UNIVERSITY OF GÄVLE

FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT
Department of Building, Energy and Environmental Engineering

Energy Audit of an industrial building in Sweden

Case study of a CNC processed components' producer company

Isabel Bueno Rosete

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Supervisor: Arman Ameen
Assistant supervisor: Roland Forsberg
Examiner: Mathias Cehlin

Abstract

The industrial sector accounts for almost 40 % of the Swedish energy use and in order to meet the EU's 2020 targets, an efficient production of high quality and great finish goods are more and more in demand. Moreover, it is important to develop the activities with the lowest environmental impact possible.

The energy audit process is an effective tool to achieve it. Thus, in this document the energy audit of an industrial company, Automat Industrier in Gävle, Sweden, was carried out.

The energy balance of the building and the potential energy efficiency measures were analyzed with the IDA ICE simulation.

The proposed energy retrofitting was apropos of the building envelope, the lighting system, the ventilation system and the installation of a PV system on the roof of the building.

The survey indicated that the potential energy savings of the company accounted for 62.5 % of the current electricity use and 48.8 % of the current DH use if all the proposed ameliorations were performed. The main promoter of the electricity savings is the installation of the PV system, with 85 % of influence. Almost 90 % of the DH savings are due to the measures in the ventilation system.

Financially, these savings can reach the amounts of 531 597 SEK/year for electricity and 174 201 SEK/year for DH.

Nevertheless, the ameliorations regarding the building envelope have very long payback periods. Thus, it was recommended to not pursue them. Fortunately, the energy efficiency measures providing the greatest savings' payback periods are between 3.47 years and 10.22 years long. As they are independent from each other, the owner has the freedom to decide whether to apply them or not and when if so.

Key words: energy audit, industrial energy audit, energy efficiency measures, IDA ICE simulation software and energy retrofit.

Preface

I would like to thank my supervisor Arman Ameen for all the help delivered for the correct development of this thesis. Also, I would like express my thankfulness to Roland Forsberg who was always willing to accompany me to the on-site visits to the company and pass on his knowledge.

Of course, I am very thankful to my family who has supported me not only during the thesis but also during this whole year in Sweden.

Nomenclature

Latin and Greek symbols

Symbol	Description	Unit
Q	Rate of heat transfer	W
k	Thermal conductivity	$W*m^{-1}*K^{-1}$
A	Area of the surface	m^2
$\frac{\partial T}{\partial x}$	Temperature gradient in the direction of the heat flow	K/m
R	Thermal resistance of the material	m^2*K/W
D	Thickness of the material	m
A	Heat transfer coefficient	$W*m^{-2}*K^{-1}$
T_w	Wall temperature	K
T_∞	Ambient temperature	K
ε	Emissivity of a body	-
σ	Stephan Boltzmann's constant, 5.67×10^{-8}	$W*m^{-2}*K^{-4}$
U	U-value	$W*m^{-2}*K^{-1}$
R_{si}	Thermal resistance of the inner surface	m^2*K/W
R_{se}	Thermal resistance of the external surface	m^2*K/W
η	Efficiency	-
ρ	Density	kg/m^3
c_p	Specific heat	$kJ*kg^{-1}*K^{-1}$
V	Flow	m^3/s
ΔT	Temperature difference	K

Abbreviations and acronyms

Letters	Description
EU	European Union
SMEs	Small and Medium Enterprises
DH	District Heating
CNC	Computer numerical control
IDA ICE	IDA Indoor Climate and Energy
PV	Photovoltaic
ISO	International Organization for Standardization
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
HVAC	Heating, Ventilating and Air-Conditioning
IAQ	Indoor Air Quality
CAV	Constant Air Volume
VAV	Variable Air Volume
VAT	Value Added Tax
AHU	Air Handling Unit
PPD	Predicted Percentage of Dissatisfied
IR	Infra-red

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1 Introduction

1.1 Background

Energy is a key factor in the way to development, not only for the industrialized countries but also for all the countries that want to improve their standard of living. In consequence, the worldwide energy usage has increased exponentially in the last decades.

Unfortunately, around 80 % of the production of this energy comes from fossil fuels, which have a negative environmental impact. Moreover, these energy sources are limited and unevenly distributed in the world, which makes them expensive and can create uncertainties in terms of supply.

However, it wasn't until a little more than a decade ago, that this fact raised some concern among the world leaders. It became obvious that the system of energy production, distribution and usage had to be transformed.

So, in 2007 the EU's (European Union's) leaders set three main targets for the year 2020 and in 2009 they incorporated them into legislations. These targets are: 20 % reduction in the greenhouse gases emissions in relation to the levels of 1990, 20 % share of renewable energy in EU and 20 % of energy saving by improving energy efficiency (Climate Action - European Commission, 2018).

As part of EU, Sweden has to accomplish the targets stated above and has been working towards achieving them throughout the years. For that, multiple energy and climate policies and regulations have been carried out; such as, fuel and energy taxation, implementation of the green certificate system to support the production of electricity from renewable sources… (Krook Riekkola, Ahlgren and Söderholm, 2011).

Moreover, to improve the energy efficiency on diverse fields the Swedish government has promoted various energy audit programs. Even though they are mainly focused in the industry sector, due to greater saving potential, they are also addressing residential, agriculture, business… sectors (Berg and Törnell, 2016).

Apart from being a great instrument to improve the energy efficiency, energy audits are a decisive tool for industrial companies that want to reduce their production costs. These two are the main reasons why energy audits are so popular nowadays.

1.2 Energy in Sweden

Although this document is focused on the industry sector, more concretely in the SMEs (Small and Medium Enterprises); it is of great help for the understanding of its importance to have an overall vision of the energy situation in Sweden.

Hence, in Figure 1 the total energy supply by energy use from 1970 to 2016 is presented. It can be estimated that the energy supply grew steadily until 1985, and since, it has been oscillating in the range between 550 and 600 TWh. Being in 2016 the value of the supplied energy in Sweden of 564 TWh.

From the chart the most important ideas that should be deduced are the following: Sweden has decreased its dependency in crude oil and petroleum products from the mid-80s onward and, in consequence, the fossil fuels now account for less than a third of the supplied energy. However, the biomass growth has not stopped since 1970 accounting in 2016 for almost a quarter of the supplied energy.

In spite of the intention of the Swedish government to phase out the nuclear energy; due to the amendment of the nuclear law in 2010 that permitted the replacement of nuclear reactors, nuclear energy still constitutes an indispensable cornerstone for the supplied energy (Edberg and Tarasova, 2016). In fact, it delivers one third of the total energy supplied in Sweden in 2016.

Lastly, it should be mentioned the importance of hydropower and wind power in the Swedish energy system. The first one’s contribution has remained constant in the last 3 decades and, although in smaller scale, wind power has gained strength since 2010. Both energy sources are considered to be renewable.

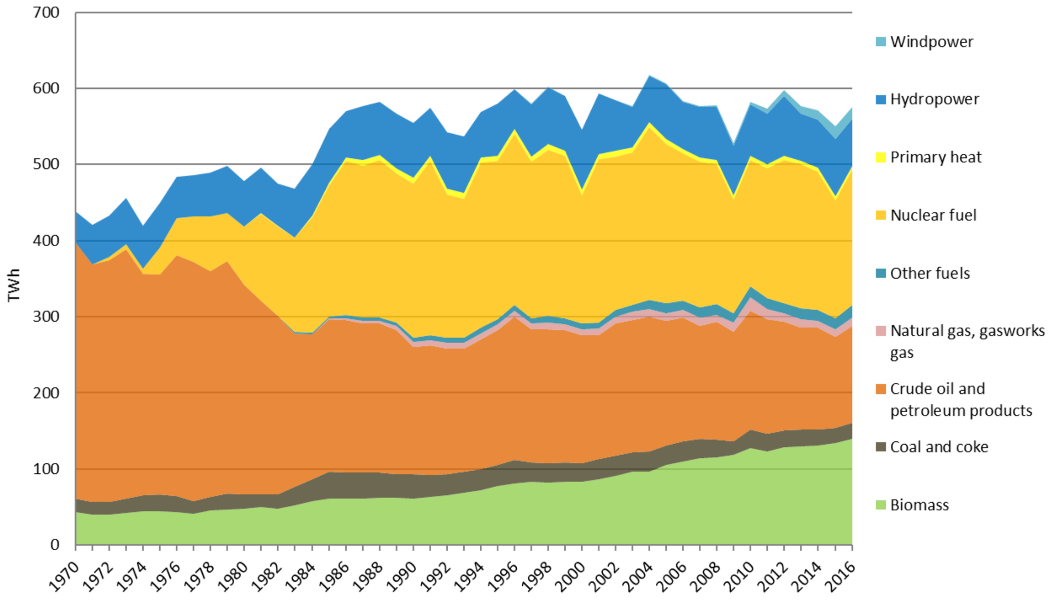

Figure 1.Total energy supply by energy source, from 1970, TWh. Source: Swedish Energy Agency and Statistics Sweden.

Nevertheless, not all the energy supplied has a final purposeful use. This is due to the multiple losses, the energy that is needed to use by the energy sector and the non-energy use. Thus, if these 3 elements could be reduced, less energy had to be supplied in order to achieve the same energy for a final profitable use. In this reduction, the energy efficiency measures play a decisive role.

In Figure 2 the evolution of total energy use by final use is shown. It can be estimated that since 2009 the losses group has significantly decreased, mainly the nuclear power losses. The energy sector's own use of energy has also diminishsed in the last few years. The latter could be for heating, lighting, business electricity… Meanwhile, the non-energy use has remained constant in the last decade.

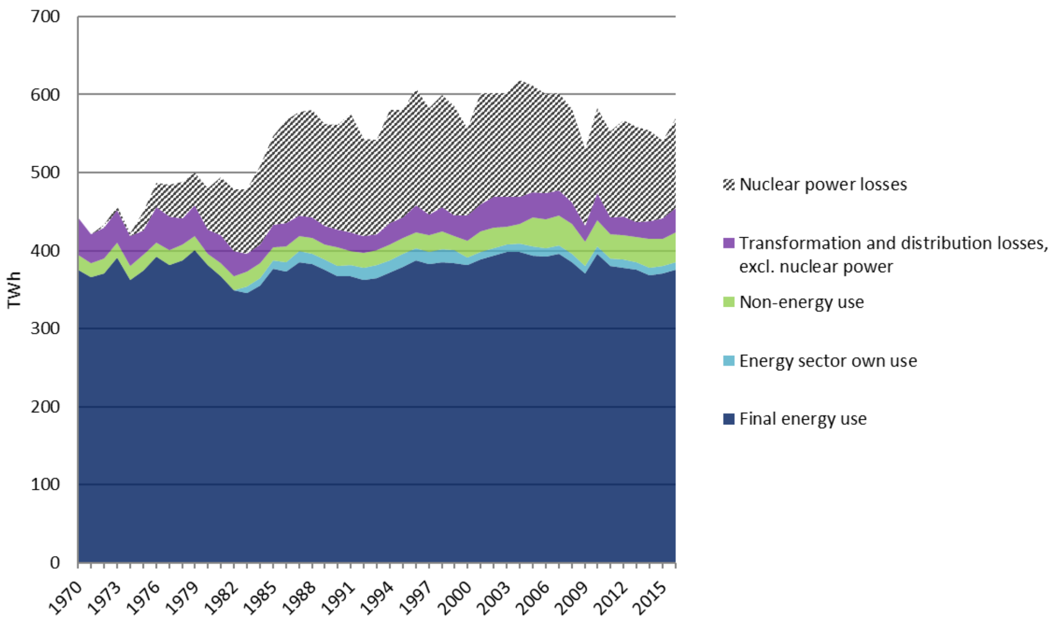

Figure 2. Total energy use by final energy, losses... Source: Swedish Energy Agengy and Statistics Sweden.

Also, the final energy use in Sweden can be divided in 3 main sectors: industry, domestic transports and residential and services. The energy used by the industrial sector is mainly biofuel and electricity. For domestic transport oil products in the form of petrol, diesel and aviation fuel are the most popular. The residential and service sector is mostly provided with electricity, oil and biofuel (Swedish Energy Agency, 2015).

In Figure 3 the share of each of them in the total final energy use in 2016 is presented. The residential and services' sector have the largest energy use (39 %), closely followed by the industrial sector (38 %); and lastly, the domestic transports' sector is the one with the lowest energy usage (23 %).

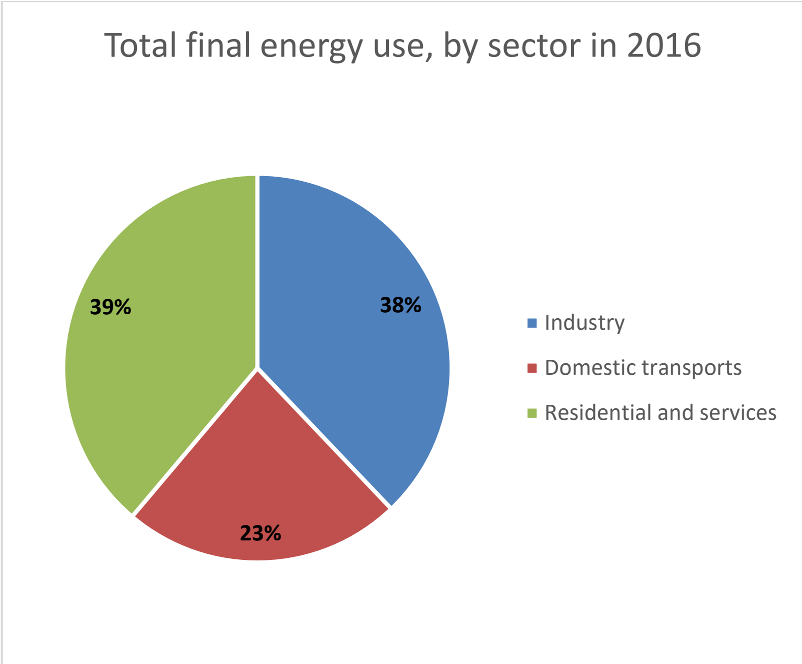

Figure 3. Total final energy use by sector in 2016. Source: Swedish Energy Agency and Statistics Sweden.

