UNIVERSITY OF GÄVLE

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

Energy Audit for an Old Industrial Building in Gävle

Unai Cano Gurpegui

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Supervisor 1: Roland Forsgberg
Supervisor 2: Taghi Karimipanah
Examiner: Shahnaz Amiri

ABSTRACT

The Swedish industrial sector has overcome the oil crisis and has maintained the energy use constant even though the production has grown. This has been achieved thanks to the development of several energy policies, by the Swedish government, towards the 2020 goals.

This thesis carries on this path and performs an energy audit for an old industrial building in Gävle (Sweden) in order to propose different energy efficiency measures to use less energy while maintaining the thermal comfort. The building is in quite a bad shape and some of the areas are unused making them a waste of money.

By means of the invoices provided by different companies, the information from the staff and some measures that have been carried out in-situ, the energy balance has been calculated from where conclusions have been drawn.

Although it is an industrial building, the study is not going to be focused in the industrial process but in the building's envelope and support processes, since the unit combines both production and office areas. Therefore, the energy balance is divided in energy supplies (district heating, free heating and sun irradiation) and energy losses (transmission, ventilation hot tap water and infiltrations).

The results show that the most important supply is that of the DH whereas the most important losses are the transmission and infiltration. Thus, the measures proposed are focused on the reduction of this relevant parameters. The most important measures are the renovation of the windows, heating systems valves and the ventilation. The glazing of the dwelling is old and some of it is broken accounting for quite a large amount of the losses. The radiator valves are not properly working and there does not exist any temperature control. Therefore the installation of thermostatic valves turns out to be a must. Moreover, some part of the building has no mechanical ventilation but conserves the ducts. These could be utilized if they are connected to the workshop's ventilation which is capable of generating sufficient flow for the entire building.

Finally, although other measures could also be carried out, the ones proposed appear to be the essential ones. A further analysis should be carried out in order to analyze the payback time or investment capability of the company so as to decide between one measure or another. A market study for possible new tenants for the unused parts of the building is also advisable.

ACKNOWLEDGMENTS

I would like to thank all the people that helped me not only in the realization of this thesis but in my whole stay in Sweden. My family and friends have always been there for when I had problems or I needed their help. They made my stay easier, gave me the support I needed in the good and bad moments.

Moreover I would like to thank my supervisor Roland Forsberg without which this thesis would not have been possible. He helped me and taught me a lot. It is always great to have a person with the wide experience and the knowledge he has.

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TABLE OF CONTENTS

1. INTRODUCTION

1.1. Background

The building sector is considered the biggest single contributor to world energy usage (more than a 40% [1], and greenhouse gas emissions (over one third [2]). Therefore, in the last years, different policies have been carried out in order to improve the efficiency of the both old and new constructions. Whereas new buildings have more strict regulations in order to achieve the stated energy efficiency, old buildings remain having a poor one. This old buildings require a further study, in case a renovation is required, in order to turn it more energy saving.

1.1.1. The Swedish industrial sector

Energy carriers and energy use

Although Industrial production has increased since 1970, the energy use has remained constant (around 38% of the final energy use). In the year 2013, the main energy carriers used in the industry were biomass and electricity (38% and 35% respectively). The fossil fuels took 23% and the remaining 3% was contributed by the district heating. The next figure [figure 1] shows the final energy use in industry for the different energy carriers during time.

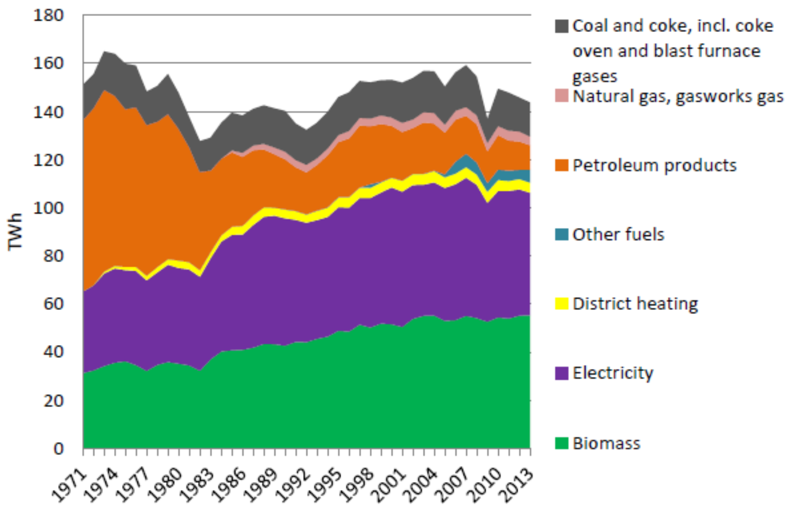


Figure 1: Final energy use of the Swedish industrial sector from 1971 to 2013. [3]

As it can be seen in the figure [figure 1], the electricity and biomass share have increased since 1971 whereas petroleum products have suffered a noticeable reduction. The biomass growth has been due to pulp, paper and wood industry which is one of the most important industries in Sweden. The reduction in petroleum derivatives escalated after the oil crisis of the 1970 and the market moved to a cheaper and less contaminant energy carrier such as LPG (Liquefied Petroleum Gas).

The proportion of electricity of the total industrial energy use has increased from 21 per cent in 1970 to 35 per cent in 2013. During the same period, the use of biomass has increased from 21 per cent to 38 per cent of industry's total energy usage. In this way, petroleum product usage decreased from 48% in 1971 to 7% in 2013.

The share of coal and coke has remained constant due to its use in the iron and steel industry.

Energy use by industry type

If the focus is to put in the different industry types, more than 75% of the energy use goes to three sectors of the Swedish industry [figure 2]. These are the pulp and paper industry, the iron, steel and metal industry and the chemical industry.

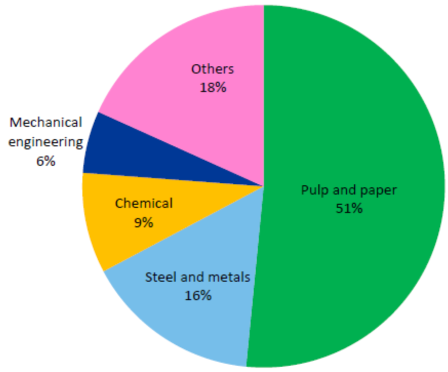


Figure 2: Final energy use in the industrial sector by industry. [3]

As it can be seen [figure 2], more than half percent of the usage goes to the pulp and paper industry. The main energy carriers are electricity and black liquor (which is obtained from the wood after some chemical processes).

In the steel and metal industry (accounts for around 15%), the main energy carriers are coal, coke and electricity. And in the chemical industry (around 10%) the main energy carrier is electricity.

1.1.2. Swedish industrial energy policies

Since the oil crisis energy efficiency policies have grown on importance. The most successful factor has been the conversion of oil to other energy carriers. The European Union has played an important part in the energy efficient policies with the European Energy End-use Efficiency and the Energy Service Directive (ESD). By these directives a 9% reduction of energy usage between the Member States is thought to be accomplished in 9 years since its application. One of the most important approaches these directives take into account is the independent energy audits for Small and Medium Enterprises (SMEs). Beyond 2016, the reduction of 20% of GHG (Green House Gases) by the year 2020 is one of the most important objectives the Union has. In 2012 the ESD was updated by the European Energy Directive (EED) which focuses more on energy use efficiency.

At the same time, five mayor policies where developed in Sweden for the energy efficiency improvement in the industrial sector: the Swedish Environmental code, the PFE (program for improving energy efficiency in energy-intensive industries), the Swedish energy audit program, the EKO-energi and the Project Highland. [4]

The Swedish Environmental Code

Most of the environmental legislation is joined in the Swedish Environmental Code, which came into force in 1988. Although the code has potential, because it combines supervision and permits for the different companies, its impact has been very limited and it has been only in the past years when it has been started to become more used. [5]

PFE

As a consequence of the electricity tax of 0.5€/MW introduced in 2004, in 2005 the PFE was initiated. It is a long-term agreement between the electricity-intensive Swedish industry and the Swedish authorities by which the tax is removed if some requirements are fulfilled.

The first two years, the company should undertake an energy audit with a system approach which will lead to some energy efficiency measures that will be implemented in the following three years. These measures must show an energy reduction of at least the tax value. There are also other mandatory procedures the company must take into account.

In this way, a hundred companies joined the program and a total of 1.45TWh/year where saved. [4]

The Swedish energy audit program

From 2010 until 2014 the Swedish energy audit program was effective. This program targeted companies which consumed more than 500MWh/year and aid for the half of the cost of the energy audit up to 3000€. The company then should report the audit with a plan for energy reduction to be accomplished in two years. [6]

The EKO-Energi

Despite the program was not quantitatively evaluated, it included 72 large energy-intensive industrial companies between the years 1994 and 2001. [7]

Project Highland

From 1990 to 2010 the biggest Swedish energy program offered energy audits in six municipalities of which 140 were performed in the industrial sector. However, the program had some drawbacks. The audits were not complete because the Swedish Energy Agency was afraid they will be a risk of competitiveness between companies in and out of the program. [4]

1.2. Energy audit

According to Oxford Dictionary, an energy audit is: "An assessment of the energy needs and efficiency of a building or buildings" [8]. And in a more technical way Wikipedia says:

> An energy audit is an inspection, survey and analysis of energy flows, for energy conservation in a building, process or system to reduce the amount of energy input into the system without negatively affecting the output(s). In commercial and industrial real estate, an energy audit is the first step in identifying opportunities to reduce energy expense and carbon footprints [9].

The ASHRAE (American Society of Heating Refrigerating and Air-Conditioning Engineers) divides the different audits in 4 levels (from Level 0 to Level III). In this project, the analysis will include the Level I and some parts of the Level II:

- The analysis of the energy invoices, and the installed equipment.
- Measurements of the operating conditions.
- The analysis of the building behavior with the environmental conditions and operation.
- The energy balance.
- The proposal of some energy efficiency measures.

1.3. Aim and limitations

This case study will consist of a survey in which the energy balance is going to be calculated by means of the invoices and the measurements carried out in the company; and an energy saving measures proposal.

The energy audit is going to be carried out in an old industrial unit which has a higher energy consumption than desired and poor thermal comfort conditions. The study is not going to be focused in the industrial process but in the building's envelope and support processes, since the unit combines both production and office areas.

In addition, several energy efficiency measures are going to be proposed taking into account both the profitability and the environmentally friendly approach.

There are though some parameters that can affect in a great way the obtained results. These parameters are hard to predict and the value can vary from time to time due to different conditions. They include: occupant behavior, lighting control, unknown construction materials and their properties or climate [10]. The in-depth study of these parameters is not part of this thesis. In this way, the estimations taken into account will be normalized and checked with experienced professionals of the matter.

1.4. Object description

The building that is analyzed in this thesis is located in Gävle (Sweden) and was built in 1958. In the next figures, the location of the building is shown in the map of Gävle [figure 3] and the zoomed map of the building [figure 4].

Figure 3: Satellite Map of Gävle with the location of the company. Source: Google Earth

Figure 4: Satellite view of the roof of the building. Source: Google Earth

As it has been stated, some parts of the building are considered office areas, some storage areas, some production areas and some abandoned areas. It takes up about 5400m^2 and it consists of two floors with a production area that is two floors high. The plans showing the distribution of the nave can be found in the Appendix I section.

