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Energy optimization at a chemical industry enterprise

Case study – Perstorp AB

Sandra Leksell and Anna Pärsdotter

Thesis for the Degree of Master of Science

Department of Energy Sciences
Faculty of Engineering LTH
LUND UNIVERSITy
P O Box 118, S-221 00 Lund, Sweden

This master's thesis, Energy optimization at a chemical industry enterprise, has been performed at Perstorp Specialty Chemicals AB. The thesis has been carried out in cooperation between Lund University, Faculty of Engineering, Department of Energy Sciences, and Perstorp AB.

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Efficient Energy Systems

Department of Energy Sciences

Lund University - LTH

Box 118, 221 00 Lund, Sweden

www.ees.energy.lth.se

Acknowledgment

This master's thesis has been performed at Perstorp Specialty Chemicals AB in Perstorp, located in Scania, Sweden. The project has been carried out in cooperation between Lund University, Faculty of Engineering, Department of Energy Sciences and Perstorp AB. The aim of the thesis was to evaluate the energy consumption at the chemical industry Perstorp AB, this was performed by developing statistical models and evaluating the energy management at the enterprise.

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Lund, March 2013
Anna Pärsdotter and Sandra Leksell

Executive summary

Title: Energy optimization at a chemical industry enterprise
Case study - Perstorp AB

Authors: Sandra Leksell and Anna Pärsdotter

Supervisors: Patrick Lauenburg, PhD, Dept. of Energy Sciences, Faculty of Engineering, Lund University and Daniel Hansson, Technical Manager, Perstorp Specialty Chemicals AB

Background: The industrial sector in Sweden consumed 152.4 TWh energy in 2010, which represented 36% of Sweden's total energy that year. The chemical industry accounted for 11.4 TWh (7.5%). Energy efficiency measures and improvements are given priority by enterprises today, due to increasing energy prices and implemented energy policies. To reduce the competitive threat caused by increasing energy prices, Swedish companies have two options; either negotiate a lower energy price from the energy companies or work internally with energy efficiency measures. Industries located in colder climates, having a temperature dependent production, are additionally affected by increased energy prices. Perstorp Specialty Chemicals initiated this master's thesis, because they have experienced a variation in steam consumption at their factories. They believed the reasons behind the variety were that production rate affected the energy consumption, that a cold outdoor temperature resulted in energy leakage and that the base load was similar throughout time. Despite this, they have never performed any thorough energy analysis that confirms to what extent these factors affect the energy usage in the factories.

Objective: The objective of this master's thesis was to evaluate the energy consumption, mainly steam usage, at the chemical industry Perstorp AB and this was performed by developing statistical models and evaluating the energy management at the enterprise.

Methodology: This master's thesis is divided in two parts, and several different methods have been employed in both. The first part is an Energy usage analysis, which began by creating an overview of the production site and factories. The overview was made after visits to the factories and studies of theirs flow charts. Finally the processes were discussed with employees at Perstorp. Relevant and available energy data were then assembled and evaluated. An energy audit, founded on the energy data, for four polyol factories was performed, where large energy consumers were identified. Later, the energy performance of these factories was evaluated. The latter included a study of which variables that affected the steam consumption, and it was based on the statistical model *multiple linear regression.*

The second part, Evaluating Perstorp's energy management, began with a literature study and an interview with a PhD-candidate at Lund Faculty of Engineering. After this, interviews were performed with employees at Perstorp to gain knowledge on how the energy management was handled at the company. After the interviews, an overview was made of the energy management and working methodology. Energy efficiency measures within the company and possible improvements regarding their management were suggested.

Conclusion: The main conclusion from the Energy usage analysis, was that the statistical method used, *multiple linear regression*, can only be applied for some systems. The method is straightforward, proving a correlation, in this case between steam usage and other variables. If the system was complex, with reflows, heat recovery, leakage or other factors affecting the steam consumption, the modelling gave a poor result. However, if the system is simpler, e.g. with a product inflow heat exchanged against the steam flow, or heating of component, where the steam consumption correlates to the temperature, the method can be of great use. The models for two out of four factories resulted in a better correlation. One of the factories with poorer result was examined more carefully with diverting result for the components. Some of the steam consumption should be correlated towards the outdoor temperature instead of production rate, when calculating the company's energy budget.

Regarding the second part; the energy management at Perstorp is organized, although it can be improved. The impression the authors got after finishing the interviews at Perstorp was that energy is an important issue, though it is not prioritized from the company's board. Furthermore, the Energy Coordinator believes that the level of ambition can increase at the company. Nevertheless, Perstorp has some good examples of well-practiced energy management: weekly discussion regarding energy ratios, a follow up if the ratio is higher than expected and an Energy Coordinator that wants to improve their ambitions. Still, there are some fields within the energy management at Perstorp that can be improved, most importantly creating an Energy group, which can get a comprehensive view concerning energy issues. Additionally, Perstorp can improve the follow-ups after energy projects are implemented, create long-term energy goals and make the staff aware of these and have better training for the staff.

Keywords: Energy efficiency, Process industry, Steam consumption, Multiple linear regression, Energy management system, Perstorp AB

Contents

1 Introduction

1.1 Background

The industrial sector's usage of energy is the main subject of this master's thesis. A study regarding how the management interact with energy saving policies companies faces today, is also a focus in the thesis. The industrial sector worldwide used 9.3% of the world's oil consumption, 34.9% of the world's natural gas consumption and 77.4% of the world's coal consumption in 2009 [1]. Global warming, as a result of increasing greenhouse gases from burning fossil fuel is today a worldwide rising concern.

In Sweden the industrial sector consumed 36% (152.4 TWh) of the country's total energy production in 2010 [2]. This makes energy efficiency an important issue for the Swedish industrial companies. To be competitive means using the most energy saving production facilities.

Energy efficiency measures and improvements are given priority by enterprises today, due to increasing energy prices and implemented energy policies. Increasing energy prices, on a national basis, have a devastating effect on the competitiveness for manufacturing enterprise in Sweden. Industries located in countries with colder climates and have a temperature dependent production are even more affected by increased energy prices. These negative effects may lead to companies moving abroad or being forced to cut back on production. On the other hand, if a company faces increased energy costs, it can increase the motivation to take action on energy efficiency measures. Energy efficiency measures may have a positive effect on the total cost for a company and may lead to increased productivity, giving increased profits. [3]

After Sweden deregulated the electricity market in 1996, the electricity price first decreased but after 2000 it has increased again. Swedish companies' competitiveness has been negatively affected as a consequence of rising energy prices. Sweden, in comparison with European competitors, has historically had low electricity prices, which have influenced the Swedish industry to use electricity instead of other energy carriers. [3]

To reduce the competitive threat, Swedish companies have two options: either try to negotiate a lower energy price from the energy companies or work internally with energy efficiency measures. Energy efficiency measures are complex and involve a variety of technical, organizational as well as behavioural factors [3]. Even though these efficiency actions are complex, they are a part of companies' policy and image today.

Perstorp Specialty Chemicals initiated this master's thesis, because they have experienced a variation in energy usage: the factories use different amount of steam, even though the same amount of product is produced. It is particularly the steam usage that varies and Perstorp had some assumptions regarding the variations: that production rate affected the energy consumption, that a low outdoor temperature result in energy leakage and that the base load was similar over time. Despite this, there has never been any thorough analysis performed confirming to what extent the different factors affect the energy usage in the factories. Among the staff at Perstorp, the key figures regarding steam are often discussed; the ratio between steam utilization and total production. These key figures are used when planning the budget, therefore it is of importance to test the relationship between the steam usage and the production rate.

1.2 Objective

The objective of this master's thesis was to evaluate the energy consumption at the chemical industry Perstorp AB, which was performed by developing statistical models and evaluating their energy management. The energy usage analysed was the steam consumption at Perstorp AB. The two purposes are:

Part I: Find explanations why Perstorp's energy consumption varies over time.

Part II: Evaluate Perstorp Specialty Chemicals AB's energy management.

1.3 Constrains

The master's thesis was carried out at Perstorp Specialty Chemicals AB, Perstorp, Sweden. The evaluation of their energy management systems was limited to their site, and was compared to Kemira Kemi AB's work methodology. For the energy usage analysis four chemical factories were in focus and for one of them more a detailed study was carried out. The energy usage analysis was restricted to the statistical model *multiple linear regression*, based on measured data. Due to a time limit, the theoretical energy usage was not calculated.

1.4 Method

In this master's thesis, several different methods were employed in both parts. The Energy usage analysis began by creating an overview of the site and its factories including the chemical processes, the main energy carriers and the energy flows. The overview was established by visiting the factories and studying the flow charts. Thereafter, interviews with the employees at Perstorp were carried out. Relevant and available energy data were evaluated and assembled. The plausibility of the measured data were evaluated, together with the measurement technique. An energy audit founded on the energy data for four polyol factories was performed where the large energy consumers were identified. Later, the total energy performance of these factories was evaluated. The latter included a study of variables affecting the steam consumption. It was based on the statistical model *multiple linear regression.* The variables analysed in the *multiple linear regression* were: outdoor temperature, production rate, cooling water temperature, water concentration and product flow in the factory. Because of the time limit for the master's thesis, only one polyol factory was investigated more thoroughly. The components in this factory were analysed.

The second part, Evaluation of Perstorp's energy management, started with a literature study and an interview with a postgraduate at Lund University, Faculty of Engineering, Department of Environment and Energy system. Subsequently, the authors performed interviews with employees at Perstorp to gain knowledge how the energy management was handled at the company. The interviewed staff had the following positions:

- Two Production Engineers: technicians whose work task includes operating the factory.
- Two Process Engineers: persons with a Master of Science in Engineering that mostly work in projects.
- One Factory Manager.
- The Production Manager: head of the Factory Managers and a part of the board.
- The Technical Manager, who also is the Energy Coordinator at the site.

After the interviews, an overview of the energy management and working methodology towards energy efficiency within the company was made. Possible improvements were then suggested. Kemira Kemi AB in Helsingborg was visited, in the purpose of comparing Perstorp's and Kemira's energy management methods.

2 Perstorp AB

In this chapter, a short introduction to the company Perstorp AB is presented.

The chemical company Perstorp AB was founded in 1881 by the Wendt-family in Perstorp municipality, located in the wooded area of northern Scania, which is in the southern part of Sweden. Today the company has expanded and has factories in 10 countries, offices in 22 countries and over 1500 employees. In Sweden Perstorp has two sites, one in Perstorp and one Stenungsund. Perstorp produces specialty chemicals and is a world-leading producer of some of particular chemicals. The company produces chemicals worldwide that are used in five different areas [4]:

- paint and coating
- plastic material
- forage and food
- formalin technique and catalysts
- fuel.

2.1 Description of Perstorp Specialty Chemicals AB

The part of Perstorp AB located at the Perstorp site figures under the name Perstorp Specialty Chemicals AB. This thesis only deals with the site in Perstorp, which from now on will be referred to *Perstorp*. On this site, several different factories produce chemicals. The chemical substance formalin is developed from methanol and is used as a basis for the manufacturing of various polyols. A polyol is a polyhydric alcohol and has different properties depending on the molecular characteristics. Other chemical substances are produced on the site as well, but they are outside the scope of this thesis. The main focus is on the production of four polyols: Polyol A, Polyol B, Polyol C and Polyol D. [5]

The traditional Perstorp vinegar is however no longer produced on site. Nowadays the vinegar is simply bought and only bottled at the Perstorp site. [5]

2.1.1 Energy usage and production

Polyol factories utilize both electricity and heat for the various industrial setups. The chemical reaction is endothermic and therefore heat demanding. As a heating source, two different systems with steam are linked to the factories. The two steam flows have different pressure and therefore various heating values. On the contrary to the polyol production, the formalin reaction is exothermic and yields heat. This heat converts water into steam, which is dispatched to factories on the site. The steam generated from the formalin production supports approximately 30% of the steam demanded on the site. The remaining steam is produced on the site in a steam plant. The steam plant has two main boilers and two supporting oil-boilers. The primary boiler is a circulating fluidized bed (CFB) boiler that utilizes solid bio-fuels, particularly forestry by-products and peat. Next to this boiler Perstorp has a combined boiler in which fluids, e.g. rest methanol from the processes and oil, at peak load, are combusted. The company's site Perstorp has a contract with the Perstorp municipality to support the county with district heating. Other companies in the surrounding industrial park buy district heating and steam as well. The steam plant produces electricity through a back pressure turbine, which is connected to the CFB-boiler and it produces 10% of the electricity needed on the site. [5]

3 Theory I - Energy usage analysis

This chapter will introduce Perstorp's energy usage and a short introduction to the theory behind a process industry. Statistical models that are used to evaluate energy consumption are presented as well.

3.1 Process industry

3.1.1 Steam as an energy carrier

The adding of energy carrier in the form of steam accounts for a significant amount of the total energy used in process industries [6]. Steam is both easily accessible and cheap, furthermore it has technical advantages by being efficient in transferring large amount of energy. Moreover it is easy to distribute through pipelines [7]. The thermodynamic properties of the vapour differ in pressure, temperature and the percentage of water mixed in the vapour. If a saturated gas is compressed to a higher pressure, the ideal gas law says that the temperature then also increases if the volume is held constant. This gives the gas a higher enthalpy and therefore higher heat content. When the vapour condenses, the change in energy, $\dot{Q}$, is:

$$\dot{Q} = \dot{m}_{steam} \Delta H_{vap} \tag{1}$$

where $\dot{m}_{steam}$ is the mass flow (kg/s) and ΔH_{vap} is the enthalpy of vaporization (kJ/kg). ΔH_{vap} changes when the pressure of steam changes.

The change of energy (here convection) in a flowing fluid, $\dot{Q}$, is instead:

$$\dot{Q} = \dot{m} c_{pm} \Delta T \tag{2}$$

where $\dot{m}_{steam}$ is the mass flow (kg/s), c_{pm} is the specific heat capacity (kJ/kgK) and ΔT is the change in temperature (K). c_{pm} varies with the substance and thermodynamic properties.

Steam can enter the industry in pipeline networks, and then either be mixed with a product flow or return as a condensate. If the steam returns to the steam plant as a condensate, the vaporizing heat has passed on to the product flow in a heat exchanger. Heat is transferred from the warm substance to the colder through a solid wall.

In this chapter, steam-using components will be presented. All of these components have some sort of heat exchanger, where the hot steam emits essential heat to the product flow [8].

3.1.2 Industrial components

There are many components in a process factory. Though, there are a few components at the Perstorp site that utilizes more steam in relation to others, making them more interested in the energy usage analysis. All components listed, with one exception, are part of some kind of separation process. A separation process separate reaction products, concentrate products or clean waste streams leaving a factory. All these processes are based on differences in physical and chemical properties [9]. The component not using a separation process is a dissolver that adds liquid to the process solution.

Evaporator

During evaporation a solvent is evaporated from a solution and the solvent is usually water. After the evaporation, the solution contains a higher concentration of a not volatile substance. This process demands heat which is received from a heat exchanger where steam condenses and emits heat. The feed receives the heat from the heat exchanger and in turn also creates steam, so called secondary steam. An evaporator consists of a heat exchanger followed by a separator where the separation of the solution and secondary steam take place. The secondary steam is transferred to a second evaporator where it is heat exchanged against the feed, leading to a larger concentration of solvent in the solution. These steps usually repeat from three to nine times and more solvent is removed in every step. Before the solvent is evaporated it ought to be preheated to a temperature close to its boiling point [10]. The Perstorp site has several evaporators in its processes. Later in the report, especially one evaporator will be analysed.

Drier

In a dryer, unwanted liquid is removed from a solid material. There are several different ways to dry a substance, e.g. vacuum drying and freeze drying [9]. At the Perstorp site, the product is dried with outdoor air which is preheated in heat exchangers. The dryers are of a fluidized bed type, where the heated air then passed through the moist product mass, warming it and the unwanted moisture is vaporized. The outdoor air is preheated with steam in a countercurrent heat exchanger. Before the product reaches the drier, some liquid has been removed with a band pass filter or in a centrifuge. Two dryers at the Perstorp site are further examined.

Steam compressor

A steam compressor is used to increase the pressure of steam, so it can recirculate and be used again, instead of introducing primary steam from the steam central [11]. A steam compressor uses electricity, which means that it can be misleading to introduce the steam compressor as a large consumer of steam. If the steam compressor is part of a closed system where the same steam flow is circulating, new primary steam partially has to be added since there always is leakage in a system. Leakage of steam can occur both in pipes and components connected to the circulating steam flow. A steam compressor results in a lower cost of the steam. A steam compressor system in one factory is analysed in the result.

Distillation

In distillation, a fluid is partly vaporized by boiling. This vapour holds a larger concentration of more volatile substances than the original fluid. A volatile substance normally has a lower boiling point. The distillate leaves a distillation column and then condensed to liquid form in a condenser after the column. The remaining liquid in the column has a higher concentration of substances with a higher boiling point. The initial fluid enters the column as a feed on the side. This process can be divided into several steps, called a fractional distillation [9]. At the Perstorp site, steam is heat exchanged against a recirculating flow at the bottom of the column. One distillation column at Perstorp is connected to a steam compressor system. The energy usage in this distillation column is investigated later in the report [12].

Steam ejector
Steam ejectors can be used to create vacuum and rationalize distillation columns. A steam ejector is a pump with no mechanical parts that utilizes steam as fuel. As described above, the gas stream leaves the distillation columns and led over to a condenser. A vacuum is created by the vapors condense and also by utilizing the steam ejectors. The gas that does not condense will be pumped out from the condenser through the steam ejectors. Depending on the cooling water temperature, condensation occurs differently; a lower cooling temperature provides a greater cooling capacity, thereby less steam needs to be tended by the steam ejectors. Steam ejectors are included in the analysis, by indirect means, when examining the effect of the cooling water temperature on the energy usage.

Dissolver
Contrary to the other components described, a dissolver is not a separating substance, instead it mixes a slurry or solid mass with a liquid during stirring. At the Perstorp site, dissolvers are used before the slurry is purified once again. Heat is added in the dissolver [11]. An energy usage analysis is performed for one dissolver on the site.

3.2 Statistical methods

In order to evaluate the energy consumption in factories, different statistical methods can be utilized. To gain specific information on how the steam usage in a certain factory at a certain time is energy efficient or not, the steam consumption can be compared to historic consumption where the conditions were similar. Statistical models based on past energy data can present when there was a higher steam consumption alternatively when there was a greater usage variation.

Before the data is analysed for correlations and conclusions can be drawn, one has to evaluate the data. Only data that is relevant for the model is included.

3.2.1 Multiple linear regression

As a first step it can be beneficial to examine if the steam consumption is affected by one or several variables, for which examples could be the production rate or the outdoor temperature. This dependency can be evaluated with the model multiple linear regressions, with n explanatory x-variables:

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \ldots + \beta_n x_{ni} + e_i \tag{3}$$

where e_i is an independently calculated normal distributed random variable. The different β-values represent the extent of influence the various variables where x_i, has on y_i. y_i is the response variable of the multiple linear regression, which in this case is the steam consumption, while the x_i-values are regressor variables. β_0 is the intercept and represents the value of y when the regressor variables are zero. To clarify, x_i are vectors containing e.g. measured values for factors affecting the steam consumption at the time i, and y_i a vector holding the measured steam consumption at the same time i.

There is a possibility that a linear relationship between the response variable and a subset of the believed regressor variables does not exist. This can be tested with a hypothesis test, where the appropriate hypotheses are:

$$H_0 : \beta_0 = \beta_1 = ... = \beta_n = 0$$

$$H_1 : \beta_j \neq 0 \text{ for at least one } j$$

If H_0 is rejected, and at least one of the β-values are separated from zero, the response variable, y, is then dependent on this regressor variable, x_i [13]. This can be clarified by looking back at Equation 3; if, e.g. β_1 can equal zero, the variable x_{1i} is multiplied with zero, resulting in a non-existing influence on y. It can, of course, be the case that more than one response variable is influencing the regressor variable. [13]

3.2.2 Influence of variables

The regressor coefficients, β_j describe how much y is changing when the value for x_j is increased by one unit. However, it does not give any indication which regressor variable that has the largest influence on y, since the regressor coefficient is correlated to the unit of the variable, e.g. °C or ton/day. To be able to compare the amount of influence the different regressor variables have on y, they have to be standardized. For each regressor variable the following equation has to be applied:

$$X_i = \frac{x_i - \bar{x}}{stdev(x)} \tag{4}$$

where x_i is each measured x-value, which is subtracted with the mean value for the x-vector, $\bar{x}$. This is then divided with the standard deviation for the x-vector. This is performed for each x-vector. The newly developed vectors are then used in the multiple linear regression described above (Equation 3) and new β-values are received. The magnitude of the absolute value of the new β-values ranks how much that variable affects the steam consumption. [14]

3.2.3 Determination coefficient - R^2value

Coefficient of determination, R^2-value, is the proportion of the total variation in the dependent variable, y, and can be explained by variation in the independent variable, x. An explanation coefficient of 0.70 means that one can explain 70% of the variation in the dependent variable with the variation in the independent variable [15], i.e. an R^2-value of 1.0 equals a 100% dependency. The R^2-value is a measurement of the linear adaptation strength and enables comparisons of very different results. To clarify, the coefficient measures the strength of the linear relationship and can be used to compare different models. One problem regarding the R^2-value is that it is sensitive to outliers, a single value may have a great impact on the coefficient [16].

3.2.4 Expected values

Within the study performed in this thesis, the equation for the multiple linear regression (Equation 3) holds a y_i vector and x_{1i}, x_{2i}, $\ldots$, x_{ni} vectors that represent measured values of the steam consumption and the variable that might affect it. In that case, the amount of dependency, disguised as the β-values are unknown. However, once these β-values are computed, the expected steam consumption at a certain time i can be calculated. In equation 5, the expected steam consumption for a certain time i, is Y:

$$\begin{bmatrix} Y_1 \\ Y_2 \\ .. \\ .. \\ Y_i \end{bmatrix} = \beta_0 + \beta_1 \cdot \begin{bmatrix} x_{11} \\ x_{12} \\ .. \\ .. \\ x_{1i} \end{bmatrix} + \beta_2 \cdot \begin{bmatrix} x_{21} \\ x_{22} \\ .. \\ .. \\ x_{2i} \end{bmatrix} + ... + \beta_n \cdot \begin{bmatrix} x_{n1} \\ x_{n2} \\ .. \\ .. \\ x_{ni} \end{bmatrix} \tag{5}$$

The expected steam consumption, e.g. at day 1, is calculated by inserting the computed β-values and the measured values of the x variables at day 1. The result is a vector with all expected values for the steam consumption, from day 1 to the day n.