Therefore, it is obvious that the industry sector has a strong relevance in the Swedish energy system and has a high potential for saving energy and costs.

1.3 Energy in the Swedish industrial sector

As mentioned before, in the industrial sector the main energy carriers are biomass and electricity, accounting for the 40 % and the 34 % respectively in the year 2016 as it can be appreciated in Figure 4. However, fossil fuels only stand for 20 % of the share, an amount that has decreased in the last decades due to their high price and the environmental policies. It is remarkable how DH (District Heating) covers 3 % showing that the Swedish industries are moving towards a more environmentally friendly behavior.

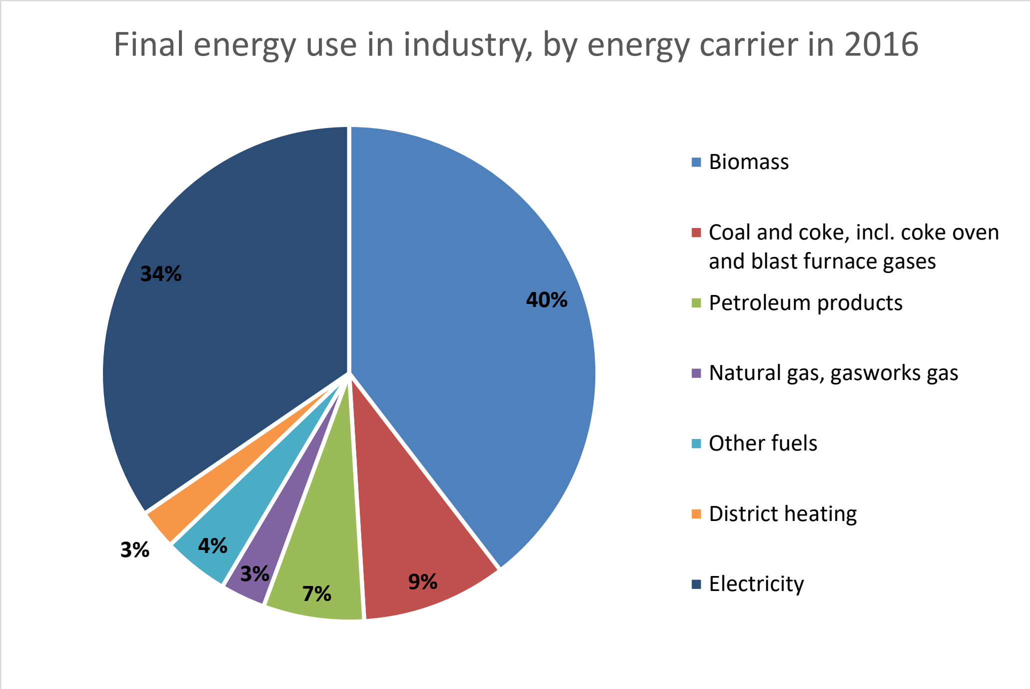

Figure 4. Final energy use in industry by energy carrier in 2016. Source: Swedish Energy Agengy and Statistics Sweden.

In Figure 5 the share of the different industries among the industrial sector is shown. It can be concluded that the pulp and paper industry is the dominant industry in Sweden with a total amount of the 51 % in 2016. The steel and metals industry and the chemical industry are next, accounting for 15 % and 9 % respectively. The mechanical industry is estimated to be 5 % of the total share. As in this thesis an energy audit of a company that produces components with CNC (Computer numerical control) machines was carried out, this is the type of industry that was analyzed and to which the results can be more relatable.

The rest of the energy use falls on the following industries: food, beverages and tobacco; non-metallic minerals; wood products; and small industries and others.

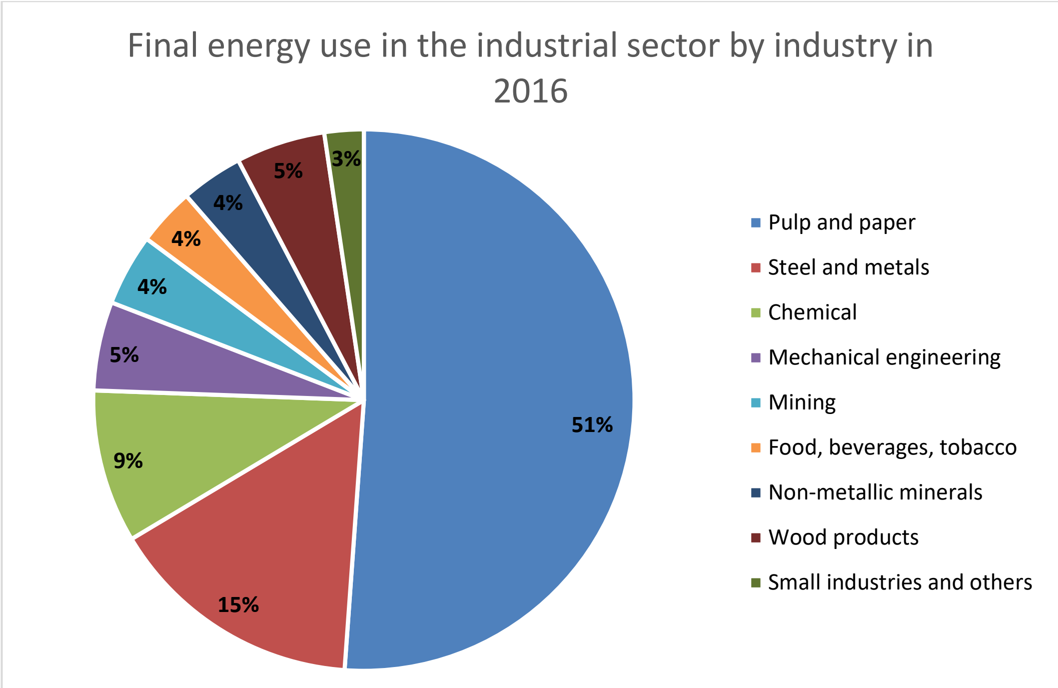

Figure 5. Final energy use in the industrial sector by industry in 2016. Source: Swedish Energy Agengy and Statistics Sweden.

When speaking about energy in the industrial sector in Sweden, it is important to keep in mind that they have great policy measures and programs to meet the EU's targets not only for 2020, but also for the years to come.

The EU Emission Trade System, energy and carbon dioxide taxes are the most important policies applied to the industrial sector.

Regarding energy efficiency, there are 3 main programs that the Swedish government has implemented as the Swedish Energy Agency stated (2015): 'The Program for Improving Energy Efficiency in Energy-intensive Industries', 'Support for energy audits' directed to small and medium enterprises and 'The Act on Energy Audits in Large Enterprises'. The first two have been already concluded, while the last one is still in effect forcing all the large companies to carry out an energy audit once every 4 years.

Lastly, 'The electricity certification system' is a policy measure that promotes electricity production from renewable sources. For each MWh of renewable electricity an electricity certificate is given to companies. These certificates have a resale price and electricity suppliers and some electricity users are demanded to have certain amount of them, so an electricity certificate market is created (Swedish Energy Agency, 2015).

1.4 Literature review

The main goal of this document was to reduce the energy use of an industrial building and analyze the economic effects of this reduction. An energy audit was carried out in order to identify the current energy situation of the plant and the most suitable energy efficiency measures for it.

Thus, in the literature review the importance of the energy audit process will be highlighted making reference to previous studies. Also, how an energy survey should be carried out and effective energy efficiency measures will be established.

For the literature review the main webpage domains used to search information were ‘Science Direct’ and ‘Libris’. The keywords employed in the research were the following: energy audit, industrial energy audit, energy efficiency, IDA ICE (Indoor Climate and Energy) simulation software and PV (Photovoltaic) system.

As stated by Kluczek and Olszewski (2017), the energy audit process involves on-site visits to the company for measurements, analysis of the energy balance, detection of the energy efficiency measures and an energy and cost analysis of each of them. In the study is remarked that “Energy audit programs reveal that 60 – 90 % of the measures implemented by industrial SMEs concern support processes”. Being that, the energy audit developed for this research didn’t involve the retrofit of the production processes.

In what the energy efficiency measures concern, the researcher considered some peer-reviewed article for a better understanding of the options in the studied factory. Below the most significant ones are presented.

The retrofit of the building envelope was proven to be a cost-effective energy retrofit by Dongellini, Marinosci and Morini (2014). In the study an amelioration of 80 – 90 % regarding the insulation of floors and roofs concluded in a 225 000 kWh/year energy savings and in a 33 000 €/year cost savings. Apropos of the windows, the energy efficiency measure proposed involved changing them to models with lower U-values. The energy savings consisted of 200 000 kWh/year and the cost savings of about 30 000 €/year. However, due to its long payback period the retrofit wasn’t advised to be performed.

It was concluded by the researcher that not only the energy and cost savings should be regarded while performing an energy audit, but also its profitability.

Another interesting study by Heidari et al. (2018), remarked that by switching to more energy efficient LED lamps the electricity use worldwide for lighting could be decreased by 80 %, saving $140 billion with low payback periods. This indicates that, although in a much lower scale, great savings could be achieved in the case study of this thesis and it is worth the analysis.

As indicated by Tallini and Cedola (2016) heat recovery in industrial facilities constitutes a great energy efficiency measure. As a matter of fact, Uz (2018) estimated the savings for manufacturing SMEs to $14 540 a year in a study where measures were proposed for those companies to face the 2 000 California energy crisis. Low paybacks were presented.

In a study carried out by Molin et al. (2016), the PV solar energy was presented as a very powerful energy resource capable of providing more than a half of the electricity use for residential buildings. A survey was carried out determining that a Linköping's neighborhood constituted by a total roof area of 2 000 m^2 had the maximum potential to generate 88 % of the total electricity used. This percentage would decrease when the tilt deviated from the optimal.

Thus, the energy audit and the possible energy efficiency measures were proved to be effective. The energy audit method was confirmed to be the ideal process to reduce the energy use in the company studied in this research.

1.5 Case study: Automat Industrier industry

In this document the development of an energy audit of a Swedish company called Automat Industrier is carried out. The enterprise is located in the North of Gävle and produces components processed with CNC machines.

This company was founded in 1946 and it has provided since high quality, flexible and efficient processes. The aim is to offer the most cost-effective prices for the CNC components, while having the smallest environmental impact possible. Proof of that is their certificates, as the certificate ISO (International Organization of Standardization) 9001:2015 and ISO 14001:2015 regarding manufacturing of machined components for the engineering industry (Automatindustrier.se, 2018).

In order to keep in the environmentally friendly path this industry has two main energy efficiency problems which need to be solved: the thermal balance between the overheated areas and the cold areas in the plant has to be adjusted and the ventilation system needs to be improved.

Regarding the energy carriers, the company uses electricity to feed the equipment and lighting in the plant. For space heating and warm water, DH is employed.

In Figure 6, an overview of the plant can be seen where it can be appreciated that is a one-story installation.

Figure 6. Automat Industrier plant. Source: Automatindustrier.se (2018)

1.6 Aims and limitations

The main aim of this thesis is to propose some energy efficiency measures by performing an energy audit of the company and simulating it with the IDA ICE software.

The energy efficiency measures included solutions for the 2 prime issues the industry is facing. Thus, some alternatives for the uneven thermal situation happening in the plant were proposed and improvements for the ventilation system were presented. However, other measures were also studied.

Along with that, a simple economic analysis was performed so the company can decide if they are interested in implementing the energy saving improvements proposed.

Also, as the company wants to move forward to environmentally friendly energy sources, the possibility of installing a PV system on the roof of the plant was studied and its profitability analysed.

Due to the limited time there was to develop this research, it wasn't possible to make measurements in the equipment and their demand was deduced by subtracting the lighting's energy use to the electricity bills. Although it doesn't adjust to reality, for the simulation the distribution of the equipment throughout the plan was considered even.

Moreover, for the IDA ICE software simulation various plans of the plant were provided with information about geometrical dimensions, ventilation system, insulation, etc. Nevertheless, these drawings were designed in 1975 and in consequence they weren't updated. Anyway, the plans were assumed valid for the thesis since the changes that happened in the last years were considered of small influence and it was impossible to obtain the information regarding the changes due to time limitation. Of course, this affected to the accuracy of the results.

So, the audit wasn't totally accurate but enough to have an overall idea of what improvements can be made.

1.7 Approach

To develop this thesis, the first step is an on-site visit for some meetings and measurements. With the acquired information as input data, a base model was built in the IDA ICE software and simulations made. Different models were carried out in the software with energy efficiency measures and the consequent results were analyzed. The study was completed with an economic analysis of the improvements proposed.

2 Theory

2.1 Energy audit

An energy audit consists of an energy survey and analysis of a facility to identify the potential energy efficiency measures that could be applied to improve the energy efficiency of the building studied and reduce the energy use. To examine the profitability of the proposed improvements, an economic analysis is carried out (Murphy, 2014).