The building heating system is connected to the district heating grid and it doesn't have any other heating system but electric radiators that are not functioning and other electrically heated ventilation systems that are connected by the staff of the company.

The building's is owned by the company Svedinger Fastigheter AB and the company that is using it for production (Tunnplåt i Gävle AB) pays for a rent.

Tunnplåt i Gävle AB produces a variety of lockers, hangers, shelves and benches for schools and gyms. They have, among several machinery, a paint oven which as is going to be explained later is used for the heating of the ventilation system of the production area.

2. METHODS

2.1. Research approach

First of all, to correctly perform an energy audit and therefore to save energy by applying the proper energy saving measures, it is necessary to find the problems the object has; the over consuming processes so to speak.

Therefore, an energy balance must be carried out to know the consumption of every process. In this way, an energy saving measure can be applied and compare its effect with the previous situation in order to check how much energy is going to be saved; and, how much money the company will save and in how much time.

Sometimes it is difficult to know all the data and some parameters can be very complicated to define. However, when this happens, the parameters are defined by convention and based on past experiences. An example of this is the building materials that are used in the envelope of the building. Since the plans are quite old and the company does not have information on it, they have to be estimated. This so, the estimation has been done according to the year of construction.

Some other assumptions have been made and they will be explained in their proper section.

For methodical calculations, tables and figure drawings, excel sheets are going to be used. When it comes to the drawings of the building, AutoCAD is a really useful program where different sketches can also be drawn. For aerial maps or street views of the building, Google Earth is going to be used.

2.2. Energy balance

The energy balance is the comparison of the different heat flows going in and out of the building. The parameters that complete it are usually divided into three groups:

1. Heat flow through the building's envelope.
    - Heat loss through walls, ceiling, floor, windows and doors.
    - Heat loss due to infiltrations.
    - Sun irradiation through the windows.
2. Internal heat generation.
    - Free heat from the people.
    - Free heat from lighting.
    - Free heat from diverse equipment.
3. Energy supply for thermal comfort.
    - Heating and cooling.
    - Ventilation.
    - Hot tap water.

Although all the parameters do not have the same importance, every one of them has been analyzed in order to carry out the energy audit.

A balance is then made by the different parameters where the energy supply and the energy demand should sum the same. It is usually presented in a bar diagram style. An example of one is shown in the next chart [figure 5].

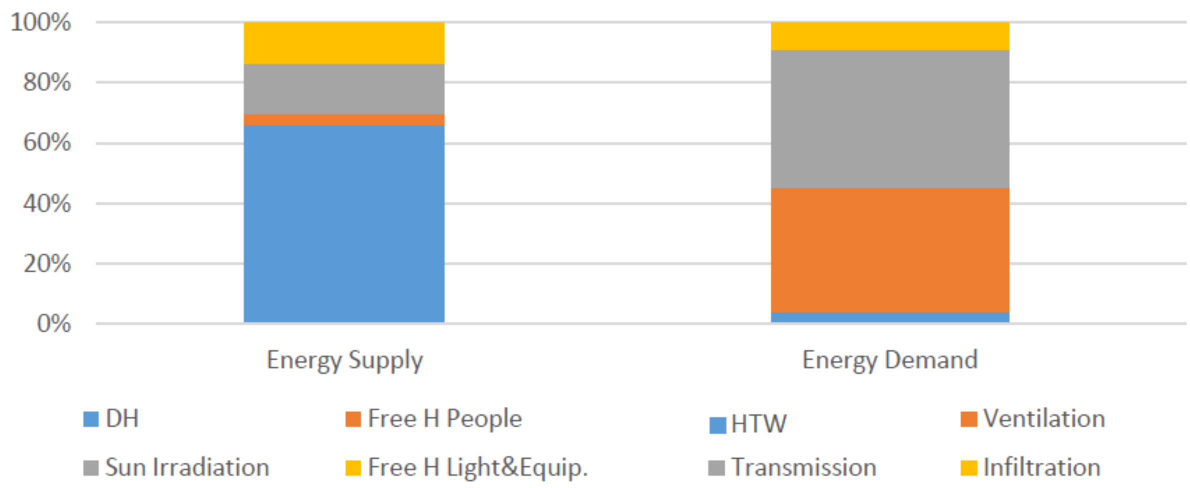


Figure 5: Example of a bar chart for an energy balance of a building.

To summarize, the energy balance equation could be expressed as:

$$E_{transmission} + E_{ventilation} + E_{HTW} + E_{infiltration} = E_{DH} + E_{Internalgains} + E_{sunirradiation} \quad (1)$$

Every term is going to be explained in its section of the results.

2.3. Data collection

The data collection is going to be achieved by the invoices provided by the housing company and the measures made in the building in-situ.

In the Appendix I section the plans or the building can be found. From these plans the measures of the building and orientation have been calculated; always double checking with the in-situ measurements. Due to the bad quality of the pictures and the scale errors, some lengths are not correct in the plans provided.

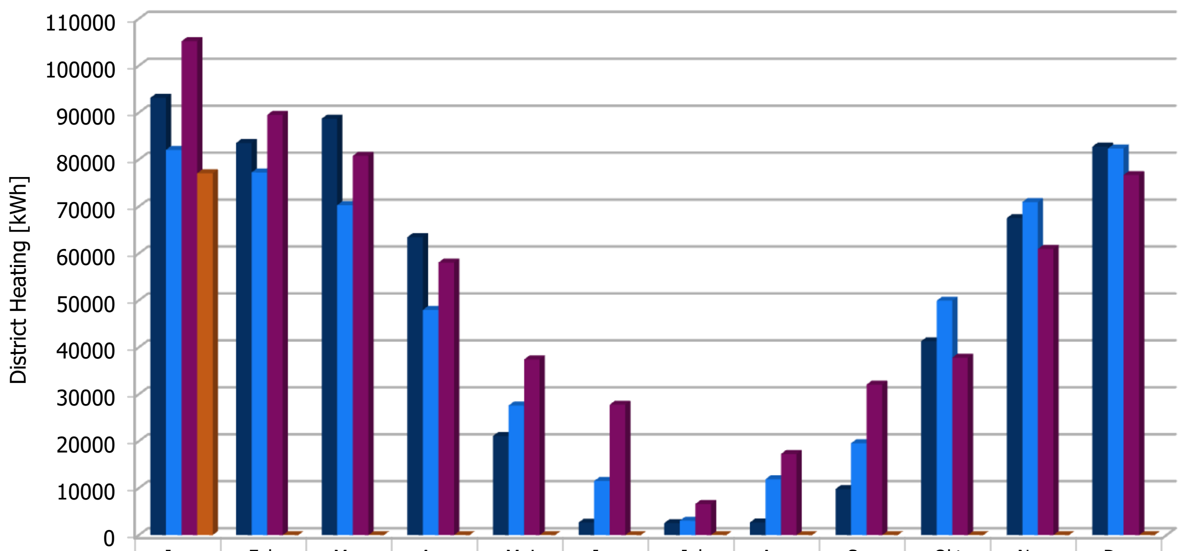
Thereby, the part of heat flow through the envelope has been calculated with data provided for the Gävle area and some in-situ measurements. The internal heat generation has been calculated by the information provided by the staff of the company and the counting of the equipment and lighting of the building. And finally, the energy supply has been obtained from the invoices provided by the housing company. However the ventilation has been obtained from information provided by the staff and measurements done in-situ.

2.3.1. Invoices

Both the DH data and the electricity consumption are provided by Gävle Energi and the HTW (Hot Tap Water) data is provided by Gästrike Vatten. The variations during the years and the months will be commented in the discussion section.

District heating

The next charts show the DH consumption of the building in terms of kWh of energy (normally air corrected). The first one [figure 6] shows the data per month for the years 2013-2016 whereas the second one [figure 7] shows it for the whole year.



	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
2013	93175,22	83534,94	88724,16	63479,08	21126,44	2669,59	2560	2683,333	9814,051	41307,17	67551,53	82776,32
2014	82074,56	77270	70296	47975,71	27603,36	11533,38	3070	11907,61	19573,41	49948,9	70956,4	82373,34
2015	105227,4	89526,85	80813,28	58075,48	37427,11	27794,59	6640	17290	32081,41	37795,69	60963,55	76722,59
2016	77083,75	0	0	0	0	0	0	0	0	0	0	0

Figure 6: District heating consumption chart per month 2013-2016. Corrected to the outdoor temperature.

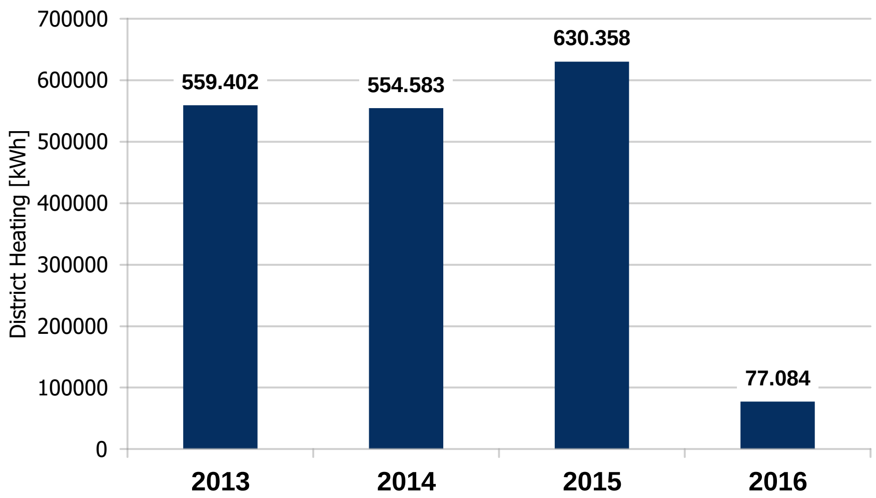
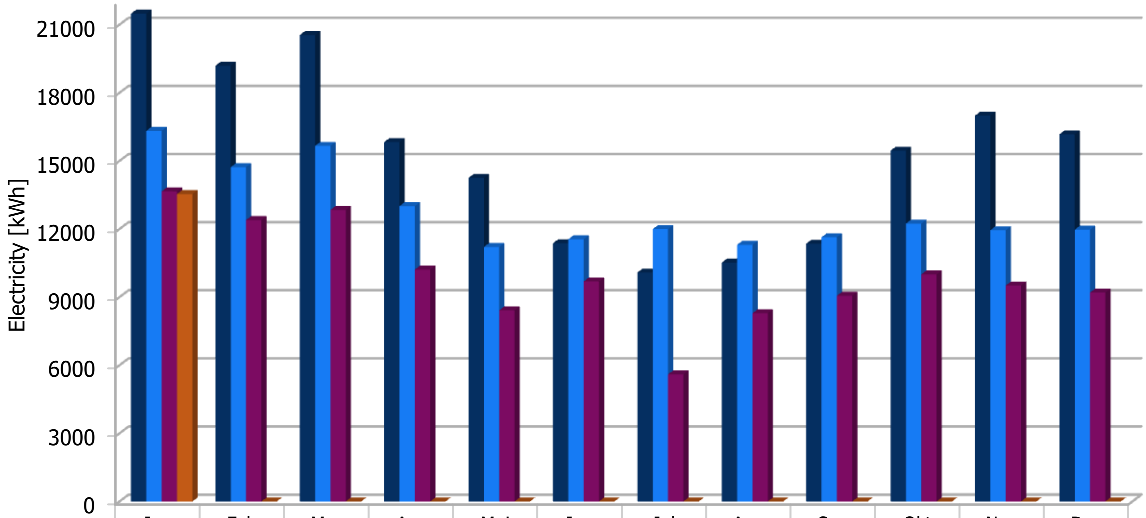


Figure 7: District heating consumption chart per year 2013-2016. Corrected to the outdoor temperature.