To acquaint whether the steam consumption at a factory is high or low during a day with certain condition, one has to know what the steam consumption has been during days with similar conditions. For example, these conditions could be the specific production rates that day or how cold it is outside. This is what the multiple linear regression provides a measure of. For a certain day, the actual measured value for the steam consumption that day, can be compared to the expected value (based on the regression model) the same day. This difference gives an indication on whether the steam consumption is higher or lower than days with similar conditions [17].

Within this thesis, the expected steam consumption, Y, is subtracted from the actual measured steam consumption, y, to gain a difference Δ:

$$\begin{bmatrix} \Delta_1 \\ \Delta_2 \\ .. \\ .. \\ \Delta_i \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ .. \\ .. \\ y_i \end{bmatrix} - \begin{bmatrix} Y_1 \\ Y_2 \\ .. \\ .. \\ Y_i \end{bmatrix} \tag{6}$$

In equation 6, Δ represents the residuals of the model and is used to validate the model. The days where Δ is positive, the measured steam consumption is larger than the expected one. It could be of interest to further investigate these conditions; to see why the steam consumption was larger than expected according to the statistical model.

3.2.5 Multicollinearity

Collinearity is a linear relationship between two explanatory variables. When there is a high correlation between the explanatory variables one may say that multicollinearity exists. Multicollinearity refers to a situation in which two or more explanatory variables in a multiple regression model are highly linearly related [16]. A problem regarding some of the analyses in this thesis is that multicollinearity may occur, this since both the production rate and the inflows to components are added to the model, see section 5.4.5 and 5.5.4. The inflows of the components are most often dependent on the production rate. When two regressor variables are dependent on each other this creates problems [17]. Multicollinearity may also occur when adding both outdoor temperature and cooling water temperature, which is the case for Polyol B, see section 5.5.2.

4 Theory II - Energy management

This chapter is based on a literature study concerning the best practices of energy management in industries.

4.1 Management control measures in Sweden

4.1.1 Program for energy efficiency

The Program for Energy Efficiency, PFE, is a Swedish management control measure for companies in the manufacturing industry. The industries that join the PFE are energy intensive and use electricity in the manufacturing process. In 2004, the European Union decided to increase the tax on electricity used in industrial processes from 0 to 0.5 Eurocent per kWh and the PFE is a result of this energy tax directive. The Swedish law concerning PFE (2004:1196) came into effect the 1 January 2005. Companies that join the program do so voluntarily and for a limited time period of five years. For this they obtain a 0.5 Eurocent tax reduction per bought kWh electricity. To be entitled for this tax reduction, the companies have to agree with the conditions of the PFE, which include implementing an energy management system and performing an energy audit. During the first five-year period, the program had 110 participating companies, which led to a reduction of 1.45 TWh of electricity and resulted in a tax credit of 150 million SEK per year. [18]

4.1.2 Energy management system

In order for a company to be a member of the PFE it has to implement an energy management system. In 2011, a new international standard for energy management systems was published, ISO 50001. It is based on past energy management standards: BS EN 16001 and SS 62 77 50, and is well integrated with other management systems, such as the environmental management system ISO 14001. An accredited certification company can certify that the manufacturing company's energy management system follows the standard. [19]

When a company implements an energy management system, an energy policy needs to be established. After that, energy goals and procedures that match the energy policy can be implemented. Furthermore, the company also has to implement necessary routines, monitor the manufacturing processes and conduct an energy audit [20]. The result from the energy audit can contribute to the company in question by supplying basic knowledge that can be used to appoint energy goals, which are supposed to be challenging, but also achievable [19]. An energy management system can create energy consciousness within an energy intensive company and is also helpful when the company want to improve the management regarding energy efficiency. The system is useful when the energy management ambitions are structured and incorporated into the daily operations [20].

Energy audit
The first step when implementing an energy management system is the establishment of an energy audit. When an energy audit is conducted for an industry or a building, the aim is to acquire a greater knowledge of the energy usage.

The first step of the energy audit is mapping of the energy carriers, and it is defined how they correlate. The energy usage varies in components, including which the largest energy users are can be pointed out. The goal of an energy audit is to obtain an idea of possible energy efficiency improvements. The main interest of the energy audit is energy savings, however, there can also be positive side effects: an awareness of the technical conditions and environmental impact can be enhanced. The energy audit can be carried out either for a part of a production site or, if possible, on more than one site simultaneously. The European Commission has named this multiple energy audit a “horizontal audit”. [21]

The Swedish Energy Agency have proposed a help manual, describing the work process with an energy audit, including the recommended preparatory work and an evaluation [22]. In the guide it is recommended that five primary parts should be included:

- description of the industry
- the energy usage
- the expected energy usage in short term together with energy usage in a longer term
- the potential measures for increased energy efficiency.

4.1.3 Tradable renewable electricity certificates

The electricity certificate system was introduced 1 May 2003 in Sweden, with a mission to increase the share of renewable electricity. The goal was to increase electricity from renewable energy and peat with 25 TWh by 2020 compared to levels in 2002. One certificate is awarded to producers for each produced MWh electricity from certificate-entitled facilities. The certificates are based on peat and renewable energy sources such as wind, solar, geothermal, wave energy, certain biofuels and small-scale hydropower. The electricity certificate system provides electricity producers with an extra income that makes it more profitable to invest in renewable electricity. [23]

Suppliers of electricity and electricity-intensive industries, which have been registered by the Swedish Energy Agency, are examples of so-called quota liable companies that are under the law of electricity certificates. They must buy a certain share of certificates in relation to their electricity sales or electricity use. This quota creates a demand for certificates, which can be traded in the electricity certificates market [23]. At the end of 2012 and 2014, a large number of older electricity generating facilities will cease to get certificates for their electricity production. This is because of the purpose of the certificate system: to promote the production of electricity from renewable energy sources and peat. If many old self-supporting plants are awarded certificates, it can cause unjustifiably high costs for electricity customers. Plants in operation before the system started in 2003, are entitled to get certificates by the end of the year 2012 [24].

4.1.4 European Union Emission Trading Scheme

The emissions trading system (ETS) is an economic instrument, comprising all members of the European Union and created to meet requirements to reduce greenhouse gas emissions set by the Kyoto Protocol. ETS was introduced 1 January 2005 with the overall goal to reduce greenhouse gas emission from energy-intensive industries and energy producers, in a cost-effective way. The first ETS trading period lasted for three years, from January 2005 to December 2007. The second trading period began in January 2008 and lasted until December 2012, with an expanded number of plants included in the system. The third trading period will run from January 2013 to December 2020. During the third period, further greenhouse gases and more industries are being included. Companies having high cost to reduce their emissions can buy allowances from firms with lower abatement costs, which lead to a cost-effective control system. [25]

During the second trading period, companies were awarded free emission allowances based on historical emissions, i.e. free allocation known as "grandfathering". The historical emissions are based at the years 1998-2001. [26]

4.2 Energy management in industrial companies

Energy has historically had low priority for management attention in industrial companies, since energy costs often are a minor part of the total costs, however this has started to change. Research on energy management in industries have not been carried out in a great extent and there are especially some areas within this field that have not been given much attention. Some of these areas are: reviews on the degree of implementation after performing an energy audit, studies of the actual energy audit method itself and improvement potential for the method. Energy management is important and will play a central role in the transition to a more efficient energy system in industrial companies. The most important driving force for companies to implement energy efficient measures is reduced costs. The other two most important driving forces are the existence of an enthusiast and the existence of a long-term energy strategy. [27]

A difficulty regarding energy management measures in manufacturing companies is that resources within the corporation often are allocated to the company's core activity. Energy efficiency measures are not a core activity for many industrial companies since it gives no profit, leading to a decreased interest in energy efficiency. A solution to this problem could be engaging an energy consultant company whose core activity is energy management strategies. However, engaging an external consultant can work poorly, supposedly if the person responsible for a process is not responsible for the energy management. Then there is a risk of an energy efficiency opportunity is unnoticed. [27]

Success factors regarding an efficient energy management strategy include an energy audit, full support of the highest board, a long-term strategy, measurements at departmental level and visualization of energy use in different departments. A management control measure that reaches a step further than merely offering a traditional energy audit is desirable. Examples of new control measures could be actions that also focus on establishing an energy management in the internal organization. However, in smaller organizations it can be difficult to establish a full-scale energy management, due to e.g. lack of resources.[28]

By adopting energy management practices, research and experience in other European companies reveal that industrial companies may save up to 40% of their total energy use. Successful strategies with energy management starts with an energy audit and having the strategies established by the highest board. Furthermore, it is of importance that companies establish an energy strategy with goals for energy savings and an action plan. A successful strategic work in companies varies, but they do have certain factors in common, which are listed below. In their strategic work, the companies [29]:

- perform an initial energy audit,
- have the support from the senior management,
- monitor their energy use,
- recognize that management is as important as technology,
- have an on-going and coordinated program for energy saving projects,
- have an energy management program that involves motivation and training of staff.

The conclusion is that all industrial companies, regardless of size and total energy used can benefit from a good energy management [29].

4.2.1 Driving forces for energy efficiency

Driving forces for companies to invest in energy efficient technology can be divided into four different categories [27]:

- market related incentives
- management control measures affecting the industrial sector
- potential future industrial management control measures
- behaviour and organization.

The main driving force for companies to implement energy efficient measures is associated with market related incentives, maximize profit and minimize expenses. Therefore, reduced energy costs are a motivation for energy efficiency measures. This is strengthened by the threat of rising energy prices in the electricity market. Another example of market related incentives is the international competition; efficient energy use can lead to lower variable production costs. [27]

Future industrial management control measures also affect companies motivation to invest in efficiency measures. Control measures that have the potential to be implemented in Sweden are for example government-funded energy analysis, investment in energy efficient technologies, preferential loans for investment in energy efficient technologies, support from energy experts for specific issues and general energy councils [27].

Behaviour of staff and organization of energy issues at a company, affect the level of implementing changes. Examples of this type of driving force can be: the environmental profile of the company, enthusiasts in the company, a long-term energy strategy, environmental/ energy management system, network within the company and/ or external pressure from various environmental organizations (Non-Governmental Organizations). Further examples are working with measurements of energy data and ratios/ key figures. Measurements provide information on how energy is used within the company along with insight about how the energy use fluctuates and where potential savings could be done. [27]

4.2.2 Barriers to energy efficiency

Energy efficiency measures are necessary in companies if one want to mitigate climate change and decrease the usage of fossil fuels. In addition there is a chance for companies to decrease their energy costs. Not all cost-effective measures are implemented, in spite of the fact that companies may decrease their energy costs. Many publications show that there is a gap between the potential cost-effective energy efficiency measures and measures actually implemented. This phenomenon is called the energy gap or energy paradox [27]. The energy efficiency gap is explained by a number of barriers to energy efficiency. These barriers can be divided into three wide categories: economical, organizational and behavioural. They are explanatory variables from a theoretical perspective. A summarized table over these barriers is presented in Table 1 [30]. The three categories will be presented one at a time.

Economic perspective
One example of an economic barrier is hidden costs; economic analysis does not include any costs related to a technology investment, such as management time or disruption of production. The supply of capital is another barrier; a company may lack access to capital to invest in energy efficiency technologies. Companies strive for a short payback time for all investments, and the risk of long payback for energy measures may also be a barrier. This can have its origin in natural risk aversion [27]. Another economic barrier to energy efficiency is a so-called split incentive, which occurs when end-users in a company are not held responsible for the costs of their energy use. If each end-user (a division) does not pay for the used energy separately, it gives less incentive for the division to reduce the energy use. To overcome this barrier, split incentive, a company's energy use should be sub-metered to enable cost allocation based on the actual consumption of each division or process that constitutes a cost center [20].

Behavioural perspective
Individuals within an organization make not only limited rational decisions, but also systematically one-sided and incorrect decisions. With this knowledge it is easier to overcome the energy gap. When improving the energy efficiency management in an organization, there are four factors to consider. Firstly, the type of information that is given to the staff is important in order to encourage efficient decision-making. The information ought to be simple, vivid, specific and should be personalized. Secondly, the credibility of the information source

Table 1: Different barriers and examples based on Sorrel et al. (2000) [30].

Perspective	Examples	Actors	Theory
Economic	Imperfect information, hidden costs, risks. Instead of being based on perfect information decisions are made by rule of thumb	Individuals and organizations conceived of as rational and utility maximizing	Neo-classical economics
Behavioural	Inability to process information, type of information, trust, inertia	Individuals limited rationally to non-financial motives and a variety of social influences, opponents to change within an organization result in overlooking cost-effective measures	Transaction cost, economics, psychology, decision theory
Organizational	Energy Manager lacks power and influence; organizational culture lead to neglect of energy/environmental issues	Organizations has the idea for a social system influenced by the goals, routines, culture, power structures etc.	Organizational theory

is essential. Credibility and trust in the source of information are important if energy efficient technology is to be implemented in a company. If individuals within an organization feel inertia towards energy decision-making, these decisions can be rejected. This is the third factor. The last factor is environmental values, which may be an important factor in leading individuals towards the energy efficient behaviour. Motivated individuals or organizations with environmental values can give energy-efficient investments a higher priority. [30]

Limited rationality is furthermore another barrier; instead of making decisions based on complete information, decisions on gut feeling are made, which contributes to that energy-efficiency investments will not been performed. [27]

Organizational perspective
The organizational perspective is the least developed perspective explaining the energy gap. It is a diverse view that uses a variety of ideas to explain different aspects of organizational behaviour. In organizational theory, where the perspective has its origin, there are two ideas that can be useful in understanding organizational barrier to the energy gap. These two ideas are "power" and "culture". Power means the relationships inherited in organizational structures and how these affect the ability of individuals or divisions to influence the decision-making. Energy usually has a low priority within organizations, leading to restrictions on the Energy Coordinator trying to implement energy efficiency measures. The second idea is organizational culture and it refers to values, principles and norms of behaviour in the organization, and how these in turn encourage or discourage investment in energy efficiency. Culture, regarding if environmental values are embedded within an organization or not, are important. [30]

For policy-makers and employees at companies it is important to understand the gap in order to make the energy efficiency measures successful. [30]

4.2.3 Establishing change within an organization

A number of success factors, to establish change within a company and to improve the energy management, in small-and medium-sized Swedish industrial companies, are listed below. The success factors originate from a wide range of companies. These examples start with the most important factor and then are the following factors presented in a decreasing order of importance [27].

- Energy issues should be anchored in the highest board at the company.
- Establish a strategy with quantified energy reduction goals over the next 5-10 years. This decision should be made at management level.
- Establish an action plan for how the set goals can be achieved.
- Establish a register where the energy issue has an "owner", an energy controller. This person does not need to work full time with energy, but should have an operational responsibility in production, such as a Production Manager, rather than Maintenance Manager.

- Set aside money for stationary measurement of energy use, preferably at departmental level.
- Appoint an Energy Manager in each department and shift responsibility for the operational aspects of energy efficiency.
- Provide the staff with continuous training in how the company wants them to take action on energy issues and give the employees feedback on how the company stands regarding achieving the quantified goals.
- Visualize the energy work on the intranet where each department's energy use are reported.
- Establish an energy competition between departments.

Several companies have a great deal of data related to energy consumption, and how the data is stored and reported is important. It is especially important how the data is stored when energy efficiency measures are implemented. After a new action has been established it is essential to ensure that the estimated energy savings are calculated and confirmed. Continuous monitoring of energy data can be used to see when facilities within a company use acceptable levels of energy. An example on how to monitor appropriate levels is to have an alarm go off when the energy consumption is higher than acceptable. Then the Process Manager can easily react directly and find out why the facility consumes more than expected. Another example to maintain an acceptable energy consuming levels is to have daily meetings about deviations or meetings when the shift changes. [20]

Energy Management Coordinator and Energy group

When a company has implemented an energy management system it is important to have an Energy Management Coordinator responsible for the management system. The existence of a Coordinator is important because it makes it easier to implement and develop the energy management system into the companies' routines. A Coordinator's job title may vary at different companies, e.g. Process Engineer, Energy Manager, Energy Management Coordinator. However, the work tasks are similar. The Coordinator works with planning, communication and follow-ups regarding progresses, but do not usually work full time with this. However, a significant part of their work time, about 25%, is usually devoted to the management system activities. [20]

The Energy Management Coordinator may have certain contact persons within the organization, most often contacts at each important production step. These contacts can be Process Engineers who report to the Coordinator whenever needed, or division-level Coordinators [20]. These people can form an energy group that usually consists of 3-4 people in a company with 300 employees. The energy group may consist of the Coordinator, division-level Process Engineers and technical experts recruited from the maintenance and from the project departments. This group should meet regularly a few times per year to organize and evaluate proposed energy efficiency measures and prepare decisions on implementation [31].

It is easier for the Coordinator to follow-up on energy saving possibilities if a register of the energy saving opportunities within the company is kept, then no possibilities are forgotten. The energy saving opportunities should also remain in the records after they have been implemented. This since the organization needs to retain knowledge on which measure that had a positive result and which did not. It is also easier for the Coordinator to motivate its existence for the board if a register is kept of what measures that have been implemented and how much energy that was saved. [32]

Monitoring energy use

Measurement of energy consumption is important for companies striving to save energy because it enables optimization potentials. Monitoring the actual performance of energy-consuming equipment and afterwards comparing the result, both to the theoretical value and industry norms, can help to reduce waste and maintain the established level. Energy consumption should be compared to other measurements that affect energy usage, for example production volume [29]. After measurement of energy consumption, development and application of energy efficiency indicators and key figures can be made. Usually key figures are ratios describing the relationship between an activity and the required energy. In the industrial sector one example of activity is the production process of a product, which can be described in both economic and physical terms resulting in either economic or physical indicators [33]. Many companies describe the work with key figures as enlightening, but is also complicated by using the relevant dimensions and putting energy use in relation to the relevant figures [27]. If the energy is used and monitored efficiently, new opportunities can be identified, leading to increased savings from efficiency investments [29].

Motivating staff to save energy

One important success factor for efficient energy management in companies is the motivation of staff. Even if the main opportunities to save energy are linked to process equipment at a chemical industry, human dimensions exist as well, for example how the staff operates a factory. Employees need to be motivated to save energy and this is accomplished by using energy goals. The staff's environmental concern, personal value and recognition of their achievements are the key motivators. A newsletter and posters may increase awareness of energy saving possibilities for the employees. Training of the staff is more important for employees who have greater influence on energy consumption. The training can consist of two steps for companies that have had little education in the past: firstly an initial training for a period of two weeks or a month. Secondly a strategy for integrating energy management training in already existing company systems, for example job descriptions, and introduction courses. [29]

In the energy management system standard ISO 50001, it is requested that a company identifies what type of training that is needed and for which staff. Training is important since energy efficiency improvements can be achieved from different divisions, for example at operation and maintenance, purchasing and project planning. The organizational structures within a company are always shifting when employees change positions and technical systems are altered when new technology is installed and these changes lead to continuous training. [20]

5 Result and discussion I - Energy usage analysis

The results from the statistical models are presented in this chapter. The polyol factories are presented one at a time. The steam usages in the factories are mapped, i.e. a minor energy audit is carried out, and the correlation between the steam usages in the components is presented. All factories analysed in this thesis have two steam pressure systems, one high and one low. The low pressure steam systems are named LP steam and the high pressure steam systems HP steam. Which factors that affect the steam consumption is presented, together with the amount of influence.

5.1 Introduction to the polyol factories

The energy necessary for the industrial processes varies between the factories on the site, depending on the size and the complexity of the factory. Energy is added to the processes through steam and electricity. The steam and electricity usage on the Perstorp site during 2011 can be seen in Figure 1. The total energy usage for this year was approximately 550 GWh. Four different polyols are produced at the site, named A-D. Polyol A and Polyol B together consume 50% of the total energy usage. A formaldehyde factory only consumes electricity, since it is an exothermic reaction. Polyol C and D are produced in the same factory and are therefore shown together.

Figure 1 displays a greater steam consumption compared to electricity usage. Due to this only steam usage was analysed within this thesis. Additionally, the steam usage varies more than the electricity usage, therefore making steam easier to affect.

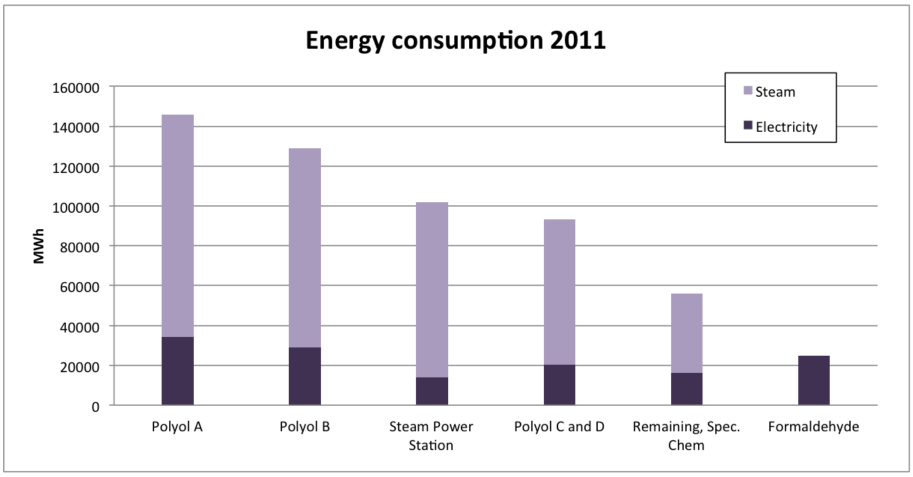

Figure 1: Energy usage on the site, 2011

The four figures below, Figure 2, 3, 4 and 5, illustrate the steam consumption for the four Polyols between January 2009 and October 2012. Both steam systems, HP and LP steam, are included in the figures. The steam meters have occasionally been broken and therefore many values are missing in the figures. Although, regarding Polyol C and D (Figures 4 and 5), the meters are not broken during all the gaps, instead most of the gaps represent time periods when the factory produced the other polyol.

Polyol A uses more LP steam than HP steam, approximately three times the amount of HP steam. For Polyol B, the meter for HP steam was locked at specific maximum before February 2011 and it was calibrated to solve this problem. Therefore no values are included in the Figure before this date. Polyol B uses slightly more HP steam compared to LP steam.