However, not all energy audits are the same. In fact, ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) has defined 3 different types of energy audits depending on the depth of their analysis and the reliability of their results (Thumann, Niehus and Younger, 2013):

- Level I: Walk-through analysis. It involves the analysis of the energy invoices and a brief on-site visit to conclude the overall energy situation of the facility. This audit only identifies the low-cost or no cost energy measures and provides an initial economic data that needs to be further studied.

- Level II: Energy survey and analysis. It consists of a more elaborate energy survey and analysis. Thus, various on-site visits are required for data collection and meetings with the owners. It provides a breakdown of the energy use in the building, which allows the auditor to identify where the most cost-effective energy measures can be found. An economic analysis is carried out to study the profitability of the proposed improvements.

- Level III: Detailed analysis of capital-intensive modifications. It is centered in the extended analysis of the possible capital-intensive measures identified in a Level II audit. This supposes that an even more detailed data collection and economic analysis have to be performed, including pondering the possible risks, so the results are of high reliability.

Taking into account that the time for the development of this thesis is limited, the energy audit that will be carried out for this research will be a Level II audit which perfectly meets the requirements for the thesis.

2.2 IDA ICE simulation software

As mentioned before, the IDA ICE software was used to perform a dynamic simulation of the plant. The version of the software was 4.7.1.

This software "… *is a dynamic whole-year simulation software where the energy balance of a building and its thermal indoor climate are studied"* (Milić, Ekelöw and Moshfegh, 2018).

As stated by Milić, Ekelöw and Moshfegh (2018), IDA ICE calculates the building energy use and allows the user to create an idea of which the possible energy saving measures could be and how much energy could be saved. For this, the program analyses the building envelope and the energy systems in it.

For the simulation, the building is divided in zones, each of them corresponding to a room of the building and configured with their own parameters.

Moreover, the IDA ICE software requests some input data, for example the layout of the plant, building envelope properties, building operational parameters, HVAC (Heating, Ventilation and Air-Conditioning) system parameters, etc. to develop a dynamic simulation (Jung et al., 2018). Therefore, it is important to make sure that data can be provided for the research. Besides, for the simulation, the location of the building and climate and weather conditions are required.

2.3 Heat transfer

"Heat transfer is a discipline of thermal engineering that concerns the exchange of thermal energy from one physical system to another" (Heat transfer, 2011).

This phenomenon occurs because of a temperature gradient between two systems, which provokes a heat flow from the high temperature system to the low temperature element as it is explained in Heat transfer (2011) article. Heat transfer can happen as heat conduction, convection, radiation and phase-change of bodies. In reality, systems suffer a complex combination of all of them. Nevertheless, for this thesis the first three are the ones that are most relevant.

The fundamentals of these three heat transfer means are explained with laws of physics, as it can be appreciated in the following subsections.

2.3.1 Conduction

To transfer heat by conduction two or more bodies have to be in physical contact, since the heat exchange happens due to the intermolecular interplay between the bodies. It could be because of the vibration of atoms against each other or the movement of electrons. For solids, conduction is the most common way of heat transfer. However, fluids aren't as good heat conductive bodies (Heat transfer, 2011).

Hence, in buildings conduction happens when there is a temperature difference between the inner and external sides of an element of the building envelope.

The heat flux transferred by heat conduction is defined by Fourier's first law, which is displayed in the next equation.

$$Q = -k * A * \frac{\partial T}{\partial x} \tag{1}$$

Where: Q =rate of heat transfer by conduction (W)

k = thermal conductivity of the materials (W/m*K)

A = surface area (m^2)

$\frac{\partial T}{\partial x}$ = temperature gradient in the direction of the heat flow (K/m)

Thermal conductivity is a thermal property that depends on the material used, as each material has its own constant value.

Another property of interest for this study is the thermal resistance, which is shown in the equation below.

$$R = \frac{d}{k} \tag{2}$$

Where: R = thermal resistance of the material (m^2*K/W)

d = thickness of the material (m)

k = thermal conductivity of the materials (W/m*K)

Thermal resistance measures how well a material resists a conductive thermal flow. So, when insulation needs to be strengthen the resistance has to be increased. It could be either by thickening the insulation or by changing to a material with a lower thermal conductivity (Thumann, Niehus and Younger, 2013).

2.3.2 Convection

Convection happens within fluids, which transport the heat through zones with different temperatures. This method of heat transfer can happen naturally or artificially. The first one happens due to the buoyancy forces that appear because of the temperature fluctuations that make density vary. The second one happens when convection is forced with fans, pumps… (Heat transfer, 2011).

As stated by Davidzon (2012), convection transfer is defined by Newton's law of cooling which is presented in the following equation.

$$Q = \alpha * A * (T_w - T_\infty) \tag{3}$$

Where: Q = rate of heat transfer by convection (W)

α = heat transfer coefficient ($W/(m^2*K)$)

A = surface area (m^2)

T_w = temperature of the heating surface (wall temperature) (K)

T_∞ = ambient temperature (K)

For convection, thermal resistance is defined as it can be seen in the next equation.

$$R = \frac{1}{\alpha} \tag{4}$$

So, in the factory analyzed in this thesis, the heat exchanged in the air itself will happen this way.

2.3.3 Radiation

This means of heat transfer consists of emitting or absorbing energy in form of electromagnetic waves or particles. This heat transfer can happen trough physical materials or through vacuum. Every body that has a temperature above the absolute zero emits radiation that is absorbed by the surrounding surfaces (Heat transfer, 2011).

The radiation absorbed by a body is defined by the equation below:

$$Q = \varepsilon * \sigma * A * T^4 \quad (5)$$

Where: Q = rate of heat flow by radiation (W)

ε = emissivity of a body (-)

σ = Stephan Boltzmann's constant, 5.67 x 10^{-8} ($W/(m^2*K^4)$)

A = surface area (m^2)

T = temperature (K)

In a building, radiation has its importance in the roof and the windows. In fact, radiation can significantly increase the temperature of the external side of the elements. In consequence, the temperature difference between the sides will be augmented, inducing a greater conductive heat flow. This will create a greater heat gain inside the building (Thumann, Niehus and Younger, 2013).

2.3.4 U-value

The U-value, also known as thermal transmittance, is one of the most used parameters to determine how good the insulation of a building is. Well insulated facilities have low U-values, while edifices with poor insulation have greater U-values.

To calculate the U-value of the elements of the building envelope the following equation is used.

$$U = \frac{1}{R_{si} + \sum R + R_{se}} \quad (6)$$

Where: U = U-value (W/m^2*K)

R_{si} = thermal resistance of the inner surface (m^2*K/W)

R_{se} = thermal resistance of the external surface (m^2*K/W)

It is important to keep in mind that it isn't always easy to identify what are the materials that compound the insulation of a building and their thickness when the facility is already built.

"Four approaches are available to estimate U-value of existing buildings:

- *Estimation based on data obtained by historical analysis of building or analogies with similar and coeval buildings using specific technical databases.*
- *Estimation based on the nominal design data.*
- *Estimation based on the actual data obtained by structure identification (sampling or endoscope method).*
- *In situ measurements using HFMs."* (Ficco et al., 2015).

For the case of this thesis, the U-value was calculated using the nominal design data, since the drawings of the factory were provided. Nonetheless, the owner wasn't able to find any updated plans, so the ones that were used are from 1975. In spite this, the building's structure hasn't changed a lot since then and utilizing them is valid.

2.4 Lighting system

The lighting system is the auxiliary process that has to satisfy the lighting demand of the company. A great designed lighting system should provide an adequate visual performance and visual comfort to the people in the building and reproduce properly the colors. Besides, it is important that the lighting installation has a cost effective and easy maintenance process, being that lights have to be changed multiple times during the utility of the edifice.

This auxiliary process uses electricity as its energy carrier, so all the energy efficiency measures proposed reduced the electricity usage. Those measures could be exploiting natural lighting so the artificial one can be reduced or switching to a more efficient type of lamps (Zanardo et al., 2018).

2.5 Ventilation system

As the lighting system, ventilation system is an auxiliary process. Usually, and in this particular case, it is in charge of achieving an adequate thermal comfort and IAQ (Indoor Air Quality) in a building. To determine which values are suitable, occupancy and space area are the main variables taken into account (Thumann, Niehus and Younger, 2013).

Regarding the driving force of the ventilation system, it can be classified in: natural ventilation, mechanical ventilation or a combination of both. In the company studied, a mechanical ventilation system is installed. However, when it is too warm in some zones, because of the uneven thermal situation they are facing, they resort to natural ventilation by opening external doors.

Depending if there is the possibility to vary the air flow or not, there are two main types of ventilation systems: CAV (Constant Air Volume) and VAV (Variable Air Volume). When having rooms of great volumes and high heights in a building, like in industrial facilities, there is an uneven distribution of occupants and equipment. In consequence, the load distribution is not evenly spread throughout the plant. To solve this, a division of the building into smaller zones and the installation of a different VAV system for each of those zones or groups of zones is proposed by Zhou, Wang and Huang (2017). Nevertheless, due to its antiquity, the factory has a CAV system installed.

2.6 Cost savings

As mentioned before, the energy carriers of the plant are electricity and DH. The first one supplies energy to the equipment, the lighting and the fans and pumps of the HVAC system. DH supplies energy for the space heating and hot domestic water.

For the energy audit, the owner has provided the bills of the last two years for each energy carrier which was helpful to determine how to calculate the energy savings. In Appendix A, both invoices belonging to March 2018 are shown and explained.

In regards to the electricity, one part is purchased from Gävle Energi Elhandel and the other part from Gävle Energi AB. In total what the company is paying is a fixed price for the annual subscription rate, the electricity price and some other fees. VAT (Value-Added Tax) is applied to all of them.

For this case, the fixed price wasn't taken into account since it has to be paid regardless the usage. The other two depend on the kWh used monthly and were the ones used for the estimation of the electricity cost savings. They were presented as a single value for simplification reasons. It should be noted that, even though in the invoices in Appendix A the VAT is charged to the company, the amount of money due to this tax is returned to the enterprise at the end of each month. Thus, the VAT wasn't applied to the savings and the formula that was used is the one in the next equation.

$$Cost\ savings\ (SEK) = A * Electricity\ savings(kWh) \qquad (7)$$

Where A: Electricity price = 0.767 (SEK/kWh)

Moreover, the company is connected to Gävle Energi AB DH grid. For this energy carrier there is a fixed annual fee and the energy price depends on the purchased MWh. To both of them the corresponding VAT is applied.

As it is shown in the equation below, for the DH cost saving calculation the price of each MWh was relevant, since the VAT is returned at the end of each month.

$$DH\ price\ \left(\frac{SEK}{MWh}\right) = B * DH\ savings\ (MWh) \qquad (8)$$

Where B: Energy fee= 457 (SEK/MWh)

2.7 Photovoltaic solar energy

In order to switch to more environmentally friendly energy sources, the company is willing to explore the possibility of installing photovoltaic panels on the roof.

Photovoltaic panels are formed by an ensemble of cell panels which are made of semiconductor materials. These materials are the ones enabling the photovoltaic effect, which converts the radiation of the sun into electricity.

In spite of the high initial cost of the installation of a photovoltaic panel system, the operational and maintenance costs are low. Moreover, they use a free energy resource and is a clean energy.

Although a large area is needed to install a photovoltaic system, in this case study that wasn’t an obstacle since there is enough space in the roof. Nevertheless, the performance of the panels depends on solar irradiation which varies with time (Sampaio and González, 2017).

3 Method

To carry out the energy audit presented in this thesis, the method that was followed is the energy management system. This process can be divided into 6 steps as it can be seen in Figure 7 (Kluczek and Olszewski, 2017):

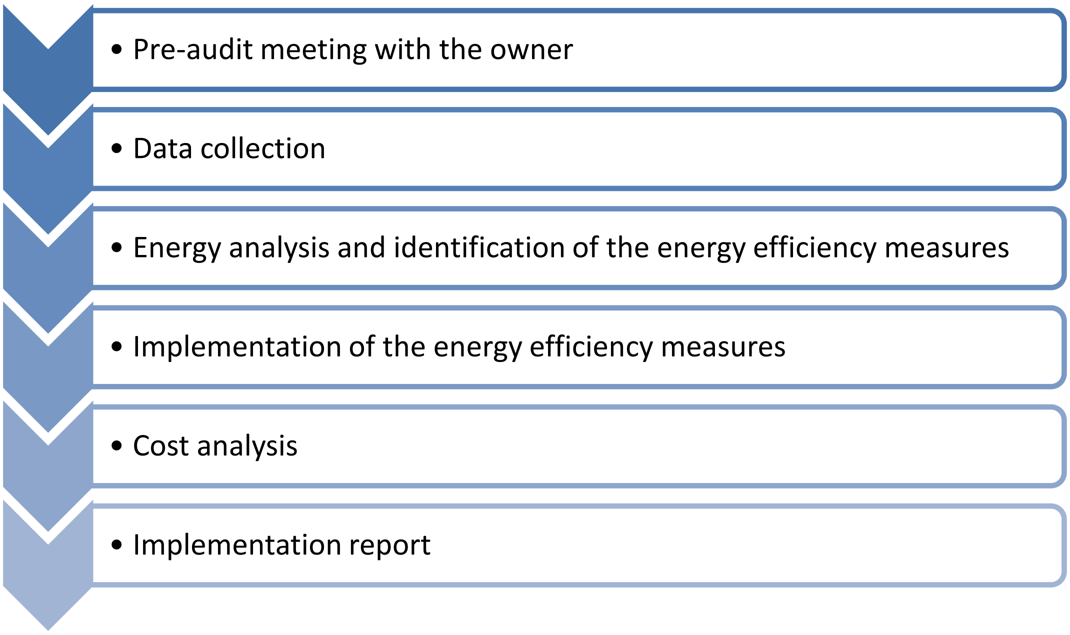

Figure 7. Energy management system.

