, Wilson, Rorrer, 2001).

4.2.2 Pinch analysis

Pinch analysis can be used to analyse industrial process systems and determine how much heat that has to be added, how much excess heat there is and how much heat that can be recovered within the process. Pinch technology is also a useful tool to investigate how to integrate heat exchangers to achieve maximum heat recovery.

Process streams that are in need of cooling are hot streams and streams that need heating are cold streams regardless of their actual temperature. There are two types of heat exchangers; internal heat exchangers are used between streams while external heat exchangers are either heaters or cooler. When there is a heat exchange between streams the temperature difference between them cannot be less than the minimum temperature approach, ΔT_{min}, which is set by the user based on economical considerations.

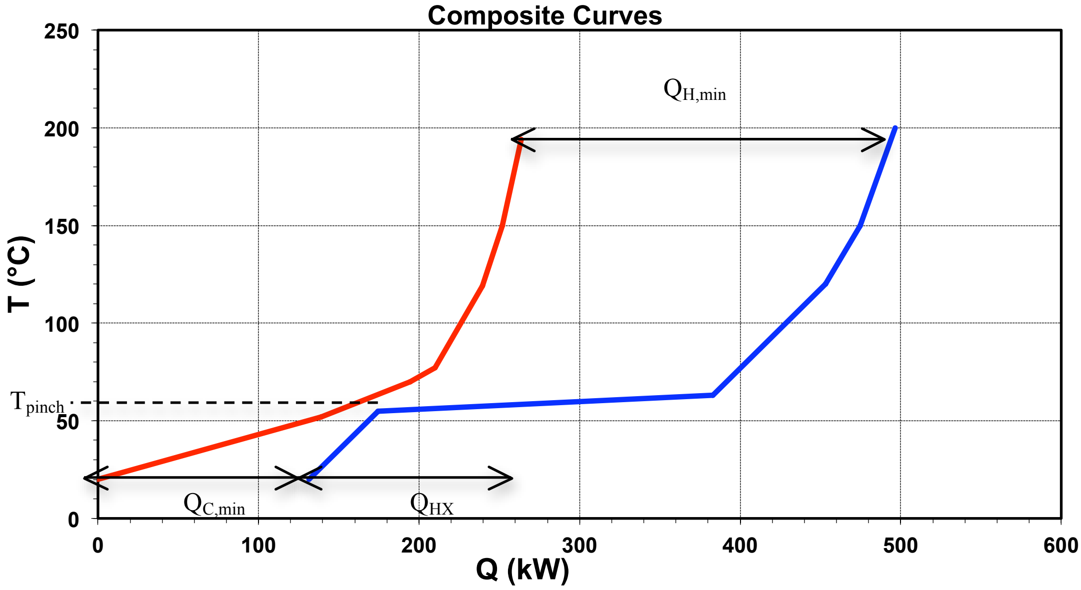

Figure 4.4: Example of composite curve

The heat content in the streams and the temperature differences are used to construct hot and cold composite curves, see Figure 4.4. These curves should be overlapped as much as possible. In the overlap zone internal heat exchange, Q_{HX}, is possible. Were they do not overlap external heating, $Q_{H,min}$, or external cooling, $Q_{C,min}$, has to be provided. The minimum temperature difference, ΔT_{min}, is the factor that determines how much overlap there can be. The point where ΔT_{min} occurs is called the pinch. Heat exchange should be avoided across the pinch in order to maximize the heat recovery.

When designing a HEN for maximum energy recovery the streams above and below the pinch are matched by starting from the pinch and working outwards in both directions, see Figure 4.5. In the figure cold streams are blue, hot streams are red, heat exchangers are grey, external coolers are light blue and external heaters are orange. When heat exchange occur between two streams at least one of the streams should be ticked-off, meaning that the cooling or heating requirement should be satisfied for at least one of the streams. This way of designing the heat exchanger network will make the most of the heat exchange with the least amount of heat exchanger units (Industrial Energy Systems, 2008).

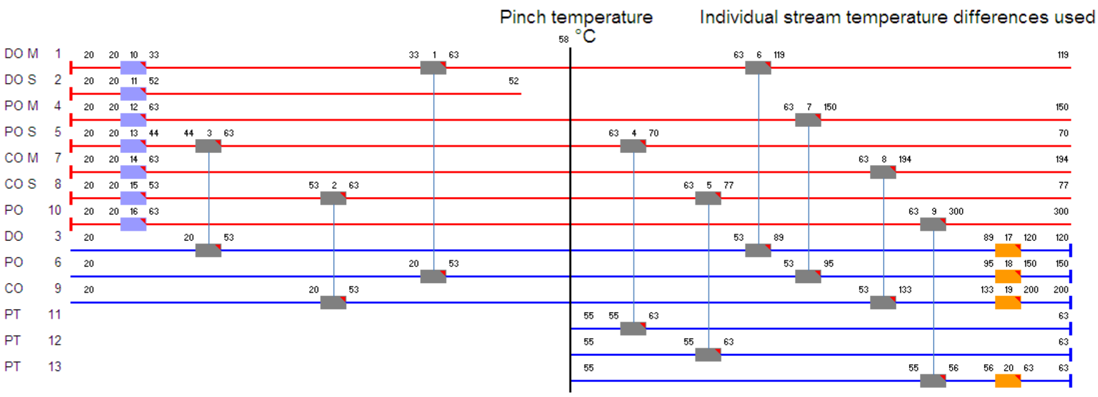

Figure 4.5: Example of heat exchanger design for maximum heat recovery

4.3 Economic assessment

Two ways of calculating the economy performance of energy efficiency measures were used in this master's thesis. The first way is the payoff period and the second way is the net present value method. Also, a sensitivity analysis was conducted to investigate what effect the changes in energy prices will have on the results.

4.3.1 Payoff period

This method describes how long time it will take before the energy cost savings will correspond to the investment, see Equation 4.8. With this method it is possible to rank the different possible investments. However, this method does not account for the time value of money, nor does it quantify the total economic value of the investment over its lifetime. In this respect the payoff period is a good indicator of economic risk.

$$Payoff\ period = \frac{I}{S_i - O} \quad (4.8)$$

In Equation 4.8, I is the initial investment, S_i is the savings created by the investment and O is the operating cost (Grubbström, Lundquist, 1996).

4.3.2 Net present value

The net present value method accounts for the time value of money as well as quantify the total economic value for the investment over its lifetime. With the net present value method it is possible to evaluate if an investment is profitable by comparing the initial investment with all future cash flows, see Equation 4.9. If the present value is higher than zero the investment will be profitable. The method uses the interest rate to recount all future payments to the monetary value of a reference time (Grubbström, Lundquist, 1996).

$$NPV = \sum_{i=0}^{N} a_i \cdot (1 + r)^{-i} \quad (4.9)$$

where a_i is the net payment (saving S_i – operating cost O) within period i to year N, $(1+r)^{-i}$ is the discount factor and r is the interest rate. The net payment for the investment year, a_0, is the same as $-I$, where I is the initial investment.

The net present value ratio gives a possibility to rank investment alternatives against each other. This method compares the net present value with the initial investment and the higher the result the better the investment, see Equation 4.10.

$$NPVR = \frac{\sum_{I=0}^{N} a_i \cdot (1+r)^{-i}}{|a_0|} \quad (4.10)$$

where a_0 is the basic investment and the other variables are the same as in equation 4.9.

4.3.3 Sensitivity analysis

A sensitivity analysis was performed in this project with respect to the increasing energy prices. The economic calculations were made with the energy prices QPC AB had in 2010. In the sensitivity analysis the same calculations were made, payoff period and net present value, but with the expected increased energy prices instead of 2010's prices.

According to some energy market forecasts, the price for LPG is expected to increase by 60%, the price for electricity by 50% and the price for district heating by 30% from 2010 to 2020. In the same time period the carbon dioxide emissions associated with electricity generation are expected to decrease by seven percent (Harvey, 2011-01-20).

5 Description of current status

The parts that are to be powder coated hangs on a conveyor that is about 300 meters long and it takes about five hours for the parts to travel through the complete treatment process. The conveyor can carry 150 kilograms per meter. A layout of the plant is shown in Figure 5.1. Specific values for flows, temperatures and heat loads can be seen further down in the chapter.

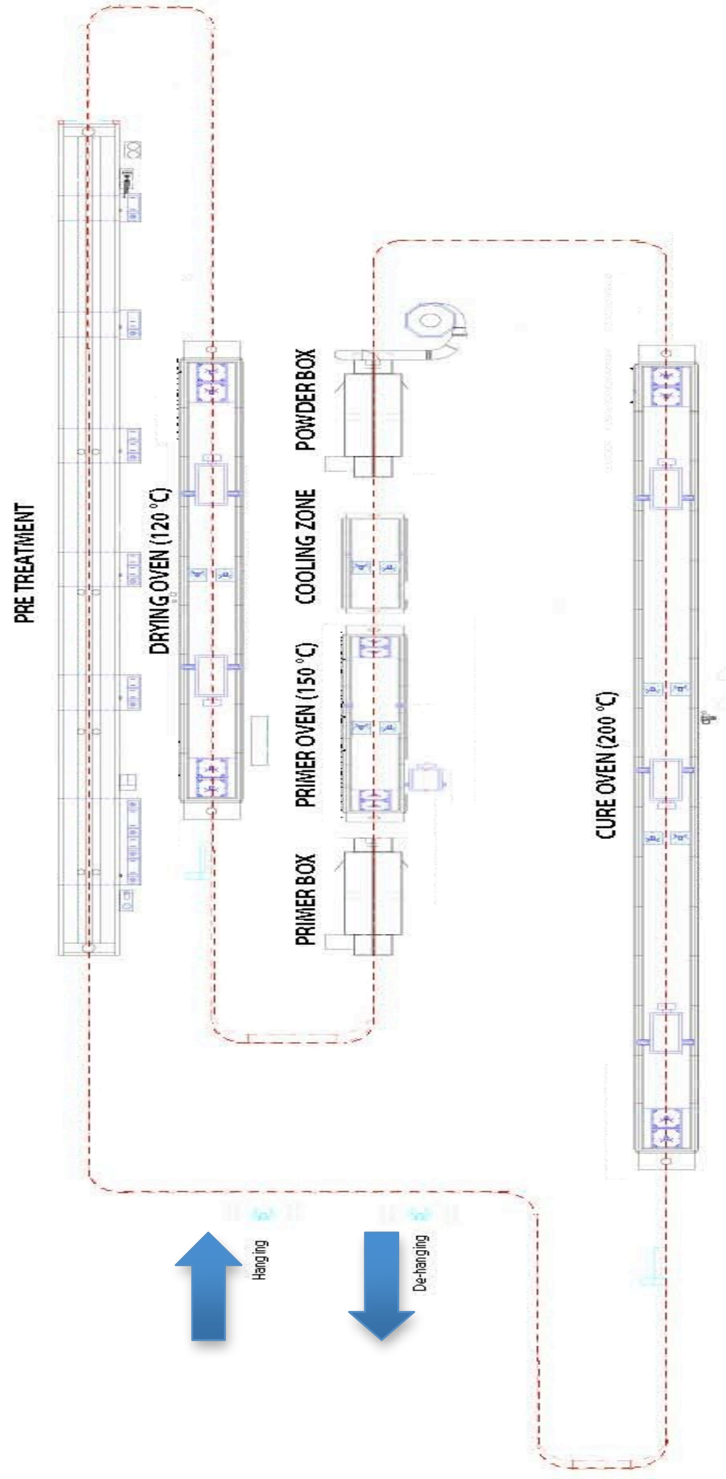

Figure 5.1: Layout of QPC AB's process

5.1 Pre-treatment

The first unit in the process is a pre-treatment zone that contains six steps. The first bath is an alkalic degreaser process. The water temperature here is 55°C and the water is heated in a plate heat exchanger by district heating which can be seen in Figure 5.2. The second and third baths are rinse steps where ordinary water is used which leads to cooling of the parts going through the pre-treatment. The parts carry some hot water from the first step. This in combination with the temperature of the parts leads to that the temperature of the water in step two is about 30°C. The fourth step is also a rinse step but here ionised water is used instead. To get a higher protection against rust the chemical Tectalis is used in the fifth step and after this there is another rinse step with ionised water. It is only the first step that is heated. In the end of the pre-treatment compressed air is used to blow off water from the parts.

In the pre-treatment the water goes against the stream of the parts. Clean water is added in the last step to insure that the parts are as clean as possible in the end of the pre-treatment unit. There is a constant flow of water going from bath six to bath five and from bath five to bath four and so on, see Figure 5.2. This stream compensates for the vaporised water in the first step and for the water that stays on the parts when leaving the pre-treatment. The water used in the pre-treatment goes through a cleaning procedure to obtain ionized water.

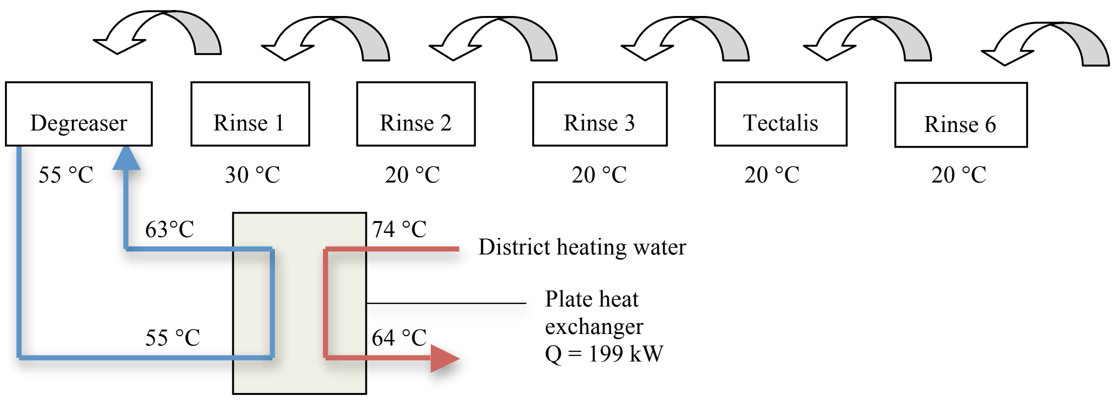

Figure 5.2: Counter-current for water flow in the pre-treatment unit

5.2 Drying oven

The second part of the process is a drying oven. The temperature in this oven is 120°C. The oven is equipped with two gas burners and uses LPG as fuel. The oven is a direct oven so the flame from the burner goes straight into the oven. In this oven all of the remaining water that is left on the parts from the pre-treatment evaporates. The air from the oven goes via a fan and a pipe through the roof, resulting in hot air being released to the environment.

The oven is illustrated in Figure 5.3. The black arrows represent the airflows in and out from the oven. 70% of the air going out via the airlocks in each end of the oven is taken from outside the oven and 30% is taken from the hot air inside the oven. The dotted arrows represent the flow for the parts that are to be powder coated.