Electricity

The next charts show the electricity consumption of the building. The first one [figure 8] shows the data per month for the years 2013-2016 whereas the second one [figure 9] shows it for the whole year.



	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
2013	21487	19192	20546	15830	14253	11374	10084	10522	11354	15451	16993	16171
2014	16324	14726	15663	13009	11208	11550	11997	11305	11637	12238	11946	11971
2015	13658	12395	12842	10215	8421	9689	5599	8292	9060	10001	9509	9203
2016	13539	0	0	0	0	0	0	0	0	0	0	0

Figure 8: Electricity consumption chart per month 2013-2016.

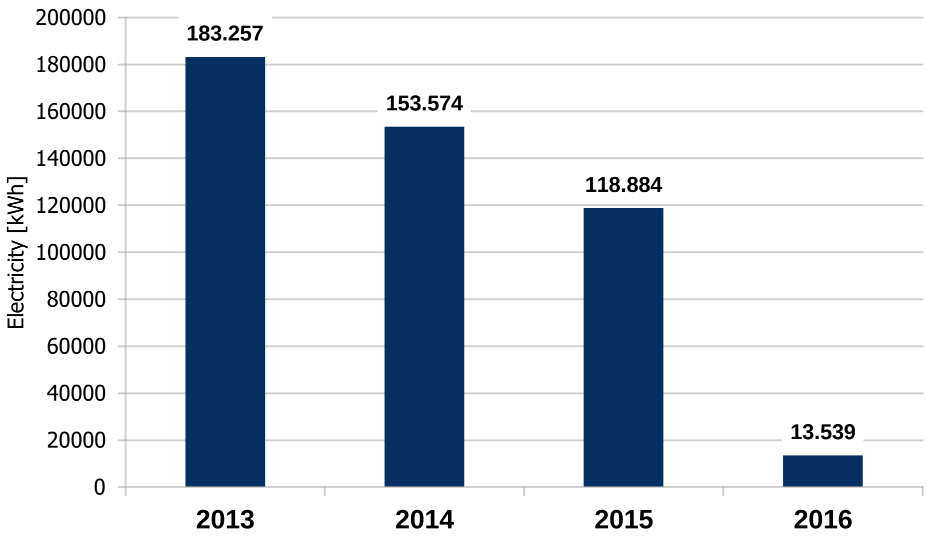


Figure 9: Electricity consumption chart per year 2013-2016.

Hot tap water

The tap water consumption is delivered by Gästrike Vatten. As the HTW cannot be obtained since the system uses the DH grid to heat the water, it is going to be calculated using the cold tap water. The cold water consumption of the building is estimated to be 515m^3 per year. The HTW consumption comes from the use of it in the kitchen and in the bathrooms (half of the staff takes a shower after work).

2.3.2. Visit to the company

In the number of visits to the company, several problems have been detected in the different components of the building. The way of fixing these problems will be explained in the discussion section.

- Windows:
  Some windows both in the first and second floors have holes or are broken. This fact will cause higher infiltration loss. Moreover, the windows are quite old and some have suffered damage due to water or humidity. The same happens to one skylight found in an unused area. Some windows have old insulation in their joints and some others are lacking insulation. However, some of the windows have already been changed for energy saving windows in the office area that is being used. The next pictures [figure 10-12] show the described issues.

Figure 10: Picture of a broken window of the first floor.

Figure 11: Picture of the damaged skylight.

Figure 12: Picture of the windows with damage due to water infiltrations.

- Heating system
  The spaces are heated using wall radiators. These are very old and the valves cannot be properly regulated. The heating system is not controlled by any means: even with 25˚C in the rooms, the system was still on. Some of the unused rooms have electric radiators. However, these are not used. The next pictures [figure 13-16] show the different types of radiator and the regulation systems they have.

Figure 13: Radiator type 1.

Figure 14: Radiator type 2.

Figure 15: Radiator type 3.

Figure 16: Electric radiator.

- Lighting
  The lighting in the building is consisted on fluorescent and halogen lamps. The fluorescent ones are located in the production, storage and office area and remain on while the production is being carried out. The rest of the building uses halogen lighting. In the corridor, the switching system works with presence sensors so the working time is lower. The remaining areas are operated with switches. The office can be estimated to be operational all the time while the kitchen and the bathrooms are in use less time.

- Ventilation
  The building ventilation consists of natural ventilation and mechanical ventilation. The mechanical ventilation is only present in the production area and it is quite a modern systems. However, the rest of the building does not have any type of mechanical ventilation so it is ventilated by the workers when they open the windows or by differences in pressure between the inside and outside.

  The inexistence of mechanical ventilation was noticed by the instrumentation [figure 18] and confirmed by the staff of the company. The air capture hood was measuring some ventilation in different exits. However the rates were really low and they varied a lot from one exit to another. Nevertheless, the workers spend most of the time in the production area. In this area the thermal comfort should be ensured.

  For this purpose, a balanced system is used. The extract and supply flows are constant and it is heated with the excess heat that comes from the painting oven and/or the DH grid. The system is designed to work only with the heat provided by the oven. However, sometimes (when outside is too cold) the excess heat is not enough and the DH comes into play. When it is -5˚C outside, the DH systems starts to work to ensure a 20˚C temperature in the supply stream. The next picture [figure 17] shows a diagram of the described system.

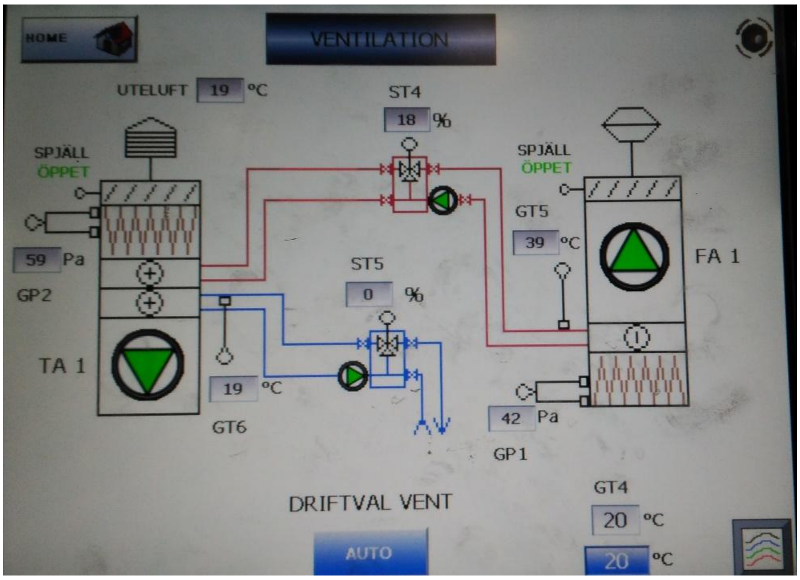


Figure 17: Mechanical balanced ventilation of the production area.

In the moment the picture was taken [figure 17], the outdoor temperature was 19˚C and it has to be elevated until 20˚C. The residual heat from the oven is used, which at that moment was at 18% of the flow since the required heat is minimal. As it can be seen, the DH system does not provide heat because it is not necessary.

The nominal values for the system components can be found in the Appendix III section. According to the staff, the system is usually working at 25-50% of its nominal capacity with a supply air velocity of 1.5m/s.

Measurements

Since the plans of the building weren't exact enough, some measurements where required. These were made by a laser meter [figure 18]. Once the principal measures were taken, the rest could be extrapolated in the plans in AutoCAD.

Figure 18: Laser meter. Source: GetMeter.

For the ventilation measuring, an air capture hood has been used [figure 19] which can measure both extract and supply ventilation. This device has been used to confirm that the ventilation in the office area is inexistent.

Figure 19: Air capture hood. Source: TSI.

For the temperature measuring, a multi-function ventilation meter has been used [figure 20]. Although these meters are used to calculate air velocity, it also incorporates a temperature sensor.

Figure 20: Multi-function ventilation meter. Source: TSI.

3. RESULTS

3.1. Energy supply

3.1.1. DH

The DH consumption has varied in the three years of data that has been provided by the company. Therefore, an average number is going to be used for the calculations.

$$\boldsymbol{DH} = 559.4 + 554.6 + 630.4/3 = \mathbf{581.4}\boldsymbol{MWh}$$

3.1.2. Free heating from workers and electric appliances

Workers

The free heating of the workers is defined by the number of workers, the activity they are performing and the number of hours they stay in the company. In this way, it can be calculated following the next formula.

$$E_{workers} = N_{workers} \cdot q_{activity} \cdot h_{workinghours} \tag{2}$$

Where:

$N_{workers}$: The number of workers in the company [-].

$q_{activity}$: The heat a person is generating depending on the activity that is performing [W].

$h_{workinghours}$: The number of hours the staff works during the year [h].

The staff of the company is formed by 13 workers. As they are working in an industrial process standing up most of the time and performing different weight lifting and moving, the heat produced is going to be considered as 120W for each worker. The company is opened from 7:00 until 16:00 during weekday and it is closed during the weekend. Therefore 1800h/year can be estimated for the working hours.

$$\boldsymbol{E_{workers}} = 13 \cdot 120 \cdot 1800 = \mathbf{2.81}\boldsymbol{MWh}$$

Lighting

The next table [table 1] shows the data explained before for the lighting characteristics of the building and the free final power obtained from it.

Table 1: Free heating from lighting.

Zone	Bulb type	Power [W]	Lamp Nº	Switching system	Working time [h/year]	Free heating [MWh]
Production area	Fluorescent	32	345	Switch	1800	19.872
Corridor	Halogen	30	25	Presence sensor	1260	0.945
Offices	Fluorescent	32	8	Switch	1800	0.4608
Bathrooms	Halogen	30	8	Switch	720	0.1728
Kitchen	Halogen	30	6	Switch	900	0.162
						21.6126

Rest

Apart from the lighting, other electrical devices can be found, such as 2 computers, one fridge, one dishwasher, 4 microwaves, and one printing machine. It is assumed that the fridge is working during all the year, the microwaves and the dishwasher during one hour a day, the printer during two hours a day and the computers during all production hours.

In this way, the next table [table 2] shows the usage and power [11] for the different appliances and the final heat gain.

Table 2: Free heating from the rest of the electric appliances.

Appliance	Nº	Power [W]	Working time [h/year]	Free heating [MWh]
Microwave	4	1000	200	0.8
Fridge	1	200	8760	1.752
Dishwasher	1	1200	200	0.24
Computer	2	100	1800	0.36
Printer	1	50	400	0.02
				3.172

Total

To calculate the total free heating (FH), the free heating from workers, lighting and rest of appliances is summed. However, it has to be taken into account that in summer, the input is not necessary. This is why the total number must be 2/3 of the one that has been calculated.

$$\boldsymbol{FH} = (2.81 + 21.61 + 3.17) \cdot \frac{2}{3} = \mathbf{18.39}\boldsymbol{MWh}$$

3.1.3. Sun Irradiation

First of all, when calculating the sun irradiation, the orientation of the building must be obtained. The next picture [figure 21] is a diagram of the building with the orientation degrees of the walls.