In this case the last step of going back to the company to see if they have implemented the proposed measures won't be done, because the company is not obligated to carry them out.

It should be noted, that for all the energy related calculations the researcher utilized the IDA ICE simulation software.

3.1 Materials

As mentioned previously, multiple drawings of the factory were provided with geometrical dimensions, ventilation system information, insulation information, etc. However, these plans were designed in 1975 and some information was unclear in them or inexistent.

Thus, the dimensions that were missing and were required for the IDA ICE simulation, were measured using a distance laser meter. The one utilized is from the brand BOSCH and the model is the DLE 70. In Figure 8 a picture of the device is illustrated.

Figure 8. Laser distance meter.

It can measure up to 70 meters in the direction the laser is faced. The origin of the measure can be adjusted to different parts of the gadget, but it is usually used starting from the bottom of the device. It is very simple to use; the user just has to make sure that there isn't any obstacle in the way of the laser meter.

Besides, when comparing the ventilation system drawn in the plan to the one inspected in the on-site visit a big difference was discovered. This was the reason why flows and geometry of the main ventilation systems were measured. The data for the smaller ventilation systems were deduced with the aid of the error obtained in the main ones and a simple correction factor[1] was established.

To measure those flows, a thermo-anemometer was used. With this device the speed of the flow was measured in m/s. For that, it has an extensible pin with a sensor in its ending that measures air speed, temperature and humidity. For a correct measurement the sensor should always be facing the air flow and be perpendicular to the cross section of the duct. As all the studied ducts are of big dimensions, multiple measures were taken and the average was calculated by the device. In Figure 9 a picture of the instrument is displayed.

[1] $Correction\ factor = \frac{Measured\ data}{Drawing\ data}$

Figure 9. Thermo-anemometer.

As the IDA ICE requires the ventilation flow in l/s and the thermo-anemometer measures the speed in m/s, it was necessary to know the geometry of the ducts to do the conversion. The calculation of the air flow through a duct in l/s is shown in the next equation.

$$Q = v * A * 1000 \tag{9}$$

Where: Q = air flow (l/s)

v = air speed (m/s)

A= cross-section of the duct (m^2)

3.2 Procedure

3.2.1 Pre-audit meeting with the company

The first step in the development of this thesis was to have a meeting with the owner of the company. He explained which his main concerns regarding the energy performance of the building were. He provided information about schedules, occupancy, equipment, etc. and showed the researcher around the company. The latter was very useful to get an overview of the company and identify which measurements should be made.

3.2.2 Data collection

The study continued with the collection of energy invoices of the last 2 years, plans of the layout of the building with windows and doors, architectural drawings and ventilation plans. However, the schemes were antiqued and weren't updated.

Thus, for the ventilation some extra measurements were required, which served to complete the provided drawings and to analyze their reliability. It was concluded that the air flows shown in the drawings were inexact and, comparing an on-site measured value and a drawing value of the same AHU (Air Handling Unit), a correction factor was deduced.

The lighting system wasn't defined in the plans, so they were counted visually in one of the visits to the company. Their wattage and light type was also registered.

Lastly, the type of window glazing was identified visually.

3.2.3 Energy analysis and identification of the energy efficiency measures

For the energy analysis and the following identification of which energy efficiency measures should be carried out the IDA ICE simulation program was used.

First of all, the layout given by the company was drawn with the AUTOCAD program. Once this was done, the drawing was imported to the IDA ICE software and the construction of the base model began.

For that, for each room of the drawing a zone was created and windows and doors were defined in the building body.

From there onward, some input data was introduced into the model so it could be as similar as possible to the performance of the real model as stated by Jung et al. (2018).

- <u>Location and climate data:</u>

For the location, as Gävle wasn't in the database, Söderhamn's ASHRAE 2013 file was utilized. This city is close enough from Gävle to have a successful simulation. For the climate data, the user was able to load into the program a file with Gävle's weather information. This file was downloaded from Rokka.shinyapps.io (2018) in the IDA ICE software format.

- Description of the building:

The program requires the materials used and the thickness of them to define the insulation. It has to be configured for the walls (external and internal), for the roof and for the floor. The software itself calculates the U-value of the insulation with the data provided.

In this case, the insulation is not uniform and the building can be divided in to two different zones depending on the insulation their envelope has. These two zones are the office zones and the manufacturing zone. Taking into account that very different activities occur in them, it is logical to have different architectural characteristics. Moreover, in the office area there is a part which has a different insulation in the roof than the rest. The limits between those two areas can be seen in Appendix B, as well as, the office area with different roof.

In the Appendix B Table 1, Table 2 and Table 3 are presented with the materials, thickness and U-value of the insulation of each zone.

In regard to the height of the building, it is also different for the two established zones. The office area has an inner ceiling between the floor and the roof and the manufacturing area does not have a ceiling. Both zones have gable roof, but the manufacturing area's building part has greater height than the offices.

In order to resemble the real building as much as possible, all the windows were defined as 2-pane glazing and in each case their dimensions adjusted. Also, the doors were configured to be always open in case of inner doors and never open for the external doors.

In Appendix B the areas for the building envelope, floor and windows and average U-value are presented.

- Thermal bridges:

Thermal bridges were all configured to typical.

- Ground properties:

The ground model used for the simulation was the default one, which is ISO-13370.

- Infiltration:

Since the analysis of the air tightness and each pressure difference wasn't carried out, they were supposed to be 0.5 ACH at pressure difference of 50 Pa, which was the default setting in IDA ICE.

- Domestic hot water consumption:

The owner supplied a previous study where it could be appreciated that the warm water consumption accounted for the 3 % of the district heating use.

- Heating and cooling units:

In the factory there were no cooling units. Nevertheless, there were radiators in the office area which were simulated as ideal heaters of 1000 W each.

- HVAC system:

In the company there are 14 different AHUs: 5 standard air handling units without heat exchanger and cooling coil, 2 supply air only unit without cooling coil and 7 exhaust air only units. All of them have a CAV system. The air flows to each room are provided in Appendix B. Regarding the schedule of the fans of the AHU, for the offices there were set to start functioning at 7:00 AM and stop at 6:00 PM. For the AHU in the manufacturing zones, the fans followed the working time in that area.

- Internal temperature:

The internal temperature was set between 21 ºC and 25 ºC.

- Internal heat gain:

For the internal heat gain the occupancy, the equipment and the lighting were accounted. The three of them have the same schedules. The office hours were configured from 8:00 AM to 5:00 PM and in the manufacturing area there was activity 24 h every day of the week except Saturdays. The dining room schedule and dressing room schedule was deduced by the information provided by the owner. From the invoices, it was deduced that July's activity is the half of the activity of the other months.

Occupancy was estimated by the researcher employing the information provided by the owner and the activity seen during the on-site visits.

The contribution to the heat gain of the equipment in the production area was greater than in the office area, since multiple machining and CNC machinery is employed in the factory. For each office, one equipment of 200 W was estimated. The equipment in the production zone was concluded subtracting the lighting's energy use and the office equipment's energy use from the electricity bills. Although it is not accurate compared to the real distribution of the plant, the obtained value was divided evenly through the manufacturing area. In Appendix B the energy use of the equipment is shown.

With respect to the lighting, in Appendix B the number of lights in each zone and their wattage are detailed.

Once all the data was inserted into the software, the building model was simulated. To validate the model, the electricity and DH use of the building was compared with the energy bills provided by the company. This validation indicated how similar the model was to the real performance of the factory and gave the percentage of error.

Knowing that the model, which will be called base model from now on, was acceptable; the energy balance was analyzed and the sources of the main energy losses were identified. By examining the simulation results, some possible energy efficiency measures were detected.

3.2.4 Implementation of the energy efficiency measures

According to the ameliorations, different changes were made in the parameters of the base model and new simulations were performed when needed. With the aid of the energy balance a comparison with the base model was developed, enabling the researcher to determine the potential of the retrofits.

3.2.5 Cost analysis

To study the profitability of the energy efficiency improvements, a simple cost analysis was performed. There the initial investment, its payback and the economic savings were provided.

4 Results

In this chapter the most remarkable results are presented. For a better understanding of them, in Appendix C the layout of the plan is displayed indicating which zone belongs to which room.

4.1 Validation of the base model

As stated before, the energy invoices were a reference to determine if the base model was acceptable or not and how reliable it was. In Figure 10 and Figure 11 the representation of the purchased energy can be seen for the last two years.

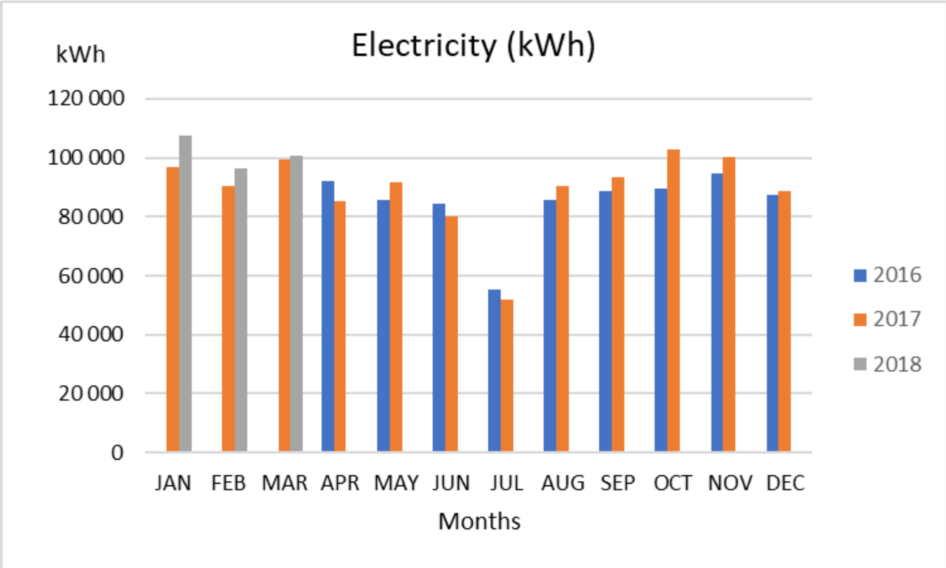

Figure 10. Purchased electricity in the last two years.

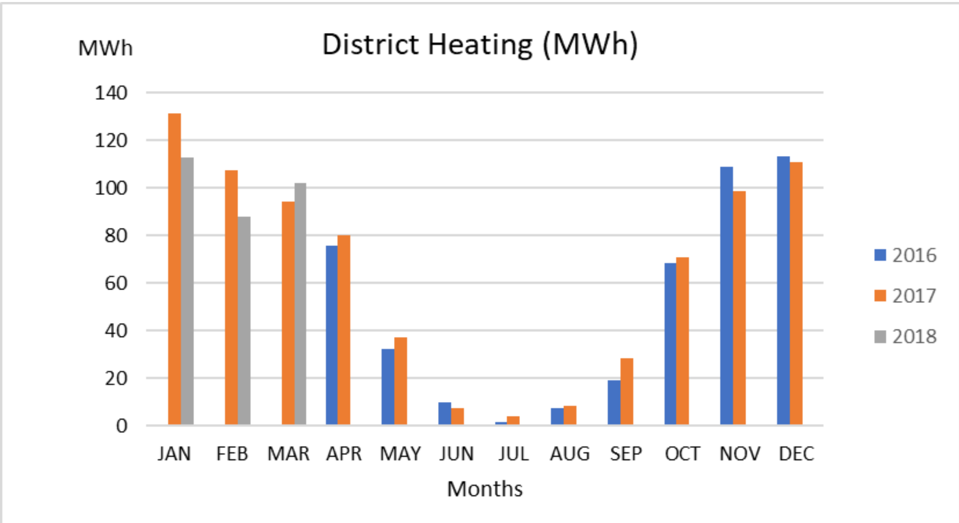

Figure 11. Purchased district heating in the last two years.

With the information in the invoices the annual mean energy use was calculated and this value was used for the comparison. In Table 1 yearly energy use is shown and in Table 2 the relative error[2] between the base model and the invoices is presented.

Table 1. Yearly mean energy use.

	Base model	Invoices
Electricity (kWh)	1 108 732	1 070 341
DH (MWh)	780.32	759.11

Table 2. Relative error of the base model.

	Error
Electricity	3.46%
DH	2.72%

It can be seen that the errors are small and acceptable for electricity and DH, so the base model was validated. The relative error indicates the deviation that the base model has in comparison to the real performance of the factory.

4.2 Energy balance of the base model

A 2018 yearly simulation was carried out for the base model. One of the main results of interest was the energy balance, since it allowed to identify the sources of the heat losses in the building easily. In Figure 12, the energy balance of the company is displayed.