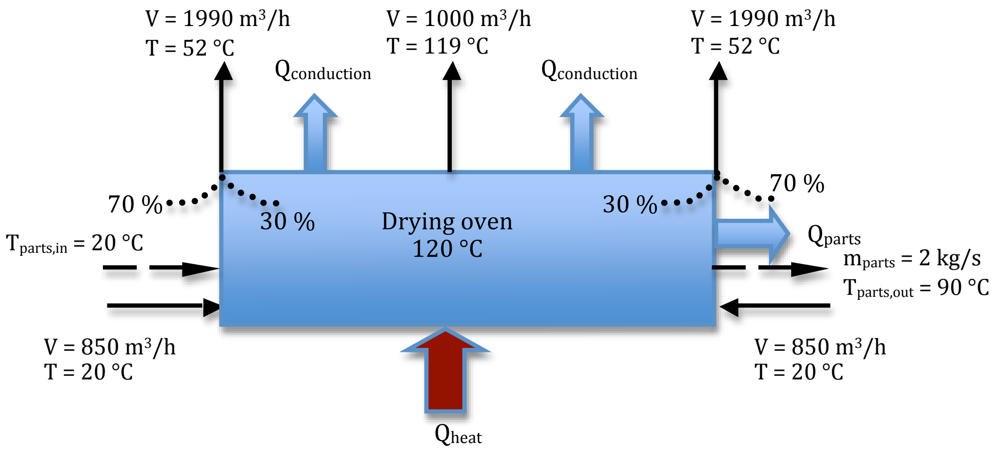

Figure 5.3: Illustration of the drying oven

In Figure 5.3 the ingoing airflows were calculated using mass balances, including density changes leading to that the hot flow have larger volume than the cold flow, see Appendix 2. The mass flow for the parts was estimated and all other values were measured.

5.3 Primer

The parts continue into the primer box where a first layer of paint can be applied if needed. Not all powders need this application so this part can be turned off. Therefore, this oven is not appropriate for integration with other process units. The primer box needs a lot of ventilation leading to high electricity consumption. In connection with the primer box there is a primer oven with a temperature of about 150°C. This oven uses LPG as fuel and it is an indirect oven, meaning that there is a wall between the heat source and the air in the oven. The exhaust air from this oven is also released via a pipe through the roof. The oven cures the first layer of paint and the parts can continue into the cooling area.

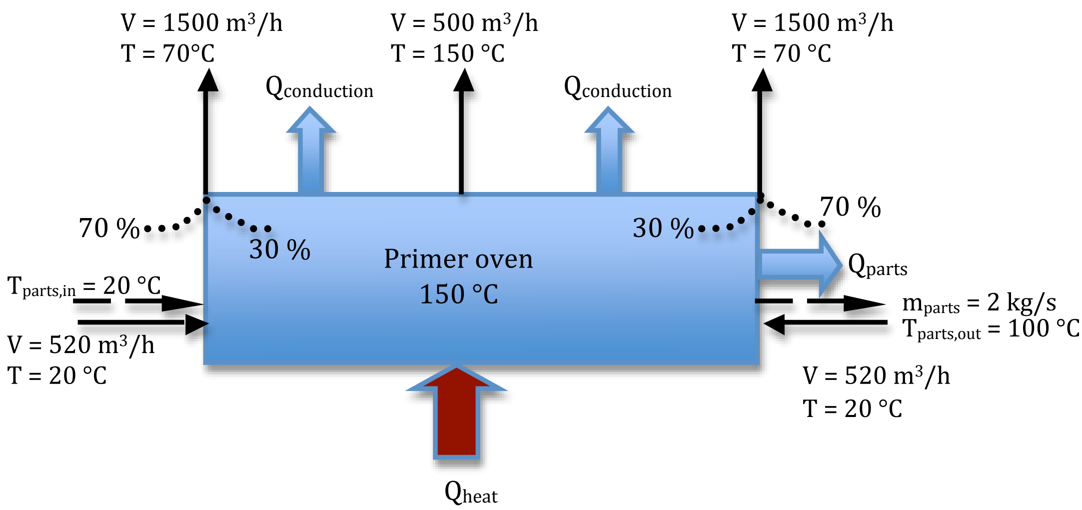

Figure 5.4: Illustration of the primer oven

The cooling area is a capsulated area where outside air is used to cool the parts. The hot air is then released to the environment via a pipe through the roof.

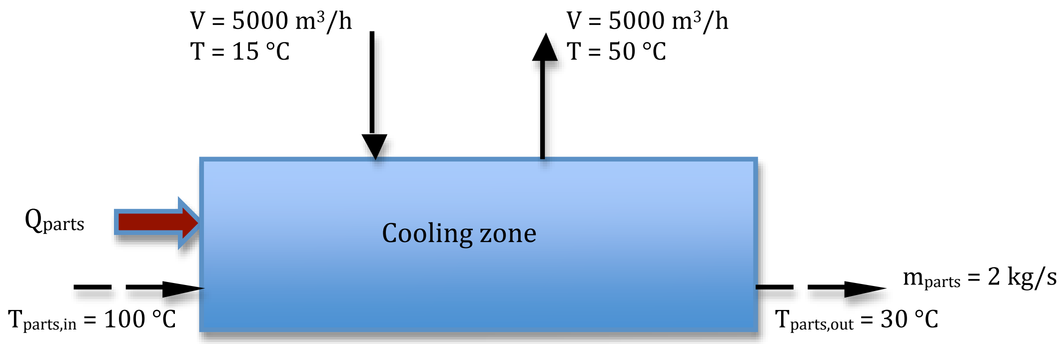

Figure 5.5: Illustration of the cooling zone

5.4 Powder box

The next step in the process is the powder coating box where the top layer of paint is applied. The powder is applied either by electrostatic charging or friction charging. Friction charging is the most commonly used technique. The powder particles are charged when leaving the nozzle making them stick on the grounded parts. With electrostatic charging the parts is grounded and there is an electrode on the nozzle. Because of this there is a voltage field between the nozzle and the parts making the powder particles move in the direction of the field. For electrostatic charging one big nozzle is used while for friction charging many small nozzles are used that enables a higher precision for this technique.

A lot of ventilation is needed in the powder box leading to high electricity consumption here as well. A programme connected to the box sets the amount of ventilation that is needed. The air to the ventilation is taken immediately below the ceiling in the room. A fan drives the air out from the box and through a cyclone. The cyclone collects large powder particles and smaller powder particles sticks in a filter. These particles are lead back to the box and are reused. The efficiency for the powder is about 95%, meaning that 95% of the used powder actually stays on the varnished parts. The box is self-cleaning so changing colour only takes about five minutes and it also provides a good work environment.

5.5 Cure oven

The last step in the process is the cure oven. The temperature in the oven is about 200°C and the exhaust air goes via a fan out through a pipe in the roof. The oven is equipped with three direct gas burners and uses LPG as fuel. The ingoing air to the three ovens goes through the openings in both ends of the ovens. The air is sucked in due to vacuum pressure in the ovens. To prevent heat from the three ovens to go out in the room airlocks are used at both ends of the ovens. After the last oven the coated parts stays on the conveyor until cooled off and is then dehanged.

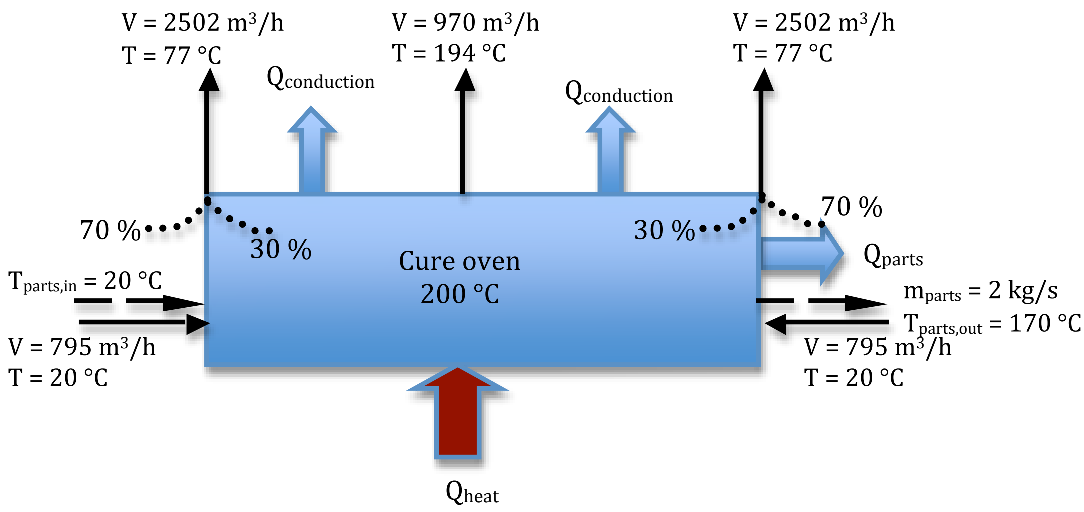

Figure 5.6: Illustration of the cure oven

During breaks and shorter stops in the production the temperature in the ovens is decreased. Ventilation within the whole process and heating in the pre-treatment unit continue at full capacity. During longer stops such as during the night, the process is fully turned off. Timers are used to start the heating of the ovens and the pre-treatment unit so that they are hot when the employees arrive in the morning to start their shift.

6 Results

In this chapter the results for the energy audit, the analysis of energy efficiency measures, the economic assessment as well as the suggestions for efficiency improvements are presented.

6.1 Energy audit

The results for the energy audit are divided into three parts. The first part describes how much energy is used for the production processes and the support processes respectively. The second part is a description of the energy use within the plant and the third part is a benchmarking between QPC AB and LaRay AB.

6.1.1 Unit processes

The unit processes are divided into two parts, production processes and support processes. All parts within the plant that is related to the production are production processes. These processes are pre-treatment, drying oven, primer box, primer oven, cooling zone, powder box and cure oven. The production processes uses 86% of the total energy consumption. The support processes include everything that is not included in the production processes such as lighting, computers, charging of forklifts, dehumidifier and the compressor. The support processes uses 14% of the total amount of energy.

6.1.2 Energy use

The energy audit is based on instantaneous measurements for the different units of the process as well as on the logging that was performed during one week. The values from the logging were used to evaluate how many hours the different parts of the process are in use each day as well as to get an average value for the electricity usage. The calculated energy use of electricity was compared with the electricity invoices. This comparison made it possible to extrapolate the logged and instantaneous measurements to the usage of one year. The usage of district heating and LPG was based on the monthly values for the consumption stated on the invoices. Invoices for one year have been compared concerning all three energy sources.

Figure 6.1 shows how much electricity that is used in the whole plant per hour during an average production day. The production starts around six in the morning and is usually terminated around four in the afternoon. The electricity use is the same from day to day if there is no overtime. The electricity consumption peaks at about nine am with 200 kWh/h. This peak is due to that the primer box, primer oven and cooling zone are used in periods from seven am until eleven am. When this peak occurs during the day may vary due to the time periods when the primer part is running. However, it has been seen during the logged week that the primer oven is used approximately the same amount of time each day.

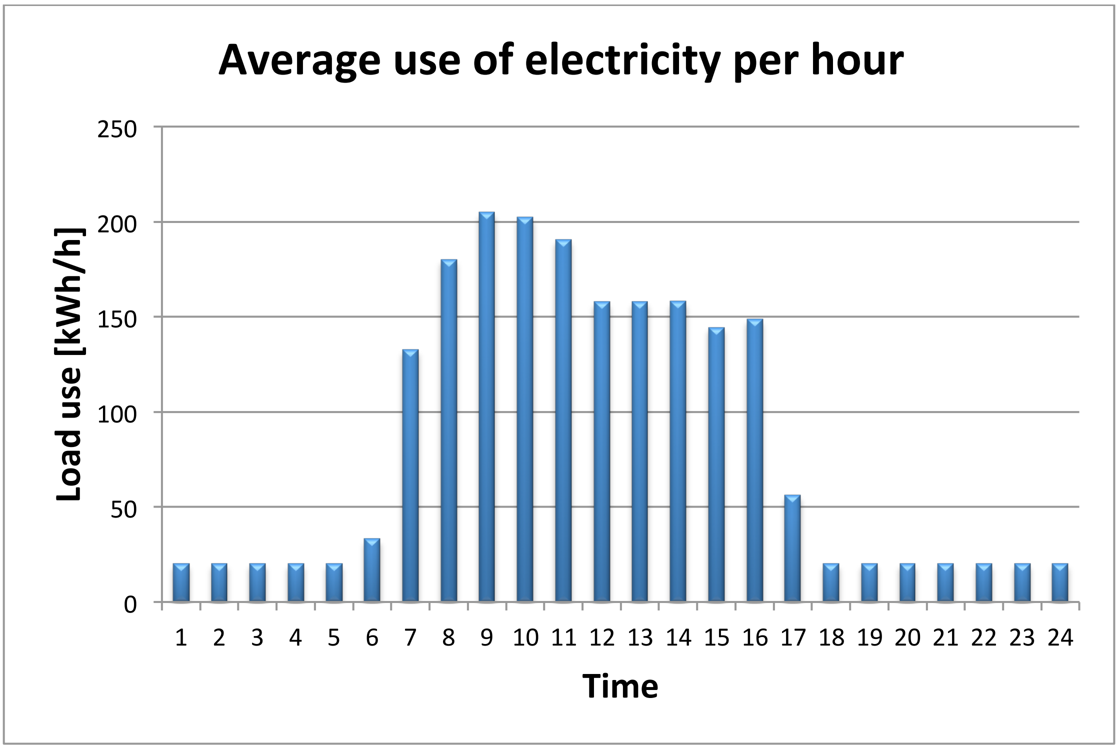

Figure 6.1: Use of electricity per hour during an average production day

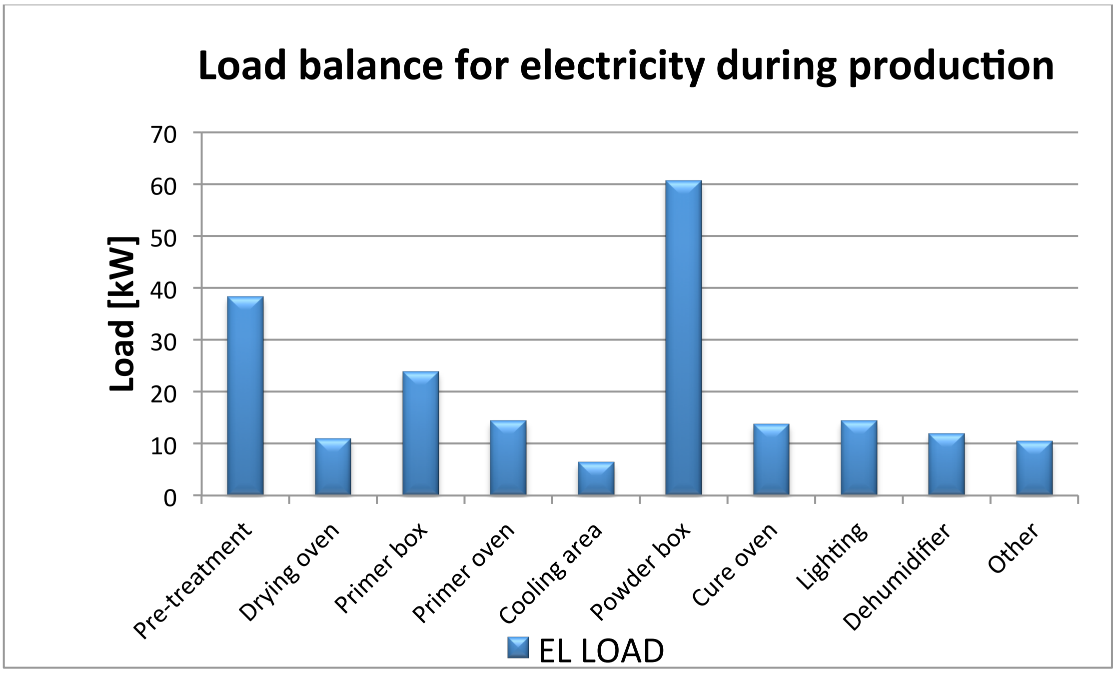

Figure 6.2: Load balance for electricity use during full production

Figure 6.2 shows how the electrical power load is distributed between the different parts within the plant. This graph illustrates the power load when all parts within the process is running and can therefore be compared with the peak at nine am in Figure 6.1. It can be seen that the powder box is a large consumer of electricity due to its high need for ventilation. Another large consumer of electricity is the pre-treatment unit.