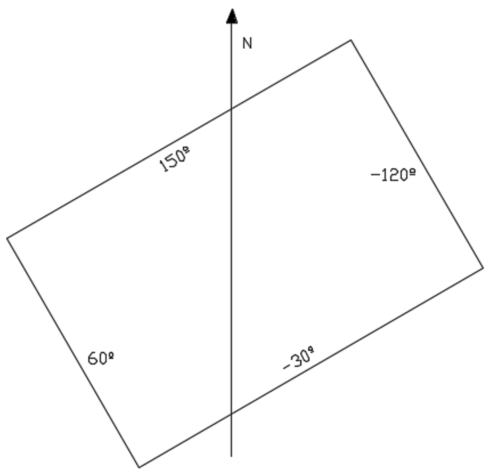


Figure 21: Building diagram with wall orientation for sun irradiation calculations.

The orientation is a fixed number according to the direction towards the north. (See Appendix II – Figure 31)

For a latitude of 60˚ (the location of Gävle) the tables provided by Roland (see Appendix II) have been used, using the next formula for every month:

$$E_{sun} = W_{sun} \cdot \sum_{i} A_{win_i} \cdot f_{sunfactor_i} \cdot f_{cloudfactor} \cdot Days \quad (3)$$

Where:

W_{sun}: Is the sun irradiation for each month and each orientation [Wh/m^{2}day]. (See Table 10)

A_{win}: Is the area of a concrete type of window [m^2]. (See Table 13)

$f_{sunfactor}$: Represents the amount of irradiation that goes through the window [-]. (See Table 13)

$f_{cloudfactor}$: Represents the coverage of the sky by clouds in a specific month [-]. (See Table 12)

Days: The days each month has [day].

Using an Excel sheet, the sun gain for every wall has been calculated following the formula mentioned before. In this way, the next result table has been obtained [table 3]. All the calculations are explained in the Appendix II section.

Table 3: Sun irradiation data for the walls of the building.

	"-120 N"	**"-30 E"**	**"60 S"**	**"150 W"**	**TOTAL [MWh]**
Sun Irradiation [MWh]	1.87359	32.98443	5.21496	0.00	**40.07**

In the next figure [figure 22] a cake type graph is represented where the previous data is shown. As it can be seen, the eastern wall represents most of the sun irradiation gain.

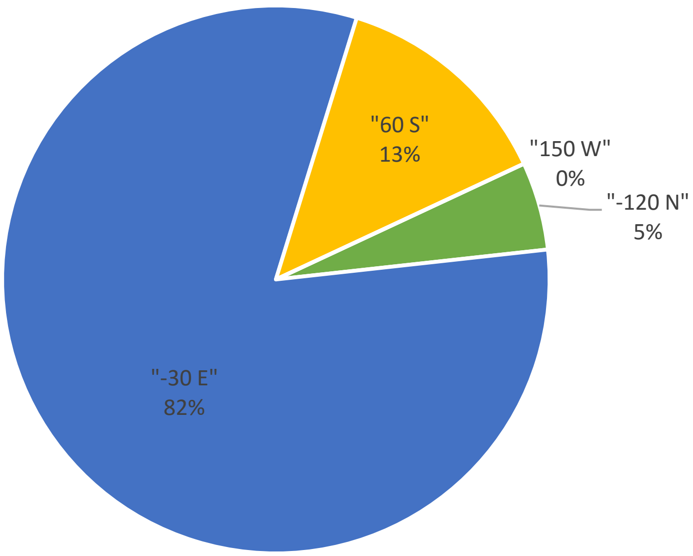


Figure 22: Cake diagram for the different wall irradiations.

3.2. Energy demand

3.2.1. Transmission losses

For the transmission losses, the following formulas are used. For the power usage and energy usage respectively.

$$Q = \sum \frac{U \cdot A \cdot \Delta T}{1000} \; [kW] \tag{4}$$

$$E = \sum \frac{U \cdot A \cdot q_{degree-hours}}{1000} \; [kW] \tag{5}$$

First of all, the UA values for every outside surface have to be calculated. Then, the formulas are applied with the proper temperatures and the $q_{degree\text{-}hour}$ value for Gävle. This has been done and explained in the Appendix II since a lot of areas are measured and the math used is simple. In this section, a summary of the results is going to be presented. The next table [table 4] shows the important data that is going to be used for the energy balance calculation.

Table 4: Transmission losses from the windows, doors, walls, ceilings and floor.

	Windows	**Doors**	**Walls**	**Ceiling**	**Floor**		**TOTAL**
UA [W/K]	317.11	194.12	1098.69	2167.20	167.86	3161.22	
T_{out} [˚C]	-18.00	-18.00	-18.00	-18.00	-18.00	5.00	
Q [kW]	11.10	6.79	38.45	75.85	5.88	37.93	**176.01**
E [MW]	32.66	19.99	113.16	223.22	17.29	325.61	**731.94**

$$\boldsymbol{E_{transmission} = 731.94MWh}$$

3.2.2. Ventilation

The only part of the building that is ventilated mechanically is the production area. Therefore, the rest of the building is ventilated naturally.

Natural ventilation

The natural ventilation, as it cannot be calculated, it is going to be considered as a rest and it will be used to balance eq. 1. Usually, it corresponds to between 5-15% of the total energy demand.

Mechanical ventilation

The mechanical ventilation provides all the heat necessary to maintain the workshop at 20˚C throughout the year. A big part of that heat is considered to be free heating since it comes from the oven in the process. This so, some part of the transmission loss of the building (the part of the production area) is compensated with this free heat. If a duration diagram is analyzed [figure 23], it can be calculated the heat percentage that will be needed with the DH.

$$DH_{\%} = \frac{A_{DH}}{A_{TOT}} \cdot 100 = \frac{90.42}{2008.74} \cdot 100 = 4.5\%$$

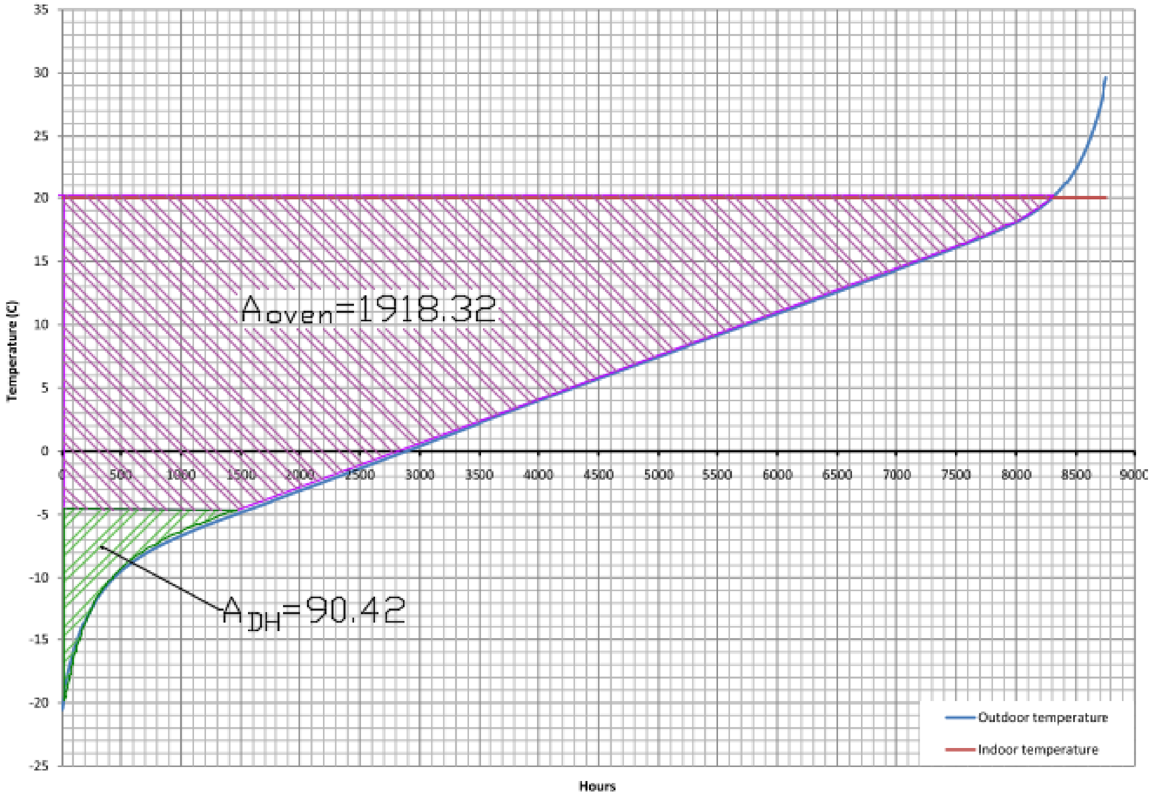


Figure 23: Duration diagram for Gävle with the areas for free heating and DH heating of the ventilation of the workshop.

However, the free heating only compensates the workshop area that takes about 27.5% of the total volume of the building. Knowing this, the transmission losses that are compensated by the oven can be calculated the following way:

$$E_{freevent} = 0.275 \cdot E_{transmission} \cdot (1 - 0.045) = 192.226MWh$$

Like this, the real transmission losses are reduced to:

$$\boldsymbol{E_{real\ transm}} = 731.94 - 192.23 = \mathbf{539.71MWh}$$

And the ventilation cost from the DH is calculated with the part of its percentage (4.5%):

$$\boldsymbol{E_{DHvent}} = 0.275 \cdot E_{transmission} \cdot (0.045) = \mathbf{9.06MWh}$$

3.2.3. Hot tap water

The hot tap water is used in the building is office, kitchen and bathroom areas but not in the process. The water is heated by the DH grid so the exact amount of used hot water is very difficult to calculate unless it is being measured by some meter. This so, it is going to be estimated from the cold tap water consumption. A normal value for the estimation is 30% of the CTW. Using the following formula and assuming the temperature difference as 50˚C:

$$\boldsymbol{E_{HTW}} = 0.3 \cdot V_{CTW} \cdot \Delta T \cdot \rho \cdot C_p \cdot \frac{1}{3600} = 0.3 \cdot 515 \cdot 50 \cdot 1000 \cdot 4190 \cdot \frac{1}{3600} = \mathbf{8.99MWh}$$

3.2.4. Rest

The infiltration losses are really complicated to calculate, and more so at this big scale. Therefore, in this case, they are going to be used for balancing the energy supply and demand (eq. 1) along with the natural ventilation. This so, the rest of the losses are:

$$E_{rest} = 82.1MWh$$

They account for about 13% of the losses, which is a usual value for this type of building.

3.3. Energy balance

If the results calculated above are summarized in a table, we can obtain the energy balance of the building. This is shown in the next table [table 5] along with the bar charts where the percentage of each process is represented

Table 5: Energy balance for the building.