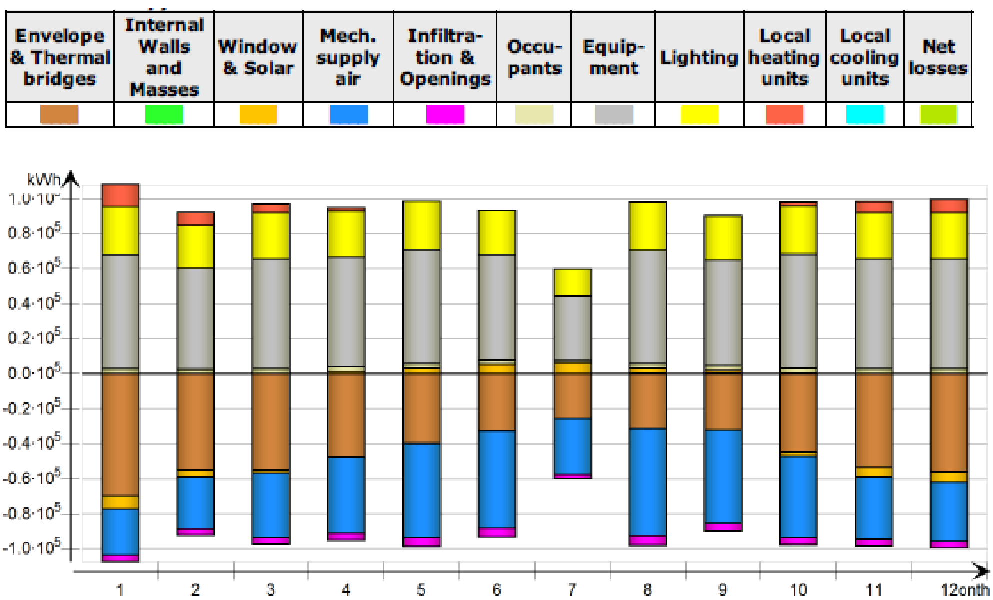

Figure 12. Energy balance of the base model.

[2] $Relative\ error = \frac{Base\ model - Invoices}{Base\ model}$

From Figure 12, it was concluded that the principal energy losses happened through the building envelope and thermal bridges and through the mechanical air supply. In consequence, some energy efficiency measures related to them were studied among others.

In order to enlarge the knowledge regarding the energy losses, the energy balance during heating and cooling processes were compared as it is illustrated in Figure 13.

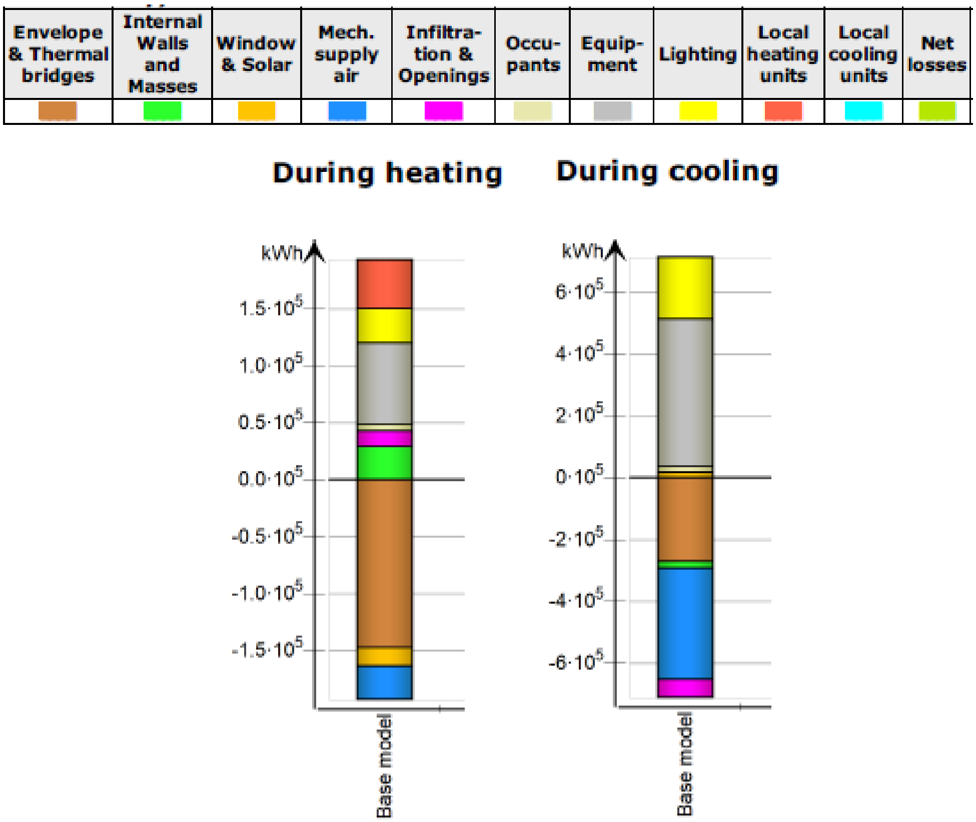

Figure 13. Energy balance during heating and cooling processes.

In the diagrams above, it can be estimated that when heating of the factory was needed, 75 % of the losses happened through the building envelope and the thermal bridges. On the other hand, while cooling of the company was necessary the losses through mechanical supply air were dominant.

Regarding the thermal comfort of the workers, the people in the office area showed a PPD (Predicted Percentage of Dissatisfied) of 15 % during the colder months[3]. Nevertheless, the discomfort during the warmer months[4] was higher, reaching a PPD of 60 % in the worst cases. For the workers in the manufacturing area, the PPD during the colder months remained around 10 %, having peaks of greater discomfort. For the warmer months, the PPD increased to a mean value of 30 % having peaks of up to 80 %.

For the analysis of the thermal comfort in the company the Fanger's indices provided by IDA ICE were interpreted. An example of the Fanger's indices for a room of the office area and for a room in the manufacturing area are shown in Appendix C.

More or less, the results adjust with the concerns conveyed by the owner. However, the obtained outcomes weren't totally accurate since the equipment in the manufacturing area was supposed to be evenly distributed for the simulation, causing the uneven thermal situation[5]: the area with more machinery has too high temperatures in the warmer months while in the colder months the area with less equipment suffers from too low temperatures.

For the IAQ regarding the CO_2, in almost all the rooms in the plant the level of pollution was of 500 ppm or less being in the worst case 700 ppm. So, CO_2 is not a concern for the company, being that 1 000 ppm is the value that ASHRAE Standard 62 recommends not to surpass (Indoor air quality guide, 2009). However, due to the machinery and materials used in the production area, there are other hazardous particles which IDA ICE does not take into account.

[3] Colder months: January, February, March, April, October, November and December
[4] Warmer months: May, June, August and September.
[5] An energy efficiency measure regarding this issue will be presented in this document.

4.3 Energy efficiency measures

4.3.1 Case 1: Retrofit of the building envelope

As concluded from the energy balance of the base model, the losses through the building envelope and thermal bridges were consistent. That is why the origin of these losses had to be studied more deeply. In Figure 14 the distribution of these losses between the different elements of the building envelope are shown.

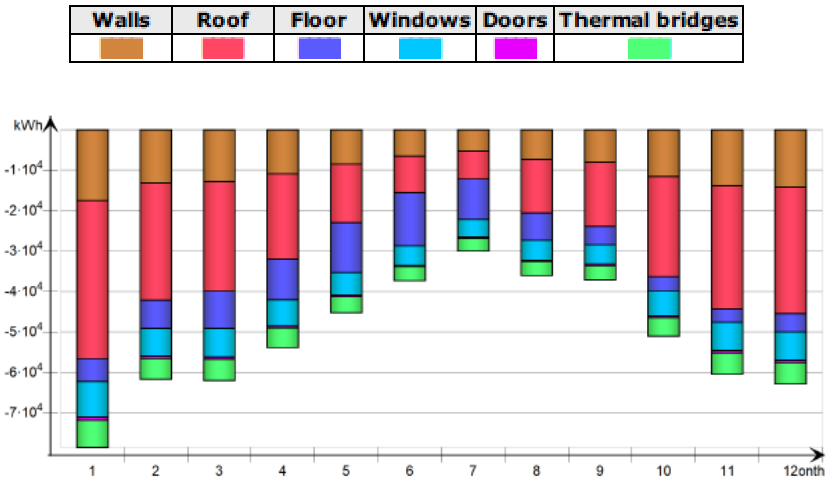

Figure 14. Distribution of the losses through the building envelope and thermal bridges.

Clearly, the greatest energy losses happened through the roof of the facility. Nevertheless, through the walls and floor a considerable amount of energy was also being lost. In consequence, the improvement of the building envelope's insulation was studied. It should be noted that changing the insulation in the floor is a very costly task, being that it requires moving all the heavy machines and some of them are attached to the floor. Thus, the amelioration for the floor's insulation wasn't studied.

A new simulation was performed adding layers of different thickness of light insulation (k= 0.036 W/(m*K)) to the roof and the external walls of both office and manufacturing zones. In Table 3 and Table 4 it can be seen which thickness was applied to each element, and the old and new U-values obtained.

Table 3. Added insulation and U-values for offices' zone.

	Offices' zone			
	Added material	Added thickness (mm)	Old U-value (W/(m^2*K))	New U-value (W/(m^2*K))
External walls	Light insulation	100	0.237	0.143
Internal walls	-	-	-	-
Internal floor	-	-	-	-
Roof	Light insulation	200	3.057	0.170
Floor	-	-	-	-

Table 4. Added insulation and U-value for manufacturing zone.

	Manufacturinfg zone			
	Added material	Added thickness (mm)	Old U-value (W/(m^2*K))	New U-value (W/(m^2*K))
External walls	Light insulation	200	0.592	0.138
Internal walls	-	-	-	-
Internal floor	-	-	-	-
Roof	Light insulation	240	0.316	0.102
Floor	-	-	-	-

By the application of these changes, the heat flow through the building envelope was reduced and the required DH energy decreased, leading to some economic savings. In Table 5 the energy and economic savings due to this improvement are shown.

Table 5. Energy and cost savings for envelope retrofit.

	DH energy savings (MWh/year)	DH cost savings (SEK/year)
Insulation's retrofit	35.92	16 415

However, in the limitations section the insulation of one part of the manufacturing zone was already improved. Nonetheless, the owner wasn't able to provide information regarding the type of insulation installed and the thickness of it.

Thus, for these calculations the information provided by the plans was used and the calculated savings may vary. The researcher advices, to carry out an architectural study before the implementation of this energy efficiency measure to identify the current insulation. If it is found out that the U-value of that zone is greater than the one achieved in this retrofit, the placement of light insulation thick enough to achieve the U-value proposed in this document is recommended. The zone with different insulation is 'Workshop 2' and can be located in Appendix B.

Besides, heat losses through windows were also a motive of study. Therefore, another simulation was pursued by only changing the windows from 2 pane glazing windows to 3 pane glazing windows with lower U-value. In Table 6 the U-value of these two types of windows are presented.

Table 6. Window types and their respective U-values.

Window type	U-value (W/(m^2*K))
2 pane flazing windows	2.9
3 pane glazing windows	0.7

In Table 7 the energy and cost savings obtained thanks to this retrofit can be seen.

Table 7. Energy and cost savings for window's retrofit.

	DH energy savings (MWh/year)	DH cost savings (SEK/year)
Window's retrofit	8.57	3 916

Lastly, the base model with the combination of the mentioned changes in the insulation and windows was simulated. This helped to establish the savings, which are displayed in Table 8, if the 2 improvements were implemented simultaneously.

Table 8. Energy and cost savings for insulation's and window's combined retrofit.

	DH energy savings (MWh/year)	DH cost savings (SEK/year)
Insulation's and window's retrofit	40.88	18 684

In conclusion, the combination of both energy efficiency measures is the option that allows more energy and money to be saved.

4.3.2 Case 2: Retrofit of the lighting system

The lighting system was accounted for the 27.6 % of the total electricity usage. Thus, reduction in its usage could generate substantial electricity savings. In the plant there are 5 types of lamps, of which one belongs to the lighting in the toilets. The latter weren't studied for this energy efficiency measure, since they were hardly ever switched on and constituted around 2 % of the total number of lights in the plant.

The other kind of lamps are shown in Table 9 , where the lumens for each of them are stated. The aim of this amelioration is to reduce the electricity demand while providing the same lumens to each room as in the base model. The proposal to carry out this measure is presented in Table 10.

Table 9. Current lamps in the factory.

Type of lamp	lumens/lamp	Number of lamps
PHILIPS TL-D 18W/840 1SL/25	1 350	108
PHILIPS TL-D 30W/33-640 1SL/25	2 100	47
PHILIPS TL-D 36W/840 1SL/25	3 250	203
NARVA LT 58W T8/840	5 250	713

Table 10. Proposed retrofit for the lighting system.

New type of lamp	lumens/lamp	Needed number of lamps
PHILIPS MASTER LEDTube 13W865 G5	1 600	92
PHILIPS 16.5T8 LED/48-5000	2 500	40
Master LEDtube UO 24W830 T8	3 400	194
LEONLITE 4ft LED Linear Light 40W	5 250	713

The calculated energy and cost savings of electricity are displayed in Table 11.

Table 11. Energy and cost savings for the lighting system's retorfit.

	Electricity energy savings (kWh/year)	Electricity cost savings (SEK/year)
Lighting system's retrofit	107 258	82 310

4.3.3 Case 3: Ventilation system's retrofit

For the ventilation system two possible energy efficiency measures were studied. Both ameliorations involved the installation of heat exchangers to benefit from the high temperatures of the exhaust air of the AHU in the company. Air to air counterflow heat exchangers were used for the analysis of this retrofit and their efficiency was assumed to be 80 % (http://www.uk-exchangers.com/, 2018).

The first option consisted of adding to the base model a heat exchanger in the 2 standard AHU with highest air flows in the plant, these being the AHU for the offices and the AHU for 'Workshop 2' and 'Workshop 3'. The purpose of both heat exchangers was to preheat the supply air transferring heat from the exhaust air, and like that, reducing the DH energy needed to rise the supply's air temperature. In Table 12 the potential energy savings and economical savings are displayed for this option.

Table 12. Energy and cost savings for the ventilation system's retrofit. Option 1.