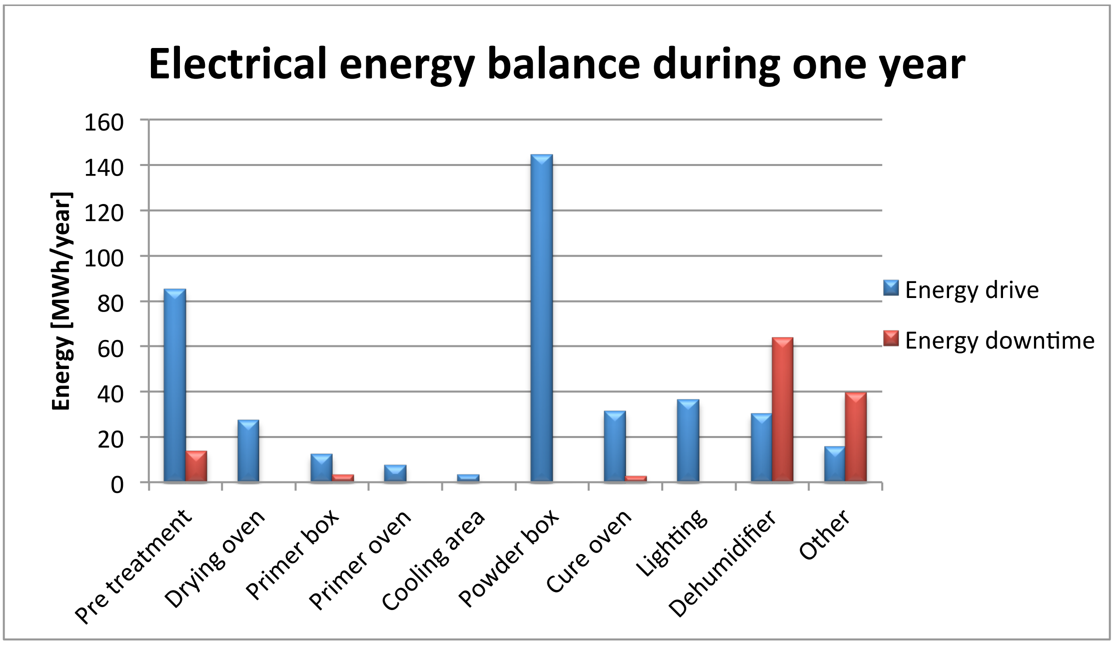

Figure 6.3: Electrical energy balance for electricity during one year

Figure 6.3 shows the use of electricity during one year and includes periods were the plant is turned off. For running times of the processes within the plant see Appendix 1. The powder box is the largest consumer of electrical energy. The primer box, primer oven and cooling area are only used during a short time each day and this makes them small in the energy balance. The graph shows that the parts in the process are small consumers of electricity when the plant is not running. The pre-treatment uses electricity during the downtime due to a circulation pump that is on all the time. Charging of trucks is performed during nights and is included in “Other” consumption in the figure. The dehumidifier is on all the time.

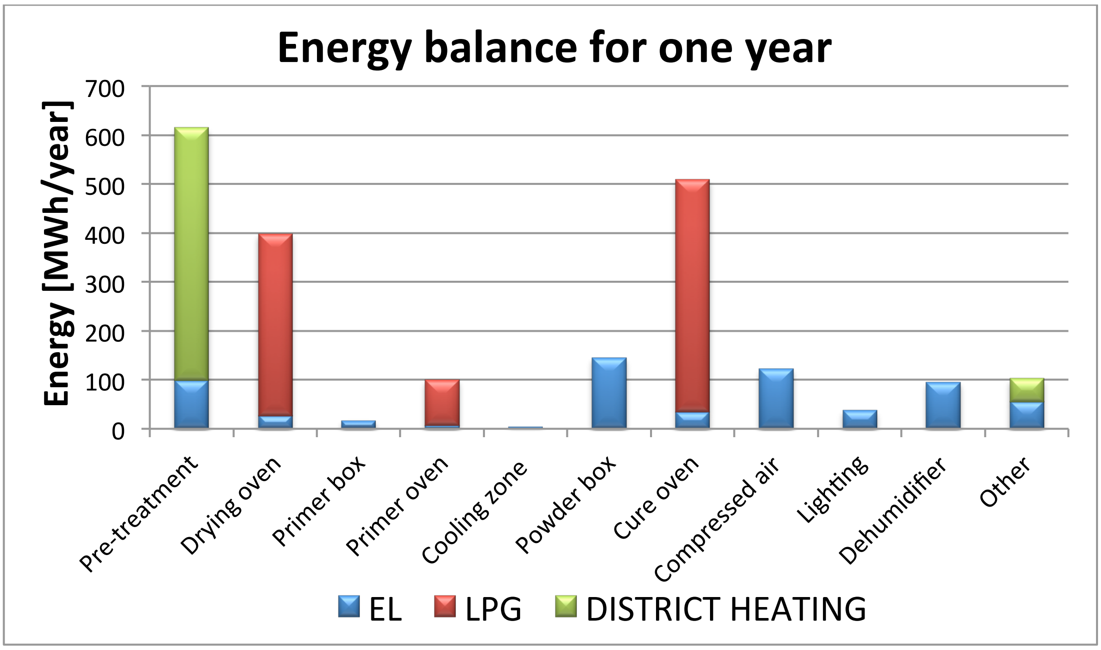

Figure 6.4: Energy use for all energy sources during one year

The energy balance for one year includes the use of electricity, LPG and district heating. As can be seen the pre-treatment is the only consumer of district heating within the process. During winter some district heating can also be used to heat the building. The drying oven, primer oven and cure oven are all users of LPG. The distribution of LPG in Figure 6.4 was based on the maximum load of the burners as well as on calculations of mass and energy balances. The energy use per unit is also illustrated in a fish bone diagram, see Figure 6.5. For each process unit the energy use is presented separated on electricity, LPG and district heating. Compressed air is within parentheses since it is included in the facility rent and not in the electricity invoice as it is today.

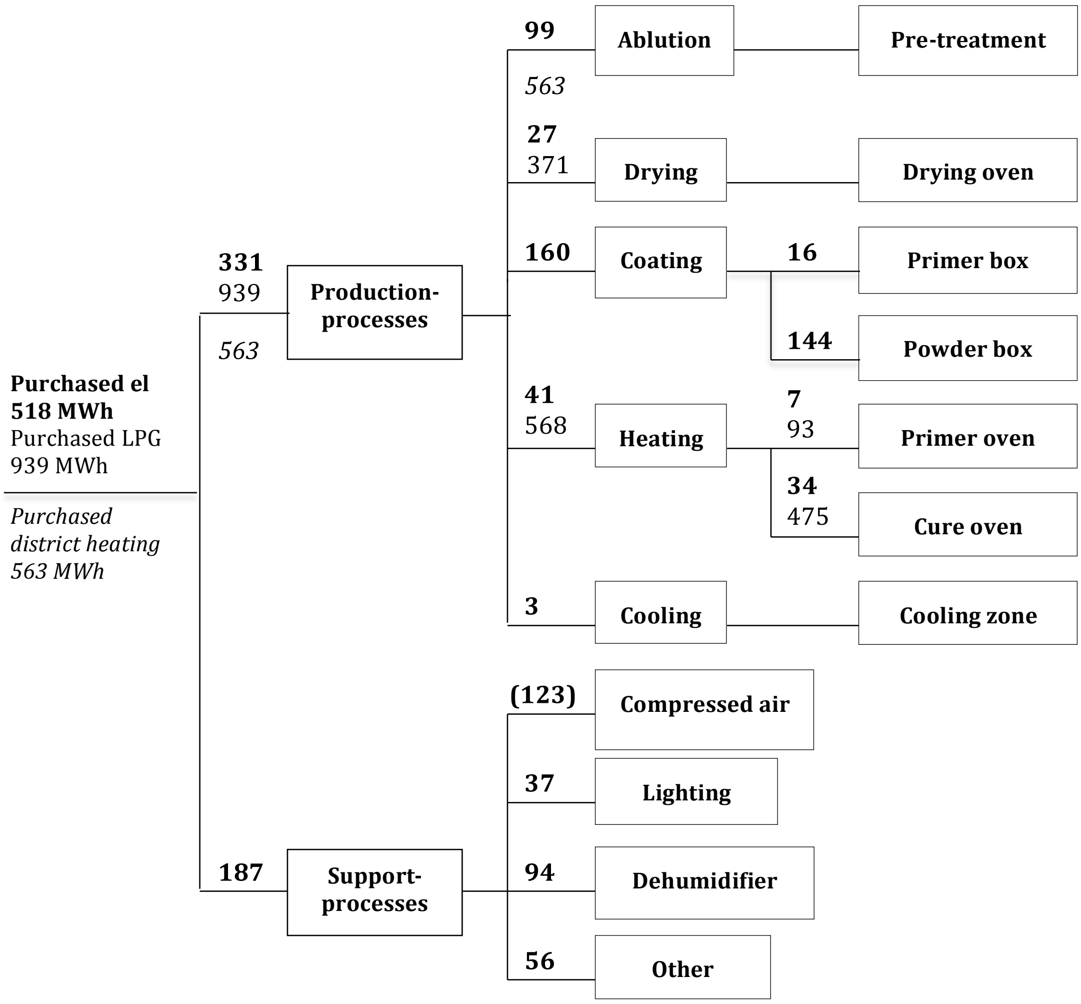

Figure 6.5: Fish bone diagram for the energy use in MWh

The energy distribution, Figure 6.6, shows how large parts of the annual energy use that comes from each energy source.

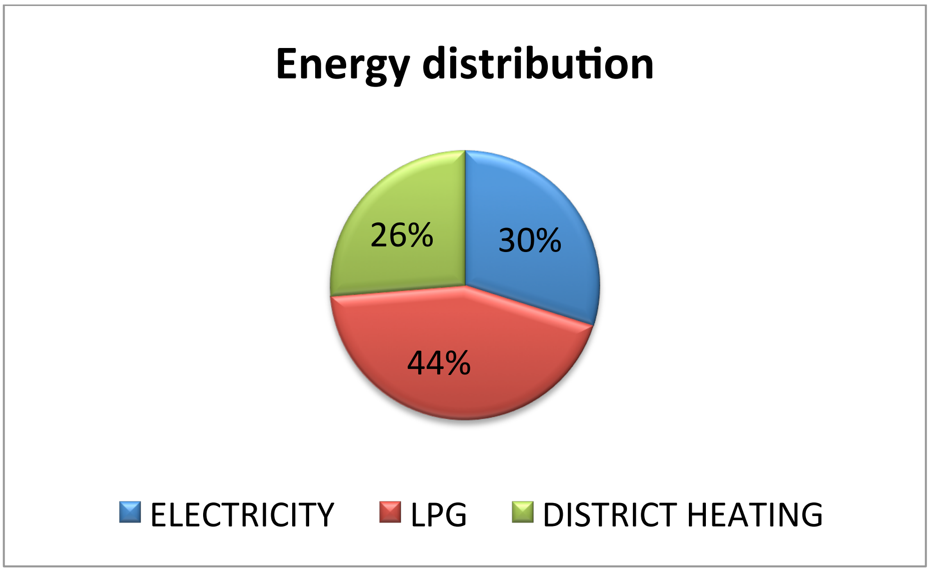

Figure 6.6: Energy distribution for the three energy sources

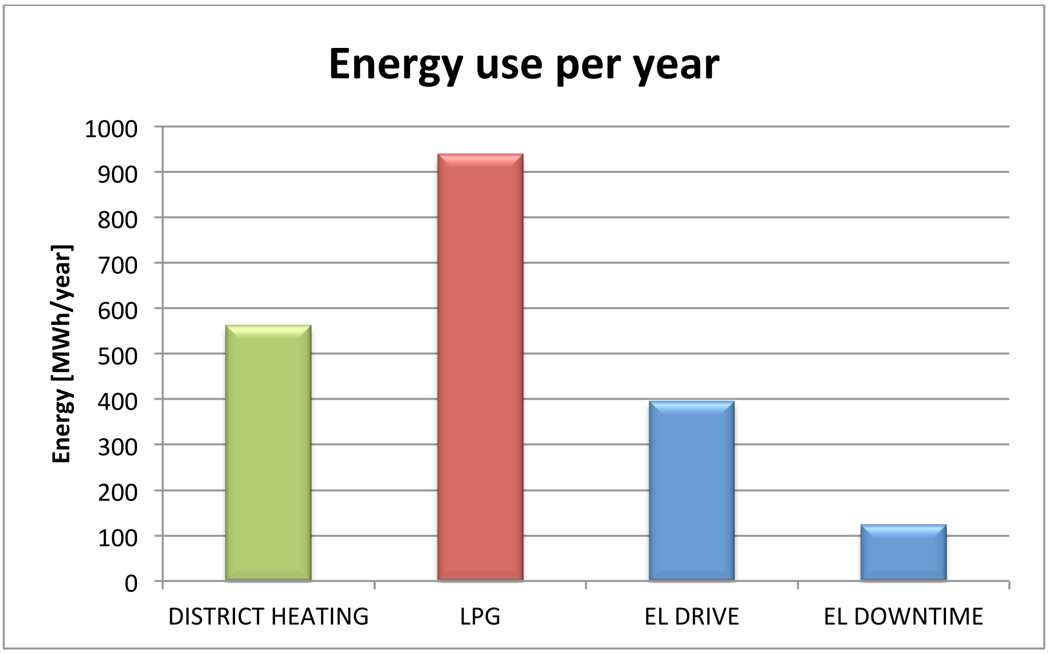

Figure 6.7: Total energy use during one year

Figure 6.7 above shows the total energy use for the different energy sources during one year. LPG is the largest energy source followed by electricity and district heating.

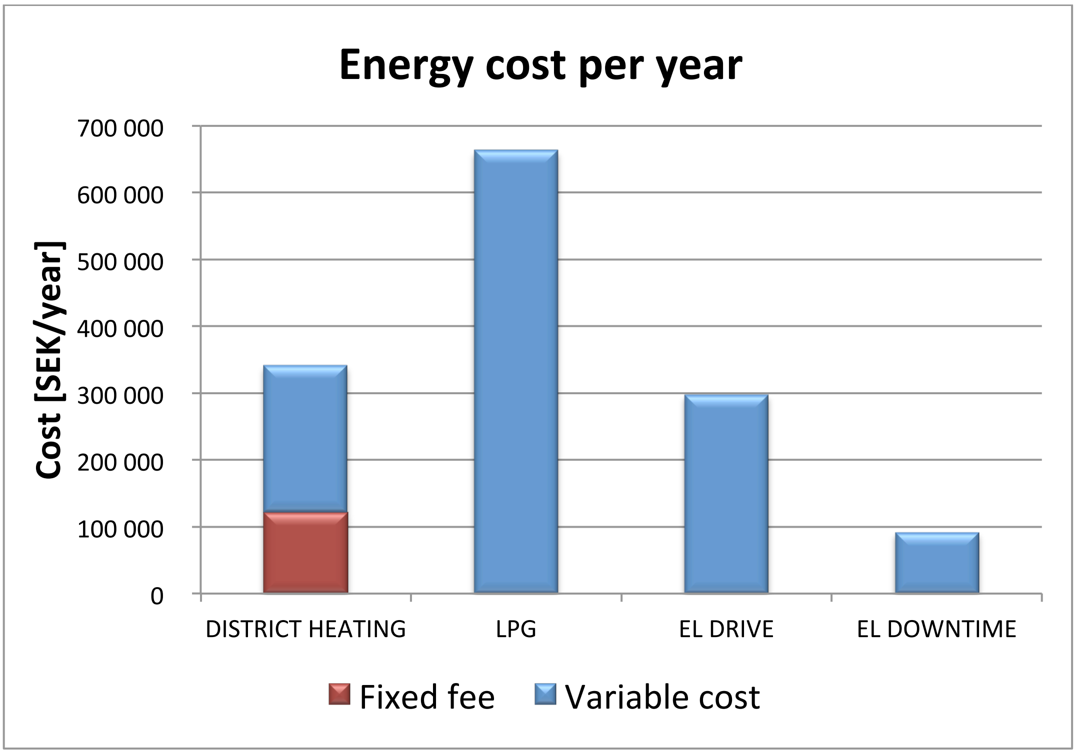

Figure 6.8: Cost for different energy sources during one year

The last graph, Figure 6.8, shows the yearly cost for the energy sources. The costs are separated into fixed fees and variable costs. LPG has the largest contribution to the total cost. This graph is based on the invoices for LPG and district heating and on a combination on these two for the electricity. As stated earlier the electricity consumption is based on the logged and instantaneous measurements but the calculated values have been compared with the values stated in the invoices.