	Process	Energy [MWh]	%	TOTAL [MWh]
Energy Supply	DH	581.40	90.86	**639.86**
	Free Heating	18.39	2.87	
	Sun Irradiation	40.07	6.26	
Energy Demand	HTW	8.99	1.40	**639.86**
	Ventilation	9.06	1.42	
	Transmission	539.71	84.35	
	Infiltration	82.10	12.83	

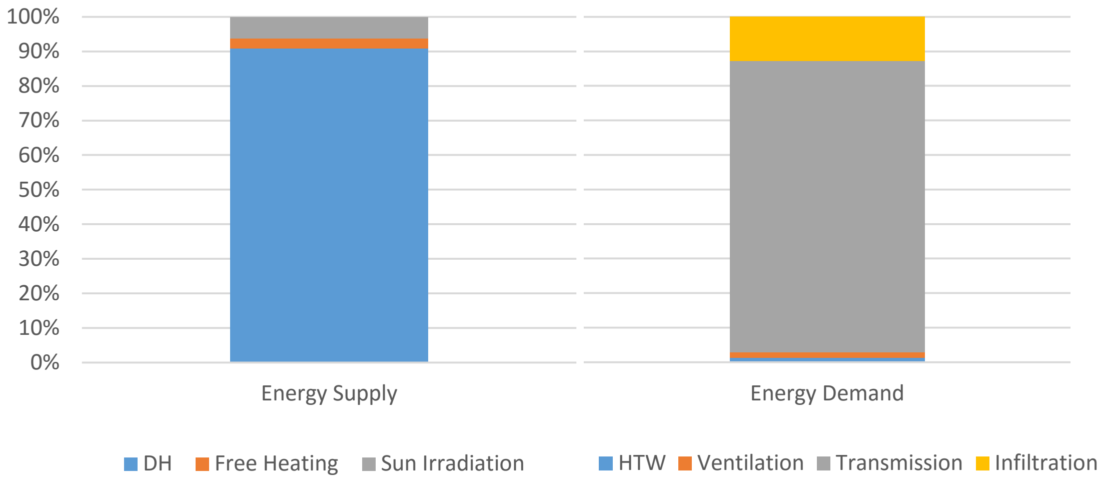


Figure 24: Bar chart of the energy balance for the building.

3.4. Energy saving measures

Once the balance is done, the measures have to be proposed. At this point, the focus has to be done in the more energy wasting parts. For this, the majority of the measures have to be done in the transmission and infiltration part. However, sometimes the saving is not the only aspect that has to be taken into account. The thermal comfort of the workers has to be assured also.

3.4.1. Windows

The changing of the window will reduce both the transmission and the infiltration loss. If every window is changed for an energy saving window such the ones that have already been changed (U=1.3W/m^2K), the UA value will be reduced to 148.252W/K, less than half of the original value. The energy loss will be reduced to 15.27MW only in the transmission part. However, this number will be much higher if the infiltration loss reduction could be calculated. Moreover, the thermal comfort of the office areas will improve highly since the infiltrations are reduced.

Even so, it has to be taken into account that the changing of the windows comes with a big first investment.

3.4.2. Envelope

The part from where the building losses more energy are the walls ceiling and floor areas. In the market there are several alternatives to improve the insulation of these areas. However, since the prices vary and the insulation level can be decided, a more in-depth analysis is needed. On the other hand, different studies show that the investments in insulation are profitable in the long term [12].

3.4.3. Ventilation

The most important step to achieve thermal comfort in the building is to have a proper ventilation and air quality. The actual system must be improved to reach these goals.

It is proposed to use the modern ventilation system of the production process to ventilate the entire building. For this, the needed ventilation has to be calculated. A common formula for the calculation is as follows:

$$\dot{v} = 7\frac{l}{s} \cdot person + 0.35\frac{l}{s} \cdot m^2 floor\ area \tag{6}$$

Taking into account that the company has 13 workers and that the floor area is 8730m^2, the following value is obtained. The floor area is calculated by adding the two floors minus the floor area that is occupied by the process (which takes up two levels).

$$\dot{v} = 7\frac{l}{s} \cdot 13 + 0.35\frac{l}{s} \cdot 8730 = 3146.5\frac{l}{s} \cdot \frac{1m^3}{10^3 l} = 3.15\frac{m^3}{s}$$

Taking into account that the nominal value of the supply flow of the ventilation system is 5.69m^3/s, it is enough to fulfill the ventilation needs. However, the energy needs will be higher since the DH consumption will be higher.

4. DISCUSSION

4.1. Invoices

As it can be seen in figure 6, there are some variations on the DH consumption throughout the months. In summer there is less consumption (almost zero) whereas in winter is high. Totally logical since in winter the temperatures are much colder than in summer and almost all the energy provided by the DH grid is directed to the radiator systems that heats the building and the production ventilation system.

As it can be seen in figure 7, the DH consumption changes also throughout the years. It is logical since the need of heat is proportionally related to the climatic conditions. Therefore, from year to year variations can occur. For example, the past years, the DH consumption is been higher.

On the other hand, if the electricity consumption is analyzed, it has suffer an important decrease in the past year [figure 9]. This could be due to different energy efficiency measures carried out in the company or a difference in the production routine of the process. As it can be seen in figure 8, the electricity consumption remains quite constant during the year. In winter it is a bit higher because of the electrically heated ventilation it exists in some areas of the building.

In regards of water consumption, the data obtained has little accuracy. The water company (Gästrike Vatten) does not measure the consumption monthly. They send a worker to the water meter and they check the consumption from time to time making a yearly approximation. Moreover, the building itself doesn't have any way to measure the water it has consumed by means of hot or cold water consumption. For this, another estimation has to be made to calculate the HTW. A water meter for the HTW consumption should be installed in order to get more accurate data and evaluate the measures that can be applied in order to save energy. An example for its improvement may be the installation of water economizers or the reduction of the hot water temperature.

4.2. Obtained results

As it was expected, the DH takes up most of the supply part of the energy balance. The free heating is quite small because the building is big in comparison with the amount of people working there and the appliances. However, the machinery and the electric ventilation part has not been accounted for. If it had, this number would turn out to be bigger, but it has been not possible to calculate it. The sun irradiation is also small in comparison. Nevertheless, the building being of an industrial type, it has fewer windows than normal. For example, there is an entire wall that has no windows (the 150W direction) [figure 21]. In this way, it is intended to concentrate most of the windows in the part of the building that is facing the biggest sun irradiation (the -30E direction) [figure 21]. A lot of heat is lost through the windows; facing them to the east makes this loss to be compensated.

In the part of the energy demand, the transmission loss is highly compensated with the ventilation heat obtained from the paint oven. However, one part of the ventilation heat comes from the DH. This part has been taken into account as loss also. Nevertheless, the transmission loss is the most important loss, which makes sense since the building is so big (a lot of envelope areas). The HTW consumption is also small in comparison because of the nature of the building and the production process. The water usage is not as big as it could be in a residential building and the process does not require any water. Finally the rest part of the energy demand is used to balance de equation. The obtained value is inside the rage that was expected. However is bigger than usual because the big infiltration losses that the building has.

4.3. Energy saving measures

4.3.1. Windows

Every window should be changed to triple-pane windows or energy saving windows. Even more, for a country like Sweden where the outside temperatures tend to be cold in winter.

Examples of the window types that could be applicable include, vacuum glazing, triple-glazing and the use of aero gels [13]. Furthermore, replacing building transparent surfaces with polycarbonate improves the use of daylight at a lower cost while the energy savings increase [14]. Additionally, this material is more resistant that the common glass reducing the possibility of its breakage from thrown objects. The company has some broken windows due to this problem. The first floor windows could be changed for polycarbonate since they cannot be opened and their only purpose is to bring light to the production area.

The skylights are not useful because they are located in areas that are not used. A lot of energy is lost through them. It could be a good idea to isolate them to avoid this loss.

However, this could turn out to be really expensive if every window is changed. Therefore a more complex analysis is needed. If the housing company cannot rent the unoccupied areas, the investment could turn out to be unprofitable.

4.3.2. Heating system

The use of thermostatic valves can save up to 10% of the energy usage in some cases [15]. In this one, it could also turn out to be higher since the control of the temperature is bad. There should not be any heating system connected when the temperature is above 21˚C.

It is not recommended to use electric heating. The efficiency is really low if we compare it to that of the DH. Moreover, in this case that he DH grid is available; to use electric heating does not make sense. This is why it should be used just in some specific occasions (but not in this situation). In case the unused areas are rented to another company, new radiators should be installed and connected to the DH grid.

Finally, even though it is not a priority, the radiators themselves could be changed for more modern ones. This way the energy saving will be higher although the initial cost will be high also.

4.3.3. Lighting

The lighting is good overall. However, the offices and bathrooms do not have presence sensor and lighting sensor switches which could be also installed. In this way, the savings in lighting can be up to 80% in cloudy days [15].

4.3.4. Ventilation

Even though the actual ventilation capacity is big enough to satisfy the needs of the entire building, the ventilation conduits are not connected. As the system is functioning now, the old and new systems work independently. To fix this, a proper connection must be installed and the old tubes must be cleaned. Finally, the supply exits must be updated from manual to controlled. This way, the flow can be regulated in each exit.

5. CONCLUSIONS

First of all, the main objective of performing an energy audit and proposing some energy efficiency measures has been fulfilled. The different processes have been analyzed in order to discover why the building is consuming more than desired.

The total energy supply for the building located in Industrigatan 7 (Gävle) is 639.86MWh where the DH accounts for more than 90% of the needed energy. This system is one of the best heating methods there are. This is why its use is highly recommended unlike others such as electric heating.

The biggest part of the energy losses come from transmission and infiltration summing 621.81MWh and accounting for more than 97%. The main reason for this is the time of construction of the building and the poor state in which it is. The next figure summarizes the obtained results [figure 25].

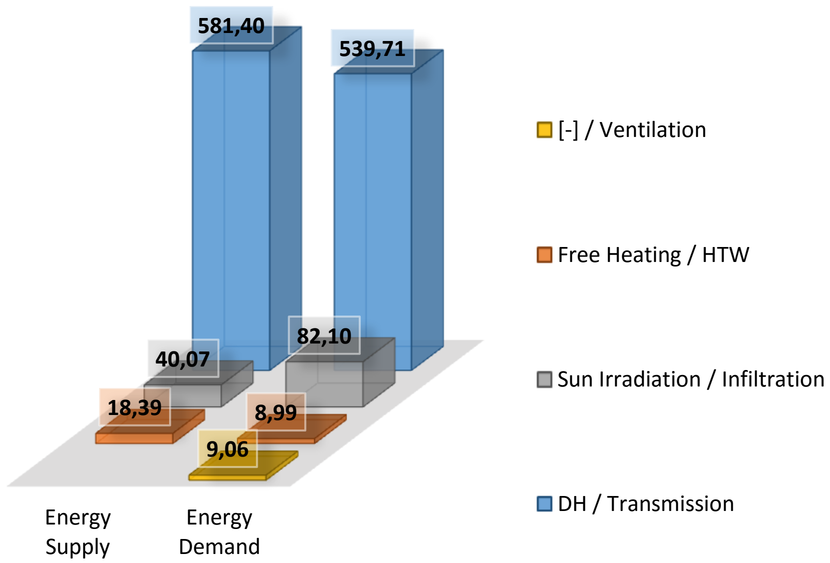


Figure 25: Energy balance. Energy supply and energy in MWh.

Although some energy efficiency measures could be analyzed, because of the nature of the building, energy efficient technologies have been proposed as efficiency measures. Being such an old building usually means that its components are damaged in an irreparable way. For this case it happens with windows, ventilation system and heating system. Moreover, this components' efficiency is really low compared to the new ones.