	DH energy savings (MWh/year)	DH cost savings (SEK/year)
Ventilation system's retrofit - Option 1	289.52	132 310

For the second option, due to its complexity, an IDA ICE simulation wasn't performed. This measure was carried out to solve the thermal uneven situation the company is facing owing to the fact that the equipment is not evenly distributed throughout the area of the manufacturing zone, and in consequence the internal heat gains neither.

The 'Packing room' was the warmest zone of the plant and the 'Workshop 1' and 'Storehouse 5' the coldest, as was stated by the owner of the company and verified by the researcher during the on-site visits. This not only was causing major discomfort between the workers, but also a great loss of energy. Thus, the possibility of installing a heat exchanger between the 2 zones was studied. The exhaust air of the 'Packing room' was directed to an air to air heat exchanger where energy was transferred to the supply air of the 'Workshop 1' and 'Storehouse 5'.

Next equation shows what is the potential heat exchanged by a heat exchanger of those characteristics.

$$Q = \eta * \rho * c_p * v * \Delta T \tag{10}$$

Where: Q = exchanged air (kW)

η = heat exchanger's efficiency (%)

ρ = air density (kg/m^3)

c_p = specific heat of air (kJ/(kg*K)

v = airflow (m^3/s)

ΔT = temperature difference between the two airflows (K)

For the calculations the heat exchanger efficiency was supposed 0.8, the air density 1.225 kg/m^3 and the specific heat 1 kJ/(kg*K). The 'Packing room' was assumed to be in balance for this energy efficiency measure. Therefore, the airflow through the heat exchanger was set to 0.526 m^3/s which was the flow supplied to the 'Packing room' in the base model.

The temperature difference was supposed to be the smallest recommended for the correct performance of the pinch effect in the heat exchanger. This temperature difference is 10 K (Misevičiūtė, Motuzienė and Valančius, 2018).

In Table 13 the benefits of this energy efficiency measure are shown.

Table 13. Energy and cost savings for the ventilation system's retrofit. Option 2.

	DH energy savings (MWh/year)	DH cost savings (SEK/year)
Ventilation system's retrofit - Option 2	50.78	23 206

4.3.4 Case 4: Installation of a PV system

In order to pursue the path of sustainability and environmentally friendly energy behavior, matters the owner of the company cares deeply about, the prospect of installing a PV system in the roof was studied.

The system was simulated in the IDA ICE software. However, the program only allows to put one PV panel in the roof, which was enough to estimate how much energy could be generated.

In the base model a 500 m^2 PV panel was installed with an efficiency of 15. 5 % and two different simulations were developed. In both of them the PV panel was facing the South direction but the inclination was changed. In Figure 15 the 3D view of the installed PV panel can be seen.

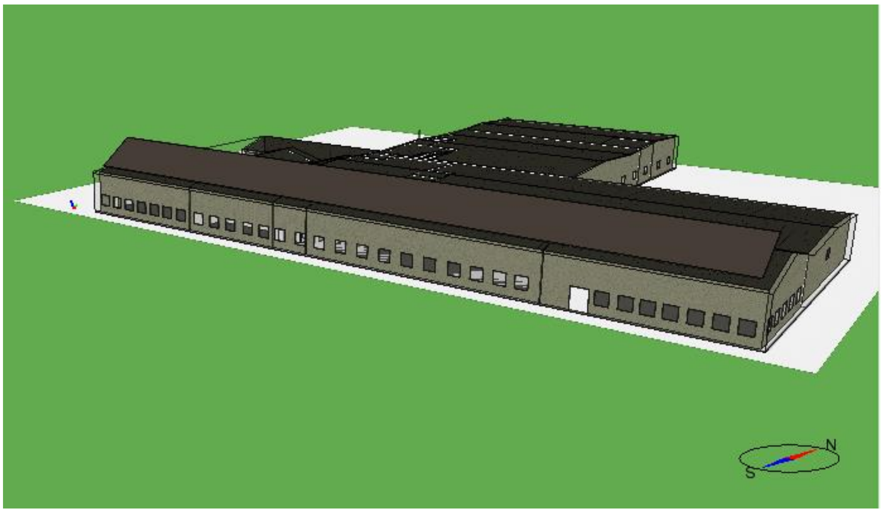

Figure 15. 3D view of the 500 m^2 PV panel.

In Table 14 the results of the simulation are displayed.

Table 14. Generated electricity for the two PV simulations.

Area (m^2)	Tilt (°)	Generated electricity (kWh)	Generated electricity (kWh/m^2)
500	35	83 638	167.28
500	55	88 167	176.33

In spite of achieving the maximum generation of electricity with a tilt of 55°, in reality this would cause shading in the surroundings of the PV panels decreasing or annulling the performance of some of the panels.

Hence, to determine the energy and cost savings regarding this measure the values obtained for the simulation with 35° of inclination were utilized. For the calculation, an installation of 3 500 m^2 of PV panels was estimated out of the 5 034 m^2 of roof. In Table 15 the energy and cost savings for this case are presented.

Table 15. Energy and cost savings of the installation of a PV system in the roof.

	Electricity energy savings (kWh/year)	Electricity cost savings (SEK/year)
Installation of a PV system	585 466	449 288

4.3.5 Summary of the energy efficiency measures

The potential savings are the maximum possible energy that could be saved. However, this implies combining all the proposed energy efficiency measures which some of them might not be profitable due to high payback periods. The profitability of the different ameliorations will be analyzed in latter sections of this thesis.

In Table 16 the potential electricity savings are shown and to which percentage of the base model's electricity use correspond those savings. In Figure 16, the breakdown of the electricity savings is displayed.

Table 16. Potential electricity savings.

Electricity			
Energy usage (kWh/year)	Potential savings (kWh/year)	Potential savings	Potential savings (SEK/year)
1 108 732	692 724	62.5%	531 597

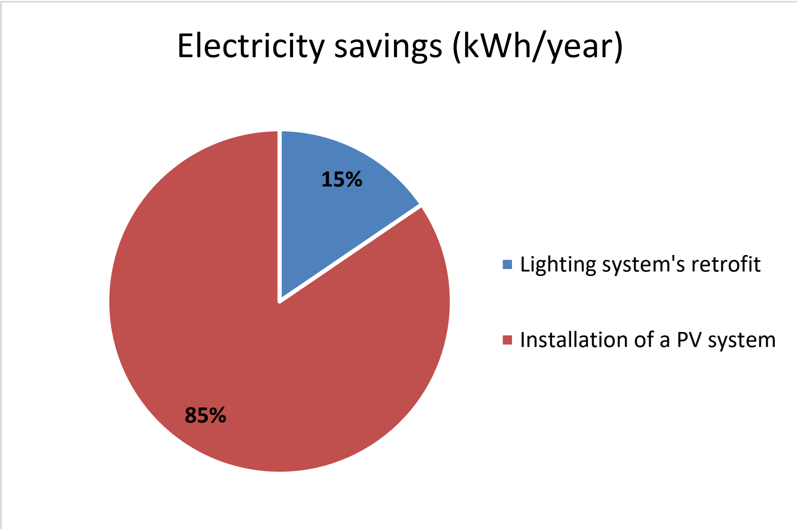

Figure 16. Breakdown of the electricity savings.

On the other hand, in Table 17 and in Figure 17 the potential DH savings and the breakdown of those savings can be seen respectively.

Table 17. Potential DH savings.

DH			
DH energy usage (MWh/year)	Potential savings (MWh/year)	Potential savings	Potential savings (SEK/year)
780.32	381.18	48.8%	174 201

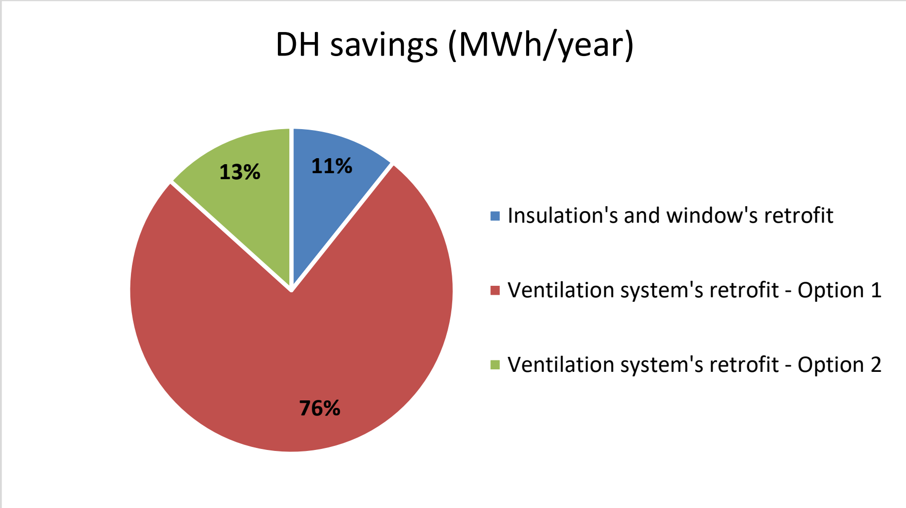

Figure 17. Breakdown of the DH savings.

4.4 Cost analysis

Before making any decision about whether to implement or not any energy efficiency measure, it is important to carry out a proper economic analysis to study their profitability.

For the development of this thesis the cost assessment consisted of calculating the payback period[6]. In Table 18 a summary with the investment, energy savings and payback period are displayed. A more detailed information about the calculation of the investment is shown in Appendix D.

Table 18. Cost analysis for the energy efficiency measures.

Retrofit	Investment (SEK)	Energy savings (SEK/year)	Payback period (years)
Insulation's retrofit	902 703	16 415	54.99
Window's retrofit	654 986	3 916	167.27
Insulation's and window's retrofit	1 557 689	18 684	83.37
Lighting system's retrofit	285 753	82 310	3.47
Ventilation system's retrofit - Option 1	1 115 492	132 310	8.43
Ventilation system's retrofit - Option 2	115 492	23 206	4.98
Installation of a PV system	4 592 194	449 288	10.22

[6] $Payback\ period\ (year) = \frac{Investment\ (SEK)}{Cost\ savings\ (\frac{SEK}{year})}$

5 Discussion

5.1 Validation of the base model

IDA ICE program has proved to be a very useful simulation software for the energy balance analysis of an already built facility. During the research, it was an essential tool to estimate the performance of the building when implementing the energy efficiency measures.

However, the created dynamic simulation was not 100 % accurate due to the assumptions and errors made by the user. For instance, for the simulation the settings for the thermal bridges and infiltration rates, the hot domestic water use, an evenly distribution for the equipment in the manufacturing area, same insulation for the whole manufacturing roof are, etc. were assumed.

This is why the validation of the base model presented errors regarding the electricity and DH use. For electricity the relative error accounted for 3.46 % and for DH 2.72 %. Those values represented the deviation of the base model and consequent amelioration in comparison with the reality.

Even so, the results obtained from the simulations performed were good enough to have a realistic understanding of the energy situation of the plant.

5.2 Profitability analysis of the retrofits

5.2.1 Case 1: Retrofit of the building envelope

For the building envelope's retrofit, 3 possible measures were proposed: the amelioration of the insulation in the external walls and roof of the building, changing the windows to ones with lower U-value and a combination of both measures.

For the first option the energy saved would be up to 35.92 MWh/year and the economic savings were 16 415 SEK/year. Nevertheless, the payback period would be 55 years due to the high investment needed in insulation because of the large areas of the envelope of the building. Being that, the payback time is too long the researcher doesn't recommend its implementation. However, the improvement of the insulation in determined zones of the building envelope could be studied in the future.

The second option's DH and cost savings would be 8.57 MWh/year and 3 916 SEK/year respectively. The payback period was estimated to be even higher than for the insulation retrofit, accounting for 167 years. This measure should not be carried out by the company since it won't pay off.

Of course, combining both options also presented a high payback period, almost 84 years.

In consequence, the researcher doesn't advise to perform any energy efficiency measures proposed in this document regarding the building envelope.

5.2.2 Case 2: Retrofit of the lighting system

In this thesis it was found that switching to more energy efficient lamps would be a great energy efficiency measure. In fact, by changing to LED lamps 107 258 kWh/year of electricity and 82 310 SEK/year could be saved. The payback period for this retrofit would be 3.47 years and can easily be performed. Therefore, the researcher recommends to implement this energy efficiency measure as soon as possible.

5.2.3 Case 3: Ventilation system's retrofit

For the ventilation system two possible options were studied, both involving the heat recovery of exhaust airflows and heat exchangers.

The first option consisted of adding a heat exchanger between the supply and exhaust air flows in two different standard AHUs: the AHU for the offices and the AHU for 'Workshop 2' and 'Workshop 3'.

By implementing this measure, the total DH energy saved would be 289.52 MWh/year and the cost savings 132 310 SEK/year. This implies a payback period of 8.43 years due to the high investment of one of the heat exchanger, because of the great airflows it has to manage. Although waiting almost 8.5 years to obtain economic savings may seem too much, the savings are great enough and the life cycle of the heat exchangers is long enough to consider this a very good option.

The second choice was to employ a heat exchanger to recover the heat of the exhaust air in the 'Packing room' to heat the supply air directed towards 'Workshop 1' and 'Storehouse 5'.

In case of the performance of this amelioration, the energy savings would be 50.78 MWh/year and the cost savings 23 206 SEK/year. The payback would account for 4.98 years, which is rather short. Therefore, considering that this measure not only would generate great financial benefits, but also would significantly improve the thermal comfort of the workers; the researcher advises to implement it when possible.