6.1.3 Specific energy usage indicators and benchmarking

In Table 6.1 the specific energy usage indicators for Quality Powder Coating AB and LaRay AB can be seen. QPC AB has a continuous drive where the coating process is always on. LaRay AB has more production time when the coating line is turned off. This is the reason for the large difference concerning energy use/production time. There is a large difference in the energy use/turnover as well. A reason for this is that the coating production is the large contributor to the turnover for QPC AB. LaRay AB offers several other services as well such as masking and mounting which leads to increased turnover with a low energy use. However, the indicator energy use/tonne powder coated parts gives a lower value for QPC AB than for LaRay AB. This shows that the process as such is more efficient for QPC AB compared to LaRay AB.

Table 6.1: Specific energy usage indicators for QPC AB and LaRay AB

Indicator	**Energy use/ production time (kWh/h)**	**Energy use/ turnover (kWh/kSEK)**	**Energy use/ tonne parts (kWh/tonne)**
QPC AB	973	107	135
LaRay AB	230	48	185

A similar energy audit as this one was conducted for LaRay AB and the graphs and results for that audit can be seen in Appendix 3.

6.2 Mass and energy balances

Since there were some flows that were not possible to measure these had to be calculated using mass and energy balances. Table 6.2 shows the values for all the measured and calculated streams used for the pinch analysis. All temperatures as well as all outflows from the ovens and the inflow to the pre-treatment have been measured. Inflows to the ovens have been calculated. Figure 6.9 illustrates all flows that have been taken into account in the pinch analysis.

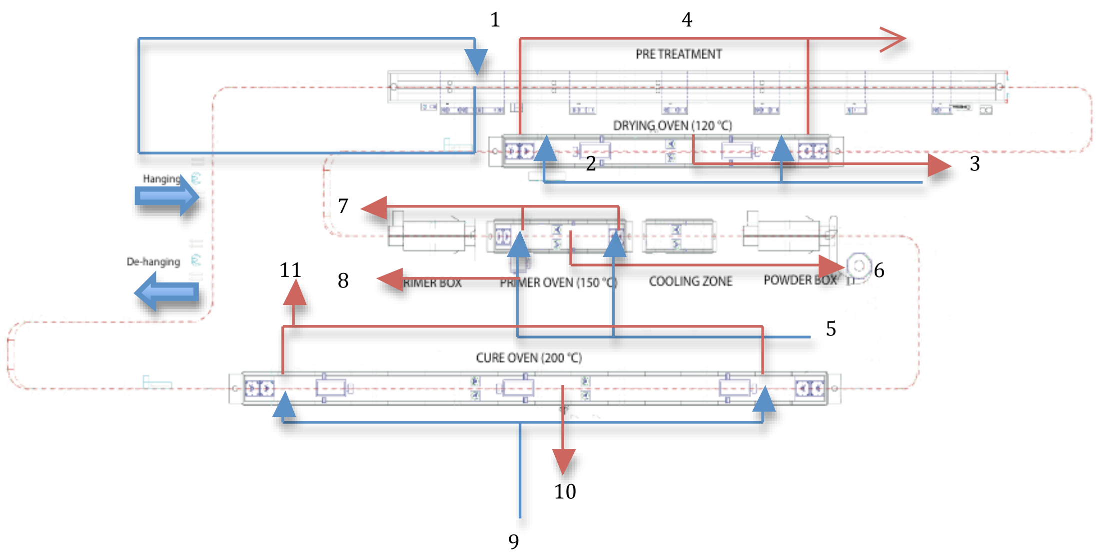

Figure 6.9: Illustration of streams used in the pinch analysis

Table 6.2: Input data for the pinch analysis

Stream		**T_{start}-T_{target} [°C]**	**Flow [m^3/h]**	**ΔQ [kW]**
1	**Pre-treatment in**	55-63	25	199
2	**Drying oven in**	20-120	1700	50
3	**Drying oven out middle**	119-20	1000	29
4	**Drying oven out airlocks**	52-20	3980	40
5	**Primer oven in**	20-150	1040	38
6	**Primer oven out middle**	150-20	500	18
7	**Primer oven out airlocks**	70-20	3000	43
8	**Primer oven burner out**	300-20	500	36
9	**Cure oven in**	20-200	1590	78
10	**Cure oven out middle**	194-20	970	46
11	**Cure oven out airlocks**	77-20	5000	87

In Table 6.3 the heat demand for the pre-treatment, drying oven, primer oven and cure oven are presented. Q_{air} is the energy needed to heat the inflow of air to the oven, Q_{parts} is the energy needed to heat the powder coated parts to a specific temperature, Q_{losses} are the total heat losses through the walls and the roof of the oven and the lid to the pre-treatment bath. Q_{heat} is the total heat demand for each process. Q_{air} is the only parameter that can be reduced due to heat exchange while Q_{parts} and Q_{losses} remains constant. As can be seen the losses through the lid for the pre-treatment bath is small and therefore there is no need for more isolation.

Table 6.3: Heat demand for ovens and pre-treatment

	Q_{air} [kW]	**Q_{parts} [kW]**	**Q_{losses} [kW]**	**Q_{heat} [kW]**
Pre-treatment (water)	173	25	1	199
Drying oven	50	70	3	123
Primer oven	39	80	1	120
Cure oven	78	150	10	238

6.3 Pinch analysis

Data for the streams in the pinch analysis is presented in the section above. The value for ΔT_{min} is 10°C between two air streams and 7.5°C between one air and one water stream. In this case the pinch temperature becomes 57.5°C and the load for heat exchange is 165 kW. The analysis show that the minimum heating demand is 200 kW and the minimum cooling demand is 140 kW. This can be compared with today's heating demand of 365 kW for the ingoing air leading to a potential for savings of 45%. It should be pointed out that this is only the savings potential for the heated ingoing air. For the total savings the heat added for the powder coated parts and the losses from the oven has to be accounted for as well. There is no cooling in the process today. Instead the heat is emitted to the environment outside the facility, which is a pinch violation. Other pinch violations today are that external heaters are used below the pinch temperature. The composite curve and grand composite curve are illustrated in Figure 6.10 and 6.11.

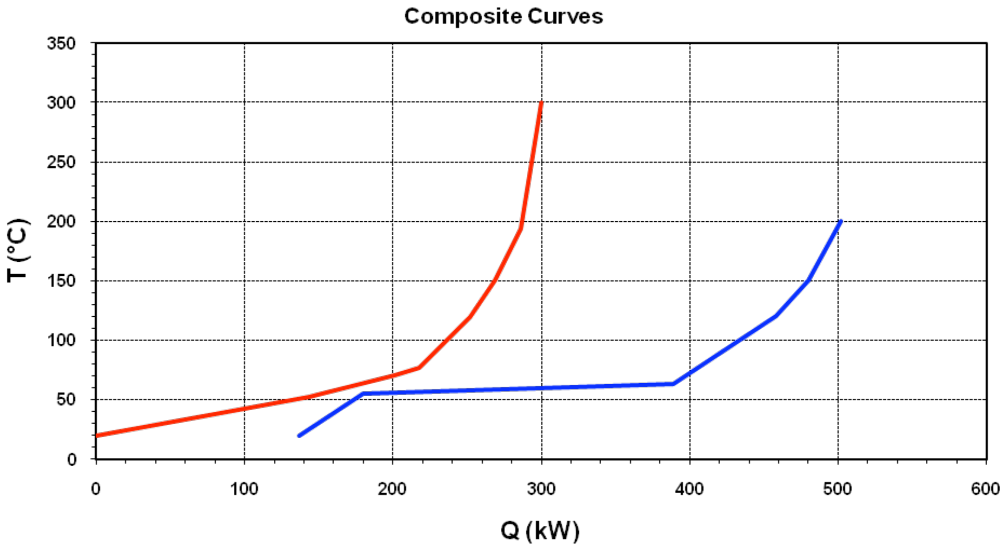

Figure 6.10: Composite curve for QPC AB

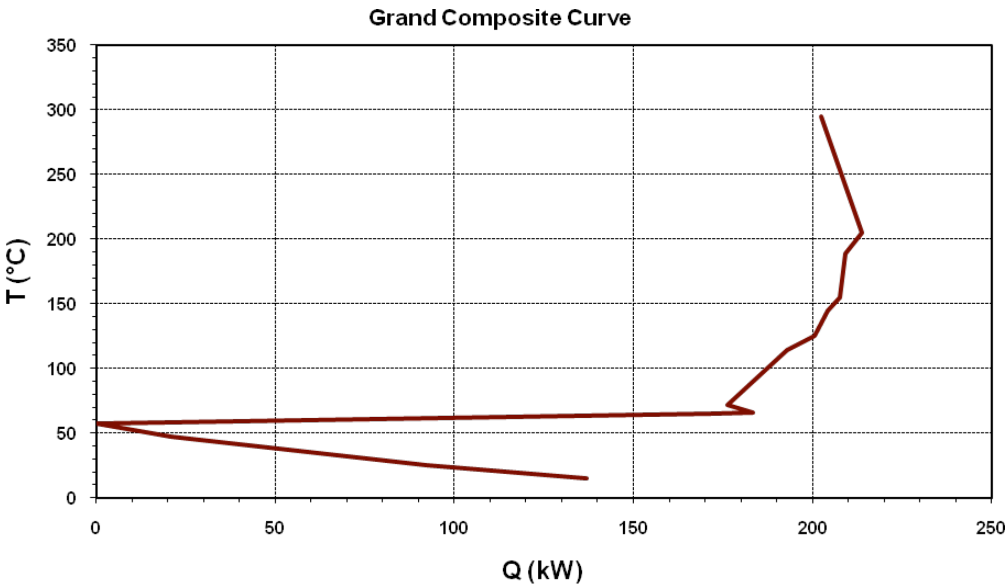

Figure 6.11: Grand composite curve for QPC AB

6.3.1 Prices and carbon dioxide emissions

In this section the energy prices and values for CO_2-emissions that was used for the calculations of the savings is presented. The energy prices were based on the energy invoices for the last twelve months. The price for LPG is expected to increase by 60%, the price for electricity by 50% and the price for biomass by 30% from 2010 to 2020 (Harvey, 2011-01-20). The average price is for the period 2010 to 2020 and was used during the sensitivity analysis, see Table 6.4.

Table 6.4: Energy prices

Energy source	Price 2010 [SEK/MWh]	Estimated price 2020 [SEK/MWh]	Average price [SEK/MWh]
LPG	707	1131	919
Electricity	755	1133	944
District heating	391	508	450

The carbon dioxide emissions for electricity are from coal power, which is the energy source that is on the margin for the Swedish energy system (Harvey, 2010-12-19). District heating is assumed to come from biomass and therefore the CO_2-emissions is zero. The emission factor for LPG is quite low in comparison with the factor for electricity (Naturvårdsverket, 2010-12-15).

Table 6.5: Values for carbon dioxide emissions

Energy source	Kg CO_2/MWh
LPG	234
Electricity	770
District heating	0

6.3.2 Maximum heat recovery case

The pinch design diagram for the maximum heat recovery case is illustrated in Figure 6.12 and the layout of the case can be seen in Figure 6.13. Values for load and FCp can be found in Table 6.6.

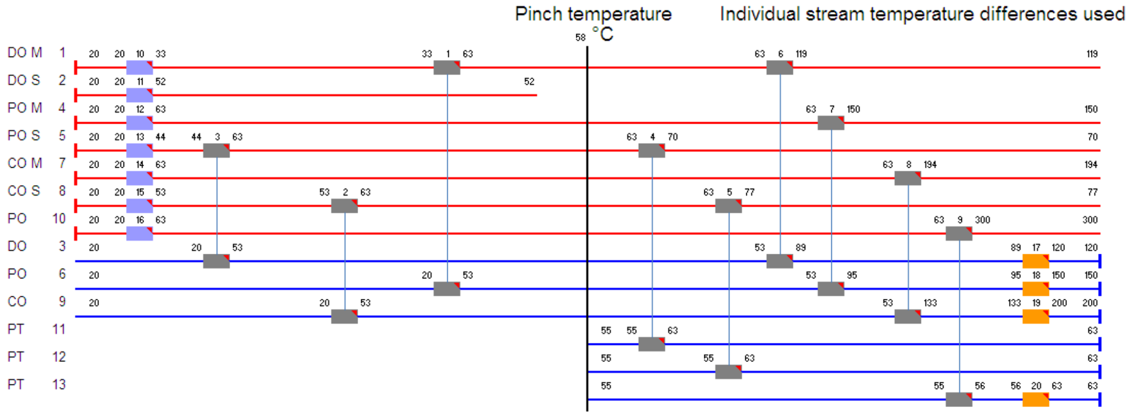

Figure 6.12: Pinch design diagram for maximum heat recovery case

Table 6.6: Stream data for the MER

Stream	Hot/Cold	Process	Qtot	FCp
1	Hot	Drying oven middle out	32	0.32
2	Hot	Drying oven airlocks out	40	1.26
3	Cold	Drying oven in	50	0.50
4	Hot	Primer oven middle out	18	0.14
5	Hot	Primer oven airlocks out	43	0.85
6	Cold	Primer oven in	38	0.30
7	Hot	Cure oven middle out	46	0.26
8	Hot	Cure oven airlocks out	87	1.53
9	Cold	Cure oven in	78	0.43
10	Hot	Primer oven burner	36	0.13
11	Cold	Pre-treatment in	6	0.80
12	Cold	Pre-treatment in	22	2.78
13	Cold	Pre-treatment	170	21.30

The ingoing flow to the pre-treatment was split into three streams to be able to follow the pinch rule that one cold stream can only cool one hot stream above the pinch. The pinch design started below the pinch. The outgoing flow from the drying ovens airlocks has to low temperature to be able to be heat exchanged against one of the cold streams. Therefore there is only three hot streams left that has sufficient FCp value to be able to be heat exchanged with the cold streams right below the pinch. The middle flow out from the drying oven has sufficient FCp value to be heat exchanged with the primer ovens ingoing flow but not for the other two cold streams. Therefore, heat exchanger number one is put between these two streams.

The ingoing flow to the drying oven and the cure oven can be heat exchanged with either the outgoing airlocks from the primer oven or the airlocks from the cure oven. The cure ovens flows are matched against each other since they are closest to each other in the process.

Right above the pinch the middle flows out from each oven can be heat exchanged with the ingoing flow to the same oven. This is also the best solution from a practical perspective. The airlocks, stream 5 and 8, can only be heat exchanged against the pre-treatment.

The flue gases from the primer ovens indirect burner were chosen to be used as an immersed heater with the pre-treatment bath.