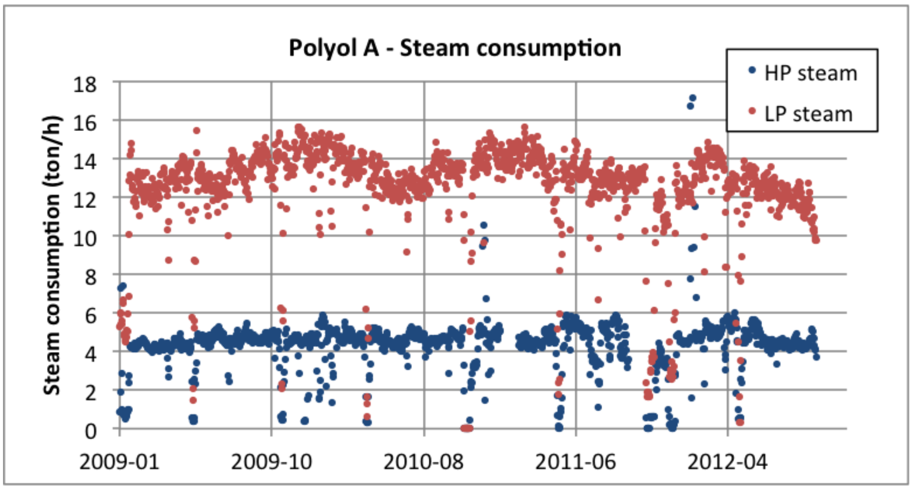

Figure 2: Steam consumption, Polyol A.

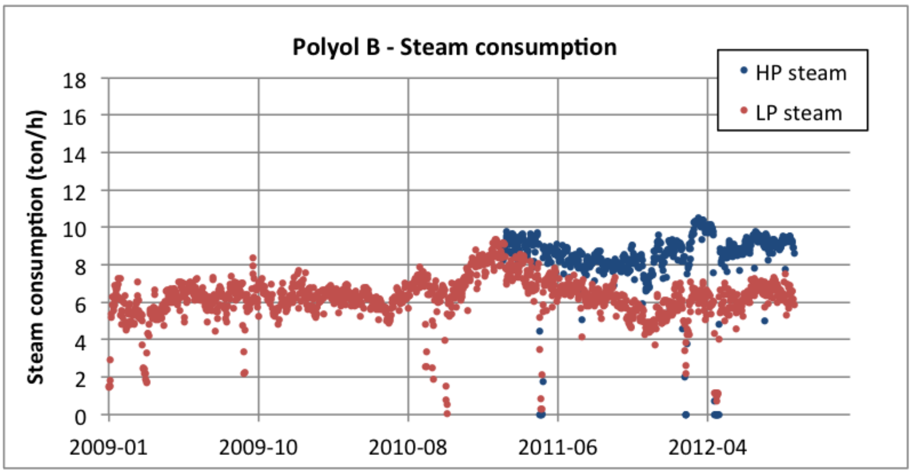

Figure 3: Steam consumption, Polyol B

The factory mainly produces Polyol C compared to Polyol D, which can be seen in Figure 4; there are less missing values compared to Polyol D's Figure 5. The factory only produces Polyol D one to two months per year. Both Polyol C and D uses approximately 3-5 times more HP steam than LP steam. The HP steam consumption also varies more than the LP steam.

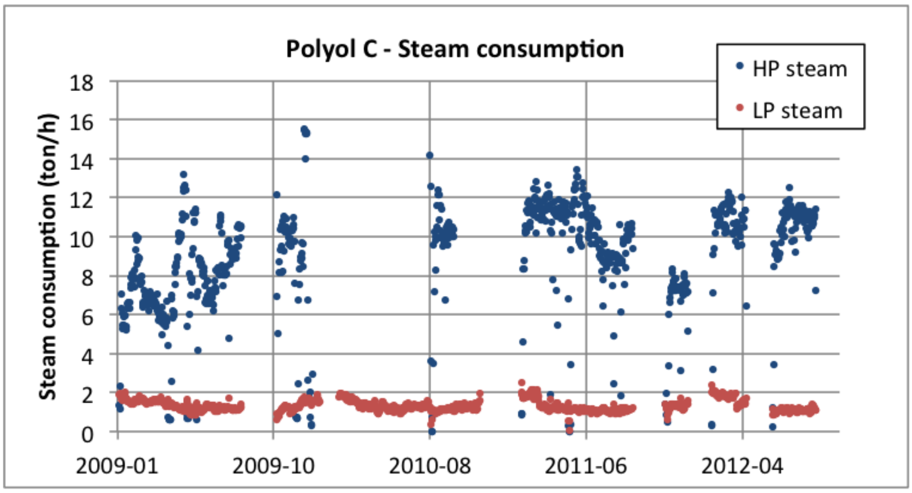

Figure 4: Steam consumption, Polyol C

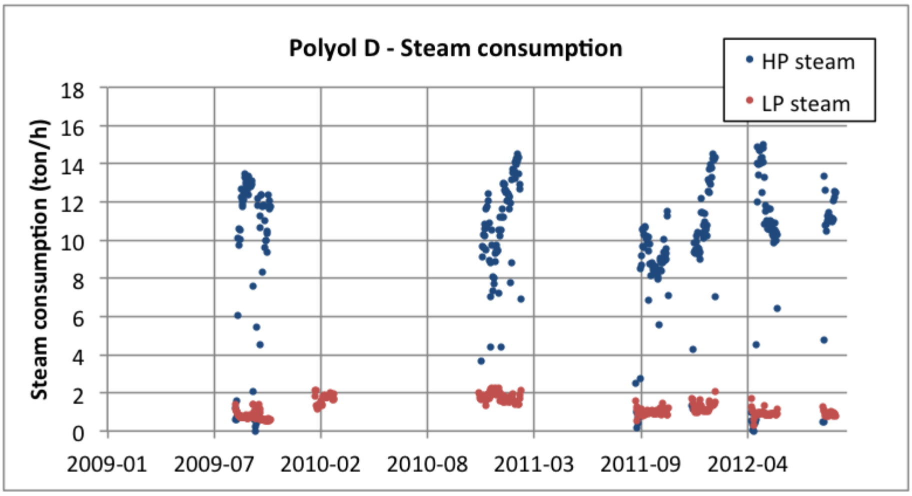

Figure 5: Steam consumption, Polyol D

5.2 Problems regarding measurements

At Perstorp, a wide range of different data is measured and saved, e.g. pressure, temperatures, flows and control mechanisms. This data is logged and stored every fifteen seconds.

It is more problematic to measure the mass flow of steam compared to a liquid. The volume of the steam passing by a meter is measured, for example, through a throttling of the flow. The volumetric flow is then converted to a mass flow with a temperature or pressure meter nearby. It is preferred to take both temperature and pressure into account, otherwise the steam is assumed to be saturated and a theoretical value of one variable is calculated. There are steam meters available on the market that measures all these variables within the same apparatus, but they are expensive in comparison to the more simple volumetric flow meters. At Perstorp, one variable is often assumed because a simpler meter is used. When more than one meter is measuring a steam flow, it is a greater risk of one meter breaking and giving an incorrect value. The number of steam flows covered by meters varies between the factories, as well as the number of meters that works and gives proper values. [34]

In order to relate the magnitude of steam consumption and create key figures, which enable comparisons, the production rate can be used. The steam consumption is often referred to in the ratio ton of steam per tons of product at the site. In each factory, the rate of production is presented on a daily base, in tons of produced product. Furthermore, there are ways to calculate the instantaneous production using the input of raw material. However, these calculations are complex and difficult to fully understand. In the energy analyses performed within this master's thesis, it was considered enough to look at the daily-based data.

As a first step in the performed data analysis, the available data had to be validated. It is commonly known among the staff that the meters sometimes are broken. If a broken meter is integrated in the process, the factory has to stop for it to be exchanged. Normally the factories have planned stops twice every year, so meters can be non-functional for a rather long time. Furthermore, if the outdoor temperature sinks below a certain temperature, a steam meter freeze if it is located outside and lack isolation. A frozen meter can show either too low or too high values. [12]

5.2.1 Valid data from the factories

As mentioned, the steam meters sometimes break and display incorrect values. All incorrect data were manually removed. To locate the inaccurate values, the Production Engineer and the Process Engineer for each factory were interviewed. All data when the production was beneath a "normal rate", according to the Production Engineers, was removed as well, since these days were not of interest. As mentioned above, the factories close down twice each year for repairs and maintenance. During these stops steam is still used for heating. If this data was included, the result could be misleading.

Some of the factories have two main meters measuring HP or LP steam. This is if the steam enters the factory on two different locations. If two meters are measuring the incoming steam instead of one, the risk that one of the meters will be broken any time increases. If one meter is broken, data from the other meter cannot be used either.

5.3 Examined variables

Steam is used in several different systems and processes in the factories. To know precisely what affects the steam consumption and to what extent is difficult. Within the scope of this study, five variables were selected for further analysis. The choice of these variables were based on discussions with Process and Production Engineers [35] [12] [36] [37]. However, not all five variables have been tested for all polyol factories; which variables that were included in the models depended on the factory's construction and the available data for that factory or component. The five variables are: production rate, outdoor temperature, cooling water temperature, water concentration in a factory and product flows. These variables are described more thoroughly below.

5.3.1 Production rate

The production rate can affect the steam demand in a process. It is often the case that more steam is used when the production rate increases. Therefore, the production rate was included as a variable in all steam models.

5.3.2 Outdoor temperature

Outdoor temperature can be an important variable for the steam flow used for the heating of facilities and pipelines. If the weather is cold, more energy for heating is necessary. Furthermore, steam must sometimes be released to avoid freezing of the pipes during a cold winter, which results in greater steam usage. Theoretically, the outdoor temperature should only affect the steam flows used for heating. However, outdoor temperature will be a factor in the multiple linear regression for all steam systems, as many of the components are situated outdoors.

5.3.3 Cooling water temperature

Cooling water temperature is another factor that can affect steam consumption. Especially the steam ejector component should be affected. Connected to the distillation column, there is a condenser that cools the gas leaving the column. Depending on the cooling water temperature, condensation occurs differently; a lower cooling temperature provides a greater cooling capacity, thereby lowering the vapour pressure of the recently liquefied gas. Cooling water temperature affects the vapour pressure of that condenser, thus the pressure at which the evaporation of a substance is in equilibrium between its liquid and solid state at a given temperature. At higher temperature of the cooling water, a higher proportion of gas does not condensate and needs to be taken care of by the steam ejectors. The steam ejectors will then be subjected to a higher burden and since they are powered by steam, the steam consumption will increase. The cooling water temperature also affects a second condenser, that is located after the steam ejectors, by condensing steam with the mixed gas from the distillation column. At lower cooling water temperature, this mixture is condensed efficiently and creates a lower pressure. A lowered pressure drives the steam mixture out from the steam ejectors more efficiently, which will lead to less steam required in the ejectors. [35]

5.3.4 Water concentration in a factory

The amount of water circulating in a factory can have an impact on the steam consumption. At all polyol factories, water has to be removed, because the raw material contains more water than the product. At Perstorp, the amount of water in the flows can be measured, either by using a density or concentration meter at the product flows. From this data can the water content can be calculated. Some product flows have density meters and other flows and tanks have concentration meters measuring formalin, which is the case for Polyol B, see section 5.5.4. Not all polyol factories measure these variables, i.e. they were only included in some models.

5.3.5 Product flow in a factory

The product flow entering the components can also have an effect on the steam usage. For example, the steam is used to dry, evaporate and separate the product flow, and thus more steam should be needed with a greater flow. However, the product flow is only measured in some components.

5.4 Polyol A

The result concerning Polyol A is presented in this section. Polyol A was investigated more thoroughly than the other polyols. Initially, a model for the entire factory's steam consumption was performed, using the main steam meter. Secondly, some components' steam consumptions were modeled, using the steam meters connected to that component.

5.4.1 Chosen data

The normal production rate for the Polyol A factory was considered to be above 65 tons per day [12]. Days when the production rate was below this, the steam consumption was not of interest. The amount of daily production data below 65 removed, was about 12% of the total data.

The Polyol A factory has four main meters measuring the incoming steam to the factory. Two are located on the HP steam system and two on the LP steam. For the HP steam flow, some of the data was manually removed because one of the steam meters freezes below a certain temperature, since a part of the pipe is not isolated. Then, the steam values were either unreasonably high or low. Because there is an uncertainty to when the data is correct, all values below -4.7°C were removed. Apart from this, there were two months in 2011 where one of the HP steam meters was broken; these values were removed as well. In total, 10% of HP steam values above the production rate 65 ton/day were deleted. All of the LP steam data above 65 ton/day was included in the model.

5.4.2 Statistical result for main meter

The steam consumption measured by the main meters (for the entire factory), was inserted in a multiple linear regression model, against the measured production rate of Polyol A and the outdoor temperature. The calculated β values can be seen in Table 12, and the standardized β values in Table 13, both in Appendix.

HP steam
The results for HP steam consumption, showed a dependency against both production rate and outdoor temperature. However, the R^2-value was low, only 7%. The β (Equation 3) for the production rate was larger than zero, i.e. when the production rate increased, the steam consumption increased as well. The temperature-β was reversed, when it was getting warmer outside, the steam consumption decreased.

A standardization of the vectors showed that HP consumption was more correlated to the production rate than for the temperature (the standardized β was higher for the production rate than the temperature)l. HP steam is used in process steps and different components, therefore not for heating of pipes or facilities, which explains the low dependency of temperature [12].

LP steam
The result from the LP steam model shows that the steam consumption was dependent on both production rate and outdoor temperature. The R^2-value was 39%. The production rate-β had a value larger than zero and the temperature-β was lower than zero. This is logic, because LP steam is used for heating of pipes and facilities. [12]

The standardization indicates that production rate and outdoor temperature have an approximately similar impact on the LP steam consumption.

5.4.3 Expected steam consumption

To receive an indication on the energy performance, an expected steam consumption was calculated and compared to the measured steam consumption. How the expected steam consumption was calculated can be studied in Equation 5. Below, the differences between the real measured steam consumption from one day and the expected values for that same day are illustrated in the figures. A positive difference, i.e. value above zero, indicates that steam consumption could have been lower according to the model. In other words: the measured steam consumption was higher than the expected one. On the contrary, a negative value means that the measured consumption was lower than the expected.

HP steam
In Figure 6, the difference between the real, measured, steam consumption and the expected steam consumption, for the HP steam system, is displayed. Since the R^2-value for the model was low, 7%, the figure should not be to carefully analysed. However, it is possible to see a variation over time. As an example,

the real steam consumption was lower than the modeled during the last months of 2012. To analyse this further it was necessary to model the steam consumption for the steam-using components.

LP steam

For the LP steam flow, there was more to look into. Figure 7 displays the difference between the measured LP steam value and the expected value. It has to be kept in mind that the R^2-value for the model was only 39%. The measured value is 1 ton steam per hour higher than the expected value at several occasions. There are a few values with a difference of over 1.5 tons per hour. These can be found during the spring of 2011. Worth noticing is the amount of values, during 2012, where the measured values are lower than the expected ones. It can be noted that the curve is similar to a sinus curve. At a first glance it seems like the curve follows the temperature gradient during seasonal variations, but this is not correct. The higher differentiating values are located during all seasons. The appearance of this curve can indicate that there is another dependency between these variables that is not linear. This dependency could be logarithmic or exponential, and the model has to be handled with caution. However, these other dependencies were not further studied within this master's thesis. This because the R^2-value was considered too low for the model to be realistic.

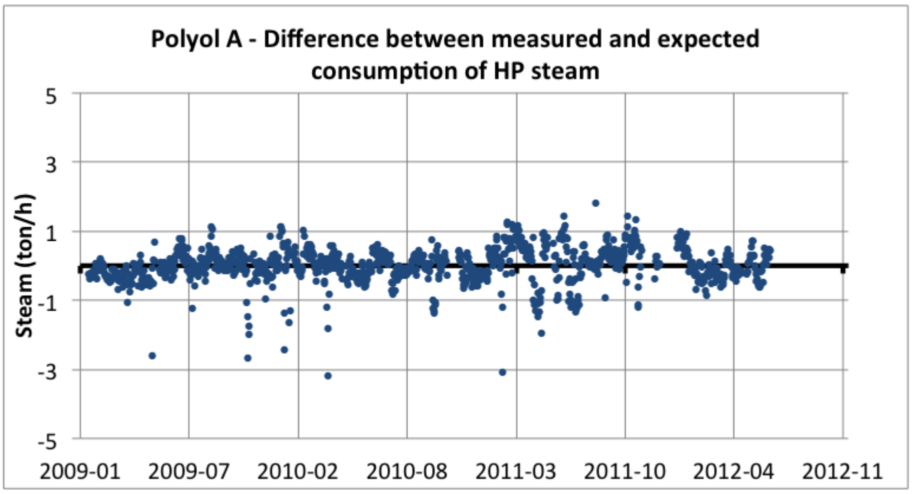

Figure 6: For Polyol A, the difference between the measured high steam consumption and the expected consumption in the statistical model from January 2009 to September 2012

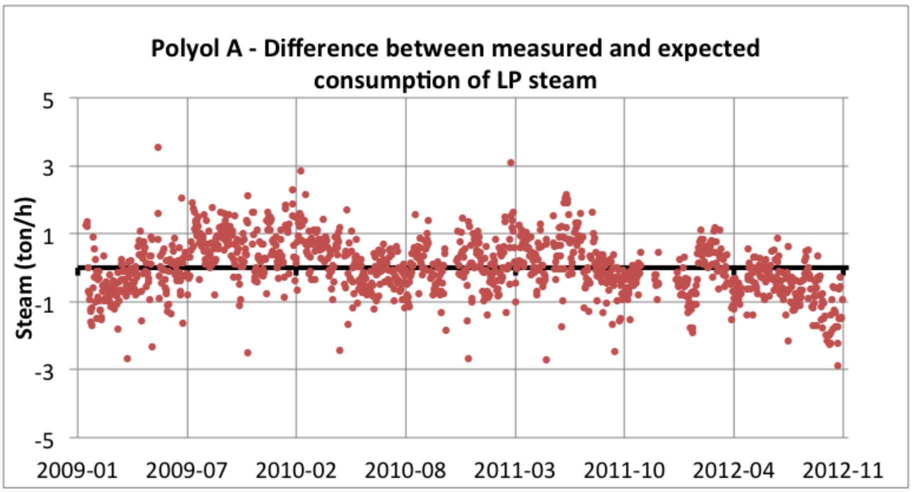

Figure 7: For Polyol A, the difference between the measured low steam consumption and the expected consumption in the statistical model from January 2009 to September 2012

5.4.4 Components for Polyol A

Because there was a time limit for this thesis, only one factory's components was analysed more closely, which is Polyol A's.

For Polyol A, the model including the main meters resulted in low R^2-values. Therefore, these models were extended to include the largest, measurable steam-using components. There were two purposes of this: improving the total model for the factory and to evaluate the steam consumption in the components. If the steam usage in a component was described in a satisfying way, this model could be of use in the daily work in the factory.

To decide which variables to add in the total model, the components and their different complexities were firstly analysed. The best R^2-values for the components can be seen at the end of this chapter, in Tables 6 and 7. As a last step, the total model and the component models were linked together.

Initially, large consumers of HP and LP steam were identified. These can be seen in Figures 8 and 9. The steam consumption is viewed as an average over a period from January 2009 to October 2012, and only for the days where the production rate was above 65 tons/day. However, some of the components' steam meters were installed during this period; Dryer 1's HP steam meter was installed in the middle of 2011, Production line D's and the Dissolver's LP steam meters were installed at the end of 2011. A larger part of LP steam is measured compared to HP steam. During 2012, when all steam meters were in place, 93% of LP steam inside the factory was measured and 63% of HP steam.

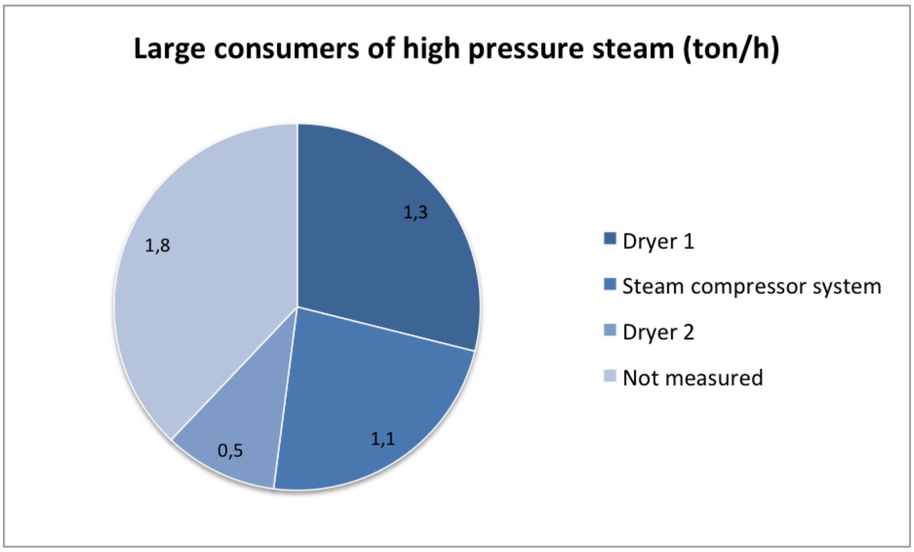

Figure 8: Large consumers of HP steam in Polyol A factory. All values are presented as average ton per hour.

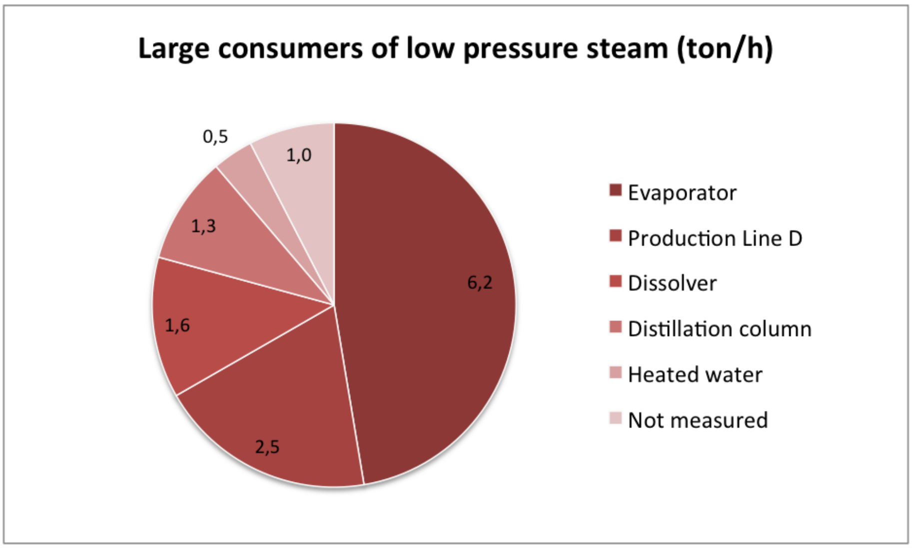

Figure 9: Large consumers of LP steam in Polyol A factory. All values are presented as average ton per hour.