5.2.4 Case 4: Installation of a PV system

The last proposed measure was to install PV panels in the large roof area of the building. From the IDA ICE simulation, it was concluded that for 3 500 m^2 of PV panels 585 466 kWh/year could be generated, which was equivalent to 449 288 SEK/year saved. The payback period for this investment would be 10.22 years. Taking into account that PV panels' lifetime span is about 25 years, this measure is a very appealing option (Nyholm, Odenberger and Johnsson, 2017).

Notwithstanding, this was a gross calculation of the energy that could be generated and, due to shading between panels and HVAC elements on the roof, the area available for installing the PV system could be diminished.

6 Conclusions

6.1 Study results

In this document an energy audit of an industrial building was carried out, with the aid of IDA ICE simulation program.

Once the energy balance of the factory was studied, energy efficiency measures regarding the building envelope, the lighting system, the ventilation system and the installation of a PV system in the roof of the facility were studied.

The survey indicated that the potential energy savings of the company accounted for 62.5 % of the current electricity use and 48.8 % of the current DH use if all the proposed ameliorations were performed. The main promoter of the electricity savings is the installation of the PV system, with 85 % of influence. Almost 90 % of the DH savings are due to the measures in the ventilation system.

Nevertheless, some of the retrofits have very long payback periods. Thus, it was recommended to not implement them. Fortunately, the energy efficiency measures providing the greatest savings' payback periods are between 3.47 years and 10.22 years long. As they are independent from each other, the owner has the freedom to decide whether to apply them or not and when if so.

Implementing the ameliorations studied in this thesis could allow the company to save 531 597 SEK/year in electricity and 174 201 SEK/year in DH.

The only measure that provided better thermal comfort than the base model was the one involving the heat recovery of the exhaust air of the 'Packing room'.

6.2 Outlook

Although this study has been very useful to determine the potential energy efficiency measures of the company and has achieved the aim of an energy audit, due to the assumptions considered it is not totally accurate.

For a more detailed survey, it would be necessary to be able to make measurements in the equipment in the factory since it accounts for a large share of the electricity use.

Moreover, to determine the temperature difference between the rooms connected by heat exchangers, it would be useful to know the temperature in each room during the different seasons of the year. Thus, the potential energy savings due to this measure would be more accurate.

Lastly, since losses through thermal bridges are of a considerable magnitude an IR (Infra-red) temperature camera could be helpful to determine them.

This would increase the accuracy of the base model, but also it would require much more time. However, the presented results in this thesis can be a foundation for an energy audit for a similar type of company that is facing energy efficiency issues as well.

6.3 Perspectives

As mentioned before, energy audits are indispensable to improve energy efficiency in buildings, whether they are industrial or not; since their main aim is to reduce the energy use by improvements of the energy efficiency. Although it can be thought that a single building will not make any difference, this energy audit is part of a bigger plan where every saving counts.

Moreover, the proposed installation of a PV system, which converts solar energy into electricity, is a great step towards a more sustainable world. Being that it promotes the use of renewable energy sources instead of the conventional fossil fuels and provides a greater energy independency.

Implementing the proposed energy efficiency measures will help in reducing the worldwide temperature increase and the climate change, steering towards a better sustainable world.

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Appendix A: Invoices

The amount paid to Gävle Energi Elhandel depends only on the monthly consumption in kWh. These are the different fees that are charged every month to which the correspondent VAT is applied: electricity price (Elpris), Swedish charges (SvK avgifter), reduced energy tax (Energiskatt reducerad) and VAT (Moms).

On the other hand, the amount paid to Gävle Energi AB encompasses the equivalent monthly percentage of the annual subscription rate (Abonnemangsavgift), transmission fees (Energiskatt), high and low load fees (Effekt höglast and Effekt låglast), reactive power fees (Reaktivt överuttag) and electricity certificate fee (Elcertifikatsavgift). Of course, VAT (Moms) is applied to all of them. In Figure 1 the March 2018 electricity bill is displayed.

FAKTURASPECIFIKATION Sida: 2/3

Faktura/OCR-nummer 21824181917

Gävle Energi Elhandel

Elhandel avtal 2061228 Timspot 1 dec 2013 - 31 dec 2018
Fakturaperiod 1 mar 2018 - 31 mar 2018

Beräknad årsförbrukning 1089690 kWh			
Timspot SvK Elpris	100561 kWh	48,66 öre/kWh	**48 933,28 kr**
Timspot SvK SvK avgifter	100561 kWh	0,58 öre/kWh	**584,35 kr**
Timspot SvK Elcertifikatsavgift	100561 kWh	3,12 öre/kWh	**3 137,50 kr**
Moms 25 % på 52 655,13 kr			**13 163,79 kr**

Gävle Energi AB fakturerar på uppdrag av Gävle Energi Elhandel
Gävle Energi Elhandel har överlåtit fordran till Gävle Energi AB

Summa Elhandel 65 818,92 kr

Gävle Energi AB

Elnät avtal 1035846 Nätavtal
Fakturaperiod 1 mar 2018 - 31 mar 2018

Beräknad årsförbrukning 1089690 kWh			
Eff lågsp. Abonnemangsavgift	31 dagar	4 500,00 kr/år	**382,19 kr**
Eff lågsp. Elöverföring	100561 kWh	5,80 öre/kWh	**5 832,54 kr**
Eff lågsp. Effekt höglast	233,667 kW	78,00 kr/kW	**18 226,03 kr**
Eff lågsp. Effekt låglast	207 kW	24,00 kr/kW	**4 968,00 kr**
Eff lågsp. Reaktivt överuttag	1,5 kVAr	18,00 kr/kVAr	**26,99 kr**
Energiskatt	100561 kWh	33,10 öre/kWh	**33 285,69 kr**
Moms 25 % på 62 721,44 kr			**15 680,37 kr**

Summa Elnät 78 401,81 kr

Övriga avgifter

Ränta, fakt nr 21810724217	**57,12 kr**
Moms 0 % på 57,12 kr	**0,00 kr**

Summa Övriga avgifter 57,12 kr

Figure 1. March 2018 electricity bill.

The bills for this energy carrier are simpler: there is a power energy fee (Effektavgift), a fixed annual fee (Fast årsavgift) and the energy fee (Energiavgift). VAT (Moms) is applied to the three of them. In Figure 2 the March 2018 DH invoice can be seen.

FAKTURASPECIFIKATION Sida: 2/2

Faktura/OCR-nummer 21824182014

Gävle Energi AB

Fjärrvärme avtal 1035847 Distributionsavtal
Fakturaperiod 1 mar 2018 - 31 mar 2018

Beräknad årsförbrukning 748,8 MWh
Beräknad årskostnad 564 818 kr

Mätarnummer 5371750		**Ställning**	**Förbrukning**	
Föregående avläsning	1 mar 2018	597,740		
Avläsning	1 apr 2018	700,080	102,34 MWh	
Taxa 4, Fast årsavgift		31 dagar	30 781,00 kr/år	**2 614,28 kr**
Taxa 4, Effektavgift		31 dagar	108 768,00 kr/år	**9 237,83 kr**
Effektavgiften baseras på E-värde 176 och ápris 618 kr				
Taxa 4, Energiavgift		102,34 MWh	457,00 kr/MWh	**46 769,38 kr**
Moms 25 % på 58 621,49 kr				**14 655,38 kr**
Summa Fjärrvärme				**73 276,87 kr**

Övriga avgifter	
Ränta, fakt nr 21810724316	**34,74 kr**
Moms 0 % på 34,74 kr	**0,00 kr**
Summa Övriga avgifter	**34,74 kr**

Figure 2. March 2018 DH bill.

Appendix B: Layout and description of the plant

In Figure 1 the office's zone is identified in the layout of the plant. The remaining zones belong to the manufacturing zone.

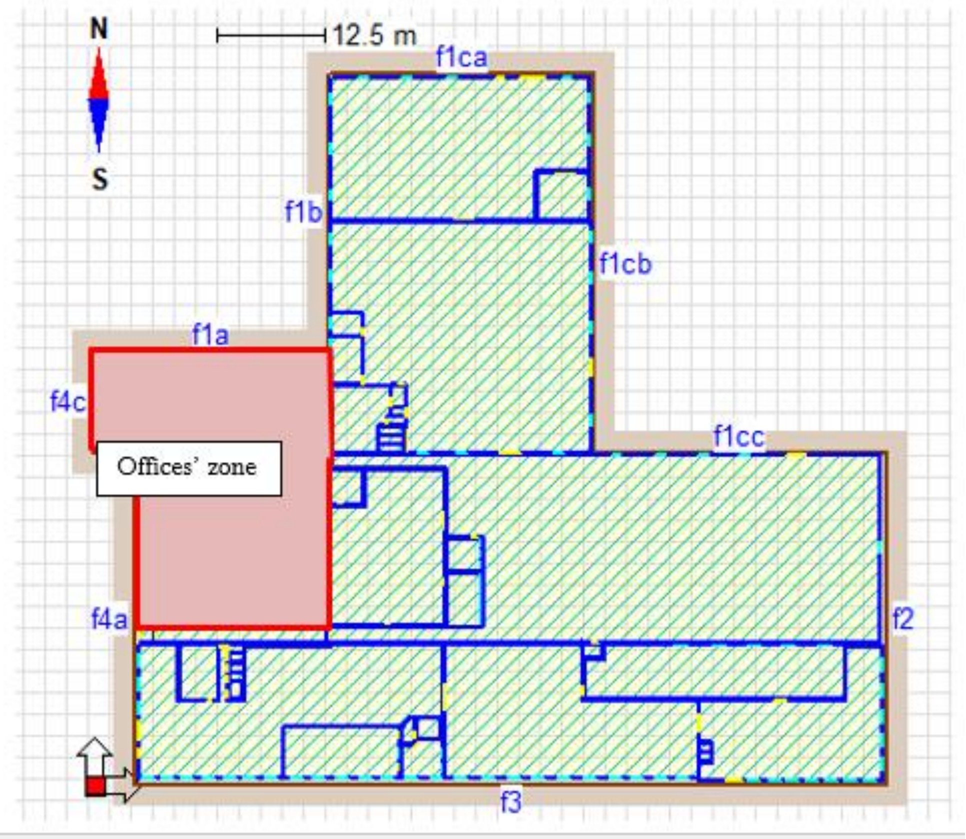

Figure 1. Limitation between the office and manufacutirng zones.

As mentioned before, there are two types of insulations in the building. One for the offices' zone and another one for the manufacturing zone. Moreover, the 'Dining room' and 'Dressing room 2' area have a different insulation in the roof and ceiling, even though they belong to the offices' zone. Information regarding the insulation in this zones can be found in Table 1, Table 2 and Table 3.

Table 1. Information about the offices' insulation.

	OFFICES' ZONE			
	Thickness (mm)	Materials	k (W/(m*K))	U-value (W/(m^2*K))
External walls	13	Gypsum	0.220	0.237
	100	Light insulation	0.036	
	50	Frames cc600	0.044	
	13	Asfaboard	0.180	
Internal walls	26	Gypsum	0.220	0.619
	32	Air gap	0.170	
	30	Light insulation	0.036	
	32	Air gap	0.170	
	26	Gypsum	0.220	
Internal floor	150	Light insulation	0.036	0.195
	31.75	Frames cc600	0.044	
	13	Gypsum	0.220	
Roof	22	Wood	0.140	3.057
Floor	150	Concrete	1.700	0.692
	40	Light insulation	0.036	
	150	Gravel	2.000	

Table 2. Information about the insulation in the different roof part.

	DINING ROOM + DRESSING ROOM 2			
	Thickness (mm)	Materials	k (W/(m*K))	U-value (W/(m^2*K))
Internal floor	5	Foor coating	0.180	2.385
	20	Light weight concrete	0.150	
	150	Concrete	1.700	
Roof	50	Light insulation	0.036	0.642
	2	Steel	60.000	

Table 3. Information about the insulation in the manufacutring zones.

	MANUFACTURING ZONE			
	Thickness (mm)	Materials	k (W/(m*K))	U-value (W/(m^2*K))
External walls	13	Gypsum	0.220	0.592
	58	Frames cc600	0.044	
	250	Concrete	1.700	
Internal walls	26	Gypsum	0.220	0.619
	32	Air gap	0.170	
	30	Light insulation	0.036	
	32	Air gap	0.170	
	26	Gypsum	0.220	
Internal floor	-	-	-	-
Roof	200	Light weight concrete	0.150	0.316
	60	Light insulation	0.036	
Floor	180	Concrete	1.700	2.850
	150	Gravel	2.000	

In Table 4 the areas of the floor, building envelope and windows are presented; as well as the average U-value of the building.

Table 4. Floor, building envelope and window area and average U-value.

Floor area (m^2)	Building envelope area (m^2)	Window area (m^2)	Average U-value ($W/(m^2*K)$)
5 034	11 551	16 171	0.485

In the next page Table 5 is shown where the supply air, exhaust air and the AHU corresponding to each zone is displayed.

Table 5. AHU of each room with their respective air flows.