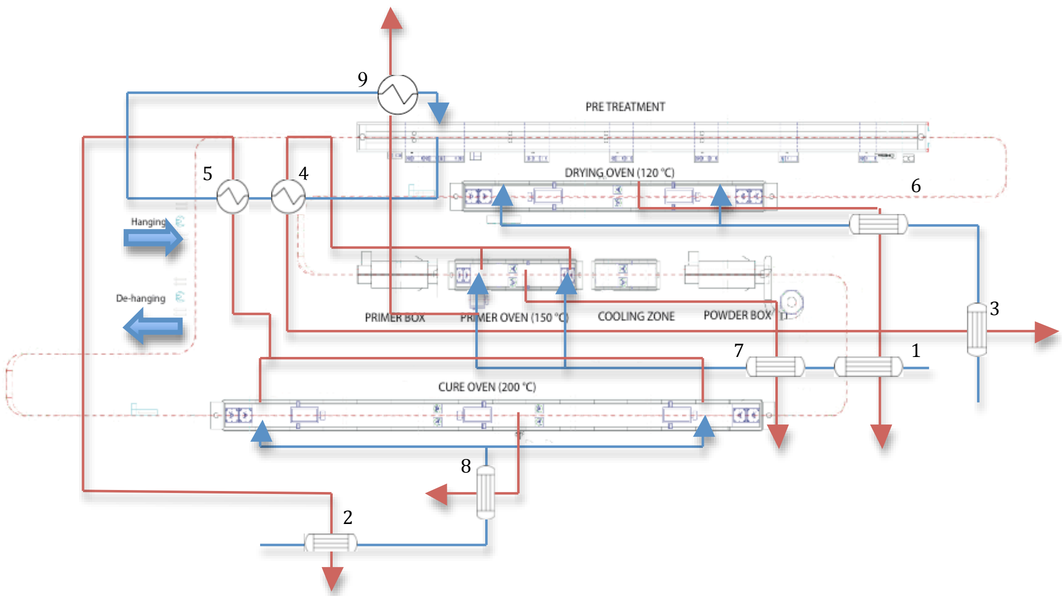

Figure 6.13: The layout for the maximum heat recovery case (MER)

Table 6.7 shows the temperature changes as well as the load and the area for the heat exchangers in the network.

This case will give energy savings of 250 MWh, cost savings of 150 000 SEK and CO_2-savings of 58 tonnes each year. This represents energy savings of 12.2%, cost savings of 10.5% and CO_2-savings of 9.4% compared to the values of today. However, the layout of this case is complicated and the investment cost will be large. It will most likely not be implemented in reality.

Table 6.7: Heat exchangers data for the MER

	Cold stream		Hot stream		Load	Area
Heat exchanger	T_{in} [°C]	T_{out} [°C]	T_{in} [°C]	T_{out} [°C]	Q [kW]	A [m^2]
1	20	52.5	62.5	33	9.6	1.7
2	20	52.5	62.5	53	14.1	1.5
3	29	53	62.5	44	16.2	2.0
4	55	63	70	62.5	6.4	1.8
5	55	63	77	62.5	22.2	4.3
6	52.5	89	119	62.5	18.3	2.0
7	52.5	95	150	62.5	12.4	0.9
8	52.5	133	194	62.5	34.7	2.5
9	56	57	300	62.5	30.5	0.9

6.3.3 Case 1

The maximum heat recovery network will most likely not be implemented in reality. Therefore three simplified cases are suggested based on the investigation of the plant as well as the running times for the units within the plant. The measures have been discussed with a designer, Ander Jansson at SCS finishing AB, of coating plants. A company in Finland as well as a company in Sweden have supported the assumption that heat exchange from the drying oven and cure oven is possible. In Finland they have heat exchanged the airlocks from the drying oven and cure oven as well as the air from the pre-treatment against space heating. There is no problem with contaminations in the heat exchanger, but filters are needed before the exchanger. The filters need to be changed every four to six months (Pinola, 2011-01). Also, the heat exchangers have to be quite rough so they are easy to clean.

Case 1 is a simple case where it is only four streams that are used for heat exchange. The heat exchange is within the same sub-process, which makes the plant flexible to changes in the future. To heat exchange the airlocks out from the ovens give small reductions for the ovens external heating demand and therefore it is only the middle flue gases that are used in this case.

In Case 1 the flue gases, middle flow, out from the drying oven and cure oven are heat exchanged with the ingoing air to the two ovens, see Figure 6.14. This case gives energy savings of 140 MWh, cost savings of 100 000 SEK and CO_2-savings of 33 tonne each year. This equals 7.0% energy savings, 7.1% cost savings and 5.3% reduction of carbon dioxide compared to today. The energy savings compared to the maximum heat recovery case is 47%. The given load and area are for each heat exchanger.

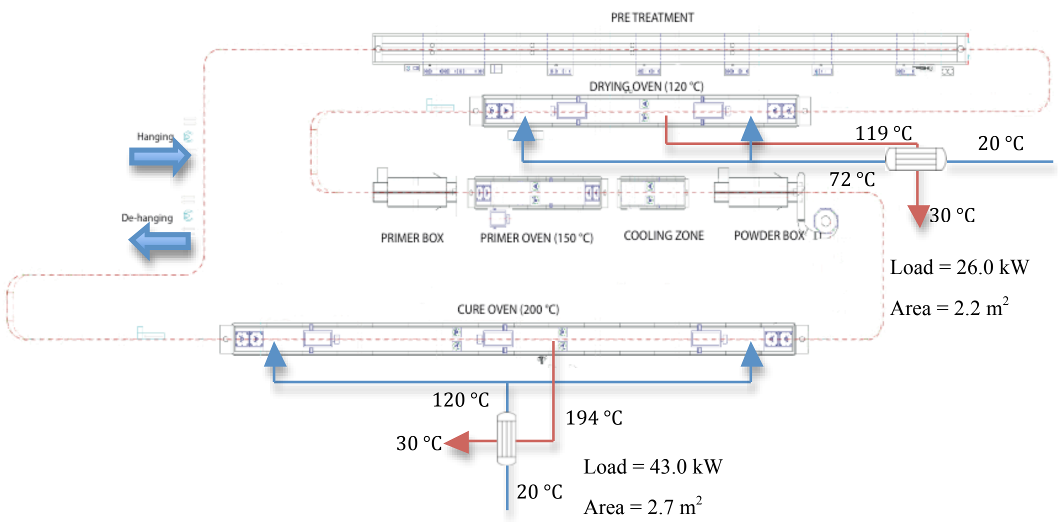

Figure 6.14: Layout of Case 1

6.3.4 Case 2

Case 2 is similar to Case 1. The difference is that the flue gases from the primer ovens indirect burner is added to the drying oven. This additional part is a cheap investment due to that there is no need for a heat exchanger.

In Case 2 the outgoing air from the middle flow in the cure oven is heat exchanged with the ingoing air to the same oven. The same happens for the drying oven, but the outgoing flue gases from the indirect burner to the primer oven is also added directly to the drying oven without heat exchange. This gives an ingoing temperature to the drying oven of 72°C when the primer oven is off and 139°C when it is on. Therefore, control of the flow from the burner has to be introduced to be able to keep the temperature in the drying oven to 120°C. The layout of this case is seen in Figure 6.15.

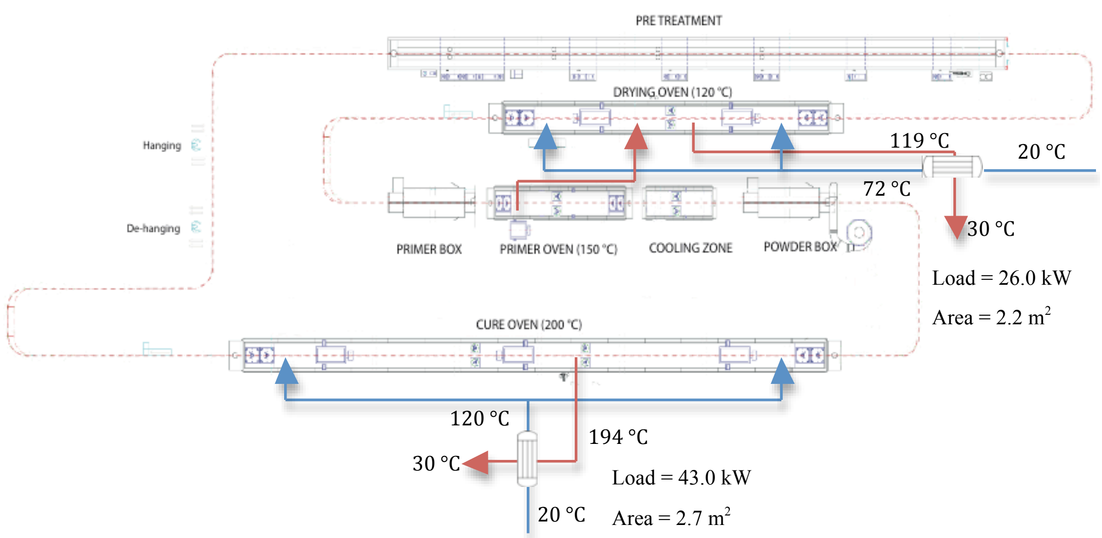

Figure 6.15: Layout of Case 2

This case gives 150 MWh less energy use, 110 000 SEK less costs and 35 tonne less carbon dioxide emissions each year. This equals 7.5% energy savings, 7.7% cost savings and 5.7% carbon dioxide savings compared with how it is today. The heat recovery compared to the maximum heat recovery case is 50%.

6.3.5 Case 3

A lot of heat follows the coated parts out from the cure oven. This heat can be used in the network by installing a cooling zone directly after the oven.

In Case 3 a part of the outgoing air from the cooling zone are heat exchanged with the middle outflow from the cure oven and is then led into the oven. The rest of the flow from the cooling zone is used to heat exchange the ingoing flow to the pre-treatment. For the drying oven the heat exchange is the same as case two and the layout is illustrated in Figure 6.16.

This case has the largest savings concerning energy and economy but lower saving concerning carbon dioxide. This is due to that the cooling zone consumes electricity, which has high emissions of carbon dioxide. District heating is reduced which has zero emissions of carbon dioxide for this process.

The energy savings is 250 MWh/year of which district heating is 95 MWh and LPG 170 MWh. The electricity use will increase by 15 MWh due to the cooling zone. The cost savings is 150 000 SEK and the CO_2-savings is 28 tonnes each year. This corresponds to 12.4% of the total energy use, 10.5% of the costs and 4.5% of the carbon dioxide emissions today. Case 3 cannot be compared with the maximum heat recovery case since there are additional streams in this case due to the installed cooling zone.

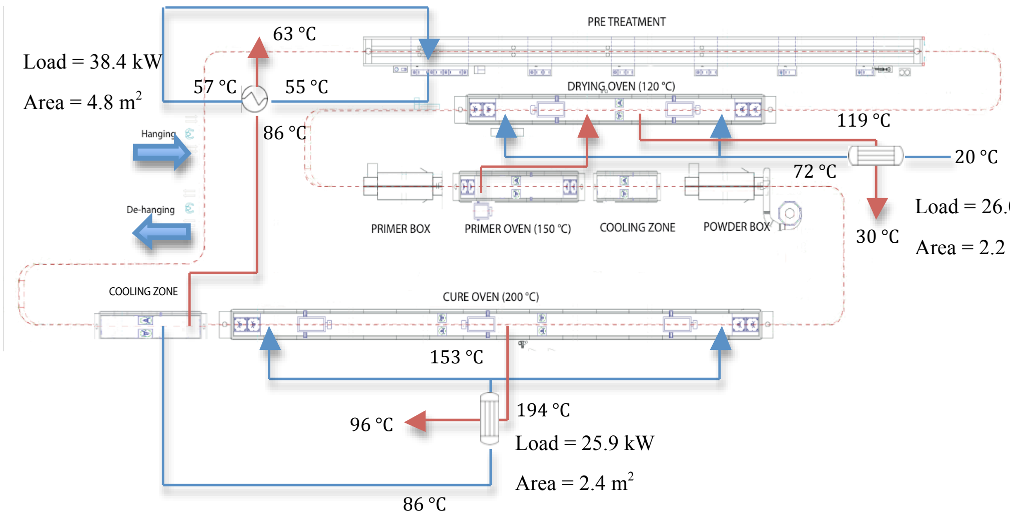

Figure 6.16: Layout for Case 3

The savings for the cases is presented in Table 6.8. The energy, cost and carbon dioxide savings are given both as an absolute number and as a percentage of today’s values. For Case 1 and 2 the amount of heat exchange is compared to the maximum heat recovery network as well. As stated above, this cannot be done for Case 3 since there are additional streams in this case compared to the maximum heat recovery network.

Table 6.8: Savings for the three cases (% of today's value within parentheses)

Retrofit	Energy saving MWh/year (%)	% of MER network	Cost saving SEK/year (%)	CO_2-saving Tonne/year (%)
MER	250 (12.4)	100	150 000 (10.5)	58 (9.4)
Case 1	140 (7.1)	47	100 000 (7.1)	33 (5.3)
Case 2	150 (7.5)	50	110 000 (7.7)	35 (5.7)
Case 3	250 (12.4)	-	150 000 (10.5)	28 (4.5)

6.4 Economic assessment

Economic calculations have been made for the three suggested retrofit options. The payoff period as well as net present value and net present value ratio are presented. The net present value has been calculated over a ten-year period. Investment costs are presented in Table 6.9.

Table 6.9: Investment costs (Jansson, 2011-01-18)

Investment	Cost [SEK]
Cooling zone	200 000
Heat exchanger air/air	60 000
Heat exchanger water/air	100 000
Piping 20 meters	15 000
Blow down zone (pre-treatment)	60 000

For the maximum heat recovery case the initial investment is based on three water-air heat exchangers, six air-air heat exchangers and 260 meters of piping. The initial investment for Case 1 is based on two air-air heat exchangers and 40 meters of piping. Case 2 is based on two air-air heat exchangers and 60 meters of piping. Case 3 is based on one cooling zone, two air-air heat exchangers, one water-air heat exchanger and 100 meters of piping. Case 3 is more expensive than the other two cases due to the installation of the cooling zone. The maintenance charge for the MER-network, Case 1 and Case 2 is based on two filter changes (2000 SEK/filter) for each heat exchanger and year. Case 3 has the filter cost for the three heat exchangers as well as an additional cost for the electricity usage for the cooling zone (12 000 SEK/year).

The economic calculations were conducted with an interest rate of 15% and 20%, see Table 6.10 and 6.11. In the economics both the investment cost and the yearly maintenance charge is included. However, the loss of income during the integration of the new components is excluded.

Table 6.10: Economic calculations at a interest rate of 15%

	Basic investment [SEK]	**Maintenance charge [SEK/year]**	**Payoff period [year]**	**NPV (10 years) [SEK]**	**NPVR (10 years)**
MER	855 000	36 000	6.4	-180 000	-0.21
Case 1	150 000	8 000	1.6	310 000	2.08
Case 2	165 000	8 000	1.6	340 000	2.10
Case 3	495 000	24 000	3.9	140 000	0.28

Table 6.11: Economic calculations at a interest rate of 20%

	Basic investment [SEK]	**Maintenance charge [SEK/year]**	**Payoff period [year]**	**NPV (10 years) [SEK]**	**NPVR (10 years)**
MER	855 000	36 000	6.4	-295 000	-0.34
Case 1	150 000	8 000	1.6	235 000	1.57
Case 2	165 000	8 000	1.6	265 000	1.59
Case 3	495 000	24 000	3.9	35 000	0.07

The MER-network will not reach profitability during a ten-year period according to the net present value method. The economic calculations show that Case 2 is the best investment. It has the highest NPV over the ten years of operation and it also has the highest net present value ratio leading to that this investment should be ranked highest of the four alternatives. However, all three cases are profitable and there are other aspects, such as work environment, that should be regarded as well.