Statistical modelling

A multiple linear regression was performed, testing the dependency between the components steam usage and the production rate and the outdoor temperature, i.e. the same statistical analysis that was carried out for the main meters. The largest measured HP steam users and their correlations are presented in Table 2. The results for the modelling of the dependency of the LP steam users can be seen in Table 3.

A more thoroughly statistical analysis was performed for six of these components. The components were studied one at a time, by interviews with personnel and reviews of flow charts. This was the basis for statistical models. The studied components were:

- Dryer 1 at HP steam system
- Dryer 2 at HP steam system
- Steam compressor at HP steam system
- Distillation column at LP steam system
- Evaporator at LP steam system
- Dissolver at LP steam system

Table 2: Dependency and R^2-value for components in Polyol A, production rate and outdoor as regressor variables, HP steam

Component	Dependency	R^2-value
Dryer 1	Production rate	35%
Dryer 2	Production rate and outdoor temperature	2%
Steam compressor	Production rate	1%

Table 3: Dependency and R^2-value for components in Polyol A, production rate and outdoor as regressor variables, LP steam

Component	Dependency	R^2-value
Evaporator	Production rate and outdoor temperature	12%
Dissolver	Production rate and outdoor temperature	70%
D-line	Production rate	45%
Distillation column	Production rate	1%
Heated water	Production rate and outdoor temperature	20%

Dryer 1 at HP steam system

There are two dryers using HP steam in the Polyol A factory: Dryer 1 and Dryer 2. They are separated from each other on two different production lines and are both the last step in the process: drying two different products. The dryers are basically working with the same principles, with some exceptions. The flow entering the dryers contains a part unwanted liquid. This entering flow is called bulk mass. To eliminate the water, HP steam is used. The steam is heat exchanged with outdoor air. This heated air is applied on the bulk mass, evaporating the liquid.

Dryer 1 is a larger consumer of steam compared to Dryer 2. One reason for this is that there is a higher quality demand on the product from Dryer 1. Before the product flow enters the dryer, it is dewatered on a band pass filter, where some liquid is removed with under pressure created by a vacuum pump. The density of the product flow is measured before it enters the band pass filter. The pressure on the filter is measured. The actual flow entering the dryer is not measured. This is because the amount of liquid remaining in the bulk mass can differ. Another complication is the variation in moisture content in the outdoor air. The steam intake is controlled against the temperature in the dryer.

This steam usage was modeled against: the flow into the band pass filter, the density of the flow, total production of the current product, outdoor temperature and pressure on the band pass filter. The result was a correlation to all variables except for outdoor temperature, and R^2- value was 52%. The flow to the band filter had the largest correlation. This dependency can be seen in Figure 10. The Figure shows both a larger consumption and variation the first five months. In Figure 11, the ratio between the steam consumption and the flow entering Dryer 1 can be seen. This ratio basically shows the same as Figure 10, but with a possibility to see changes over time. Even though the R^2-value was over 50%, there is still a part of the steam usage left unexplained.

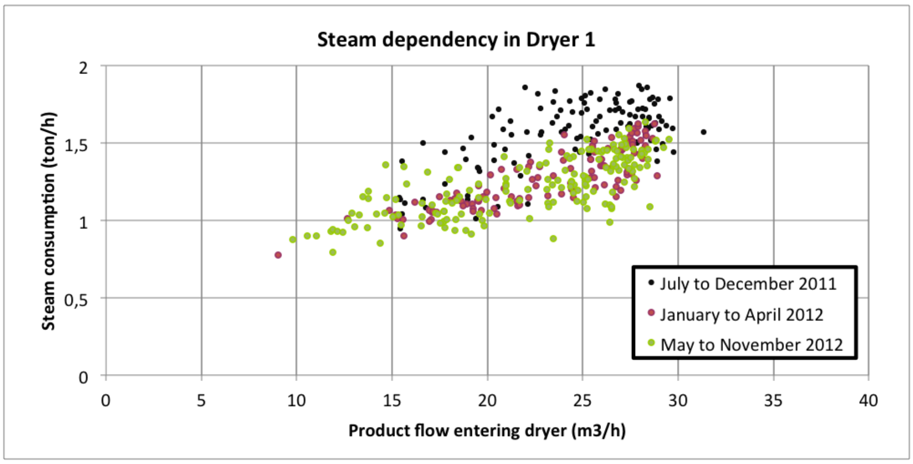

Figure 10: The dependency between steam consumption and the flow entering Dryer 1, from June 2011 until November 2012

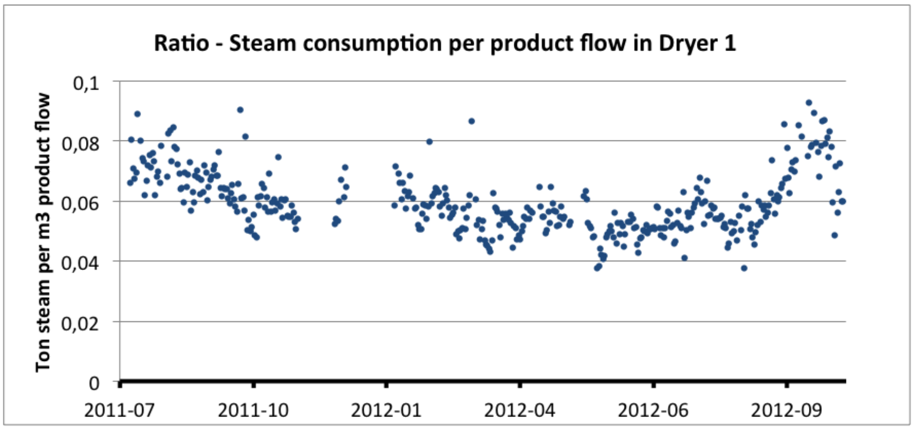

Figure 11: Ratio between steam consumption and flow entering Dryer 1, from June 2011 until November 2012. Same result as previous figure, but with the possibility to see change of ratio over time.

The expected steam consumption was calculated in the initial models for the whole factories. The difference between real steam consumption and expected steam consumption according to the model can be studied in Figure 12. In this Figure a larger steam consumption than expected can be seen for the first five months.

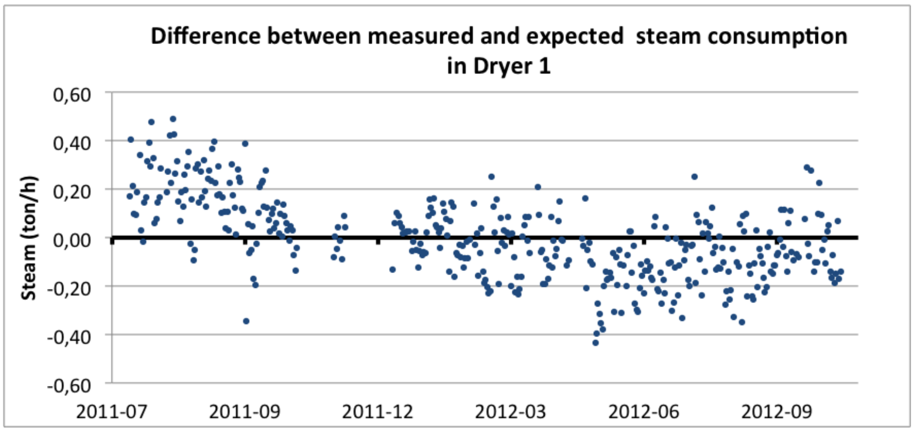

Figure 12: For Dryer 1, difference between measured and expected steam consumption in the statistical model from June 2011 until November 2012

A crystallizer located before Drier 1 in the process is thoroughly washed approximately every tenth week, removing coatings on the walls. After the cleaning, the steam consumption ought to decrease, because a crystallizer without coatings on the wall, becomes more efficient. This statement was tested in the six times the crystallizer was washed during the period the steam flow has been measured. Ten days before all the washings was compared to ten days after the washings. The average steam consumption (in kg/h) was divided with the average product inflow (in m^3/h), both in the days before and after the washes. These ratios were compared, the result is presented in Table 4. The steam ratio did decrease after the washing for four of six stops. This indicates that washing of the crystallizer can have a positive effect on the steam consumption in Dryer 1.

Table 4: The ratio between steam consumption and product flow in Dryer 1, before and after six stops for washing.

Stop	July 2011	Dec 2012	March 2012	April 2012	May 2012	Aug 2012
Ratio before (kg steam/ m^3 flow)	73.8	55.7	56.8	53.1	54.3	60.0
Ratio after (kg steam/ m^3 flow)	71.3	63.7	49.9	56.5	51.2	55.6
Difference, after-before	-2.5	7.9	-6.9	3.3	-3.1	-4.4

Dryer 2 at HP steam system

Dryer 2 is placed after the Evaporator, which is described later in this subchapter. It operates by the same principle as Drier 1. Outdoor air is warmed up in a counter flow heat exchanger, where HP steam is condensed, transferring the energy of vaporization to the air. The warm air then passes through the moist product, drying it.

Before the product flow is dried in Dryer 2, it loses some liquid in two hydro cyclones (a device that separates solid substances from a liquid) and two centrifuges. The product flows entering the hydro cyclones are measured in two different meters, one per flow. The flow of the moist product arriving to the dryer is on the other hand not measured. Neither is the moisture content of the mass known.

The amount of steam used in the heat exchangers is controlled by a temperature meter that measures the temperature inside the dryer. It is often the case that the temperature does not reach the set point. This is even though the control valve controlling the steam flow is 100% open. This equals a steam flow that is not sufficient for the mass flow entering the dryer. Dependency of the steam consumption in this component was tested against five variables; the production of product, the outdoor temperature, the flow to the evaporator located before the drier, the flow to the hydro cyclones and how much the control valve was open. The result showed a correlation against all variables except production rate and outdoor temperature and had a R^2-value of 13%. Steam consumption per hour over time can be seen in Figure 13. Worth noticing is the decrease in both variation and steam consumption in the late 2010. Around this moment was the steam traps replaced, which lowers the steam consumption. A steam trap is a device that only allows condensate to pass through, meaning no steam passes by the steam trap. When modelling only these, more stable, steam values, the R^2-value was 24%. What was interesting is the fact that the steam no longer is dependent on the flow entering the dryer and the evaporator. But since the R^2-value is low, one should not look too deep into the correlations.

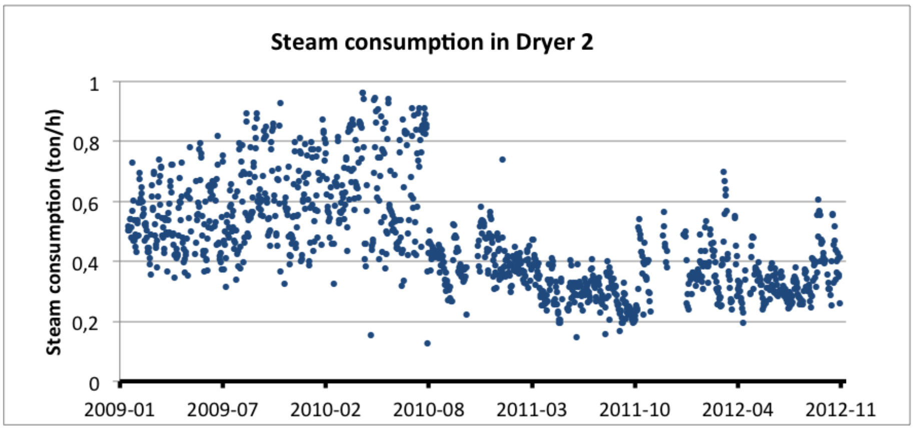

Figure 13: Steam consumption in tons per hour from January 2010 to November 2012

How the steam usage varied and its dependency on the days when the steam was sufficient, i.e. when the control valve is not 100% open, was modeled. 45 days during 2010 could be found, where the control valve was partly closed. The result was a low R^2-value of 8%, correlating to the production rate.

Steam compressor at HP steam system

The steam compressor system is a complex system, with many components. The system in holds a steam compressor connected to an evaporator. HP steam (here called primary steam, to clarify) is added as a complement to the compressed steam. One can imagine this system as a black box and inside this box steam is circulating between different components. The steam is loosing pressure when energy is transferred from the steam to the components. In the imagined box is also a power-driven steam compressor that compresses the steam by raising the pressure (i.e. energy content) of it. If there is no leakage of steam, the steam flow would be sufficient inside the black box. But there is always leakage, and therefore it is necessary to add primary steam. If the circulating flow stops, primary steam is required to start the process.

The heat exchangers in the evaporator are constantly being deaerated; inert gases (gases that are not chemically reactive) are removed from the component. With these inert gases, some steam is removed as well. The gas flow is warm and this heat is utilized in a distillation column later on the production line (meaning less primary steam is necessary in the distillation column). There are two valves that control the gas flow leaving the evaporator toward the distillation column. The amount of heat leaving with this flow is unknown.

A statistical model over the dependency of the primary steam entering the evaporator was performed. In a first model, the control valves, which measures the percentage of gas flow leaving the evaporator, were included. Together with these variables, the outdoor temperature and the product flow to the evaporator was added, resulting in a R^2-value of 9% and a correlation only to temperature and one of the control valves. In a second analysis the control valves were excluded, resulting in an even lower R^2-value of 1%. Therefore, expected steam consumption was not calculated. Steam consumption per hour over time can be seen in Figure 14.

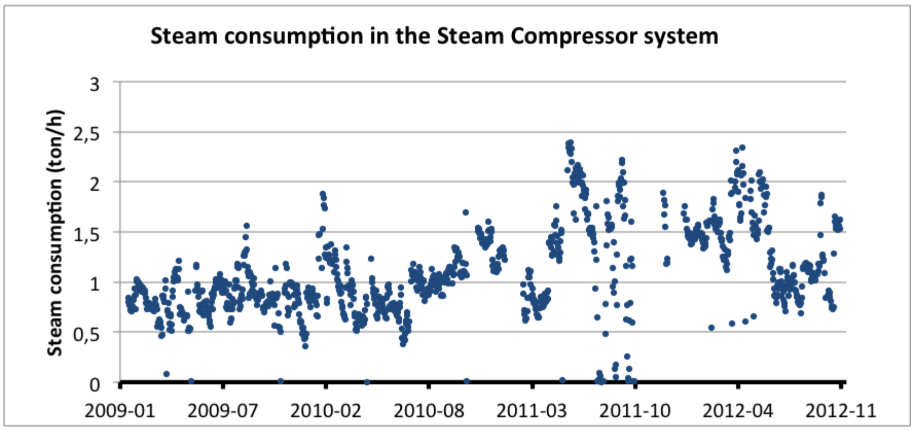

Figure 14: Steam consumption in tons per hour in the Steam Compressor System from January 2010 to November 2012

Approximately once every tenth year a lamella package is changed in the columns, improving the heat transfer surface. This happened in 2010 and the primary steam consumption was examined before and after the stop. No clear decrease could be noticed. However, it was difficult to analyse the result, as the model did describe the steam consumption inadequately.

Distillation column at LP steam system

Another consumer of LP steam is a distillation column, located near the reaction tank at the beginning of a production line. This component is partly heated by LP steam and partly with warm inert gases transported from the steam compressor system described above. The warm inert gases complicate the dependency analysis of LP steam consumption in the distillation column. If the heat flow from that system is greater, less LP steam is needed. How large the heating value of the inert gases is can differ depending on the mixture of the gas, its pressure and the size of the flow. The last, flow of the inert gases, is the only variable measured.

An analysis was performed, where the flow of the inert gases, the product flow, the production rate and the outdoor temperature were included. The model for the distillation column did result in a R^2-value of 16%. An additional model was performed with HP steam usage in the Steam compressor system, but with a non-dependency as a result. Expected steam consumption was not calculated for this component's steam usage. Steam consumption per hour over time can be seen in Figure 15.

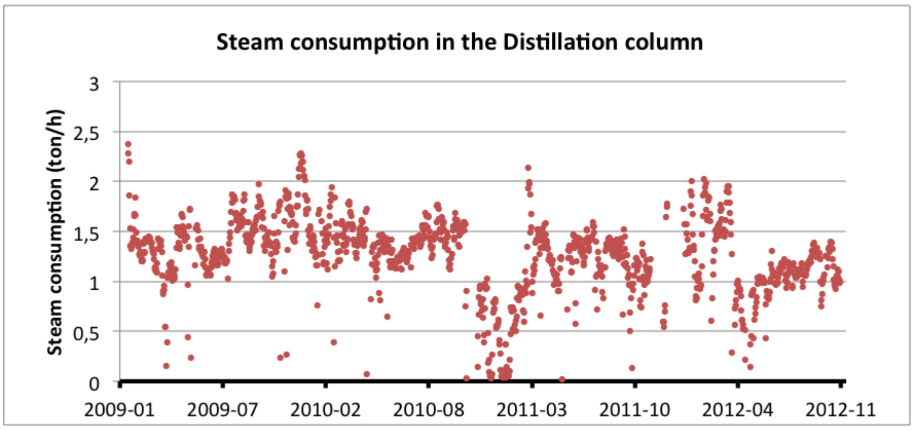

Figure 15: Steam consumption in tons per hour in the Distillation column from January 2010 to November 2012

Evaporator at LP steam system

Polyol A has an evaporator that uses approximately 40% of LP steam. This Evaporator is the largest steam consumer in the factory. The production line that the Evaporator is located on produces a by-product. A valve regulates the volume of the LP steam's flow, and this valve is manually regulated. Since 2009, the valve has been open 100% during almost all time, therefore was maximum steam used in the Evaporator. Although, 50 days were found when the valve not has been open 100%, and these days were analysed separately. This gave two scenarios to analyse, first one including all values since 2009 and second those 50 days. All Mondays and Fridays were removed, because during these weekdays a washing is performed (to remove crystals) in the Evaporator. This leads to a lower production rate these days, i.e. less steam consumption.

All days except Mondays and Fridays

Regarding all the measured values since 2009, the result showed that the Evaporator's steam usage was dependant on the inflow, the density of the inflow and the outdoor temperature. These three factors gave a total R^2-value of 58%. The inflow was the factor affecting the steam consumption mostly, second was the outdoor temperature and third the density. The density describes how much water the product flow contains, and becuase the Evaporator removes water, it follows that with more water in the product flow, extra steam is needed.

To further investigate the temperature dependency, a plot was made with the ratio between average steam consumption ($tons/h$) and the average inflow (m^3/h) together with temperature in the same figure, Figure 16. The figure shows that the ratio was higher during the cold months, which indicates that the steam is dependent on temperature. It can also be seen that the ratio has decreased since 2010, which means that the Evaporator uses less steam today. The authors asked Process Engineers and Technical Engineers working at Polyol A if they had any thoughts on why the steam and inflow ratio did decrease after 2010. They explained that nothing has changed at the Evaporator during the last years: no new installations and nothing have been modified with the regulation of the valve.

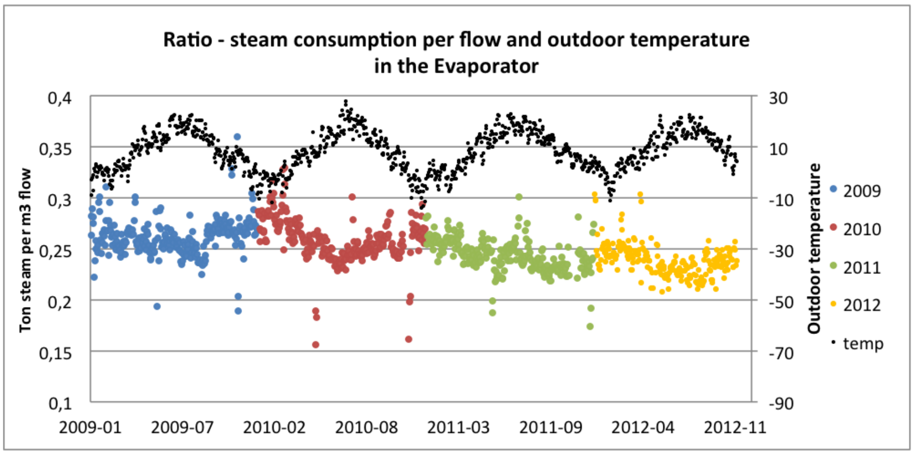

Figure 16: The ratio between steam consumption and the flow entering the evaporator, and the outdoor temperature.

The ratio did decreased especially during year 2011, which can be seen in both Figure 16 above and Figure 17 below. In Figure 17 is the difference between the measured steam consumption and the expected steam consumption showed.

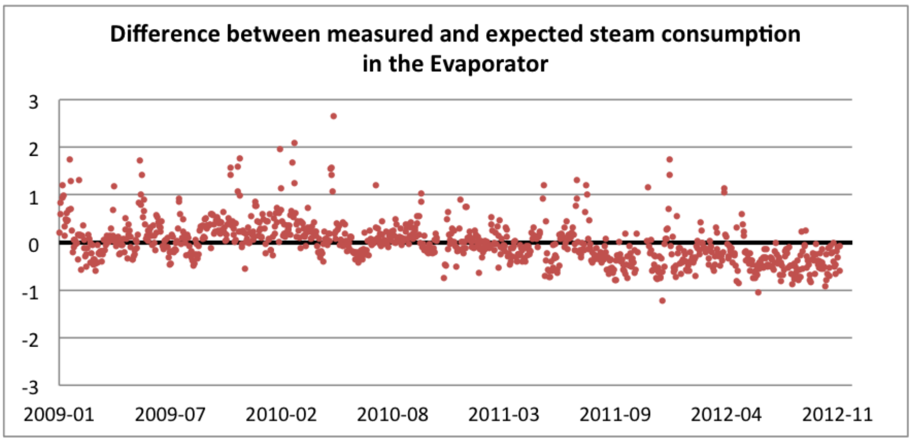

Figure 17: The expected steam consumption regarding the Evaporator.

Circulating water and steam consumption

A couple of times every week a laboratory assistant takes samples from a buffer tank and investigates the water content. This sample is taken prior the Evaporator and the solution has been through another evaporator earlier in the process (the one included in the Steam compressor system described earlier in this subchapter). The evaporator in the Steam compressor system changed a lamella package in 2010, which should improve the heat transfer. This could have been the reason that the ratio regarding steam and inflow was better the last years. As can be seen in the Figure 18 below, the ratio decreased in 2010 when the water content was reduced.