To fix this, several measures have been proposed. Among them, the most important ones are the replacement of the windows, the heating system valves and the ventilation. The changing of the windows can turn out to be a very expensive measure. However, it is a measure that has to be carried out because of the poor condition of the current glazing. The thermal comfort will be improved as well since the infiltrations are going to be reduced. The installation of thermostatic valves is a cheaper measure but a very important one. This will reduce the DH consumption when is no needed and help to maintain a constant temperature in the office areas. Both measures along with the improvement of the ventilation system will eliminate the need of opening the windows and thus reduce the losses. In addition, the ventilation system upgrade will not cost much either. The ventilations ducts are already build and if a connection is made between the workshop ventilation system (which can handle a flow big enough to feed the entire building) it will only be necessary to change the ducts exists. This measure will improve also profoundly the thermal comfort of the workers, but it can lead to a bigger DH consumption.

For achieving an even more energy efficient building further measures can be carried out. Among them the most energy saving one would be the improvement of the envelope by adding a new insulation layer. Nevertheless, it is also an expensive measure to carry out and even though it will payback, the first investment will be high. The lighting can also be improved if presence and lighting sensors are installed. The investment is not very high but the retributions will be low as well.

Further work

Apart from the saving measures, the company could invest in consumption meters for the different processes. In this way, the information that can be obtained will be more accurate and thus, the measures proposed. A hot water data, ventilation data and electric consumption data could be obtained in this way. Moreover, the staff of the company could detect energy leaks and could adjust the processes to make them more efficient.

In this way, the thesis could be useful in future studies for different companies in the area; or companies with old buildings such as this one, to know what measures are likely to be carried out. Moreover, it can be useful if the housing company decides that it should improve the energy efficiency of the building. They can take into account the proposed measures and if wanted carry out a more profound analysis to get the payback of the investments they will carry.

Apart from that, the company could improve the image of the dwelling in order to attract new clients to occupy the unused space that nowadays is just a waste of money. For this, not only the windows and ventilation should be installed, also, the electric heaters should be replaced by radiators connected to the DH grid.

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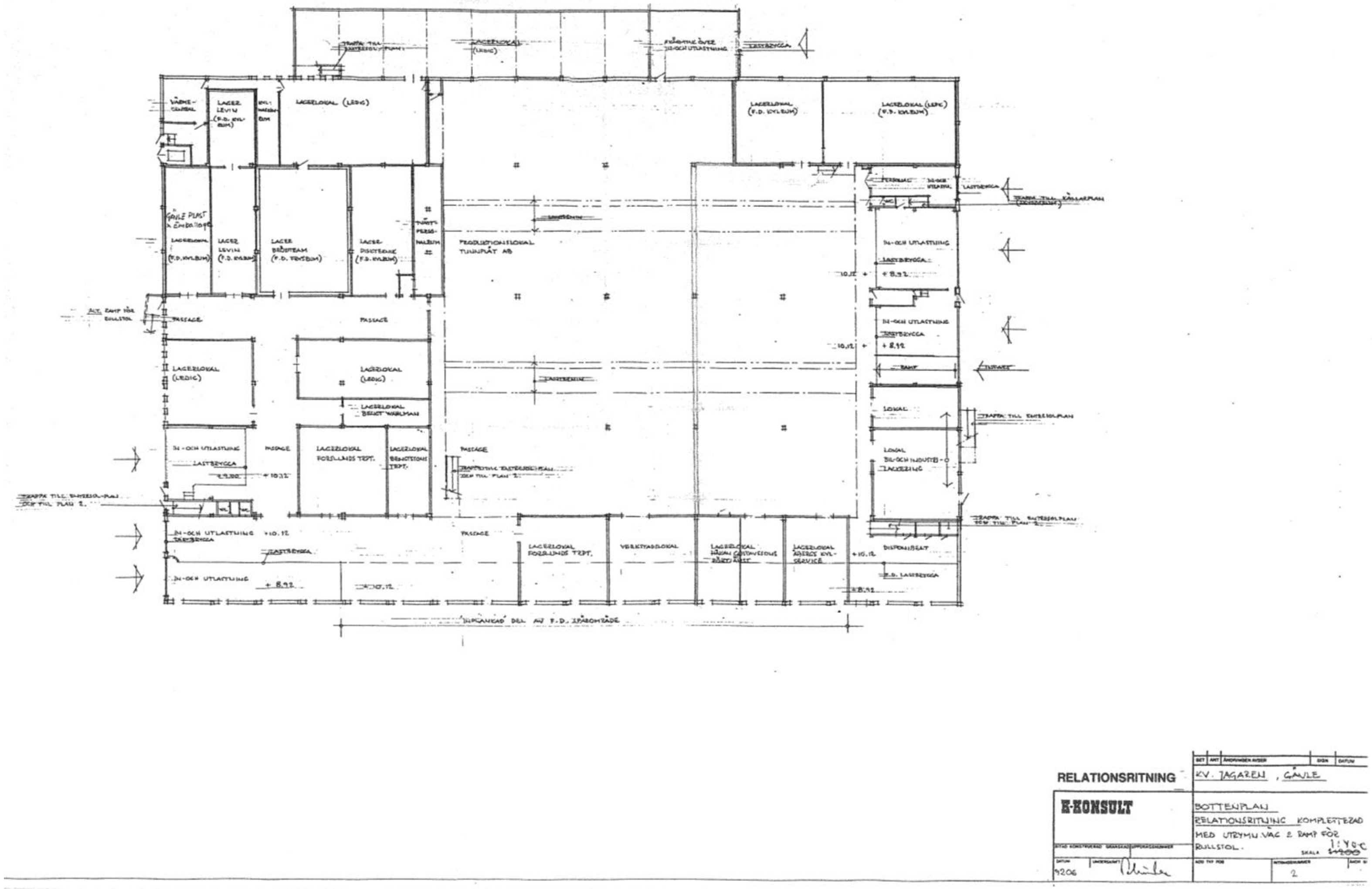
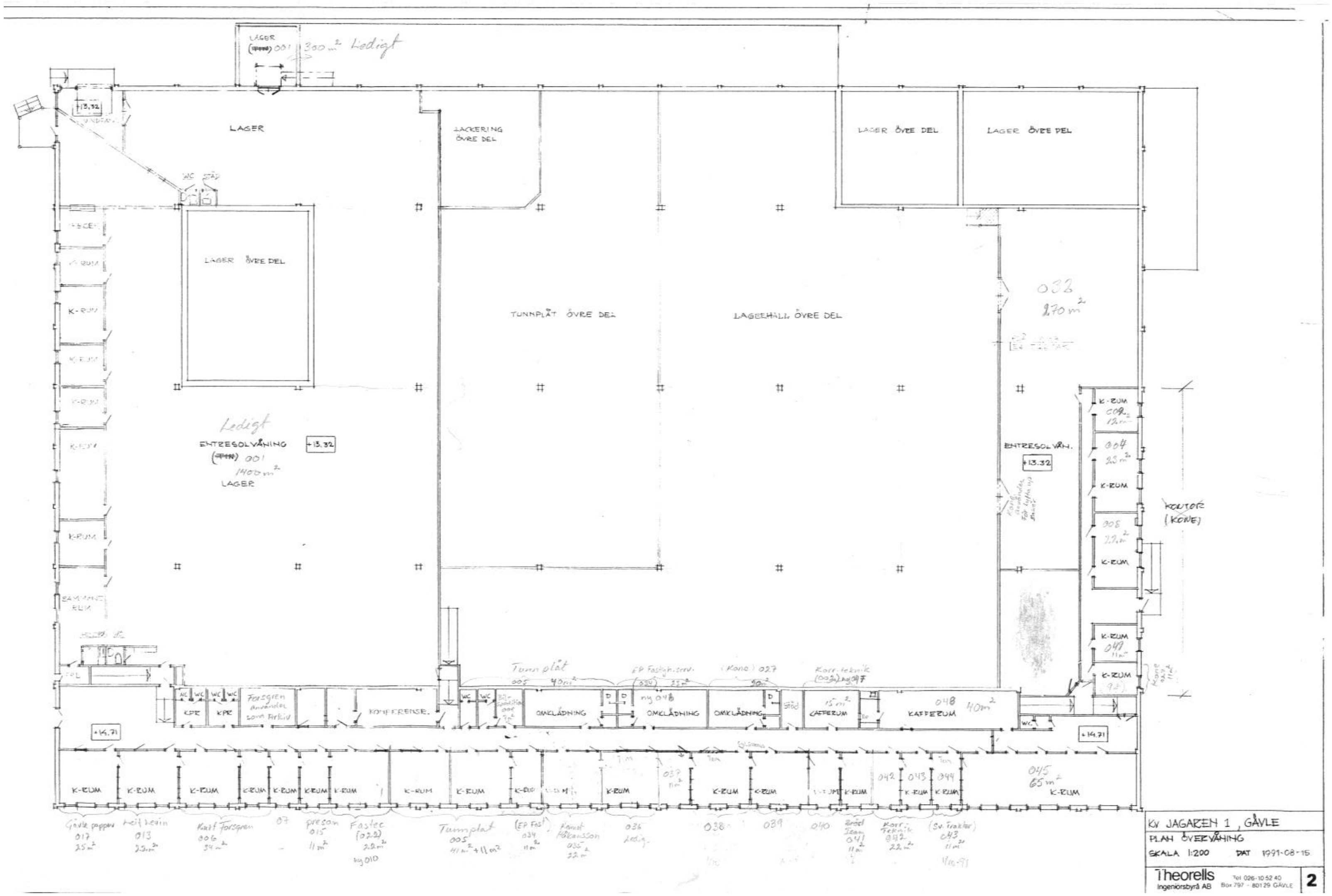
APPENDIXES