6.4.1 Sensitivity analysis

In the sensitivity analysis the average energy price during the next ten years is used which include the increased price for electricity, LPG and district heating. The price for LPG is expected to increase by 60%, the price for electricity by 50% and the price for biomass by 30% (Harvey, 2011-01-20). The results for the sensitivity analysis are shown in Table 6.12 and 6.13.

Table 6.12: Sensitivity analysis at an interest rate of 15%

	Basic investment [SEK]	Maintenance charge [SEK/year]	Payoff period [year]	NPV (10 years) [SEK]	NPVR (10 years)
MER	855 000	36 000	4.6	65 000	0.08
Case 1	150 000	8 000	1.2	460 000	3.08
Case 2	165 000	8 000	1.3	495 000	3.02
Case 3	495 000	24 000	3.0	340 000	0.68

Table 6.13: Sensitivity analysis at an interest rate of 20%

	Basic investment [SEK]	Maintenance charge [SEK/year]	Payoff period [year]	NPV (10 years) [SEK]	NPVR (10 years)
MER	855 000	36 000	4.6	-85 000	-0.10
Case 1	150 000	8 000	1.2	360 000	2.41
Case 2	165 000	8 000	1.3	390 000	2.35
Case 3	495 000	24 000	3.0	200 000	0.41

The results for the sensitivity analysis show that Case 1 will be a slightly better investment than Case 2 with NPVR as criteria. However, Case 2 has higher NPV than Case 1. The results also show that by increasing the energy prices the profit for the possible energy efficiency measures will also increase.

6.5 Other possible savings

Other possible savings include both measures to reduce the energy use as well as cost savings that are achieved by finding incorrect sources for electricity consumption and by renegotiating energy price contracts with utility companies.

6.5.1 Energy efficiency measures

There are several easy and cheap measures that can be done to reduce the energy consumption within the plant as well as some more expensive.

1. Shut of the ventilation in the powder box during breaks, saves electricity.
2. Switch to low energy lighting at all places possible, saves electricity.
3. Plan the production so the primer oven is turned on one time each day, saves LPG.
4. Shut of the dehumidifier when there is no need for it, an estimation is 30% of the year, saves electricity.
5. Change the fan engines for the drying oven and cure oven, saves electricity.
6. Change the powder box, saves electricity and use of compressed air.

Measure number five refers to the ventilation and circulation fans for the drying and cure oven. These engines are not driven at an optimal power load which leads to that the power factor, cos φ, are too small. The engines could be changed to permanent magnet motors that are easier to control.

The last measure is the most expensive action. The powder box could be changed to another powder box leading to that the electricity for ventilation would be reduced by one third and the use of compressed air would be reduced by 45%.

Measure one, three and four are free of investment cost. Number two will have some investment cost, but of smaller character. Number five and six has high investment cost. However, the machines will need changing after some years anyway and then they can be changed to better and more suited alternatives.

Table 6.14: Measures to reduce the energy consumption

Option	**Energy savings [MWh/year]**	**Cost savings [SEK/year]**	**CO_2-savings [Tonne CO_2/year]**
1	13	10 000	10
2	18	14 000	14
3	44	33 000	34
4	31	24 000	24
5	16	12 000	13
6	44 (87)	33 000 (66 000)	34 (67)

In Table 6.14, the values within parentheses are savings for reduced demand of compressed air, which is included in the rent for the building as it is today. Options 1-4 are possible to implement today without any large investments. These four measures together represent energy savings of 5.3%, cost savings of 5.8% and carbon dioxide savings of 13.4%. In the long run measure five and six are possible as well. This will increase the energy savings to 8.2%, the cost savings to 9.0% and the carbon dioxide savings to 20.8% when excluding the savings for compressed air.

6.5.2 Cost savings

Two sources for reducing the costs for the plant have been found during this master thesis. The first one was that QPC AB has paid for the neighbours lighting during ten years. This is now fixed and the electricity invoice will be reduced by approximately 100 000 SEK each year. This is already taken into account in the energy audit and the graphs above.

The other source for cost savings is that the price contract for district heating has been changed leading to a reduction of the fixed fee. This reduction is about 50 000 SEK per year.

6.6 Total savings

In the total savings all energy, cost and carbon dioxide savings are taken into account. In Table 6.15 the three cases suggested for heat exchanging, alternative 1-4 for the other possible measures and the second source for the cost savings are summarized. For this alternative the energy savings will be 12 - 18% while the cost savings as well as the savings of carbon dioxide will be around 20% compared with the start of the thesis.

Table 6.15: Total savings for the suggested alternatives, other 1-4 and second source for cost savings in absolute number and percent

	Energy savings [MWh/year] (%)	**Cost savings [SEK/year] (%)**	**CO_2-savings [Tonne/year] (%)**
Case 1	250 (12.3)	230 000 (16.5)	115 (18.7)
Case 2	260 (12.8)	240 000 (17.1)	117 (19.1)
Case 3	360 (17.8)	280 000 (19.9)	110 (17.9)

Table 6.16 shows the same as Table 6.15 with the addition of alternative five and six for the other possible energy efficiency measures. This alternative gives 15 – 21% energy savings, cost saving between 20 and 24% and carbon dioxide savings of around 25%. These results are without the savings for compressed air in option six for other efficiency measures. For Case 2 and 3 the energy savings are also presented in fish bone diagrams. One of these two cases is most likely the one that will be implemented. Figure 6.17 shows Case 2 and Figure 6.18 shows Case 3, both with all six other measures as well.

Table 6.16: Total savings for the suggested alternatives, other 1-6 and second source for cost savings in absolute number and percent

	Energy savings [MWh/year] (%)	Cost savings [SEK/year] (%)	CO_2-savings [Tonne/year] (%)
Case 1	310 (15.3)	280 000 (20.1)	162 (26.2)
Case 2	320 (15.8)	290 000 (20.8)	164 (26.5)
Case 3	420 (20.8)	330 000 (23.6)	157 (25.4)

In the fish bone diagrams today's energy use is presented on the left side of each process while the possible future energy use, including energy efficiency measures is presented on the right side of each process. The compressed air is within parentheses since it is not included in the electricity invoice today. The cost for compressed air is included in the rent for the facility.

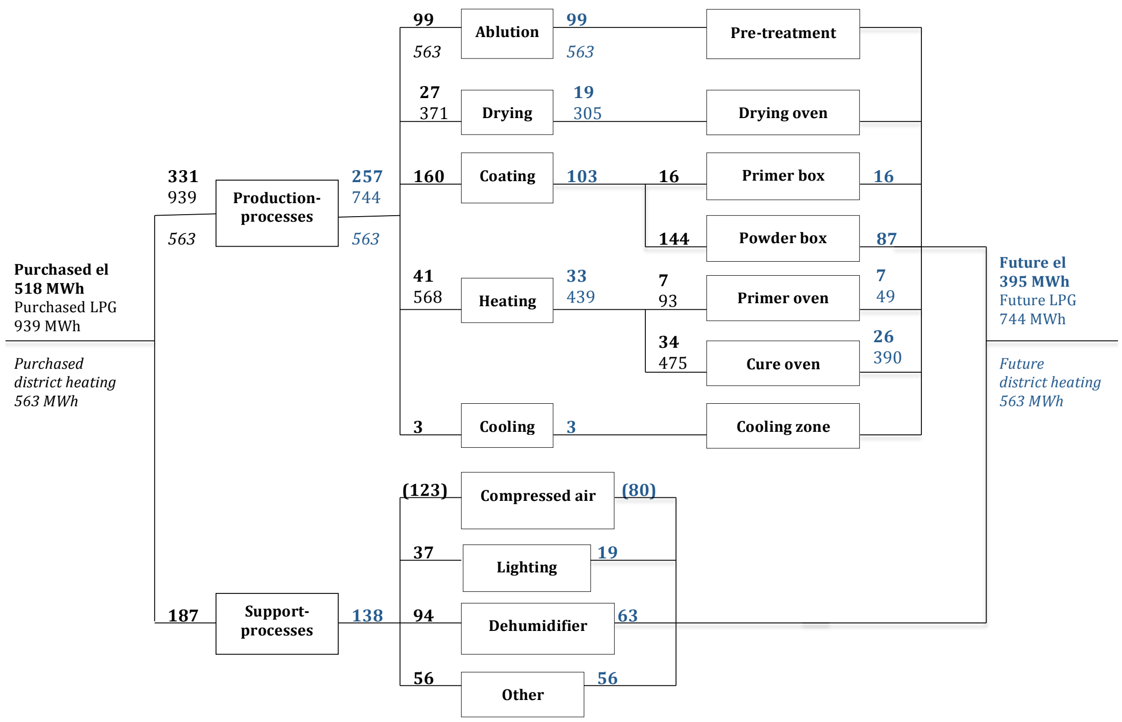

Figure 6.17: Fish bone diagram showing Case 2 and the six other measures

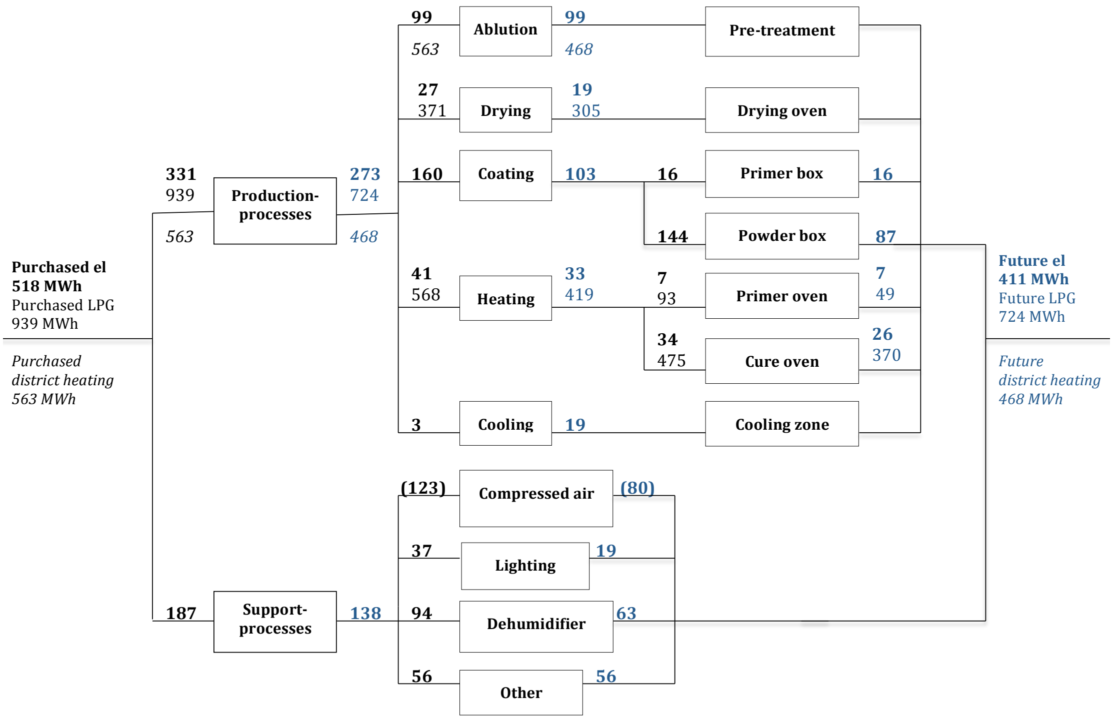

Figure 6.18: Fish bone diagram showing Case 3 and the six other measures

On short term the most likely reduction of energy usage for QPC AB is around 13%. However, a reduction for the energy of about 20% is possible in the long-term perspective. Cost savings and carbon dioxide savings will be between 15 – 20% on a short-term perspective. The energy and cost savings, without savings for compressed air, are illustrated in Figure 6.19 and Figure 6.20.

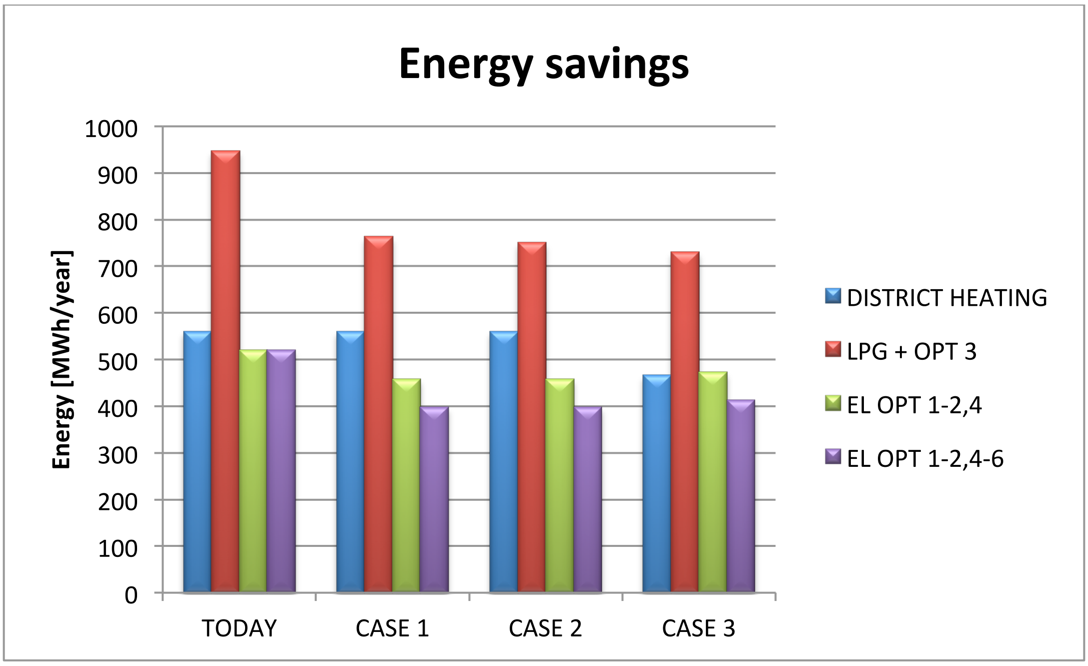

Figure 6.19: Energy savings for the different measures at QPC AB

District heating is the same for today's scenario, Case 1 and Case 2 but is reduced for Case 3, see Figure 6.19. The reduction of the LPG in this figure is based on the heat exchange cases as well as the reduction due to production planning. The electricity for Case 3 is increased in comparison to Case 1 and 2. This is due to that the cooling zone needs electricity for the fans.

The differences between the start of thesis and today in Figure 6.20 is that the electricity cost has been reduced due to the mistakes in the signal box and that the fixed fee for district heating has been reduced as well.