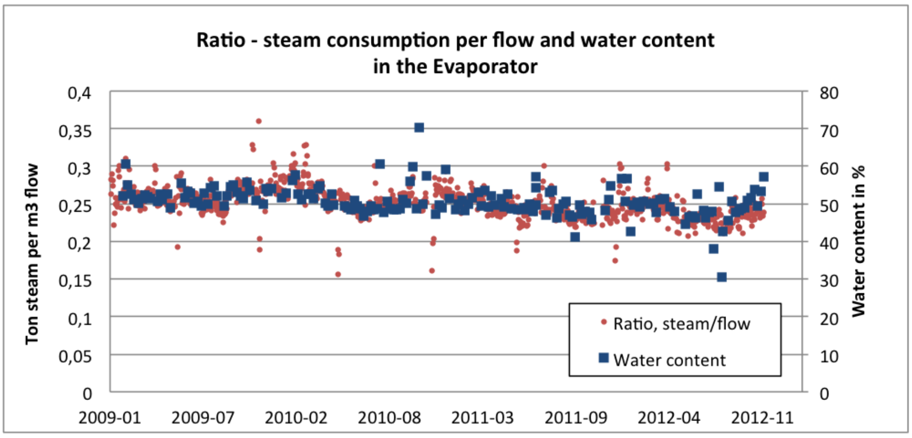

Figure 18: The ratio between steam consumption and the flow entering the evaporator, and the water content in a tank situated before the Evaporator.

Stop of production

Perstorp has a stop of production twice every year, this because they need to repair or install some components. During these stop they also wash the heat exchangers from coating to improve the heat transfer coefficient and enhance the heat transfer in the Evaporator. It was interesting to see if less steam is needed after a stop, as the heat transfer in the heat exchanger should have been improved. To investigate this, 30 measured values before and after five stops was analysed.

The expected result from the stop of production-analysis, that the ratio between steam consumption and flow should decrease, did not apply for all investigated stops. The ratio was calculated by dividing the average steam consumption during 30 values with the average product flow during these days. The ratio before and after the stops was then compared. In Table 5 the resulting values can be seen. Five stops of production were investigated and during three of them the ratio decreased, i.e. less steam was used after the washing. However, the ratio increased after two stops of production and therefore was more steam used after the cleaning. This is peculiar becuase the heat transfer coefficient ought to increase if the coating is removed. An answer to this could be that the density of the product flow after the evaporator is lower before the stop compared to after. Though, this is not the case for these stops, the density is almost the same after and before, which indicates that the flow of water the Evaporator has to remove is equivalent before and after the stop.

Table 5: Result of the ratio between steam consumption and flow through the evaporator, before and after five stops.

Stop	May 2010	Nov 2010	May 2011	Nov 2011	May 2012
Ratio before (tons steam/ m^3 flow)	0.260	0.254	0.246	0.231	0.242
Ratio after (tons steam/ m^3 flow)	0.248	0.267	0.238	0.244	0.231
Difference, after-before	-0.011	0.012	-0.007	0.013	-0.011

Valve not open 100%

During most of the time since 2009, the valve for controlling the steam flow was open 100%, i.e. there was a maximum flow of steam into the Evaporator. The steam is often set to its maximum becuase the product flow then can be at its max. If Perstorp wants to produce the maximum amount of Polyol A, the inflow needs to be at its utmost rate and therefore the steam is set to the highest value and the valve is entirely open. To investigate what the ratio was between the steam and inflow when the valve was not entirely open, 50 days was found during the autumns of 2011 and 2012. A ratio was then calculated for these days and the result was 0.24 ton steam per m^3 product flow. The ratio for all the days since January 2009, without Mondays and Fridays, was 0.25. This indicates that it is better to have a slower steam flow into the Evaporator, which was the case during these 50 days. The problem is then that not as much product is produced. When one calculates the dependency for the steam when the valve is not fully open it differs from the result when it is. During all days since January 2009, except Mondays and Fridays, the steam was dependent on inflow mostly, secondly the temperature and least the density of the out coming flow. When the valve was not fully open, the steam was 90% dependent on the inflow, see Figure 19. If one include the density, the production of total product (Polyol A) and the production of salt (by-product) the R^2-value is 91%. The temperature, which was the second largest steam dependency factor before was not even in the result for these 50 days, i.e. the Evaporator was not temperature dependent.

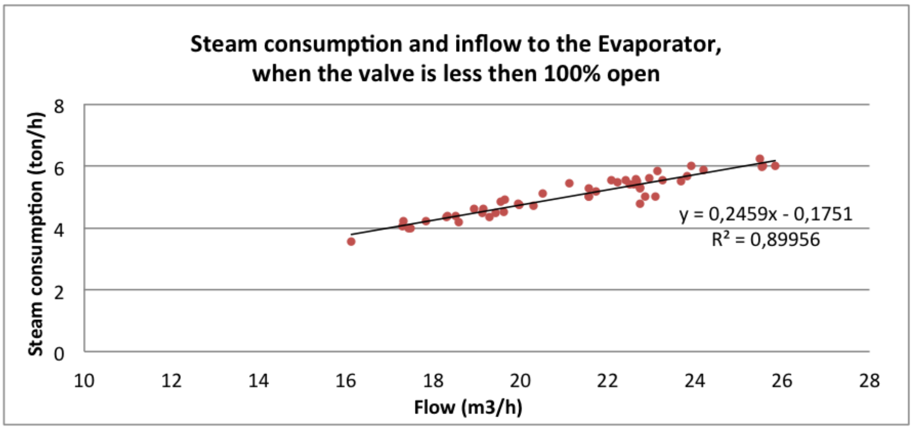

Figure 19: The dependency between steam consumption and the flow entering the evaporator, when the valve is not fully open.

Dissolver at LP steam system

A model of a LP steam-using Dissolver was performed. The model did result in a R^2-value of 70% when the factors production rate and outdoor temperature were included. This was considered to be a high dependency. When testing the steam dependency only for the production rate, the model resulted in the same R^2-value, meaning that the influence of temperature was neglectable. The steam consumption in the Dissolver showed the same dependency of the product flow entering it as the production rate. Both the production rate and the product flow entering the Dissolver cannot be in the same model due to the problem regarding multicollinearity. The ratio between steam consumption in the Dissolver and flow entering it can be seen in Figure 20. The figure displays a larger ratio during the September 2012, which probably is caused by a decrease in the product flow that month. The expected steam values were calculated for the Dissolver, based on this model. The difference between the measured and expected values is displayed in Figure 21. Worth noticing in the Figure is that the difference for a majority of the values are ± 0.2 ton/h, compared to an average consumption of 1.3 ton/h.

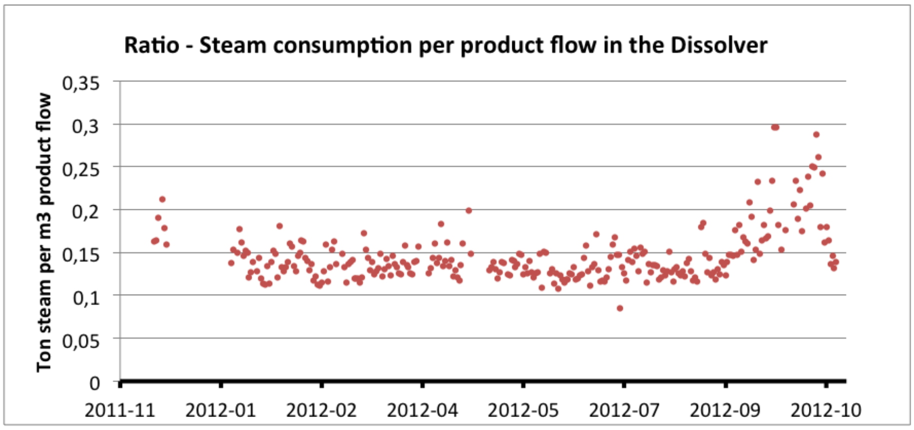

Figure 20: Steam consumption in tons per hour in the Distillation column from January 2010 to November 2012

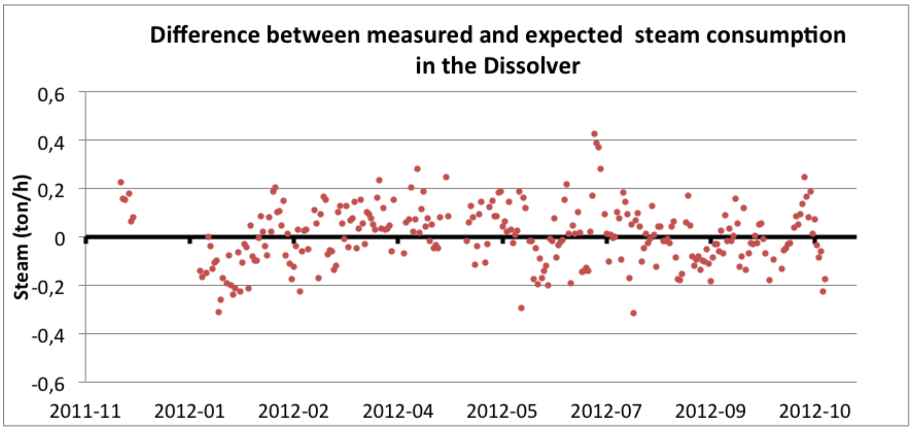

Figure 21: For the Dissolver, the difference between measured and expected steam consumption in the statistical model from January 2010 to November 2012

Table 6: Dependency and R^2-value for components in Polyol A, specific regressor variables for each component, HP steam

Component	Dependency	R^2-value
Dryer 1	Product flow, Density, Production rate, Pressure on filter	52%
Dryer 2	Product flow, Control Valve	13%
Steam compressor	Outdoor temp., Control Valve	9%

Table 7: Dependency and R^2-value for components in Polyol A, specific regressor variables for each component, LP steam

Component	Dependency	R^2-value
Evaporator	Product flow, Outdoor temp., Density	58%
Dissolver	Production rate and outdoor temperature	70%
Distillation column	Inert gas flow, Product flow, Prod rate, Outdoor temp.	16%

5.4.5 Adding new regressor variables to the total model

In this section the total model for the entire factory is combined with the components' models. The attempt was to improve the total model for the main steam meter by adding some inflows to the main components in the model. The variables outdoor temperature and production rate were still included. Table 8 summarizes the results.

For the HP steam model; the inflow to the two dryers was added since the model best described these components. The inflows did improve the model slightly, the R^2-value increased from 7% to 12%. These inflows to the two dryers affected the steam consumption more than the production rate and the temperature.

LP steam has more components and three inflows were added to the model. These inflows were to the following components: the Evaporator, the Distillation column and the Dissolver. The main steam was dependent on all these factors and the R^2-value increased from 39% to 56%. The main dependency factor was outdoor temperature. After temperature, it was the inflows to the Evaporator and the Dissolver that had the second largest influence on the steam consumption.

Table 8: Dependency for Polyol A, with and without some component's flow, and R^2-values for the models

Polyol	Steam	Dependency	R^2-value
A	HP steam	Production rate and Temperature	7%
	LP steam	Production rate and Temperature	39%
A, added flows	HP steam	Prod rate, Temperature and 2 flows	12%
	LP steam	Prod rate, Temperature and 3 flows	56%

5.4.6 Total model with fewer days

To further improve the total model containing production rate, outdoor temperature and some product flows, selected days for each steam system were studied. 117 days were included in the model for HP steam and 150 days for LP steam. During these days the actual steam consumption in the components was close to the expected steam consumption, i.e. the model did explain the steam usage in the component in a satisfying way. To find these days the authors took some coherent days when the difference between the measured value of steam and expected value was low, for the Evaporator (Figure 17) at LP steam and for HP steam Dryer 1 (Figure 12). During these days, all regressor variables as in the chapter above, 5.4.5, were analysed. The result of the models can be seen below in Table 9.

HP-steam
Of the three studied components using HP steam, only Dryer 1 was explained fairly well by the model. The statistical model explained steam usage in Dryer 2 and the Steam Compressor System poorly. The authors studied Dryer 1 more carefully, choosing 117 days October 2011 to May 2012 when the difference between measured steam value and expected value was close to zero, and the production rate was above 65 tons/day. The new R^2-value became 29% (12% before) and the steam consumption was dependent on two variables: production rate and outdoor temperature. The production rate was the factor that affects steam consumption most. The dependency increased, but the coefficient is still too low for the model to be useful.

LP-steam
Steam usage in the Evaporator and the Dissolver were fairly well explained by the models. But since the evaporator used 40% of LP steam and there was few data from the Dissolver, the authors concentrated on the Evaporator. 150 days was chosen when the actual steam was close to the expected steam for this component. This occurred during August 2010 to January 2011. The R^2-value became 52% (56% before), i.e. a lower dependency for the LP steam model. The steam usage was dependent on the same factors as before:the outdoor temperature, the production rate and three product flows. The main dependency factor was the outdoor temperature in this model as well.

Table 9: Dependency for Polyol A, with and without some component's flow, including the model with fewer days, and R^2-values for the models

Polyol	Steam	Dependency	R^2-value
A	HP steam	Production rate and Temperature	7%
	LP steam	Production rate and Temperature	39%
A, added flows	HP steam	Prod rate, Temperature and 2 flows	12%
	LP steam	Prod rate, Temperature and 3 flows	56%
A, added flows and fewer days	HP steam	Prod rate and Temperature	29%
	LP steam	Prod rate, Temperature and 3 flows	52%

5.4.7 Discussion - Polyol A

The Polyol A factory is one of the largest and most complicated plants on the site. There are several production lines resulting in more than one final product. Reflows of product and by-products are circulating between the production lines in the factory. Heat recovery is utilized, where excess heat from a process is used in another instead of using primary steam. All this makes it difficult to analyse the variations in the steam consumption. In the discussion, the two steam systems will be discussed separately since they are not connected, with one exception. HP steam usage in the Steam compressor system and the Distillation column's LP steam usage are linked. However, these components will be discussed under the valid steam pressure system. A summary of the components' result, can be found in Tables 6 and 7.

HP steam

The first, initial model for the whole factory's HP steam system ended up with poor results. R^2-value became 7%, and did only correlate to the production rate. HP steam is not used for heating, so the non-correlation towards outdoor temperature is explainable. Since the R^2-value was very low for HP steam, it is difficult to draw conclusion fron the calculated expected steam values. To continue the analysis it was therefore necessary to look into the components. Three components using HP steam were studied. During 2012, these components accounted for 63% of the HP steam usage in the factory. This equals a steam usage of over one third that was not investigated within the scope of this thesis. Discussion for the three components; Dryer 1, Dryer 2 and Steam Compressor System will be presented below.

Dryer 1

The steam usage in Dryer 1 was dependent on several variables and had a R^2-value of 52%. The largest correlation was towards the flow into the band pass filter, located before the dryer. An optimal scenario would be to prove a dependency towards the actual flow entering the Dryer, since some liquid is removed on the band pass filter, which not utilizes steam. But as described above, this is complicated. The moisture content in the flow is not measured. Another variable not accounted for is the moisture content in the outdoor air. These missing factors could be an explanation for the R^2-value of 52%, where one could say that half the steam usage not is explained. A recommendation for continued work is to measure the variation in these variables to see if the steam consumption is affected. Since the steam meter was installed during the summer of 2011, there is less data related to Dryer 1 compared to Dryer 2.

When plotting the steam consumption against the flow of the band pass filter, Figure 10, one can see that the steam usage was higher the first five months after the meter was installed. This indicates that there might have been a problem with the meter, but the Production Engineer did not recall that. Neither did he recall any changes in the way the dryer has been operated.

The analysis of the difference between expected and actual steam consumption in Figure 12 shows a larger consumption than expected during the first months. This corresponds to the previous discussion. Moreover, the steam consumption was lower during the summer of 2012. The operating staffs do not have an answer to this decrease in steam utilization. The authors believe that it could be useful to redo this analysis after next summer, to see if the steam consumption decreases during that season as well.

It would be of interest to measure the base load of the Dryer, which is the energy necessary to heat up the outdoor air to the temperature in the Drier and reducing the air humidity. The authors did not gain data over the relative humidity in the outdoor air and could therefore not perform these calculations.

Dryer 2
Steam consumption in Dryer 2 is difficult to analyse. The steam usage decreased and became more constant in August 2010. At the end of 2010 a steam trap was installed, ergo four months after August. This installation could have explained the change in steam utilization and therefore it seems strange for both the operating personnel and the authors that the steam usage reduced before the installation. The resulting statistical model after August 2010 gave a R^2-value of 26%. Why the dependency was that low can be explained by several different factors. According to the Production Engineer the meter is old and not reliable.

The moisture content in the product differs, probably because the control valve often is 100% open, equalling in a steam flow not large enough to dry the product completely. The product is not sold to an external part, it is used within the company. There was a belief that the non-existing correlation in the steam usage models depended on a not sufficient steam flow, since the control valve is completely open a majority of the time [38]. But no dependency was found when the control valve was partly closed. The moisture content of the product flow entering the dryer is unknown and this affects both the steam usage and the moisture content of the product.

The moisture content of the outdoor air differs. The same reasoning can be applied for Dryer 2 as for Dryer 1; there is a base load in heating and drying the outdoor air to the temperature in the dryer and a relative humidity of 0%. It would be of interest to perform an analysis of this steam usage, but firstly the relative humidity of the outdoor air is needed.

Steam compressor
Steam consumption in the steam compressor system showed a very low correlation to other factors. To simplify the complex system one could think that the steam usage is equal to the losses of steam. The same amount of energy leaving the system as losses has to be added as the new steam (referred to as primary steam for the steam compressor system). The main heat loss from the system is disappearing through deaeration. It is unknown how great this heat loss is. To calculate this, the composition of the gas has to be found out, among other factors. This was not analysed further in this thesis. However, this heat is reused later in the production line, in the distillation column, so one should not refer to it as heat loss, but heat recovery.

The deaeration is controlled manually and only a few of the operating personnel have knowledge of the control mechanism. A recommendation from the authors is to further investigate how the deaeration is controlled. Figure 14 shows the steam consumption in the system from January 2009. It is possible to see an increase in consumption. The average steam usage during the first ten months of 2009 was 0.8 ton per hour. During the last year the average consumption has increased to 1.3 ton per hour. This corresponded to an increased average cost of 2500 SEK per day during 2012 compared to 2009. For a year this adds up to almost 0.9 MSEK.

HP steam - The complete factory
Regarding the HP steam components, only Drier 1 resulted in an adequate model, although not good enough to be able to draw any main conclusions. With three components poorly explained there is not much more to add to the HP steam model. Although, a new simulation simulation was performed for the steam entering the factory, where the product flow to the components were added. R^2-value for the model then increased from 7% to 12% see section 5.4.5. However, in this model there is a statistical problem; multicollinearity, which says that both production rate and product flow should not be in the same model. A new additional total model was made, only including 117 days, when Dryer 1 had a steam consumption close to the expected consumption, see section 5.4.6. Though, this R^2-value was low as well, 29%.

The reason for these low R^2-value could be associated with complex steam systems and a base load that does not change with production rate and temperature.

LP steam
The Polyol A factory utilizes three times as much LP steam as HP steam. The largest steam consumer, the Evaporator, utilizes more LP steam than the total HP steam usage in the factory. The first model for the LP steam system ended up with better results than the HP steam system, with a R^2-value of 39%, dependent on production rate and outdoor temperature. In Figure 7 the difference between the measured and expected steam values is presented. This picture shows the residuals of the model, which are formed in a sinus-like curve. This behaviour of the residuals indicates that there is some other dependency in the model, e.g. a logarithmic or exponential relation. But since the R^2-value was low, the authors decided to instead analyse LP steam usage in the components. Three components will be discussed: the Evaporator, the Distillation column and the Dissolver. Beyond these three components' steam meters, are two additional LP steam meters. These two measures a production line, called Production line D, and LP steam used for heating. These were not analysed further, since the measured steam is used in more than one component, making it difficult to address. All five steam meters measured 93% of LP steam in the factory during 2012.

Distillation column
The model explains the steam usage in the Distillation column badly. The reasoning concerning the deaeration flow the Steam compressor system described above, is valid for the Distillation column as well. Heat in the deaeration flow is utilized in the Distillation column, resulting in a decreased need for LP steam

in the component.

The usage of LP steam in the Distillation column did not show any correlation to the use of HP steam in the Steam Compressor system. This contradicts from what the Process Engineer believed, showing the complexity of the systems.

The Evaporator
The steam used in the Evaporator was dependent on the product flow, its density and the outdoor temperature. The product flow was the factor affecting the steam consumption mostly, which is logical. In the model only including the inflow, the R^2-value became 47%. Including the outdoor temperature and density, gave a R^2-value of 58%. Therefore, one can assume that it is mostly the inflow affecting the steam consumption, this since; greater inflow follows more water to evaporate, thus higher steam consumption. The inflow to the evaporator is controlled from the steam flow, which in turn is controlled manually by the valve opening. If the steam flow increases the product flow can increase as well, i.e. linear dependency. Still, this is not the case, which indicates that the steam flow is not sufficient. However, the water content in the flow leaving the Evaporator is adequate throughout the year according to a Production Engineer. The employees at the factory thinks this is odd, one should notice a difference in the water content if the steam is not enough.

It is interesting that when the valve was not open 100%, the steam usage was 90% dependent on the inflow. The ratio was also lower. A suggestion to Perstorp is to perform tests at different valve openings to investigate the ratio and to see when the steam is sufficient.

The Evaporator's steam usage was also dependent on temperature, which can be explained by the fact that it is situated outside. Though, a Production Engineer at Perstorp claimed that it is isolated and shall not be affected by temperature. The authors can't find any literature regarding evaporators and steam dependency on outdoor temperature either. A suggestion is a further investigation at Perstorp, to find possible heat leaks.

The Evaporator has better ratios, regarding steam consumption and inflow, during the summer. It is interesting to see how much steam and money Perstorp could save if they had the summer ratio all year. The authors took an average of the ratio during June to August 2012 and calculated the expected steam consumption from this ratio for all values since 2009. They found out, if the Evaporator has this ratio, Perstorp could save in average 2500 SEK per day, i.e. 2.5 MSEK during all days since the 1 January 2009 (except Mondays and Fridays).

The ratio has decreased especially during the year 2011 and the Engineers do not know why. They have not changed anything in how the Evaporator was operated or installed anything new. The authors investigated if there was less water in the inflow during the last two years, which could explain the decreasing usage of steam. An explanation was found; the water content has decreased slightly after November 2010. During the autumn 2010 Perstorp installed a new lamella package in another evaporator, i.e. the evaporation of water should increase in this component and less water should then be transferred to the investigated Evaporator. This makes the authors to believe that further investments in the first evaporator are positive and should be prioritized, since the steam consumption should decrease in both evaporators this way.

After an analysis of steam consumption before and after the stop of production, a recommendation to Perstorp is that not more than two stops of production are needed for cleaning the heat exchanger. This is based on the result that two of five stops had a worse ratio after the cleaning.