Appendix I: Plans of the building

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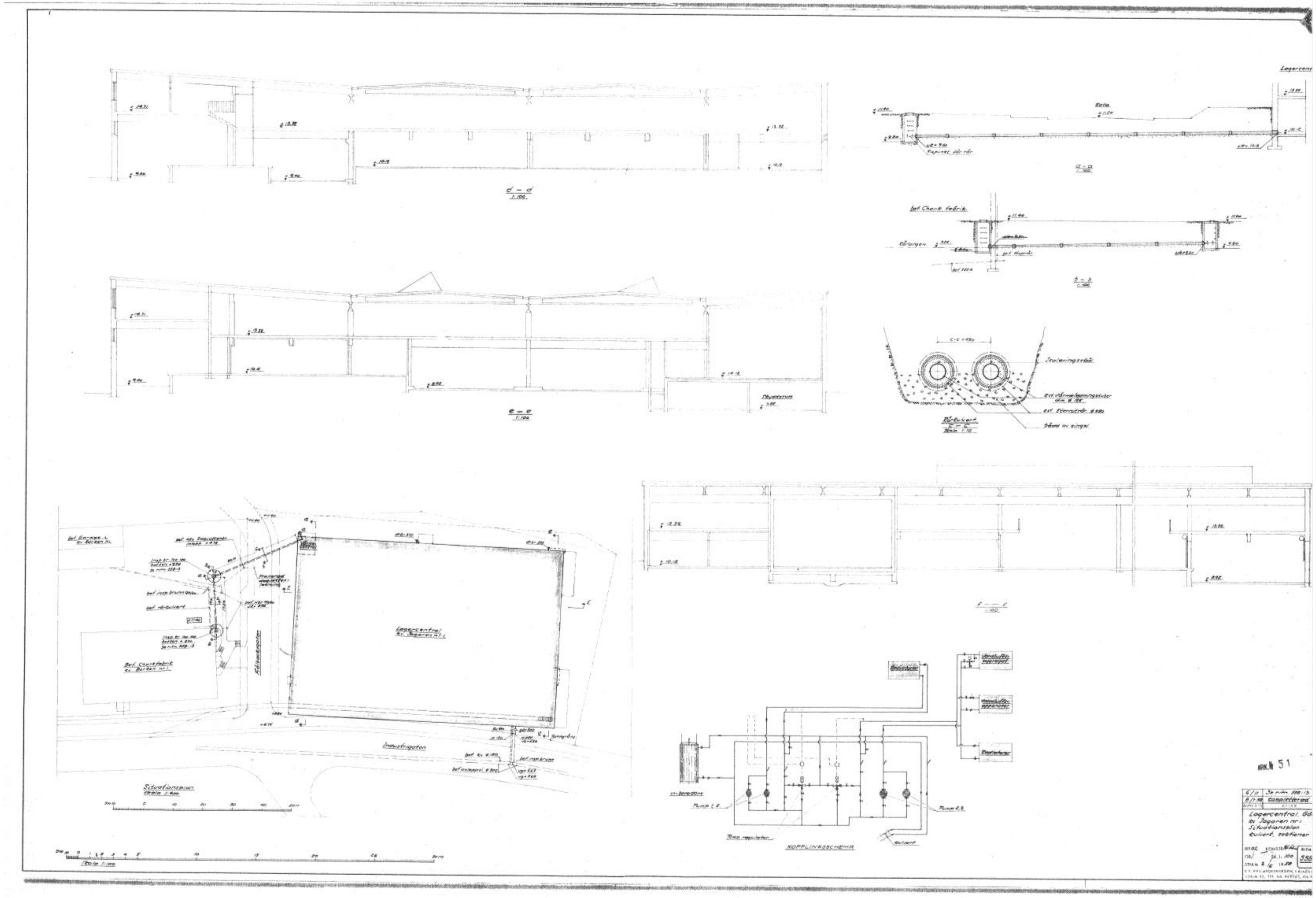
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Pump L 3
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Appendix II: Transmission and sun irradiation calculations

Transmission calculations

Windows

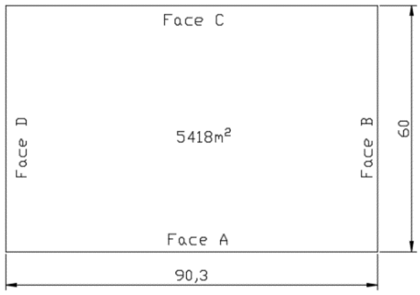

Figure 26: Diagram of the building.

FACE A

The first floor has 18 strong glass windows with an estimated U-value of U=2.9W/m^{2}K.

$$A_1 = 18 \cdot 1.17m^2 = 21.06m^2$$

The second floor has 30 2-pane windows (U=2.9W/m^{2}K) and 6 energy glass windows (U=1.3W/m^{2}K).

$$A_2 = 30 \cdot 1.85m^2 = 55.5m^2$$

$$A_3 = 6 \cdot 1.85m^2 = 11.1m^2$$

FACE B

The first floor has no windows and the second floor has 8 2-pane windows (U=2.9W/m^{2}K) of 1.6m^2.

$$A_4 = 8 \cdot 1.6m^2 = 12.8m^2$$

FACE C

There are no windows in the first or in the second floor.

FACE D

5 2-pane windows (U=2.9W/m^{2}K) of 0.7m^2 in the first floor.

$$A_5 = 5 \cdot 0.7m^2 = 3.5m^2$$

9 2-pane windows (U=2.9W/m^{2}K) of 0.7m^2, and a single big window (U=4W/m^{2}K) of 3.78m^2 in the second floor.

$$A_6 = 9 \cdot 0.7m^2 = 6.3m^2$$

$$A_7 = 1 \cdot 3.78m^2 = 3.78m^2$$

$$UA_{windows} = 2.9 \cdot (55.5 + 12.8 + 3.5 + 6.3 + 21.06) + 1.3 \cdot 11.1 + 4 \cdot 3.78 = 317.114\, W/K$$

Doors

Doors can be only found in face D and a small garage door in face C. The picture of the opening can be seen in the next figures [Figure 27, Figure 28].

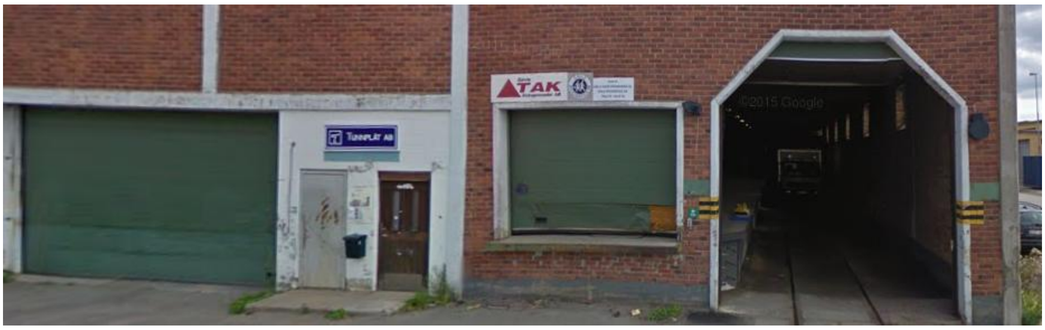

Figure 27: Picture of the entrance of the building.

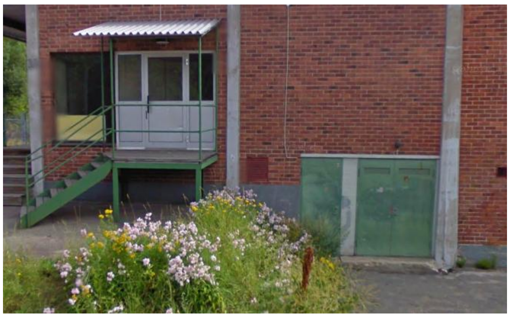

Figure 28: Picture of other entrance and the door to the DH counters.

The measures of the different doors have been taken using the laser meter and are shows in the table below [Table 6].

Table 6: Areas for the different types of doors found in the building

	Area [m^2]	U-value [W/m^{2}K]	UA [W/K]
Garage doors	56.43	2.4	135.432
Metallic doors	10.6	2.5	26.5
Wooden doors	3.1	2.04	6.324
Metallic door with windows	6.6	2.6	17.16
2-pane windows	3	2.9	8.7
			194.116

$$UA_{doors} = 194.116W/K$$

Walls

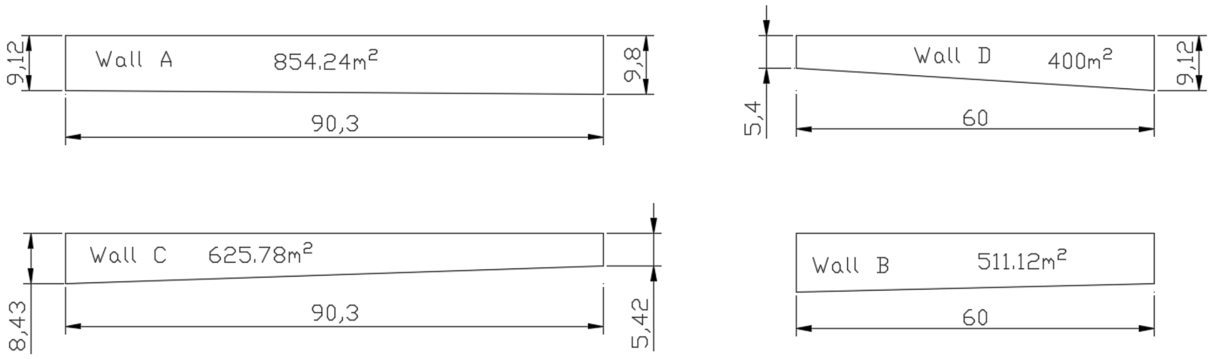

Figure 29: Sketch of the walls of the building.

The walls distances and areas are calculated in AutoCAD. The windows and doors must be taken out of the total areas. The U-value for the walls has been estimated by the year of the building's construction (U=0.5W/m^{2}K).

$$A_{walls} = 854.24 + 625.78 + 400 + 511.12 - 114.04 - 79.73 = 2197.37m^2$$

$$UA_{walls} = 1098.685W/K$$

Ceiling

The ceiling has some openings, but it is difficult to calculate them since they don't appear in the drawings. To measure them in-situ would be very complicated. The U-value for the walls has been estimated by the year of the building's construction (U=0.4W/m^{2}K).

$$A_{ceiling} = 60 \cdot 90.3 = 5418m^2$$

$$UA_{ceiling} = 5418 \cdot 0.4 = 2167.2W/K$$

Floor

It has to be taken into account the amount of floor considered as wall and the mount of wall under the floor level. The U-value for the floor has been estimated by the year of the building's construction (U=0.6W/m^{2}K).

The floor and the underground walls are drawn in the same figure [Figure 30]. The underground walls have been simplified to a triangle of which area has been obtained in AutoCAD.

The underground walls are calculated for an outside temperature of -18˚C as well as the meter of floor in contact with a wall which is not underground. On the other hand, the floor in contact with an underground wall if calculated for an outside temperature of +5˚C. This scheme can be visualized in the next figure [Figure 30].

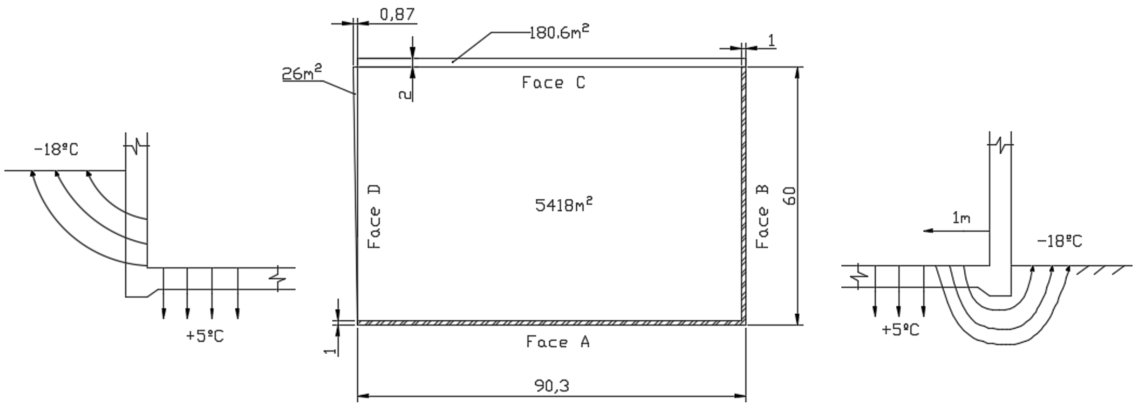

Figure 30: Sketch of the floor of the building and underground walls.

In the following table [Table 8], the different areas, U-values and outside temperatures are shown. The U-value for the underground wall to air requires a correction since it is more isolated thanks to the ground surrounding it. The next table [Table 7] shows the table from where the new U-value has been obtained (U=0.38W/m^{2}K) taking into account that the wall U-value is 0.5W/m^{2}K.

Table 7: Corrected U-values for underground walls.