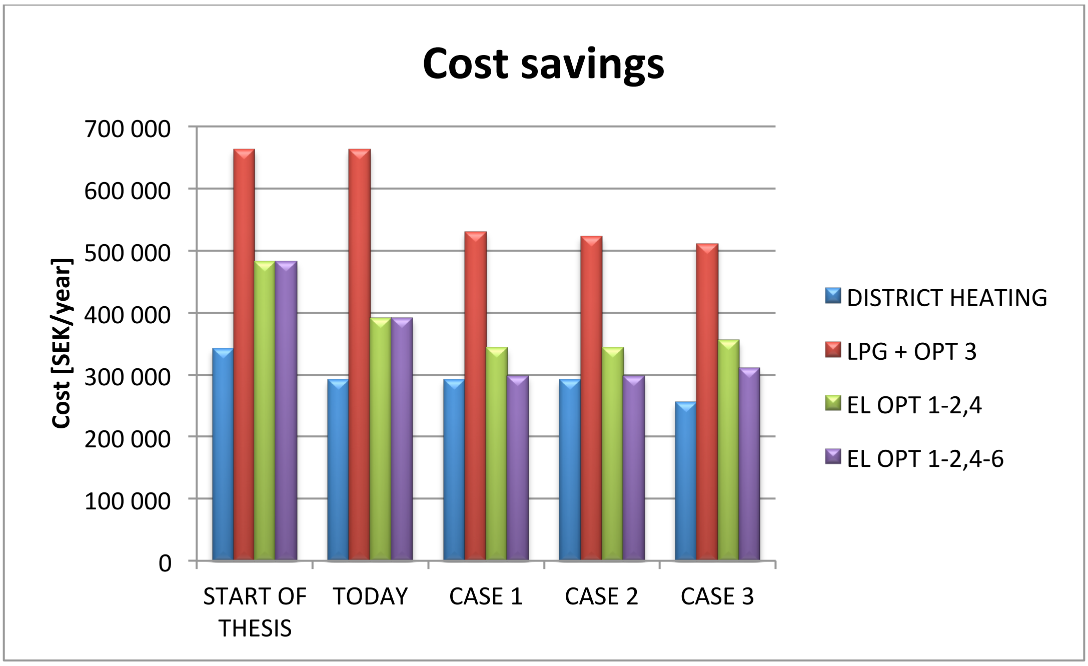

Figure 6.20: Cost savings for the different measures at QPC AB

For LaRay AB the energy savings will be around 30%. The major reason for having a higher energy reduction is because they have two shifts during one day. Because of that they also have two peaks for the energy use during one day. Reducing the second peak contributes to large energy savings. Also, LaRay AB has larger hot flows out from their ovens leading to that the ingoing air to the ovens can be heat exchanged to a higher temperature than for QPC AB. However, this is probably also one of the main reasons that LaRay AB has higher energy use per tonne of products compared to QPC AB.

Based on these two studies it is reasonable to say that the energy use can be reduced by at least 20% for the powder coating industry. In Sweden there are about 350 powder coating plants that uses more than one metric tonne of powder each year. The plants have an average energy consumption of 1.5 GWh per year, which makes a total combined energy usage of approximately 525 GWh/year. If all the plants reduce their energy consumption by a minimum of 20% this will lead to an energy use reduction of at least 105 GWh each year.

7 Discussion

All the calculations for the energy efficiency measures are based on an average mass flow for the powder coated parts. This means that if the mass flow is lower this will affect how much heat that is transported with the parts and therefore also the temperature in the outflow of air for a possible future cooling zone. However, a lower flow will also reduce the amount of LPG that is needed to heat the parts inside the ovens.

There are some energy efficiency measures that can be done rather easily, such as shut off the ventilation in the powder box during breaks. This is a measure that is possible according to Anders Jansson at SCS finishing AB. As it is today, the ventilation in the powder box is driven at full load the whole time. This is not necessary and there are possibilities to change the powder box to a new one where the ventilation can be controlled after the circumstances. This is a rather large investment and the powder box that is used today is not that old. Therefore this is not a measure that is likely to happen within the near future, but in the long term as well as for new plants. However, for the products and powders that are most commonly used there might be an alternative to control the ventilation for the present powder box by having certain settings for certain conditions.

Another cheap efficiency measure is to turn off the dehumidifier when there is no need for it. An air humidity meter is a small investment and it can tell when the dehumidifier has to be on and off.

To plan the production, especially for the primer oven, is a measure that is pointed out in the report. The largest energy use for the primer part is during start up. As it is today, the primer oven is started several times each day, which lead to a high consumption of LPG during these times. If the production were planned so that all parts that needs two layers of coating is varnished during one period each day this would reduce the energy use and the costs. Even better is if the primer oven is on during one day each week and is turned off during the other days that week.

The primer oven is used during such a short time each day so there will not be any profitability in investing in a heat exchanger to heat the ingoing air to this oven. However, if the primer part will be used more frequently than today the profitability for heat exchanging this oven will increase. Also, according to Anders Jansson, the flue gases from the indirect burner can be used directly into the drying oven without using a heat exchanger.

One option that has been discussed during this thesis is to use the airlocks from each oven as ingoing flow to the ovens. However, this is not possible since there will be some contaminations that follows the airlocks so the ingoing air will not be clean. Another reason is that there will be a risk that too much air is pushed into the oven since the flow is larger for the airlocks than for the ingoing air. The airlocks do not have enough heat content to heat exchange against the ingoing air in an economic way. However, there might be good chances to heat exchange the airlocks with ingoing air to space heating.

For the pinch analysis a ΔT_{min} of 10°C was used for heat exchanging two air streams and 7.5°C was used for heat exchanging one air stream with one water stream. However, there might be a need to increase ΔT_{min} since the heat exchangers need to be easy to clean and will therefore quite rough.

The economic results in this thesis show that the suggested Case 1 or 2 are the best investments from an economic perspective. However, Case 3 has other positive effects that are not accounted for in the calculations above. Consideration has to be taken for that a cooling zone will affect the working environment by reducing the heat that is emitted to the facility.

The economic results are based on an interest rate of 15 and 20%. A lower interest rate would affect the results by decreasing the payoff period and increasing the net present value and the net present value ratio. The energy prices are predicted to increase and the sensitivity analysis show that the maximum heat recovery case will be profitable over a ten-year period. However, this case is too complicated to be used in reality and the other three cases have a much higher profitability.

An aspect that has been considered during the calculations for savings is that it is better to reduce the use of LPG and electricity than the use of district heating from an environmental point of view. Also, district heating is cheap in comparison to the cost for electricity and LPG, which leads to that even if a certain measure has a high energy reduction for district heating the cost savings and carbon dioxide savings will not be in proportion with the energy savings.

The compressed air is not taken into account for the measure part. This is due to that the compressed air is not included in the electricity use as it is today but it is included in the facility rent. The compressed air uses an additional 120 MWh of electricity to the electricity use today, which gives a total electricity use of 640 MWh each year instead of 520 MWh as is stated in Figure 6.7. The reduction of 43 MWh of electricity each year due to the reduced demand for compressed air with a new powder box is not taken into account in the saving potential. Also, investing in a blow off zone after the pre-treatment unit instead of using compressed air as it is today can further reduce the use of compressed air. This zone will have large fans that are used to blow off the water that is left on the parts.

The statement that the Swedish powder coating industry can reduce the energy use by at least 20% is based on these two parallel master's theses. Regard has also been taken to the continuous contact with actors within the surface treatment industry as well as to the discussions at SPFs conference in Vadstena the 3-4th of November 2010. It has been seen that the powder coating industry is quite homogeneous and that the processes are similar for different companies.

The benchmarking study has shown that the best way to heat exchange is within the same sub-process. Ingoing air to an oven should be heat exchanged with outgoing air from the same oven. This will give a high flexibility for the plant since no process is dependent on another process to be able to heat exchange.

8 Conclusion

The energy audit shows that the cure oven, drying oven and pre-treatment are the largest consumers of energy and that the powder box is the largest consumer of electricity. It is also shown that the best way to reduce the energy use and the energy costs is to reduce the usage of LPG and electricity. QPC AB uses about two GWh of energy each year of which the production processes accounts for 86% and the support processes only 14%.

By the use of smart energy efficiency measures, such as turning off the ventilation in the powder box during breaks and better production, as well as investments in new equipment the electricity use can be reduced by 120 MWh, excluded the savings for reduced use of compressed air, and the use of LPG by 45 MWh each year. Heat exchanging the in and outgoing streams for the processes has been proven to give a reduction of LPG by 170 MWh each year and in addition to this the use of district heating can be reduced by 95 MWh. In total this gives an energy reduction of 21% compared to the energy use in 2010. This will also give 25% cost savings, 350 000 SEK, as well as a reduction of the carbon dioxide emissions by 186 tonnes each year which equals 30% compared with 2010.

The parallel master’s thesis done for LaRay AB has shown that the energy usage can be reduced by 30%. Benchmarking has shown that the most efficient way of heat exchanging is within the same part in the process. Ingoing air to an oven should be heat exchanged with the outgoing air from the same oven. This will reduce the investment costs as well as contribute to a flexible process. One part within the process will not be dependent on another part in the process.

The benchmarking also shows that the airlocks from the ovens usually have too small heat content to be efficiently heat exchanged against ingoing air to the ovens. However, there might be possibilities to heat exchange the airlocks against space heating. To install a cooling zone after the cure oven will be profitable but there are other investments that are better from an economic point of view. The fact that the cooling zone will give a better working environment should be taken into account as well.

Based on benchmarking between these two studies and since the powder coating industry is homogeneous, it has been assumed that this type of industry can reduce their energy demand by at least 20% which equals 105 GWh/year.

9 Future work

There is quite a lot of work left to do on the subject. A company in Finland is using the airlocks from the drying oven and cure oven for heat recovery for space heating purpose. Also, a company in Sweden uses the middle flow from the drying oven and the cure oven to heat exchange against ventilation air for space heating. Still there might be problems to heat exchange the middle flow out from the cure oven. Tests have to be done to see if the decomposition products precipitate and in that case at what temperature this occurs. This will be a crucial aspect for the efficiency of the heat exchangers.

The second thing that should be investigated is the characteristics of the different powder types. There might be powder types that have a small amount of decomposition products and are therefore more suitable for heat exchange. For coating industries that have the same type of products the whole time the choice of powder can be a large factor to reduce the energy use.

For this type of industry it should be evaluated if there is a possibility to have a compressor that is cooled with water. If this is possible the cooling water can reach a high temperature and can then be used to heat the first pre-treatment bath.

As it is today, QPC AB uses compressed air to blow off water from the parts after the pre-treatment. When the deal for the compressed air is changed it might be an idea to install a zone after the pre-treatment that uses strong fans to blow off the water instead.

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Jens Gustavsson, Nordson, December 2010

Rolf Österlund, DuPont Powder Coatings, December 2010

11 Appendix

11.1 Appendix 1 – Running times for the processes

The running times for the processes are similar from day to day. Table 11.1 shows running times for the units within the production process. Standby time is during breaks, start up time is usually in the morning (except for the primer oven) and downtime is during evenings and nights when the process is completely turned off. The process is not running during weekends.

Table 11.1: Running time for production process units during weekdays.

Unit	Drive time [h/day]	Standby time [h/day]	Start up time [h/day]	Downtime [h/day]
Pre-treatment	10.25	0	0.75	13
Drying oven	9	1	0.75	13.25
Primer box	2.30	0	0	21.70
Primer oven	2.30	0	1	20.70
Cooling zone	2.30	0	0	21.70
Powder box	10	1	0	13
Cure oven	8	1	0.75	14.25

11.2 Appendix 2 – Calculations of inflows to ovens

The volume flow for the airlocks is times two and 0,3. This is because of that each oven has two airlocks, one in each end of the oven, and that 30% of the outgoing air in these flows is taken from the hot air inside the oven. The other 70% is taken from outside the oven and is therefore not needed when calculating how much air that goes into the oven.

Drying oven:

$$\dot{V}_{in,DO} = \frac{2 \cdot 0{,}3 \cdot \dot{V}_{airlock,DO} \cdot \rho_{120°C} + \dot{V}_{middle,DO} \cdot \rho_{120°C}}{\rho_{20°C}}$$

Primer oven:

$$\dot{V}_{in,PO} = \frac{2 \cdot 0{,}3 \cdot \dot{V}_{airlock,PO} \cdot \rho_{150°C} + \dot{V}_{middle,PO} \cdot \rho_{150°C}}{\rho_{20°C}}$$

Cure oven:

$$\dot{V}_{in,CO} = \frac{2 \cdot 0{,}3 \cdot \dot{V}_{airlock,CO} \cdot \rho_{200°C} + \dot{V}_{middle,CO} \cdot \rho_{200°C}}{\rho_{20°C}}$$

11.3 Appendix 3 – Energy audit for LaRay AB

The energy audit for LaRay AB has been performed in the same way as for QPC AB. The audit for electricity is based on instantaneous measurements as well as on logging during one week. The values have been controlled with the invoices for electricity, which makes it possible to extrapolate the week to one year. The energy use of LPG is based on the invoices and energy balances for the drying oven and the pre-treatment unit. The result can be seen in this appendix.

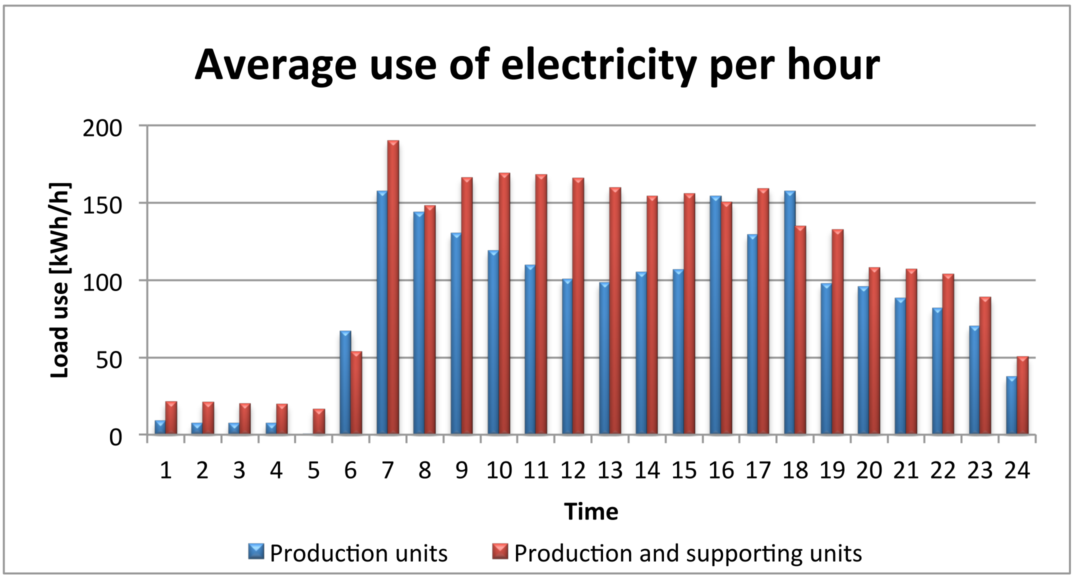

Figure 11.1: Use of electricity per hour during an average production day

In Figure 11.1 the blue stacks are only for the production units while the red stacks include the supporting units as well. As can be seen in the figure LaRay AB has two peaks for the electricity consumption for the production units. This is due to that they have two shifts working each day. The peaks reach about 160 kWh/h. One suggested efficiency measure is to reduce the second peak.

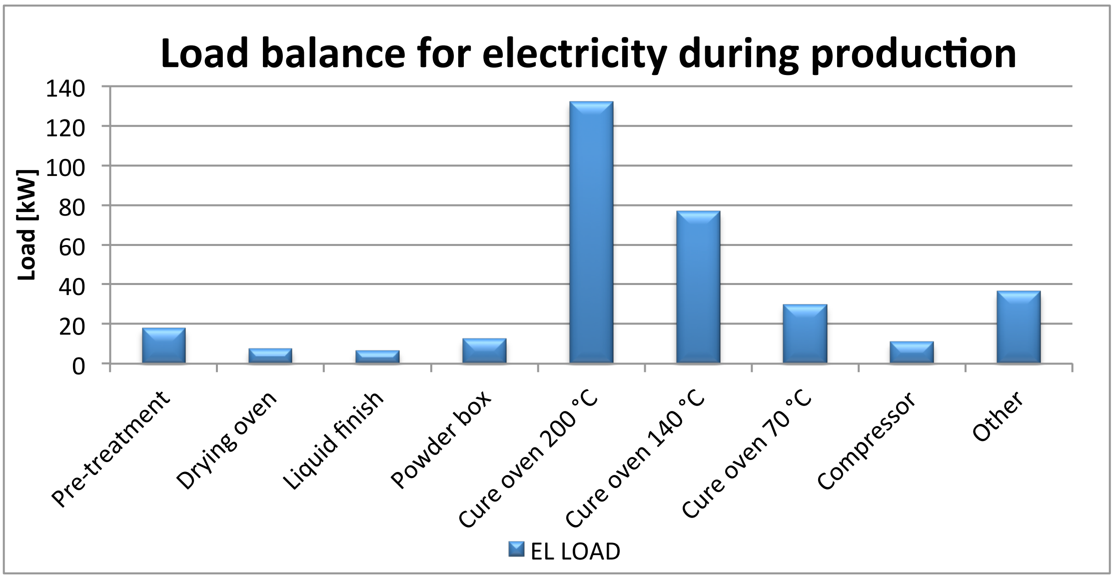

Figure 11.2: Load balance for electricity during production

LaRay AB's biggest consumer of electricity is the cure oven, see Figure 11.2. This is due to that the oven is driven with electricity instead of LPG as for QPC AB. The oven has three different temperatures depending on which parts that are to be varnished. They have quite small and sealed boxes for applying powder and liquid finish.