Dissolver
The Dissolver's statistical model did result in a R^2-value of 70% and a dependency against the product flow entering the component. This is considered to be a high dependency and a model that could be of use. The steam meter has only been operating since the end of 2011, resulting in less available data for the models, see Figure 20. This figure presents the ratio between steam consumption and flow over time. During the first part of 2012 the ratio was held rather constant, but in September it increased. After this time the factory was run in a slower production rate, resulting in a lower flow to the Dissolver, ergo a higher ratio. The difference between the measured and expected values did not show a specific pattern. During the spring, more steam was used than the expected. The Production Engineer did not have an answer to why. On the other hand, the difference is ± 0.2 ton/h, while the average steam usage is 1.3 ton/h. This is a small relative variation compared to the other models performed.

LP steam - The complete factory
The Evaporator resulted in a high dependency when the control valve was not 100% open. When all days were included in the model, the dependency was sufficiently explained, though not good enough to be useful. No dependency could be found concerning the Distillation column. The Dissolver on the other hand, had a quite high dependency between steam consumption and product flow. The most important variables for these components were added to the initial model. The R^2-value increased from 39% to 56%. The standardization showed that the outdoor temperature and the flows entering the Evaporator and the Dissolver had the largest impact on the steam consumption. This corresponds to the models for the components, where these two component's steam usage was best explained by the flows. As for the HP steam model, there is a problem with multicollinearity with this model as well. However, this model still has a R^2-value (56%) that is too low for the model to be used. In an attempt to make the total model better, 150 days were chosen when the Evaporator showed a difference close to zero between actual steam consumption and the expected one. Unfortunately did the R^2-value become lower, 52%.

5.5 Polyol B

All the result for Polyol B is included in this section. It contains a total model regarding the main steam meter, both with and without the flow into the main components.

5.5.1 Chosen data

The normal production rate of Polyol B is considered to be 100 tons/day, which is why this limit was choosen. Since the main meter for HP steam before March 2011 was not configured correctly, there are no measurements of steam consumption before that date included in the analysis. The factory has one main meter for HP steam and two meters measuring the incoming LP steam. When the production of Polyol B was over 100 tons per day between 1 March 2011 and 4 October 2012, these measurements of steam consumption were included in the analysis. The amount of data removed for the HP steam was 25% of the values, since the production rate was below 100 tons these days. The values of Polyol B that were investigated and used in this thesis regarding the LP steam were taken from 1 January 2009 to 17 September 2012, and all had a production rate of 100 tons/day. During that period less than 30% of the values had a production rate less than 100 tons per day, and therefor excluded from the calculation.

5.5.2 Statistical result for main meter

The calculated β values can be seen in Table 12, and the standardizes β values in Table 13, both in Appendix.

HP steam
To create a total model for HP steam, a multiple linear regression was performed for three regressor variables; the production rate, the outdoor temperature and the temperature of cooling water. The result from the first regression model was that one β-values expanded over zero, the regressor variable regarding cooling water temperature. This show that Polyol B does not depended on the cooling water temperature.

The result of the multiple linear regression indicates that the steam consumption concerning the main meter was dependent on the outdoor temperature and the production rate. The β-values showed that with increasing production rate the steam consumption increases. Whereas regarding the temperature, an increasing outdoor temperature results in a decrease of the steam consumption(β is negative).

A standardization of the measurement was performed, after which a standardized β-value was received. These values explained that production rate affects steam consumption somewhat more than the outdoor temperature did. These values can be seen in Table 13 in Appendix.

The R^2-value was low for HP steam; 14% and it is difficult to analyze a model that does not give a correct image of the real data. Although after looking further into some component's steam consumptions and how it varies since 2009, some days were removed. It was found, when the authors started to look more closely into the different components that during the months February to October 2012 a distillation column had very high steam consumption. After this removal, the new R^2-value was 30%, which is still low and needs to be investigated further. The component's steam variation is described in section 5.5.4

below.

LP steam
Polyol B's LP steam was examined depending on how production rate and outdoor temperature affects steam consumption, attempting to create a total model. For LP steam the cooling water was not taken into account, this since the steam ejectors only uses HP steam. The result from the multiple linear regression indicates that LP steam was dependent on both production rate and outdoor temperature. The result showed that with an increasing production rate the steam consumption increases. However the opposite regards the outdoor temperature; an increasing outdoor temperature results in a decrease of the steam consumption.

A standardization of the measured data demonstrated that the production rate affects the steam consumption somewhat more than the outdoor temperature does. The Process Engineers and the Production Engineers expected a temperature dependency. This since the end product is stored in a tank outside, and the tank needs to be heated and for that LP steam is used [35] [37].

The R^2-value was even lower for LP steam; only 8.3%, making it difficult to analyze a model that does not gives a correct image of the real data and one needs to make another model for a better analysis. Also for LP steam some days were removed, this since an evaporator had very high values during one month in 2010 and also from November 2011 to February 2012.

5.5.3 Expected steam consumption

The result from the analysis of the expected steam consumption is presented below. In the figures are the difference between the real measured values from one day and the expected values, for that day, showed.

HP steam
HP steam for Polyol B only had measured values from March 2011 since the main meter was not working properly before that date. March to May 2011 had many measured values higher than the expected value as can be seen in Figure 22, i.e. the difference between the values is positive. During the time period of June to October 2011, better values than what was expected was measured. At the end of 2011, November and December had lower production than normal, i.e. less than 100 tons per day and was not included in the analysis. Many values was above zero during 2012, especially in March and April. After analyzing the components, the authors noticed that during the year of 2012 some components; a heat exchanger and steam ejector to a distillation column had higher steam consumption than normal, which indicates that something was wrong with the component or the meter. These months have been removed and because of this there are not many values for 2012, see Figure 23. The values that remain for 2012 were both better and worse than expected. Although the worst values with unnecessary steam consumption above 0.5 tons/h during 2012 were removed. In the first Figure 22, it was many values above 0.5 tons/h.

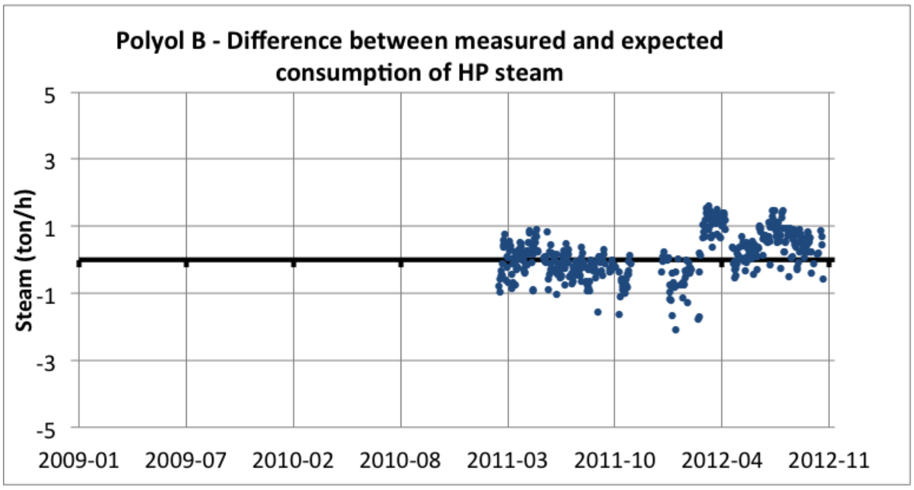

Figure 22: Difference between the measured and expected high steam consumption for Polyol B between March 2011 and September 2012

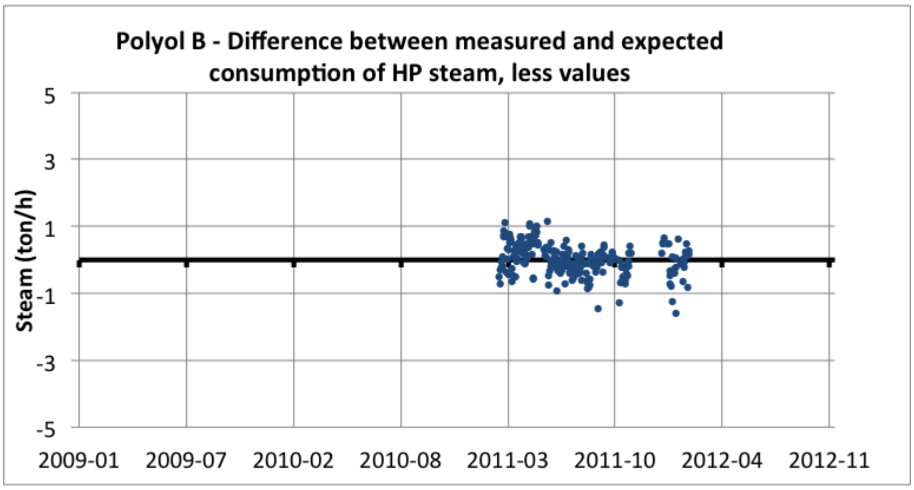

Figure 23: The difference between the measured and expected high steam consumption for Polyol B between March 2011 and September 2012. After an attempt to improve the model

LP steam

The difference between the expected steam consumption and the measured steam consumption is demonstrated in Figure 24. From March 2009 to July 2010, approximately half of the measured values of LP steam for Polyol B were better, and about half was worse than expected. The last months of that period were a bit better than expected. Whereas from March to July 2010, the measured values were lower than expected. In the time period between August 2010 until October 2011 most measured values were higher than expected values. The peak of the days with higher values occurred in March and April 2011. November 2011 until the last investigated month; October 2012, has in average been a rather acceptable period. During this time just over half of the measured values were lower than expected.

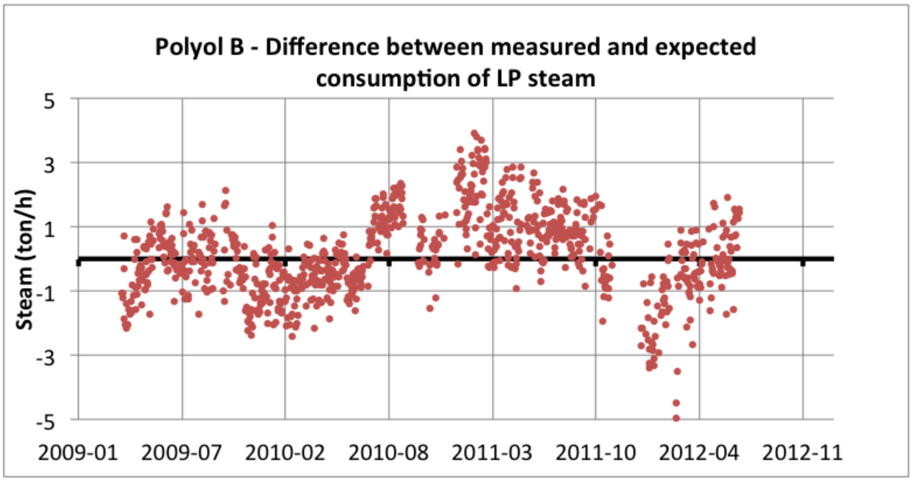

Figure 24: The difference between the measured and expected low steam consumption for Polyol B between January 2009 and September 2012

5.5.4 Adding new regressor variables to the total model

This section describes if the polyol's main meter regarding LP and HP steam, is dependent on both the production rate and outdoor temperature like the first analysis above, but here is the inflows to the main components also included in the model.

An improvement to Polyol B's model was made by adding the main component's inflow. According to this model, the results became better regarding both HP and LP steam, see Table 10. The R^2-value increased for HP steam from 14% to 64% and for LP steam from 8.3% to 51%. This indicates that adding the inflows improve the model and also show that is difficult to look at the factory as one unit, the different components have too much influence on the total steam variation. Although concerning HP steam, three of the meters regarding the inflow were installed June 2012 and this model only included 100 values.

Table 10: Dependency for Polyol B, with and without some component's flow, and R^2-values for the models

Polyol	Steam	Dependency	R^2-value
B	HP steam	Production rate and Temperature	14%
	LP steam	Production rate and Temperature	8.3%
B, added flows	HP steam	2 flows	54%
	LP steam	Prod rate, Temperature and 4 flows	46%

The latter model demonstrated that HP steam was dependent on the outdoor temperature and three inflows into three distillation columns. Other factors that were analysed and HP steam not dependent on were; the production rate, the cooling water temperature and an inflow to a distillation column. The three inflows and the temperature that affect the steam consumption had approximately the same standardized β-value and thereby influence the steam consumption equally.

Regarding LP steam, it was more complex; it was dependent on all factors except one that was analysed. The factors which were used in the analyzis were: the production rate, the outdoor temperature, the concentration of water and the inflow the following components; into two crystallizators, an evaporator and a distillation column. The one factor that affected the steam consumption the most was the inflow to the evaporator, i.e. the standardized β-value was the highest. After the evaporator it was the inflow into one of the crystallizers and concentration of water that had the second and third highest standardized β-value.

5.5.5 Discussion - Polyol B

Polyol B has like Polyol A a complicated process structure. The factory has many reflows that depends on the production rate; a high rate means that another process part receives some of the product flow. The authors did not have time to investigate all the components of Polyol B thoroughly, which would have made it possible to draw better conclusions concerning the energy performance in the factory. The total models regarding the main steam meters had from the beginning R^2-values of only 8.3% for LP steam and 15% for HP steam. These values are low why improvements had to be made if the models were going to be used to describe the steam consumption. A quite fast improvement was made; a removal of some months. When the authors investigated the components, it was found that an evaporator at the LP steam system and two components cornering a distillation column had higher values than the other months. These values were removed as an attempt to improve the model, which resulted in a better value for HP steam and the new R^2-value became 30%. However, the R^2-value for LP steam got worse; 7.3%. This shows that it is complex to make a model for the entire factory, especially when it has many reflows.

Regarding the last section 5.5.4, there is a statistical problem with multicollinearity. This is only a problem for LP steam, which according to the model is dependent on both production and some inflows. Although this model still has a R^2-value (51%), which is too low to be used in the model.

The meters concerning the Polyol B are old. Approximately 20 years old and most of them are situated outdoor. Due to this it is possible that they give incorrect values or are affected by low outdoor temperatures. It might happen that some heating cables which contain steam, can freeze and leak steam.

HP steam

The indication that the steam consumption was decreasing with increasing temperature, which was the case for HP steam, was not something that was expected by the Process Engineer and the Production Engineer. They rather predicated the opposite [35] [37]. When the outdoor temperature increases, the cooling water temperature also rises and this will increase the steam consumption due to the steam ejectors according to them. However, if the outdoor temperature rises 20°C the steam consumptions only decreases by 0.4 tons/hour. On the other hand, the only meter that was examined in the multiple linear regression, which the result was based on, is the main meter and therefore it is possible that some other components in the factory are temperature dependent. The Processes Engineers truly believe that the steam ejectors will consume less steam at lower outdoor temperatures. However, if other components affect the whole steam consumption in the opposite direction this will give another result. Yet the steam ejectors are the main consumer according to the Process Engineers, and consume approximately 35% of HP steam [39] [35]. From this the conclusion is made that it is difficult to look at a complete factory as one consumer when it exists of many small steam consumers.

If one looks at the expected steam consumption compared to the real measured values, it differs approximately ± 1 ton/h. Normal HP steam consumption is 8-10 tons/h and there is not an obvious pattern regarding the differences.

Polyol B's cooling tower was replaced in April 2012 and this had a positive effect on the cooling water temperature. The old cooling tower was about 20 years old and the temperature values before April were higher for the cooling water compared to the months after. The multiple linear regression contains values from the old and the new cooling tower, and this can obviously affect the outcome. The cooling water temperature in March 2012 was higher than normal/what was expected, but the outdoor temperature was not. Variables like this could have affected the result. This is something that could be investigated more closely. One would suggest that some months before and after the installation should be further investigated and analyzed, this to be able to see if there is a significant difference.

LP Steam

The first model which only included the outdoor temperature and the production rate gave a R^2-value of 8.3%. After an elimination of some months during the years 2010-2012, which had high measured values the new R^2-value became 7.3%. After this elimination it turned out that LP steam was only depended on the production rate and not temperature as the first analysis showed. These different results indicate that it is difficult to perform these analyses. The results are very depended on how many and which measured values that are choosen, although the result which demonstrated that LP steam was not dependent on outdoor temperature could explain why only 13% of LP steam is used for heating. This was something that the authors discovered when they started to look into the different components. On the other hand it is difficult to discuss the reasons for the result, when it poorly explains the steam consumption.

Looking at the expected steam consumption compared to the real measured values of LP steam it differs approximately ± 3 ton/h. LP steam consumption is normally 5-8 tons/h and therefore is a difference of 3 tons/h quite high. Although, since the expected steam consumption was calculated from the model which had a low R^2-value, it is difficult to discuss the reasons. The highest values at the expected figure, see Figure 22, was in April 2011, just before the cooling tower was replaced. The cooling water temperature was not added to the model since the LP steam system does not have any steam ejectors. Still, if there are other parts of the LP steam system using cooling water this may affect some outliers.

To sum up Polyol B; it is difficult to create a model concerning the entire factory's steam consumption and the production rate, a model that could have been used to calculate the key figures. The total model for both steam systems became much better after adding inflows to some components. After adding the inflows to the total model of HP steam it demonstrated that it was not dependent on the production rate. According to this result it is not correct to use the production rate as a ratio variable, which the staff does at Perstorp, when deciding next year's budget. Regarding LP steam, it is more complex since this steam is dependent on many variables. Using all these variables would make it difficult to calculate key figures.

5.6 Polyol C

This section includes results for Polyol C. Only a total model for the main steam meter has been made.

5.6.1 Chosen data

The normal production rate for Polyol C was set to 100 tons/day. Polyol C was investigated from 1 January to the 2 September 2012. During this period Polyol D was sometimes produced at the factory and these days are not included in the result below. The factory has one main steam meter for each steam flow. These meters are the same for Polyol D, since Polyol C and D are produced in the same factory, but not simultaneously. The main steam meter for HP steam was broken during most of 2010. The HP steam data that was removed during the period the factory produced Polyol C composed of 41%. For LP steam only values when the production rate was less than 100 ton per day was removed, resulting in 17% of the data.

5.6.2 Statistical result for main meter

Steam consumption in Polyol C was investigated against the variables production rate and outdoor temperature. The Process Engineer [36] recommended to include the concentration of water in the models as well. However, it turned out to be difficult to calculate since the accuracy of the data is questionable; the instantaneous flow is not measured. Instead it was possible to calculate the amount of water via a set point for the various input variables. One of the input variables was volume of condensate water, which was mixed with other chemical substances. The density of this liquid was difficult to decide since its temperature changes over time. Because of these problems, the concentration was not included in the model. The calculated β values can be seen in Table 12, and the standardizes β values in Table 13, both in Appendix.

HP steam
The result of the multiple linear regression model showed that HP steam was only depended on the production rate, not the outdoor temperature. A new regression was composed with only the production rate as the dependent variable. The β-value was positive, i.e. if the production rate increases the steam consumption also rises. The R^2-value regarding HP steam model was 55% which is okay.

LP steam
The result of the regression illustrates that LP steam was only depended on outdoor temperature, not production rate. This result was expected since LP steam is used only for heating, according to the process Engineers responsible for Polyol C [36]. The R^2-value for LP steam's model was 37%.

5.6.3 Expected steam consumption

The result from the analysis of the expected steam consumption is presented below. The difference between the real measured values from one day and the expected values, for that day are visualized in the figures.

HP steam
The difference between the expected and measured HP steam consumption can be seen in Figure 25. Regarding Polyol C's HP steam during 2009, February to September, were the measured values better than the expected. During November and December was approximately half of the values better and half worse than expected. The main meter only worked properly for two months during 2010 and therefore it is diffficult to analyze this year. 2011 was not as good year as 2009, from February to September were more values worse than expected. At the end of the year the factory produced Polyol D. The values from 2012 were like 2011; most measured values were higher than the expected values. Measured values for HP steam have gradually been higher than expected during the studied time, which could be due to one or more component used more steam.

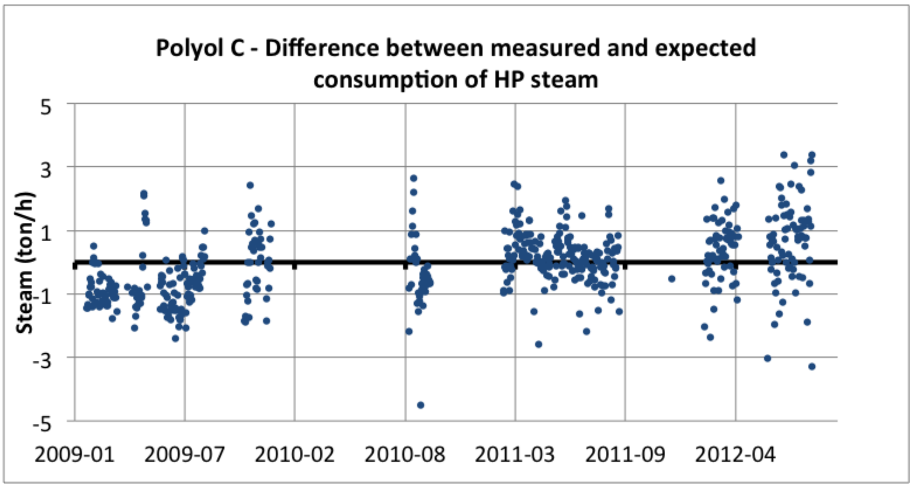

Figure 25: The difference between the measured and expected high steam consumption for Polyol C between January 2009 and September 2012

LP steam

During the first months of 2009, a half of the measured steam consumption values was better, and a half was worse, compared to the expected. From June to August, it was more values higher than expected, compared to lower. November to January 2010 were good months, almost all the steam consumption values were better than expected. From January to August 2010 it got worse, most values were above zero. After September it changed, September to November were good months, almost all the steam consumption values were better than expected. The year 2011 started with higher measured values compared to the expected ones. This only lasted for a few weeks and during this period it was very cold, which could have affected the steam consumption more than the model takes into consideration. The period March to September was better than expected. During 2012 March and April had higher measured values but June to August had lower values. To sum up, LP steam is more unpredictable compared to HP steam: it does not follow any pattern. This can be seen in Figure 26 below.