Zone name	Supply air (l/s)	Exhaust air (l/s)	AHU
Boiler room 1	0.0	0.0	No AHU
Boiler room 2	0.0	0.0	No AHU
Cleaning room 1	0.0	0.0	No AHU
Cleaning room 2	0.0	0.0	No AHU
Cleaning room 3	0.0	0.0	No AHU
Clothes' hangers room	0.0	0.0	No AHU
Conference room	30.0	30.0	Standard AHU 1
Corridor 1	176.1	176.1	Standard AHU 2
Corridor 2	0.0	0.0	No AHU
Corridor 3	0.0	0.0	No AHU
Defective room	9.1	0.0	Supply air only AHU 1
Dining room	442.1	417.5	Standard AHU 3
Dressing room 1	0.0	94.3	Exhaust air only 1
Dressing room 2	0.0	69.4	Exhaust air only 2
Dressing room 3	0.0	227.1	Exhaust air only 2
Entrance 1	0.0	0.0	No AHU
Entrance 2	0.0	0.0	No AHU
Fan room	0.0	0.0	No AHU
File room	14.6	14.6	Standard AHU 1
Inspection room 1	113.0	0.0	Supply air only 1
Inspection room 2	28.7	0.0	Supply air only 1
Locker room	0.0	7.8	Exhaust air only 1
Office 1	29.9	29.9	Standard AHU 4
Office 2	39.0	39.0	Standard AHU 4
Office 3	53.7	53.7	Standard AHU 4
Office 4	53.7	53.7	Standard AHU 4
Office 5	25.2	25.2	Standard AHU 4
Office 6	24.9	24.9	Standard AHU 4
Office 7	44.8	44.8	Standard AHU 4
Office 8	49.6	49.6	Standard AHU 4
Office 9	23.5	23.5	Standard AHU 4
Packing room	529.2	0.0	Supply air only 1
Preparation room	101.5	101.5	Standard AHU 4
Reunion room	0.0	0.0	No AHU
Storehouse 1	23.2	23.2	Standard AHU 1
Storehouse 2	0.0	0.0	No AHU
Storehouse 3	0.0	0.0	No AHU
Storehouse 4	0.0	170.9	Exhaust air only 3
Storehouse 5	1 159.8	0.0	Supply air only 2
Telecomunications room	0.0	0.0	No AHU
Toolbar room 1	0.0	434.2	Exhaust air only 4
Toolbar room 2	0.0	46.7	Exhaust air only 4
Toolbar room 3	0.0	28.1	Exhaust air only 4
WC 1	0.0	10.3	Standard AHU 3
WC 2	0.0	3.6	Standard AHU 3
WC 3	0.0	1.8	Exhaust air only 1
WC 4	0.0	2.2	Exhaust air only 1
WC 5	0.0	1.7	Exhaust air only 1
WC 6	0.0	6.9	Exhaust air only 1
WC 7	0.0	3.2	Exhaust air only 5
WC 8	0.0	3.6	Exhaust air only 6
WC 9	0.0	3.6	Exhaust air only 6
WC 10	0.0	2.3	Exhaust air only 2
WC 11	0.0	5.0	Exhaust air only 2
WC 12	0.0	3.5	Exhaust air only 2
WC 13	0.0	3.6	Exhaust air only 2
WC 14	0.0	3.5	Exhaust air only 2
WC 15	0.0	38.0	Exhaust air only 7
WC 16	0.0	26.3	Exhaust air only 7
WC 17	0.0	45.0	Exhaust air only 7
WC 18	0.0	17.7	Exhaust air only 7
WC 19	0.0	17.5	Exhaust air only 7
Workshop 1	1 407.6	0.0	Supply air only 2
Workshop 2	673.9	524.2	Standard AHU 5
Workshop 3	3 330.0	2 364.3	Standard AHU 5

In Table 6 the equipment's electricity use in each zone is provided.

Table 6. Equipment's electricity use for each room.

	kWh
Boiler room 1	574.5
Boiler room 2	457.6
Defective room	24.3
Dining room	1 989.3
Fan room	269.9
Inspection room 1	121.5
Inspection room 2	24.3
Office 1	49.6
Office 2	49.6
Office 3	49.6
Office 4	49.6
Office 5	49.6
Office 6	49.6
Office 7	49.6
Office 8	49.6
Office 9	49.6
Packing room	6 179.0
Preparation room	99.2
Storehouse 3	3 558.0
Storehouse 4	3 083.8
Storehouse 5	7 533.3
Telecomunications room	49.6
Toolbar room 1	3 710.6
Toolbar room 2	399.5
Toolbar room 3	240.5
Workshop 1	11 429.1
Workshop 2	6 063.7
Workshop 3	18 025.5

In Table 7 the distribution of the lighting system is presented.

Table 7. Lighting system by zone.

Zones	Lighting		
	Number of lamps	Watt/lamp	Total Watts
Boiler room 1	8	18	144
Boiler room 2	4	18	72
Cleaning room 1	1	53	53
Cleaning room 2	1	53	53
Cleaning room 3	1	53	53
Clothes' hangers room	2	18	36
Conference room	7	36	252
Corridor 1	56	18	1 008
Corridor 2	32	18	576
Corridor 3	6	30	180
Defective room	1	58	58
Dining room	23	36	828
Dressing room 1	6	18	108
Dressing room 2	17	36	612
Dressing room 3	32	36	1 152
Entrance 1	0	0	0
Entrance 2	0	0	0
Fan room	2	58	116
File room	4	36	144
Inspection room 1	56	58	3 248
Inspection room 2	4	58	232
Locker room	6	58	348
Office 1	6	36	216
Office 2	12	36	432
Office 3	8	36	288
Office 4	12	36	432
Office 5	7	36	252
Office 6	7	36	252
Office 7	9	36	324
Office 8	12	36	432
Office 9	6	36	216
Packing room	47	30	1 410
Preparation room	16	36	576
Reunion room	10	36	360
Storehouse 1	4	36	144
Storehouse 2	1	58	58
Storehouse 3	80	58	4 640
Storehouse 4	24	58	1 392
Storehouse 5	86	58	4 988
Telecomunications room	7	36	252
Toolbar room 1	8	58	464
Toolbar room 2	4	58	232
Toolbar room 3	1	58	58
WC 1	2	53	106
WC 2	2	53	106
WC 3	2	53	106
WC 4	2	53	106
WC 5	2	53	106
WC 6	1	53	53
WC 7	1	53	53
WC 8	1	53	53
WC 9	1	53	53
WC 10	1	53	53
WC 11	1	53	53
WC 12	1	53	53
WC 13	1	53	53
WC 14	1	53	53
WC 15	2	53	106
WC 16	1	53	53
WC 17	1	53	53
WC 18	1	53	53
WC 19	1	53	53
Workshop 1	112	58	6 496
Workshop 2	52	58	3 016
Workshop 3	276	58	16 008

Appendix C: Detailed layout and Fanger's comfort indices

In Figure 1 the location of the main rooms inside the factory are displayed.

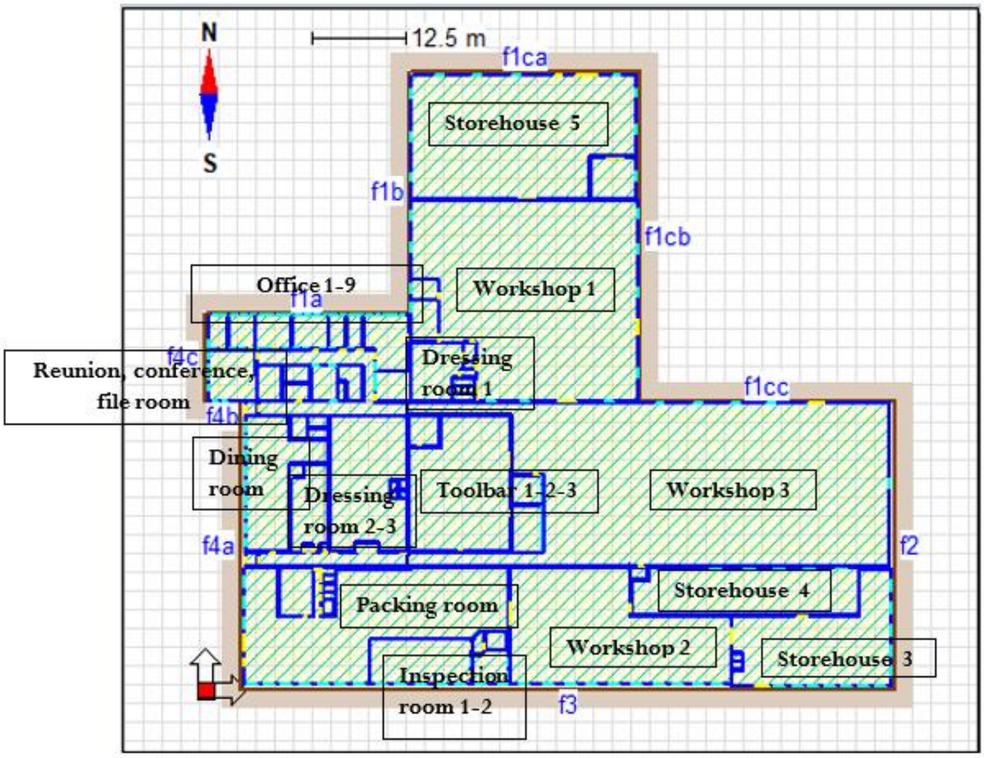

Figure 1. Layout of the plant with the main zones.

In Figure 2 and Figure 3 the Fanger's comfort indices are shown for the offices' zone and the manufacturing zone respectively.

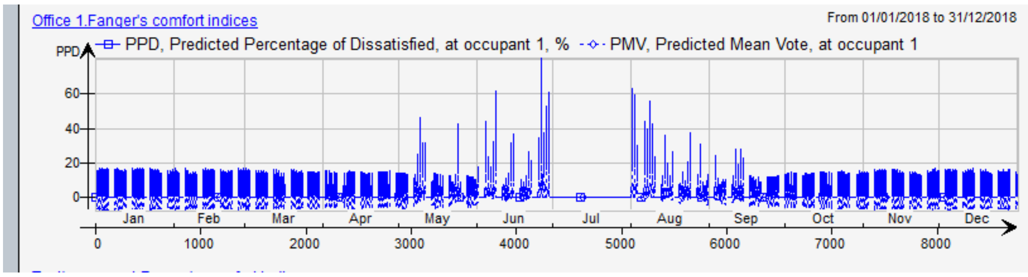

Figure 2. Fanger's comfort indices for the offices' zone.

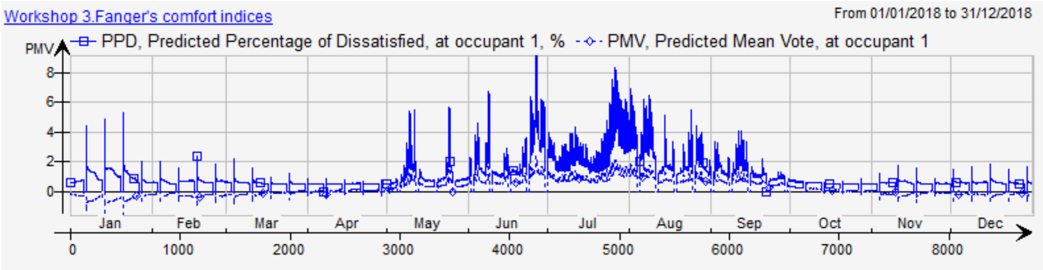

Figure 3. Fanger's comfort indices for the manufacturing zone.

Appendix D: Calculation of the cost for the retrofits

In this Appendix the prices employed for the cost analysis carried out in Chapter 4 are shown.

In Table 1 a deeper calculation for the insulation's retrofit investment is shown (Wickes.co.uk, 2018).

Table 1. Calculation of the investment of the insulation's retrofit.

	Insulation's retrofit			
	Price (SEK/m^2)	Area (m^2)	Price total (SEK)	Total (SEK)
External walls manufacturing (200 mm)	52.04	11 191	582 415	902 703
Roof manufacturing (240 mm)	64.53	4 258	274 769	
External walls office (100 mm)	25.96	198	5 136	
Roof office (200 mm)	52.04	776	40 384	

The procedure to calculate the investment for the windows' energy efficiency measure is displayed in Table 2 (Cost, 2018).

Table 2. Calculation of the investment of the windows' retrofit.

Window's retrofit			
Area of the windows (m^2)	Number of windows	Price (SEK/window)	Total (SEK)
161.7	112	5 848	654 986

To determine the price of changing the lights in the company the calculation in Table 3 were followed (Lamparadirecta.es, 2018) (AtlantaLightBulbs.com, 2018) (Lampornu.se, 2018) (Amazon.com, 2018).

Table 3. Calculation of the investment of the lighting system's retrofit

Lighting system's retrofit				
Type of lamps	Number of lamps	Price (SEK/lamp)	Total (SEK)	Total (SEK)
PHILIPS MASTER LEDTube 13W865 G5	92	180.9	16 644	285 753.28
PHILIPS 16.5T8 LED/48-5000	40	241.4	9 657	
PHILIPS Master LEDtube UO 24W830 T8	194	269.1	52 198	
LEONLITE 4ft LED Linear Light 40W	713	290.7	207 255	

For the first option of the two mentioned in Chapter 4 for the ventilation system, in Table 4 the first one's investment calculation is shown (Cdlweb.info, 2018).

Table 4. Calculation of the investment of the ventilation's sytem retrofit. First option.

Ventilation system's retrofit - Option 1			
Number of units	Required air flow (m^3/s)	Price (SEK/unit)	Total price (SEK)
1	0.45	115 492	115 492
1	4.00	1 000 000	1 000 000

However, In Table 5 the second one's investment calculation is displayed (Cdlweb.info, 2018) (Wolf-energiesystemen.nl, 2018).

Table 5. Calculation of the investment of the ventilation's sytem retrofit. Second option.

Ventilation system's retrofit - Option 2			
Number of units	Required air flow (m^3/s)	Price (SEK/unit)	Total price (SEK)
1	0.53	115 492	115 492

Lastly, in Table 6 the calculation for the PV system's investment can be seen (Simola et al., 2018).

Table 6. Calculation of the investment of the PV system's installation.

Installation of a PV system		
Peak demand (kWp)	Price (SEK/kWp)	Total price (SEK)
500.13	9 182	4 592 194