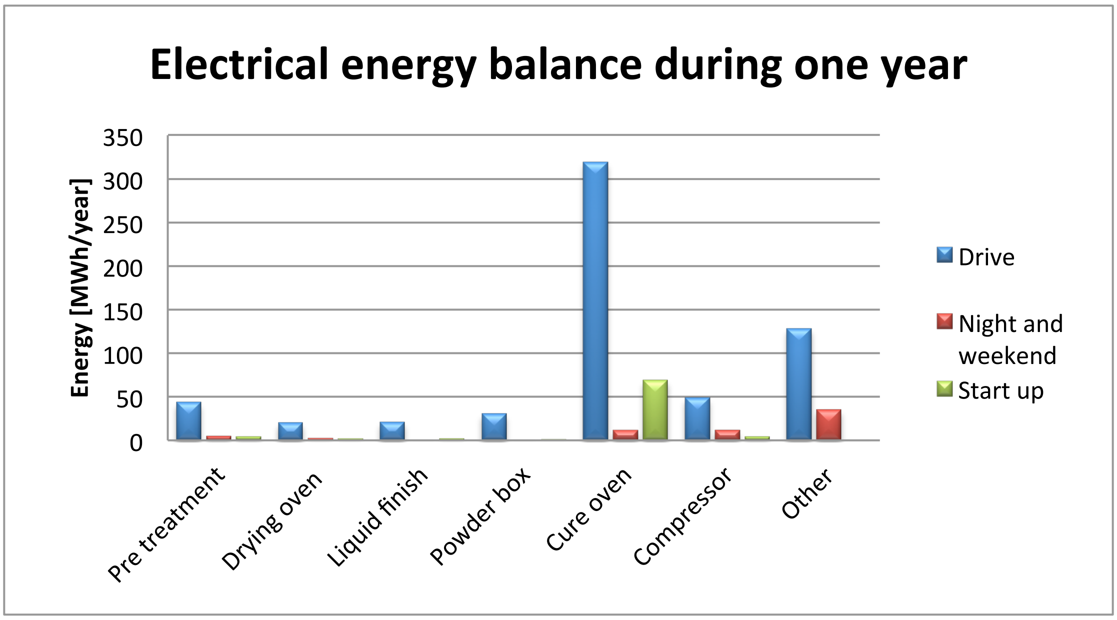

Figure 11.3: Electrical energy balance during one year

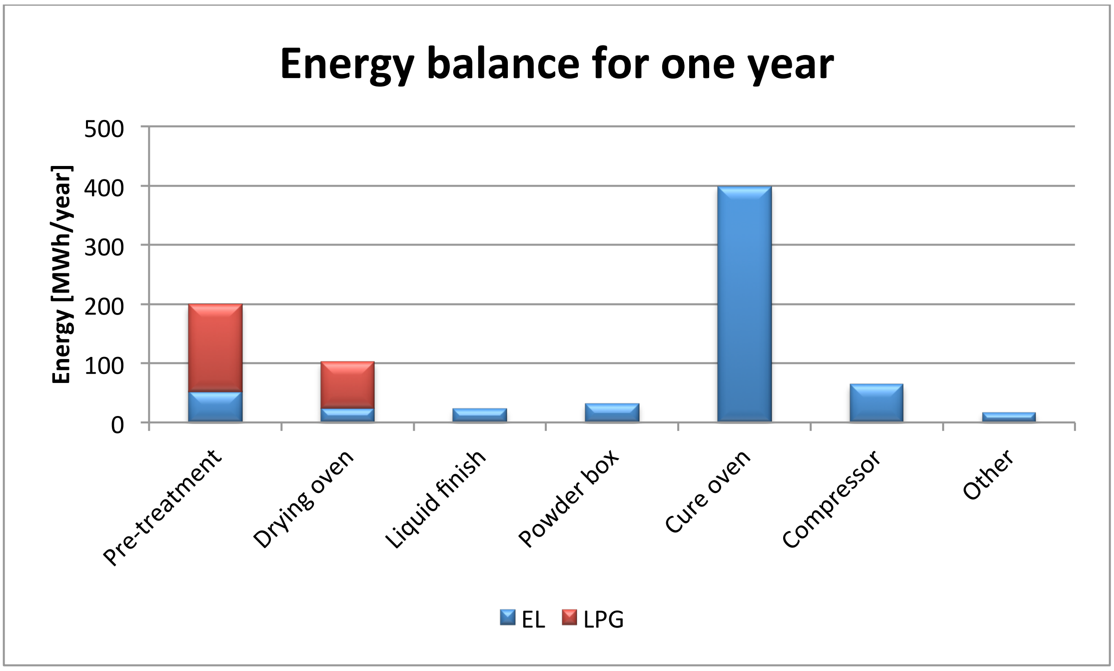

Figure 11.4: Energy balance during one year

In Figure 11.4 it is seen that the pre-treatment and the drying oven are both driven with LPG as fuel. When liquid finishing is used (65% of the drive time) the pre-treatment and the drying oven are turned off.

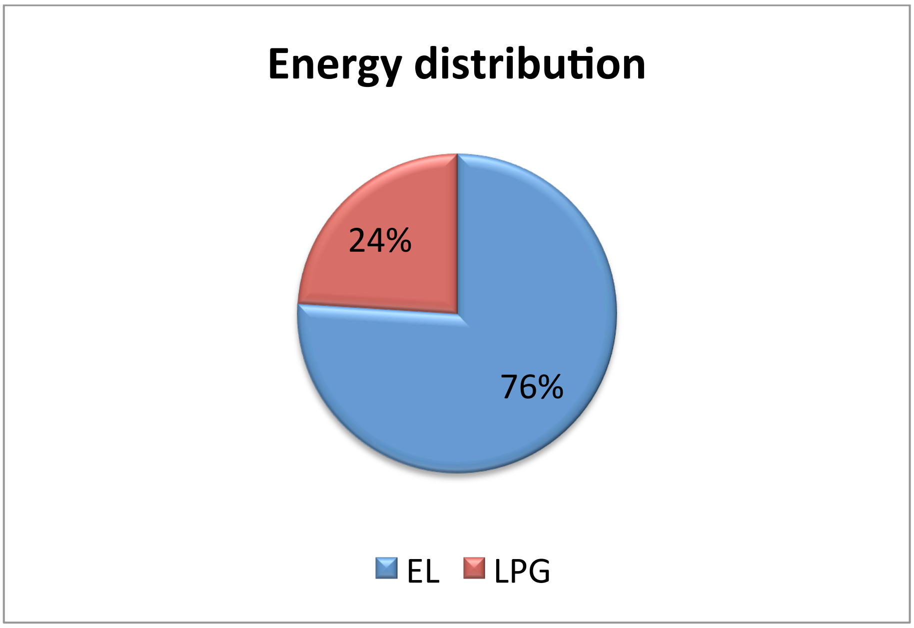

Figure 11.5: Energy distribution

The majority of the energy use is by electricity consumption. The LPG only stands for about 24% of the total energy use.

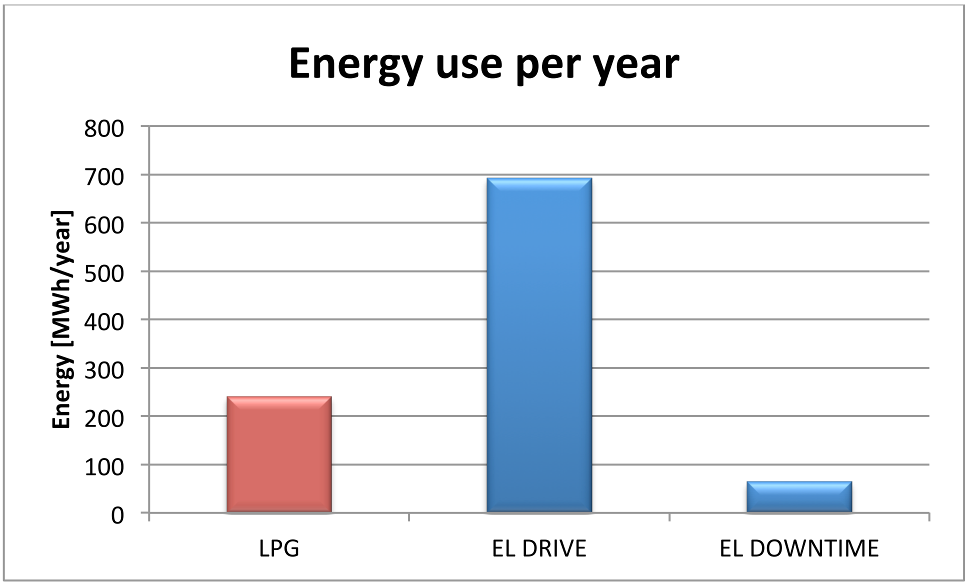

Figure 11.6: Energy use per year

The energy use, Figure 11.6, is distributed between LPG, electricity during drive time and electricity when the process is at a standstill. The total energy use per year is one GWh.

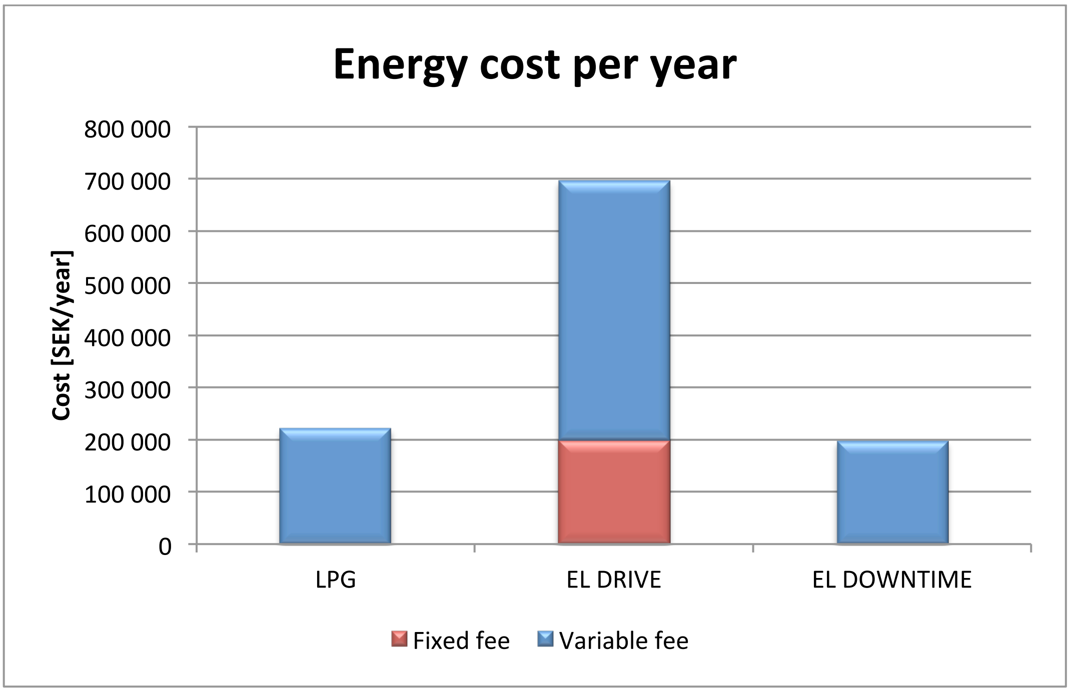

Figure 11.7: Energy cost per year

LaRay AB has a fixed fee for the electricity charge but not for LPG. The total energy cost each year is approximately one million SEK where electricity is the largest contributor.

11.4 Appendix 4 – Comments from experts within the surface treatment industry

”Med några undantag bildas inga spaltprodukter under pulverfärgens härdningsprocess men trots det avgår en liten mängd i samband med uppvärmningen för härdning. Det är lågmolekylära beståndsdelar från bindemedlen och andra komponenter i pulverfärgen. Dessa förångade komponenter ses ofta som ”skägg” vid ugnens öppningar men kan även avsätta sig i frånluftkanalerna och eventuella värmeväxlare. För att förhindra utsläpp till arbetslokalen är det därför av största vikt att trimma ventilationen i ugnen och regelbundet genom förebyggande underhåll sköta frånluftskanalerna.”

Rolf Österlund, DuPont Powder Coatings, December 2010.

”Pulverfärg är en reaktiv produkt som innehåller två komponenter, bindemedel och härdare samt olika tillsatsmedel som ger dess egenskaper, kulör, hårdhet, glans osv. Men om man bortser från de olika pulverfärgernas egenskaper så handlar härdningens resultat av två faktorer; temperatur av luft och gods men även lufthastigheten. Desto mer värme man tillför ju snabbare sintrar pulverfärgen på ett ”kallare” substrat, med den följden att temperatur eller lufthastigheten påbörjar härdförloppet. Man vill höja godstemperaturen och samtidigt sänka viskositeten på pulverfärgen så snabbt som möjligt innan härdningen äger rum. Är temperaturen för låg, eller ojämn i ugnens början kan detta påverka utflytningen negativt och utflytningen blir otillräcklig innan själva härdförloppet har börjat. Resultatet enligt denna beskrivning av pulverfärgen blir oftast en grov yta, det kallas apelsinskalseffekt. Försök att åstadkomma en jämn temperaturuppgång både på luft och gods så snabbt som pulverfärgskvaliteten tillåter, för att få bästa möjliga resultat beträffande utseende på uthärdad pulverfärgsyta.”

Jens Gustavsson, Nordson, December 2010.

”Heat that is coming from the washing line, drying oven, curing oven is connected with a pipe to the outgoing factory hall air. Distance between oven and heat exchanger is about 20 meter; temperature inside pipe is between 40- 50C. We have filter bags before exchanger and in summertime we put air straight out before it goes to the exchanger. This system is working for us and saving money also.

The air is taken from booths that are in front and end of washing line and drying oven, curing oven has double airlocks and booths in front of it so air is taken from that.

We have 1 big plate exchanger. Filter bags are before exchanger so all air that is coming through is clean, same system is with incoming air that is from taken outside. Incoming cold air that is from outside is mixed to hot air that is taken from hall and ovens. Also a burner (liquid gas) is installed after exchanger to get temperature high enough in wintertime. System is over 10 years old and in my understanding plates have never needed any cleaning, only filters need to be after 4-6 months.”

Asko Pinola, Sievi Plant Scanfil EMS Oy, Finland, January 2011.

Comments concerning the water cooled compressor

”Man kan återvinna upp till 90 % av tillförd energi från en oljefri vattenkyld kompressor. Där växlar man av värmen från kylningen till ett sekundärt vattensystem där man kan använda det återvunna vattnet (60-65 ^{o} C) till olika applikationer. En eftermonterad återvinning på en befintlig kompressor kostar ungefär 70 – 75 000 kr inkl installationskostnad. En 90 kW vattenkyld kompressor med 90 ^{o} C återvinning kostar ungefär 1 000 000 kr.”

Ulf Larsson, Atlas Copco, November 2010

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