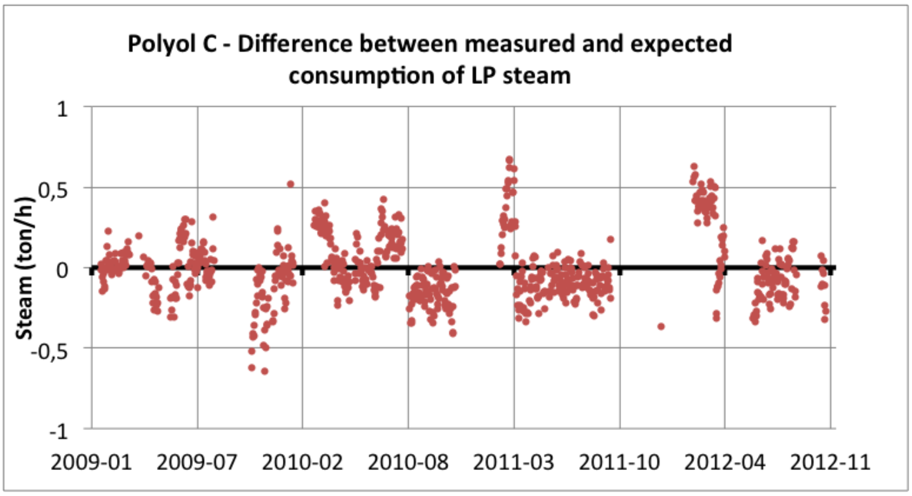

Figure 26: The difference between the measured and expected low steam consumption for Polyol C between January 2009 and September 2012

5.6.4 Discussion - Polyol C

Only a total model was made for Polyol C, since there is a time limit for the thesis. The R^2-value for HP steam was 55%, which is the best result for all total models including only production rate and temperature. Polyol C has a less complex process structure, not as many reflows like Polyol A and B. The R^2-value for HP steam (55%) implies that it is easier to create models on the steam consumption and to find normal usage for Polyol C compared to Polyol A and B. The result indicates that it is correct to use production rate as a ratio variable regarding HP steam, which the engineers do when they calculate key figures. The LP steam model had a lower R^2-value, 37%, and was only dependent on the outdoor temperature. This indicates that using the temperature would be a good idea when calculating key figures. LP steam is solely used for heating of pipes and facilities, which validates the model.

Looking at Figure 25, which displays the difference from the expected values for HP steam, the value is often higher during 2011 and 2012 compared to 2009. The reasons for this needs further investigation. Regarding the expected LP steam, Figure 26, the expected steam varies from the measured ± 0.5 ton per hour. This could seem low, but the total usage of LP steam is approximately 2 ton per hour. Since LP steam usage had a quite low R^2-value, it is difficult to reason about the model. Except from heating, LP steam is used for flushing of pipes, which is difficult to find correlations to.

5.7 Polyol D

This section includes results for Polyol D. As for Polyol C, only a total model for the main steam meter has been made.

5.7.1 Chosen data

The normal production rate was considering being all values over 100 tons per day. The amount of days below 100 tons per day was 22% of all days when Polyol D was manufactured.

The analysis for Polyol D was carried out during the time period 1 September 2009 until 26 September 2012. Polyol D differed from the other polyols: it had fewer amounts of available data. As mentioned before, Polyol D and Polyol C are produced in the same factory. Though, Polyol C has been in production more days than Polyol D during the given time. In the production of Polyol D there are two meters measuring the steam flows, one for HP and one for LP steam. As mentioned for Polyol C, the meter measuring HP steam was broken two time periods during 2010. These values, representing 14% of the HP steam data, was manually removed. The LP steam meter has according to the operating personnel been functioning during this time period, therefore was all data for this steam flow included.

5.7.2 Statistical result for main meter

The dependency for the steam consumption in Polyol D has been tested for the production rate and the outdoor temperature. The responsible Process Engineer suggested to add the water concentration to the model, but it was decided not the include this variable, see section 5.6.2. The calculated β values can be seen in Table 12, and the standardizes β values in Table 13, both in Appendix.

HP steam
The result from the multiple linear regression model showed that HP steam was only dependent on the production rate. The R^2-value was adequate, 48%. There was no correlation between the HP steam usage and the outdoor temperature.

LP steam
The regression regarding LP steam showed that the steam consumption was dependent on the temperature. When the temperature increases outside, the steam consumption decreases. This was corresponding to the engineer's assumptions since LP steam is used for heating of pipes and facilities, likewise Polyol C [36]. The R^2-value was alright for LP steam as well, with a value of 56%.

5.7.3 Expected steam consumption

The result from the expected steam consumption analysis is presented below.

HP steam
Since there are not that many values for Polyol D's steam consumption, it is difficult to draw conclusions from the model. During all periods that Polyol D were produced, there are both days with positive and negative difference, as can be seen in Figure 27. Noticeable is the last three periods, where there is a positive difference, meaning a higher measured steam consumption than the model indicates.

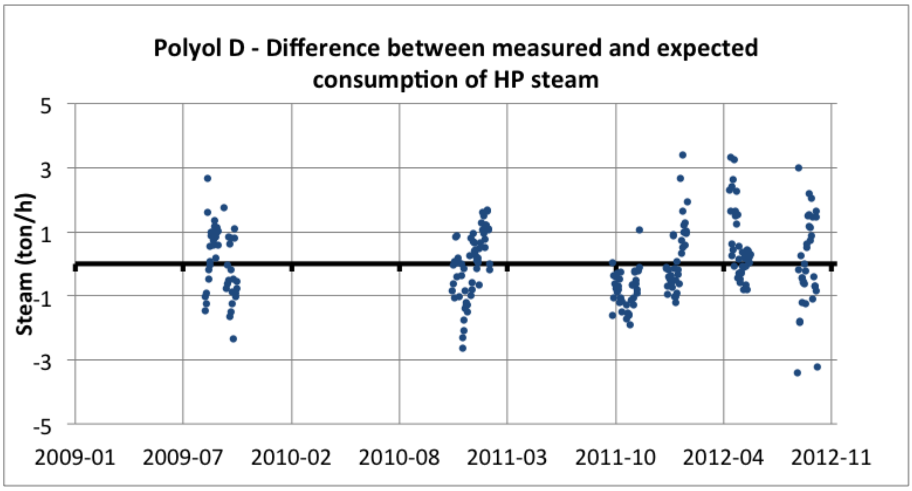

Figure 27: The difference between the measured and expected high steam consumption for Polyol D between September 2009 and September 2012

LP steam

Regarding LP steam for Polyol D there was periods where both the measured steam consumption and the expected were greater than the other, see Figure 28. There was one exception, the turn of the year 2010 and 2011, where it can be noted that all days, ignoring one, had a higher measured steam consumption than expected.

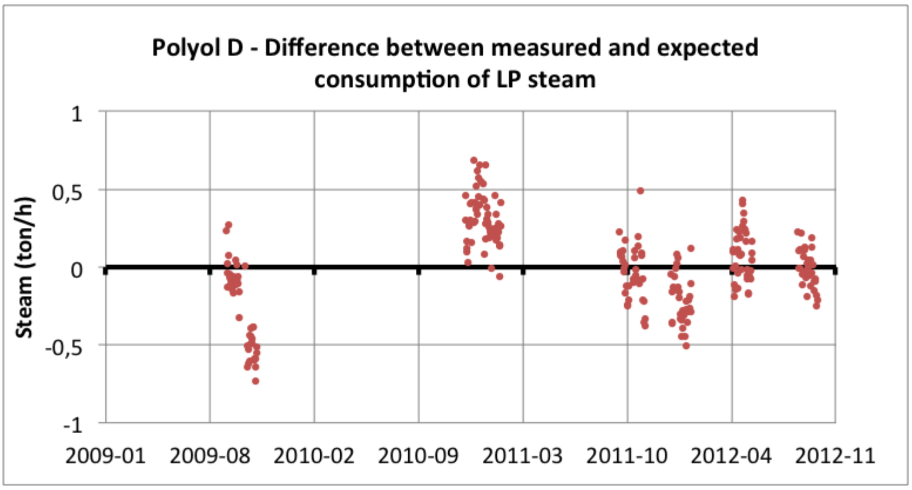

Figure 28: The difference between the measured and expected low steam consumption for Polyol D between September 2009 and September 2012

5.7.4 Discussion - Polyol D

Polyol D is, of course, similar to Polyol C since they are produced at the same factory. Hence, Polyol D also has a simpler process structure compared to Polyol A and Polyol B. This can be one explanation for the higher R^2-values for the factory. Likewise Polyol C, HP steam was dependent on production rate and LP steam usage was dependent on outdoor temperature. This is logical, since LP steam is used for heating. This indicates that temperature should be used when developing key figures for LP steam.

Regarding the Figure 27, visualizing the difference from the expected steam consumption for HP steam, one can notice a difference of almost ± 3 ton per hour. This could be explained by the large variation it was in the steam consumption for HP steam (Figure 5). The authors did not have time within this thesis to examine why the situation was like this. The few amounts of values made it difficult to analyse the situation as well. Figure 28, showing the difference from expected LP steam consumption, also in hold few values. The authors did not gain an answer to the question why more steam than expected was used during the end of 2010 and beginning of 2011.

5.8 Summary of the polyols

When comparing the polyols' models, the R^2-values for Polyol C and D was higher than Polyol A and B. The authors wanted to test whether it was possible or not to use the statistical multiple linear regression model for a factory, which steam consumption was poorly explained by the model. Therefore, Polyol C and D were excluded. Polyol D did not have many measured values, which also was an additional reason not to investigate this factory any further.

Both Polyol A and B had low R^2-values, therefore it was of interest to further investigate these factories. The models of these polyols were not as good as one could have hoped for. Finding more factors explaining the steam consumption was necessary. However, it was difficult to continue with both these factories since they are complex and the thesis has a time limit. Polyol B consists of many steam consuming components, more than Polyol A, which will make it complicated to fully understand this factory. The cooling tower in Polyol B was replaced in May 2012, which also complicates the modelling, since this affects the steam consumption. Because Perstorp replaced the cooling tower in May, it does not exist as many measured values for Polyol B as for Polyol A. Therefore, together with the existence of fewer components, it was prioritized to further investigate Polyol A. In addition, one of its components, the Evaporator, uses almost half of LP steam, which also makes Polyol A more interesting to study.

Table 11: Dependency for the polyols and R^2-values for the models

Polyol	Steam	Dependency	R^2-value
A	HP steam	Production rate and Temperature	7%
	LP steam	Production rate and Temperature	39%
B	HP steam	Production rate and Temperature	14%
	LP steam	Production rate and Temperature	8.3%
C	HP steam	Production rate	45%
	LP steam	Temperature	37%
D	HP steam	Production rate	48%
	LP steam	Temperature	56%

5.9 Discussion - Energy usage analysis

To survey the energy consumption, in order to find variations and irregular values, the authors decided to use the statistical model multiple linear regression. This model is a straightforward way to test a dependency between several factors. The steam consumption was in focus throughout the analyses, and its correlation towards other factors, e.g. the production rate and outdoor temperature. The model decides which factors that influences the steam consumption, and the magnitude of influence. However, there are things that this model does not take into account: the variation over time that affects the steam utilization values. This can be a seasonal variation, for example the periods before and after a stop of production. Furthermore, the R^2-value is a complex way to view the dependency, the usage of it is most accurate when comparing two or more models. Within this thesis the R^2-value has been used when comparing different models, for various factories and component. This was considered to be the best alternative to display the result. [17]

Another way to address the original problem would be by doing a time series analysis, instead of a multiple linear regression. The method analyses sequences of observations that is ordered, at least normally, over time. Particularly when the time space between the observations is equal. [17] [40]

As one can see in the Table 11, the R^2-values were better for Polyol C and D which both have simpler process structures. This is something the authors discovered, the complexity of some of the factories made it difficult to create models concerning the total steam meters and the total production rate. However, it worked better for factories without many reflows and this is the case for Polyol C and D. The authors find it difficult to suggest to Perstorp to continue with these type of statistical methods if the goal is to find a total model for the main meter, especially for Polyol A and B.

One way of using the result of these statistical analysis is when Perstorp will calculate next year's budget concerning steam consumption, at least for those polyol factories with okay R^2-value. If the steam is mostly or only dependent on outdoor temperature, this is something they can consider when planning the budget and not using the production rate, which is the case today. It is also something to discuss at the Monday-meetings where energy ratios are analysed.

6 Result and discussion II - Energy management

In this chapter, the result regarding how Swedish control measures affect Perstorp is presented, together with an analysis concerning Perstorp's energy management. A comparison between the energy management at the chemical companies Perstorp and Kemira is also included.

6.1 Energy management control measures today

Perstorp entered the Swedish PFE in 2005. When they implemented PFE's requirements at the Perstorp site, the main focus was on both electricity usage and steam consumption. They began by creating energy balances; measuring values for both electricity and steam. Perstorp discovered that not all components and facilities were included in the energy balances and that some were measured twice; the balances did not match up. A lot of the first years work went into allocate steam and electricity on to the different facilities. After the allocation they could quantify more exactly how much energy the different factories and their components used. This made it easier to discover energy efficiency possibilities. The cooling water streams were also mapped, since water pumps are main consumers of energy. Today, an energy management system is in use. [41]

In the autumn of 2011, the Process Engineers conducted a brief study on steam consumption for the polyol and formalin factories. These documents present data and graphs regarding steam consumption for different components of the different polyol factories during the period 2009-01-01 to 2011-09-30. The aim of these documents was to examine if any energy efficiency measures or optimization project to reduce steam consumption could be performed. The documents were intended as a pre-study and not as a finished project proposal and they only highlighted some questions regarding steam consumption. [35]

Perstorp's steam plant produces electricity from bio-fuels, which grats Perstorp electricity certificates every year. Perstorp gets between 15 000 - 20 000 certificates from the turbine, depending on delivered power and fuel mix. Today one can sell a certificate for about 165 SEK/certificate, but during the last years the price has been approximately 200-230 SEK per certificate. This gives Perstorp an electricity certificate income each year of about 2.5-4 MSEK. This will cease at the end of the year, since their turbine was installed before 2003. Perstorp is thinking of replacing the turbine to receive new certificates, but this is a great investment and firstly they need to investigate if it is profitable. [42]

Perstorp has obtained European emission allowances since ETS started in 2005, because they have two oil boilers supporting the steam production. During the first years they got, in average, 72 000 allowances/year. For the second trading period, 2008-2012, they received, in average, 53 000 allowances/year. They have decreased the usage of oil in favour for bio fuels, but oil is still used during peak load and when the bio-fuel boiler is out of commision. This has resulted in Perstorp selling emission allowances in the emission market since 2005. During the first period, they sold some of the allowances on the market, as the rules prohibited to save up certificates. For this they made a profit at about a million SEK. During the current period, companies can store allowances between periods, which for Perstorp has led to less incentive to sell allowances outside the corporate group. [42]

If Perstorp manages to implement efficiency measures for energy issues, they can save energy which results in lowered costs. Reduced energy consumption may also give higher profits concerning the control measures: more allowances to sell.

6.2 Energy management

Performing an evaluation of the energy management at Perstorp Specialty Chemicals AB is one part of this thesis. Initially a literature review was performed concerning how efficient energy management is achieved in an energy intensive company. Secondly the authors interviewed seven employees, all were anonymous, asking what they thought of Perstrop's energy management. The following employees were interviewed: four Process and Production Engineers, one Factory Manager, the Production Manager and the Energy Coordinator at Perstorp. The authors interviewed the engineers who have the greatest responsibilities for the polyol factories. As a final part, a visit to Kemira in Helsingborg was made, to be able to compare two chemistry companies and get suggestions for improvements. Kemira was well suited because of the many similarities in energy production and consumption, with Perstorp. One thing they have in common is the production of a substance that has an exothermic reaction process. This has made it profitable to supply the surrounding municipality with district heating, for Kemira it is Helsingborg and for Perstorp it is Perstorp municipality. Both Kemira and Perstorp have an Energy plant that distributes steam and electricity for their industry sites. Also, both companies joined the PFE-system in 2005 since they are energy-intensive enterprises. Kemira was visited during half a day, and the Energy project Engineer and a Technician were interviewed. Later, three Production Engineers at Kemira sent answers to the same questions as were asked to Perstorp employees. The questions that Perstorp and Kemira answered can be seen in Appendix.

6.2.1 Energy management at Perstorp and Kemira

Perstorp

Perstorp has worked with energy issues before they joined PFE, since energy is a great part of the budget. Although, after they joined the PFE in 2005 they got a better structure regarding measurements and organization; mutual excel-files were created. A full time worker was employed to handle energy measurements and energy mapping in 2005. During 2008 one of the interviewed, who today is the Energy Coordinator, gathered the excel-files and other relevant files into a PFE-folder. This folder was put on the intranet, and made available for all employees. Perstorp also installed additional steam meters in 2005 to be able to see where the steam was consumed. The interviewed that worked at Perstorp before 2005 explained that energy issues are better organized and discussed in projects today. Each factory has control over their energy consumption and the management of energy issues. One main issue that has been involved in many projects during the last years is decreasing the water content in the process flow, which indirectly minimizes the steam consumption in several components.

According to a Process Engineer at Perstorp they have changed their routines regarding purchases of mechanical components, for examples pumps, during the last years. Before new establishments and purchases, Perstorp performs a Life Cycle Cost-analysis (LCC), which includes an energy analysis, for the different suggested components. The LCC-analysis is one of the items on a checklist in Perstorp's new Project Model (PPM) which the Project Manager needs to perform before a project is finished. The PPM started during 2011 and has, according to a interviewee, helped to improve the running of projects and the follow-up strategy.

The staff at Perstorp is obliged to purchase the most efficient engine according to routines. However, machines, pumps and engines are often exchanged equal-to-equal from the storage instead of buying new ones, according to an interviewee. A problem in projects can be a conflict between the process system and the energy efficiency options; the best alternative in energy efficiency is not always the best from a process system view.

Kemira

Kemira has always worked actively with energy issues, but as these questions have a greater focus globally today and after they joined the PFE, Kemira started a mutual global energy action program. The action program is called E3, *energy efficiency enhancement*, and creates a comprehensive view on energy issues in the worldwide corporate-group. In addition, the program includes steam and other energy distributors that the PFE does not contain. Historically, every plant has been in charge over its own energy management, which still holds true today. However, today it is better coordinated at the site in Helsingborg and within the corporate-group. Within the E3, energy consumption and measures are analysed for all sites within the corporate-group (compared to PFE, which only concerns Swedish companies). Kemira was sceptic whether the implementation of the energy management system has helped to structure their energy work, this becuase routines regarding the energy management always has existed. However, some new routines have been developed and updated to meet the requirements of the ISO-standard.

6.2.2 Energy Coordinator and Energy group

Perstorp

At Perstorp, it does not exist a special employee that others report to when performing an energy project at the different factories. Still, the Perstorp site has an Energy Coordinator. After a project is implemented the Project Manager, who often is a Process Engineer, put all the information on the intranet.

Energy issues are discussed at several meetings at Perstorp. A Process Engineer for each factory performs weekly calculations regarding steam and production ratios, which is reported at Monday meetings. Energy is also discussed between the Process Engineer and the Production Manager, who is a member of the board, at monthly basis. If the ratio between energy usage and production rate is high, the board discusses this at the monthly meetings. The board believes that energy is an important question but they still can, and will, be better to show its involvement, according to the Production Manager.

The Energy Coordinator's official title is Technical Manager, and he spends approximately 5% of his work time on energy issues. This time is mainly allocated to issues regarding the management system and the PFE, which comprise reporting to the Swedish Energy Agency. The Energy Coordinator is a member of a technical council at Perstorp and this council decides which projects that shall be implemented on the site. Almost all energy projects that the council selects get the investment capital it requires, according to the Production Manager. After the economic crisis in 2008, Perstorp removed a full time employee who worked with energy issues globally in the corporate-group, and the Technical Manager took over that person's duties. Perstorp then lowered its energy efficiency ambitions. The Production Manager did not agree with this lowered ambitions; Perstorp still had a focus on energy issues and no projects were cancelled. Perstorp has always done everything that PFE demands. Though, the Energy Coordinator feels that the level of ambition can increase at Perstorp, but then they have to decide which area that is most essential. Other areas like water, ecology and security are also important, he explained.

The steam plant does not have an employee that handles energy issues for all the companies at the site. Examples of these types of issues could be investments in the boilers, which concern all companies at the industry site.

Kemira

Within Kemira there exists a sub-corporation; Industry Park of Sweden (IPOS), which run its business as an industrial park. Services and products in IPOS have been divided into four business areas: Energy, Land & Construction, Maintenance and Logistics. It is the Energy department at IPOS (consisting of the Energy Manager and the Energy project Engineer) that has the responsibility regarding their energy management and also the responsible coordination of different energy issues as total efficiency, energy counselling, purchase and sales. The Power plant at Kemira is responsible for the production and distribution of energy to all companies at IPOS. The Quality Manager is responsible for management systems, including the energy management system. Kemira has an Establishment Group, which works with existing and new projects in the industrial park. The Energy Manager and Energy project Engineer are responsible for the energy parts in projects.

There are several forums where energy issues are addressed at Kemira. Each plant has weekly reconciliations on energy issues and it is discussed at departmental or project meetings once a month. The Plant Manager is responsible for energy issues within each plant together with a Production Engineer. Also, there is an Energy production council where the Plant Manager or Production Engineer from each factory is a member. IPOS Energy manages the council. At this council, the members follow up on the plants' energy work and exchange energy information (e.g. price information, site projects, PFE, E3, etc.). The group meets once a month.

6.2.3 Monitoring energy use

Both Kemira and Perstorp measure and store data on energy consumption every tenth respectively fifteenth seconds. None of the companies have alarms warning the staff if the energy consumption is higher than normal. Both at Kemira and Perstorp, each factory must pay for their energy consumption on a monthly basis.

Perstorp
Perstorp has Monday-meetings where the Process Engineers, the Production Engineers and the Factory Manager are present. At these meetings they discuss, among other things, energy and production ratios. If the ratio is higher than budgeted, they discuss the reasons for this, and often they know why it is high. However, there is often not enough time for the Engineers to make a precise analyse on why the error occurred, according to some of the questioned. There is also a problem that the factories do not have separate meters to all steam using components. If the ratio is higher than budgeted, it can be difficult to decide which component or part of a system that used more steam than normal. There is also the problem concerning the steam meters, it is difficult to measure steam, see section 5.2. The meters connected to the components have hardly ever been calibrated, only if the operating personnel noticed large deviations in the steam consumption.

A Production Engineer at Perstorp explained that the Process Engineers are linked closer to the operation today, on a weekly basis, compared to before the PFE, due to these Monday-meetings, and this is positive. The Production manager also agrees with this, the last years have they improved the engagement of the Process Engineers at the daily operation. The Production Engineers spend some of their work time troubleshooting energy losses and deviations.

There is a process meeting once a month with the Process Engineers and the Factory Manager, where question marks in the process is discussed. Furthermore, at Fridays there is a so-called production meeting for each factory, where employees from instrumentation also are present. During both these meetings energy can be discussed, as well as any on-going energy project.

During a project, a Project manager is appointed and that person is responsible for doing the follow-up, and place it on the intranet. Altough, the follow-up part can sometimes be overlooked due to lack of time, according to some of the questioned. Follow-up is especially overlooked if a project concerns an installation of a component replacing an old one. At these projects is estimations of the energy savings at a general perspective often forgotten as well.

To have energy goals is a requirement in the ISO-standard and Perstorp have annual energy goals; to decrease energy consumption 12.9% from 2011 to 2012 and to follow the steam and electricity consumption budget. It does not exist any long-term goal regarding energy savings. However, none of the interviewed Process Engineers or Production Engineers know which energy goal Perstorp has and many of the questioned says this is something that they never talk about at meetings. They discuss the steam and electricity budget at Monday meetings but the Engineers are not aware that these are Perstorp's energy goals. According to the ISO-standard an action plan is needed to be able to fulfil all energy goals. The action plan at Perstorp is not explained in detail, it consists of some energy saving projects, and the Engineers are not aware of which these projects are.

Kemira
At Kemira, the Production Engineers examine the overall energy consumptions monthly. They also weekly examine normal data on various specific energy issues depending on the situation. The Production Engineer performs an energy analysis, and if there is a deviation other employees are consulted, who depends on the nature of the deviation. Natural gas consumption per produced product is checked almost daily at Kemira. They use natural gas when the exothermic heat is not sufficient. A Production Engineer at Kemira explains that during projects, which concern specific energy issues, energy consumption is followed up weekly or daily. Within a factory it is important that feedback is given to the Operators. Feedback, both when they have good energy ratios and when it is bad, and that changes are made to avoid negative deviations in the future.

If an E3 or PFE measure is implemented at Kemira, this is reported to the Project Engineer at the Energy plant for IPOS. Implemented PFE measures are, after each 5-year-period, reported to the Swedish Energy Agency. E3 measures are reported in a web-based tool, which the corporate-group have access to. Kemira's energy goals in E3 say that they will reduce their energy consumption with 5% per year during the years 2010-2012 and that Kemira will save 10 million Euros per year in energy costs.

6.2.4 Motivating staff to save energy

If a memeber of the staff at Perstorp has an idea on how to save energy, they can put this on the intranet in a PFE-file. The idea is then analysed by a Project group for the Perstorp site. At Kemira it works similarly; if an employee has a new idea that person can suggest the idea in a web-based tool. Then the relevant department reviews the idea if they shall implement it or not. All ideas are reviewed regularly at departmental meetings.

Perstorp
Neither the Production Engineers, Process Engineers or Factory Manager, which were questioned at Perstorp, have had an education on energy issues or energy management since they started at Perstorp. Some of them have worked at the company for 20-30 years. However, Perstorp did have a PFE-information in 2008 during two hours, which both staff from the production, the Process Engineers and the board participated in.

Kemira
In November 2012, Kemira had their first site-common energy training. This was held during two hours, involving all staff working in production. The staff learned about the energy management system, Kemira's implemented energy measures and how energy costs affect Kemira's results; that saving energy can mean saving money. During this energy education, implemented energy mea-

sures that gave a positive result from individual plants, were described as inspiring examples. Another purpose of the education was to illustrate how energy and climate are linked, and several practical examples were included on how the staff at their daily work can affect the energy usage. Beyond this one-time education, a Production Engineer has briefings and training several times a year, at one of Kemira's plants. During these briefings they analyse the energy consumption, what they can do to decrease it and how changes in the process system. How the control system can affect energy consumption is also discussed.

Kemira has consultations internally in their corporate-group, at plants that produce the same product. The different sites compare their ratios to each other and share their knowledge.

6.3 Discussion - Energy management

In this section the authors will give recommendations to Perstorp on their energy management, suggestions based on ideas from Kemira and what the literature advises companies to do. Recommendations from the interviewees are also included.

Energy management
A main driving force for Perstorp to improve their energy management is to maximize profit and minimize expenses. If Perstorp manages to implement a well-structured energy management system, they have possibilities to save energy and therefore save money. Perstorp can gain money in two ways; by decreased energy costs and by rationalizing the energy consumption and get more emission allowances to sell. During their peak load, Perstorp mainly uses oil and if they can minimize that usage by rationalization they will have more emission allowances to sell.

The energy management at Perstorp is organized, but improvements can be made. The impression the authors got after talking to some employees at Perstorp was that energy is an important issue, but the board of the company does not prioritize it. Although, energy is included in every project and the staff is aware of the fact that energy is essential, and above all expensive.

At Perstorp, the staff mostly pays attention to energy issues because they need to follow a budget, which is a company's main driving force regarding energy efficiency [27]. On projects, a LCC analysis is performed and the Production Engineers do troubleshooting in their daily work to find energy losses at the factories. The Energy Coordinator still feels that the level of ambition can increase at Perstorp, but then considerations have to be done; which area is most essential? Other areas like water, ecology and security are also important. It is the board that decides which areas Perstorp focus on and energy is an issue that could be higher prioritized. But the Production manager, who is a board member, did say that energy is important. One can understand the difficulties to prioritize all areas mentioned above at a company and Perstorp do follow the requirements regarding PFE. Still, anchor the energy management at the board is one of the success factors to establish change within a company [27]. As long as the board does not show that energy is a priority, there are no incentives for employees to focus on this issue. For example, the board at Perstorp has made it clear that security is much prioritized and therefore this question works very well, both regarding information and education.

Kemira has E3, the corporate-group's energy action program, which is something that Perstorp lack. There does not exist a group, where staff from different sites within the corporate-group meet and have possibilities to learn from each other. Perstorp has factories in other countries and it would be positive if they can share suggestions for improvements and create a comprehensive view on energy.

A positive change is that Perstorp have implemented a new project model, PPM, during 2011. All the interviewed said that the PPM has made running of projects easier. However, one thing that may improve PPM is to have a better connection with the energy management system; to clarify for Project Managers how to work and handle energy issues. Perhaps combine template documents and governing documents from the management system into an item on the checklist, or to expand the LCC-analysis. One thing lacking in projects is a comprehensive energy calculation of energy saving after the implementation is finished.

One recommendation from one of the questioned is the different best available technologies (BAT). The regular staff do not have time to check or look for BAT concerning old components. Another thesis could perhaps find different BAT and calculate energy savings regarding different components.

Energy Management Coordinator and Energy group

Perstorp does not have a Energy group. There is an Energy group within Kemira, called IPOS Energy, which is a part of IPOS. Kemira has an Establishment Group and Perstorp have a Technical council, which both works with existing and new projects at the industrial site. The council at Perstorp only discusses which new project they shall implement, and this concerns all areas on the site. It is easier to get a comprehensive view regarding only energy issues, if an Energy group exists. This group can decide from year to year, which factory or which part of a factory that needs to undergo improvements. Then they can select a few focus areas each year for implementing energy efficiency measures.

It is positive if the Energy Management Coordinator appoints certain contact persons within the organization at each important production step [20]. These contacts can be Process Engineers who report to the Coordinator whenever needed or division-level Coordinators and these people can form the Energy group. For Perstorp, this group may consist of, in addition to the Coordinator, Process Engineers from the different factories and Energy plant and Process Specialist from the factories.

At Perstorp today, it is the Project Manager who makes the follow-up after a project is implemented and put the result in the PFE-folder. This is the case for Kemira as well, but here the Project Manager also tells the Energy Project Engineer about the result. The Energy Coordinator at Perstorp must sometimes chase after the result if the Project Manager did not have time to make a correct follow-up. This is something that can be improved: that the Project Manager reports directly to the Coordinator about the result. Another suggestion is that the PPM has an item on the checklist, which includes making a comprehensive energy calculation, se above, that the Coordinator easily can retrieve from the intranet.

Monitoring energy use

It is important that at a manufacturing industry, the energy consumption is sub-metered [20]. This enables cost allocation based on the actual consumption of each division or important process. This is something both Kemira and Perstorp apply. Both companies also analyse their energy consumption ratios regularly; energy consumption should be compared with other measurements that affect energy usage, for example production volume [29].

One idea from a interviewee at Perstorp is to change the cost allocation for the factories. Today all factories at the site pay the same in SEK per tons steam independently on which fuel the steam plant uses. During the winter and reparations in their bio-fuel boiler, the steam plant uses oil, which is very expensive. Perhaps the steam plant can apply marginal cost for each factory instead. This would be an incitement to not use extra energy. A recommendation can be: during normal use, for example corresponding to the budget, the factories pay the same price, but for all energy consumption above normal they shall pay the marginal cost. This is unfortunately very difficult to implement, as it is problematic to both define and measure a normal steam consumption.

One thing lacking at Perstorp is the calibration of component's meters. Today they often blame the meters if the ratio regarding steam and production rate is high and do not investigate it more thoroughly. It is better to calibrate the meters and thus be able to trust their measurements; otherwise it is impossible to analyse any results.

None of the staff that were questioned at Perstorp were aware of their energy goals. Though, they were aware that they have budgeted goals, as these goals are included in their workload every week. What they do not know is that these are Perstorp's energy goals as well which can cause confusion if they have an education about the energy management system. Perstorp also have an energy goal regarding the site; to reduce energy consumption with 12.9%. This goal has the interviewees never heard about. This is something Perstorp can improve; the staff's awareness of their energy goals.

Motivating staff to save energy

One important success factor for efficient energy work at companies is the motivation of staff [29]. The main opportunities to save energy are linked to process equipment at a chemical industry. However, employees can for example affect how they operate the factory. Therefore they need to be motivated to save energy and this can be done through energy goals and recognition of their achievements. Training of staff is more important for employees who have greater influence on energy consumption. A newsletter, posters and publicity campaigns can increase awareness of energy saving for all employees [29]. Perstorp has never, at least during the last 20-30 years, had an education regarding energy issues for the entire staff. They did have an education in 2008 about PFE but many of these employees have other responsibilities today or do not work at Perstorp anymore; perhaps Perstorp can have training on a more continuous basis. The answer the authors got to why Perstorp didn't have a new education is that they have prioritized other areas the last years, for example safety in the working environment.

Kemira had their first site-common education this autumn, which involved all staff at production level. This is a recommendation to Perstorp, to have an internal education regarding energy goals and their action plans. Perhaps have some positive examples from the factories and also recommendations how the company wants the staff to take action on energy issues. Later it is important to give employees feedback on where the company stands on achieving the quantified goals. The litturature suggest having an energy competition between departments to increase motivation [27].

One of the most important driving forces is the existence of a so-called enthusiast at a company [27]. At Perstorp the Energy Coordinator said that he would like to spend more of his working time on energy issues and increase the ambition level, perhaps he is the enthusiast Perstorp needs? Regarding enthusiasts; the solution to an efficient energy work is not only to have one, it is also important where in the organization they are. An enthusiast with no power cannot influence on the issues. And if the board does not have energy efficiency as a priority, then it does not matter how many enthusiasts it exists in the organization.

A problem the interviewees talked about was the short payback time Perstorp requires on investments. This is something the littrature also describes; companies wish for short payback time for all investments [27]. The risk of long payback time for energy measures may be a barrier. Investments in the energy sector have the same requirements as other investments in the company, the respondents said. Many components are very old at Perstorp and they only repair modules that are necessary for the production to keep on going. The payback time has decreased the last decade, after the family Wendt sold the company, according to a interviewee. This sense among the employees can counteract approaches to influence on management; “it is too expensive to change this, therefore it's no idea to say something about it”, was an impression the authors got after completing the interviews.

Two success factors to improve energy management are establishing the following: a strategy with quantified energy reduction goals over the next 5-10 years and an action plan for how these goals can be achieved [27]. Perstorp only has energy goals concerning the next year, i.e. it is a good idea to implement new long-term goals. It is important to establish a service where every energy goal has an “owner”, an energy controller [27]. This person does not need to work full time with energy issues but should have an operational responsibility in production, such as a Production Manager, rather than the Maintenance Manager.

To sum up, Perstorp works with energy issues, but it exists many improvement opportunities and deciding what to begin with is a good start. Therefore, it is a recommendation to Perstorp to first create an Energy group that can prioritize within the energy efficiency area and decide which dimensions the area should have. These areas can for example be: BAT and standards for components at a factory, changes in how the component's steam consumption is regulated, education, energy goals and their action plan.

7 Conclusion

The conclusion from the two parts is presented below.

7.1 Energy usage analysis

The main conclusion of the energy usage analysis, was that the statistical model multiple linear regression only can be applied for some systems. The method is straightforward, proving a correlation between steam usage and in this case other variables. If a system was complex, with reflows, heat recovery, leakage or other factors affecting the steam consumption, the statistical model gave a poor result. However, if a system is more simple, e.g. with a product inflow heat exchanged against the steam flow, where the steam consumption correlates to the production rate, the method can be of great use. There are two additional problems with this model; firstly is the uncertainty with the R^2-value. This coefficient corresponds to the level of dependency between two, or more, variables. It is difficult to decide what a “good” or “bad” dependency is. Secondly there is a complication with multicollinearity in some models, where the regressor variables are dependent on each other.

At Perstorp, there are systems where the statistical model, multiple linear regression, could be beneficial, and be used to calculate a reference value of steam usage. The authors recommend Perstorp to use this model in the following systems:

- The total steam usage in the factories producing Polyol C and Polyol D were better explained than Polyol A and Polyol B. The structure of these factories is simpler, and the product flow is more straightforward. The models can be expanded to include components, to gain better information about steam dependency in these factories.
- Concerning the components at Polyol A; the steam usage in the Dissolver showed the largest dependency towards another factor: the product flow. A model can be developed for this component, calculating a reference value of the steam usage.

In several models, the R^2-value was low, making the model useless. The usage in these systems was not dependent on the factors it was tested for. Other models are necessary when gaining a reference value, in these systems:

- The total steam flow entering the factory producing Polyol A and Polyol B showed a very low correlation towards the production rate and outdoor temperature. Even after an improvement of the model, the result had too low dependencies which made the model useless. The authors do not recommend a continuous work with multiple linear regression for these factories.
- Many modeled components in Polyol A showed a small or non-existing dependency on other variables. For the following components the models are unsuited: the Steam compressor system, the Distillation column and Dryer 2.

- The result was slightly better for two components: the Evaporator and Dryer 1, but the models are still inappropriate for these components, since the dependency is too low.

Some concluding recommendations from the authors:

- To build usable models, the steam meters have to be trustworthy. Therefore, the first recommendation is to thoroughly review the steam meters, including a calibration of them.
- The result from the modelling of the factory producing Polyol C and Polyol D gave a higher R^2-value than the factories Polyol A and B. A recommendation is to continue the work with those models, including the components, in the factory producing Polyol C and D.
- On the contrary, for Polyol A and B, the steam usage should be evaluated in another way.
- For the factories and components explained poorly by the multiple linear regression, a time series analysis could give better results over the steam usage dependency. A recommendation is to initiate a new master's thesis or an internship student, performed by a student with good knowledge of mathematical statistics.
- A better model for the Dissolver could be developed, using multiple linear regression, calculating a reference value of the steam usage.
- The steam usage in the Evaporator showed a correlation to the product flow when the control valve was partly closed. This could be examined further the spring of 2013, when the production rate is planned to be lower.
- A better picture of the heat transfer from the Steam compressor system to the Distillation column is essential when mapping the Polyol A factory's energy usage. How the deaeration system is controlled has to be investigated.
- Steam usage in Dryer 1 showed a larger dependency compared to Dryer 2. A recommendation to Perstorp, concerning both dryers, is to calculate the theoretical base load, i.e. the amount of steam necessary to dry and heat the incoming air.
- A great deal of the LP steam is used for heating of pipes and facilities, e.g. LP steam in Polyol C and D. This steam usage showed a larger correlation to outdoor temperature compared to production rate. When calculating the key figures for this steam Perstorp can alternate from today's production rate to temperature instead.

To sum up: the authors chose one statistical model, recommended by an Associate Professor in the field [17], and used that throughout the analysis. If they instead had performed several different methods, it would have been easier to suggest a preferable model, useful for the factories. Regarding the choice of Polyol A; it is a more complex factory compared to the Polyol C and D factories. However, it is the largest steam consumer of the Polyol factories, and it has one component that solely stands for almost half of the steam usage in the factory. The authors wanted to improve the model for this factory, to be able to prove if this model could be used in a more complex factory. Unfortunately, this was not the case.

7.2 Energy management

The energy management at Perstorp is organized, although it can be improved. The impression the authors got after finishing the interviews at Perstorp, was that energy is an important issue but it is not prioritized from the company's board. Furthermore, the Energy Coordinator feels that the level of ambition can increase at the company. Successfully implemented energy efficiency measures are thus entirely dependent on the board. The board must decide to give energy efficiency a high priority and thereby provide the organization mandate to pursue the issue. However, there are many positive examples of well-practiced energy management at Perstorp, some are listed below:

- It is important that a manufacturing industry sub-meter their energy consumption, because this enables cost allocation based on the actual consumption of each division. This is something Perstorp apply.
- Perstorp analyses the different factories' energy consumption ratios every week in a group, which consists of Engineers and the Factory manager.
- If the energy and production ratios are higher than expected, the Production and Process Engineers try to find the underlying reasons.
- Perstorp implemented a new project model, Perstorp Project Model - PPM in 2011, which has made the running of projects easier.
- The existence of an enthusiast is a main driving force for energy efficiency and Perstorp has an Energy Coordinator who wants to increase the company's ambition regarding energy management.

Perstorp can still improve some areas of their energy management and some are listed below:

- Regarding the PPM; a better connection between the energy management system and PPM's checklist is needed, i.e. clarify for Project Managers how to work and handle energy issues.
- One thing lacking in projects is a comprehensive energy calculation concerning energy savings after the implementation is finished.
- Create an Energy group that will get a comprehensive view concerning energy issues. A group that can see the big picture and what needs to be done the most. This group can select a few focusing areas each year regarding energy efficiency.
- After the Project manager compose the follow-up after a project is implemented, this person can put the result in the PFE-folder and also tell the Energy Coordinator about the result.

- Perstorp only has energy goals concerning the next year. A success factor to improve energy management is establishing a strategy with quantified energy reduction goals over the next 5-10 years. It is therefore a recommendation to implement new long-term goals and an action plan for each goal how they can be achieved.
- None of the interviewees at Perstorp were aware of their energy goals. Therefore it is a recommendation to improve the staff's awareness of Perstorp's energy goals, both their weakly budget goals and their one-year goal of decreasing their energy consumption by 12.9%.
- An important success factor for efficient energy work at companies is the motivation of staff, because employees for example can affect how the factory is operated. A recommendation to Perstorp is to have training for the staff where they can discuss both energy goals and their action plans, and also how the company wants the staff to take action on energy issues.

The conclusion from this part of the thesis is that Perstorp works with energy issues a great deal but there is much to do and deciding what to begin with is a good start. Therefore it is a recommendation to Perstorp that they first create an Energy group that can prioritize within the energy efficiency area and also decide which dimensions the area should have.

A final conclusion is that it would be of great use for Perstorp to have a model telling the operating personnel if more steam than necessary is utilized. This thesis tested one statistical method with poor results, highlighting the complexity of the factories. Continuous work is therefore necessary, which requires an improved energy management system. Although, in time the energy usage at Perstorp could be fully mapped and analysed, resulting in a system that warns the operating staff when more steam than required is utilized. This would decrease both energy cost and climatic impact for Perstorp.

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A Appendix

Questions regarding the energy work

General questions.

- Did you work with the Energy issues before PFE was introduced in 2005?
- Have you changed your thoughts after the introduction; increased your awareness of energy issues?
- Changed the way the company works?
- Have the energy management system helped to structure and implement energy ambitions in the daily operations?

Energy Management Coordinator

- Who is the Energy Management Coordinator? Are you alone responsible of the energy management system and PFE?
- Your specific duties regarding energy?
- How many hours of your work time to you spend on energy issues?

Management and staff commitment.

- In what groupings, i.e. at which meetings, are energy on the agenda?
- In the group where energy is on the agenda, who is included in that group? (From which part of the factory)
- What concrete this group does on energy issues?
- If someone comes up with new ideas on energy efficiency, how is it handled?
- Estimate the number of employees directly involved with the energy management system and energy efficiency, either a few times or on a more regular basis.
- Do you feel that the management prioritises energy issues?
- Are you aware of Perstorp's energy goal? Which are they? Do Perstorp have an action plan to reach the goals?
- Is there someone who is responsible for each goal?

Energy cost allocation

- How are energy costs allocated? To various factories / divisions?

Monitoring and reporting.

- How often do you read and analyse energy data? Is this done in a group?
- What do you do if you find that the energy usage is higher compared to normal, the past days / weeks / months?

- After an energy efficiency investment has been implemented, who verify the energy savings?
- Who is responsible for this?
- If you want to estimate the size of the energy saving, have you developed methods to evaluate the measures.

Training

- How often do Perstorp have training for employees regarding the issue energy efficiency?
- If Perstorp has training, which employees may participate in it?
- Is there minimum level of knowledge regarding energy and energy efficiency? This is to raise awareness and motivation.

B Appendix

Table 12: Results from the first modelling with multiple linear regressions, including the steam usage dependency for the entire factories. β_0 is the intercept, β_1 the production rate and β_2 the outdoor temperature. Cooling water temperature is not included, since Polyol B is not dependent on it.

Polyol	Steam	β_0	$\beta_0$interval		β_1	$\beta_1$interval		β_2	$\beta_2$interval	
A	High	3.7	3.5	3.9	0.20	0.16	0.24	-0.0055	-0.0099	-0.0012
	Low	10.3	9.9	10.6	0.72	0.65	0.78	-0.065	-0.071	-0.059
B	High	6.0	5.3	6.8	0.64	0.48	0.81	-0.027	-0.037	-0.019
	Low	5.1	3.9	4.6	0.70	0.48	0.93	-0.039	-0.049	-0.031
C	High	2.1	1.4	2.8	1.3	1.2	1.4	-0.019	*-0.056*	*0.017*
	Low	1.52	1.50	1.55	0.0035	*-0.013*	*0.020*	-0.021	-0.024	-0.020
D	High	4.6	3.5	5.4	1.2	1.1	0.4	*-0.026*	*0.51*	0.048
	Low	1.35	1.30	1.39	0.055	*-0.019*	*0.093*	-0.042	-0.046	-0.037

Table 13: Results from the multiple linear regressions, including only the depending variables. β_0 is the intercept, β_1 the production rate and β_2 the outdoor temperature. Cooling water temperature is not included, as Polyol B is not dependent on it.

Polyol	Steam	β_0	β_1	β_2	$\beta_{0,stand}$	$\beta_{1,stand}$	$\beta_{2,stand}$
A	High	3.7	0.2	-0.0055	4.6	0.14	-0.039
	Low	10.3	0.72	-0.065	13	0.52	-0.51
B	High	6.0	0.64	-0.027	8.6	0.26	-0.19
	Low	5.1	0.70	-0.039	4.1	0.20	-0.17
C	High	2.1	1.3	-	-	-	-
	Low	1.52	-	-0.021	-	-	-
D	High	4.6	1.2	-	-	-	-
	Low	1.35	-	-0.042	-	-	-