Djup H i meter under markytan	Värmegenomgångstal k_0 (utan hänsyn till omgivande mark)										
	0,5	0,6	0,7	0,8	1,0	1,2	1,5	2,0	2,5	3,0	4,0
	Värmegenomgångstal k vid ovanstående k_0-värden										
1,0	0,43	0,50	0,57	0,67	0,80	0,93	1,11	1,37	1,60	1,81	2,19
2,0	0,38	0,43	0,48	0,58	0,69	0,78	0,90	1,06	1,22	1,36	1,62
3,0	0,34	0,38	0,43	0,51	0,60	0,67	0,76	0,87	0,96	1,04	1,18
4,0	0,31	0,35	0,38	0,45	0,53	0,60	0,68	0,74	0,81	0,88	0,98
5,0	0,29	0,32	0,35	0,42	0,48	0,53	0,58	0,64	0,70	0,75	0,84

Table 8: Areas, U-values and outside temperatures for the floor of the building.

	Area [m^2]	U-value [W/m^{2}K]	T_{out} [°C]	UA [W/K]
Floor to ground	5268.7	0.6	5	3161.22
Floor to air	149.3	0.6	-18	89.58
Underground wall to air	206	0.38	-18	78.28

$$UA_{floor1} = 167.86W/K \qquad (T_{out} = -18°C)$$

$$UA_{floor2} = 3161.22W/K \qquad (T_{out} = 5°C)$$

Transmission losses

As far as the usual calculations go, an inside temperature of 20-21˚C is the common number to choose. However, some parts of the building are not heated (because they do not need to be since there is no human activity). The temperature in this part of the building tends to be between 10 to 15˚C. Therefore, a temperature of 17˚C has been chosen to make the calculations for the entire building. This temperature is the one used to obtain the data from the tables provided by the supervisor. This data has been obtained by thorough simulation and high experience from professionals for the area of Gävle.

The next figure shows the table that has been used [Table 9].

Table 9: $Q_{degree\text{-}hours}$ value for different temperatures.

Temp °C	Summa gradtimmar, som funktion av årets normaltemperatur i °C										
	−2	−1	0	1	2	3	4	5	6	7	8
5	80750	73500	66500	59700	53200	47000	41000	35200	29700	24500	19500
6	87000	79500	72300	65300	58500	52000	45800	39700	33900	28400	23000
7	93500	85800	78300	71100	64100	57400	50800	44500	38400	32600	26900
8	100200	92200	84600	77200	69900	62900	56200	49600	43200	37100	31100
9	107200	99000	91200	83500	76000	68800	61800	54900	48200	42000	35500
10	114500	106000	98000	90100	82400	74900	67700	60600	53600	47100	40300
11	121900	113300	105100	97000	89000	81400	73900	66500	59300	52500	45400
12	129500	120700	112300	104000	95800	88000	80200	72600	65100	58100	50700
13	137000	128100	119500	111000	102500	94500	86500	78700	70900	63600	55900
14	144600	135400	126700	118000	109300	101100	92900	84700	76700	69200	61200
15	152100	142800	133900	125000	116100	107600	99200	90800	82500	74800	66500
16	159700	150200	141100	132100	122900	114200	105500	96900	88300	80400	71800
17	167200	157600	148300	139100	129600	120700	111800	103000	94100	85900	77000
18	174800	165000	155500	146100	136400	127300	118100	109100	99900	91500	82300
19	182300	172300	162700	153100	143200	133800	124500	115200	105700	97100	87600
20	189900	179700	169900	160100	149900	140400	130800	121300	111500	102600	92800
21	197400	187100	177100	167100	156700	146900	137100	127300	117300	108200	98100
22	205000	194500	184300	174100	163500	153500	143400	133400	123100	113800	103400
23	212500	201900	191500	181100	170200	160000	149700	139500	128900	119300	108600
24	220100	209200	198700	188100	177000	166600	156100	145600	134700	124900	113900
25	227600	216600	205900	195100	183800	173100	162400	151700	140500	130500	119200
	Drifttid i h/år för värmeanläggning, som funktion av årets normaltemperatur, då uppvärmning sker till minst 11 °C.										
	7550	7380	7200	7010	6770	6550	6320	6080	5800	5570	5270

So, applying the formulas, the next results are obtained:

$$Q = \frac{(17-(-18))}{1000} \cdot [317.114 + 194.116 + 1098.69 + 2167.2 + 167.86] + \frac{(17-(5))}{1000} \cdot 3161.22$$

$$Q = 138.08 + 37.93 = 176.01kW$$

For the energy losses calculation, a value of q_{degree}=103000 has been used.

$$E = \frac{317.114 + 194.116 + 1098.69 + 2167.2 + 167.86}{1000} \cdot 103000 = 7.106 \cdot 103000$$

$$E = 731.94MWh$$

Sun irradiation

Building orientation

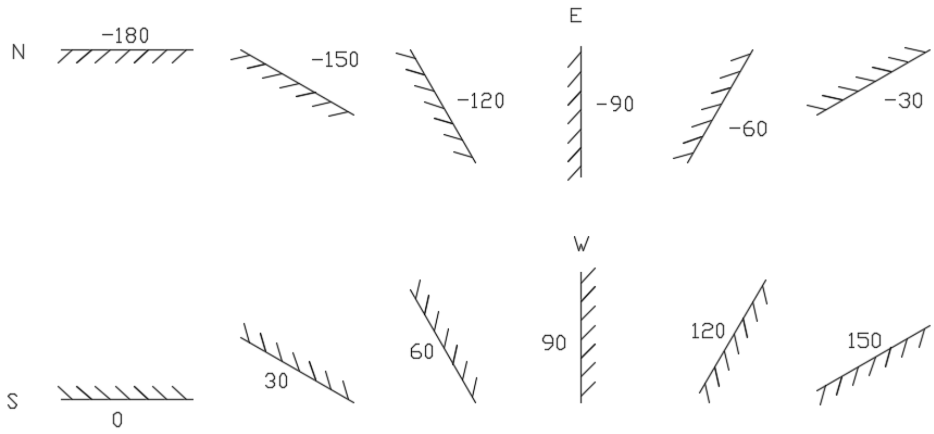

Figure 31: Orientation degree of walls.

Calculations

The next table [Table 10] shows the data for the 60˚ latitude and orientation of the building with a type 0 radiation factor.

Table 10: Data of the sun irradiation for a building located in latitude 60˚N

II:2.1.2 Dygnssummor den 15:e i varje månad av strålning mot vertikala ytor, Wh/m²dygn 151

Månad	Horisont-avskärmning,°	Vertikala ytans orientering N −180	−150	−120	E −90	−60	−30	S 0	30	60	W 90	120	150
Latitud 60°N													
Januari	0	130	130	160	550	1440	2360	2710	2360	1440	550	160	130
	10	70	70	70	90	140	180	200	180	140	90	70	70
Februari	0	370	370	640	1550	2900	4280	4880	4280	2900	1550	640	370
	10	340	340	400	1030	2240	3530	4020	3530	2240	1030	400	340
Mars	0	730	900	1720	3050	4520	5740	6320	5740	4520	3050	1720	900
	10	710	730	1290	2460	3920	5290	5970	5290	3920	2460	1290	730
April	0	1350	1990	3320	4750	5850	6370	6410	6370	5850	4750	3320	1990
	10	1170	1640	2810	4220	5420	6160	6390	6160	5420	4220	2810	1640
Maj	0	2350	3050	4460	5630	6150	5980	5730	5980	6150	5630	4460	3050
	10	1840	2570	3910	5130	5840	5920	5710	5920	5840	5130	3910	2570
Juni	0	3210	3870	5230	6190	6350	5820	5460	5820	6350	6190	5230	3870
	10	2420	3180	4570	5650	6070	5790	5430	5790	6070	5650	4570	3180
Juli	0	2830	3510	4910	5960	6280	5820	5580	5890	6280	5960	4910	3510
	10	2270	3020	4410	5540	6050	5870	5560	5870	6050	5540	4410	3020
Augusti	0	1700	2380	3720	5020	5850	6070	5970	6070	5850	5020	3720	2380
	10	1400	2020	3240	4550	5520	5950	5940	5950	5520	4550	3240	2020
September	0	900	1230	2200	3520	4820	5760	6130	5760	4820	3520	2200	1230
	10	880	1070	1930	3200	4530	5580	6080	5580	4530	3200	1930	1070
Oktober	0	510	530	1010	2110	3570	4960	5620	4960	3570	2110	1010	530
	10	470	480	650	1500	2850	4290	4870	4290	2850	1500	650	480
November	0	200	200	270	840	1910	3040	3480	3040	1910	840	270	200
	10	160	160	160	300	990	1590	1810	1590	990	300	160	160
December	0	80	80	90	350	1060	1770	2030	1770	1060	350	90	80
	10	40	40	50	60	90	120	130	120	90	60	50	40

Taking into account only the necessary numbers, the next table [Table 11] has been built. The units are Wh/m²day.

Table 11: Data of the sun irradiation for a building located in latitude 60˚N for the orientation of the studied building.

	N -120	E -30	S 60	W 150
January	160	2360	1440	130
February	640	4280	2900	370
March	1720	5740	4520	900
April	3320	6370	5850	1990
May	4460	5980	6150	3050
June	5230	5820	6350	3870
July	4910	5820	6280	3510
August	3720	6070	5850	2380
September	2200	5760	4820	1230
October	1010	4960	3570	530
November	270	3040	1910	200
December	90	1770	1060	80

The reason why type 0 radiation factor has been chose is because the windows are located in the outside wall of the building. In the next figure [Figure 32] a schema of this window collocation can be found.

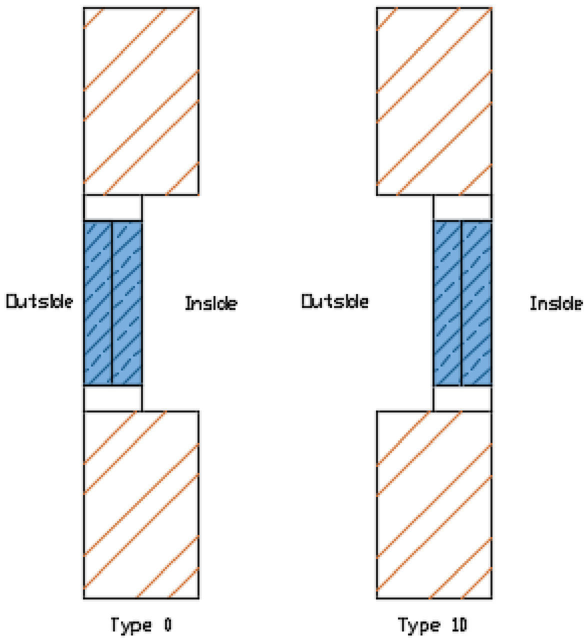

Figure 32: Possible location of the window in respect of the wall.

The next table [Table 12] shows the cloud factor for each month of the year.

Table 12: Cloud factor for Gävle (monthly value).

	Cloud factor
January	0.45
February	0.49
March	0.58
April	0.58
May	0.63
June	0.61
July	0.61
August	0.59
September	0.58
October	0.51
November	0.42
December	0.43

The next table [Table 13] shows the sun factor and area for the different type of windows.

Table 13: Sun factor and area of the different type of windows of the building.

Type	Area	Sun factor
2-pane (U=2.9)	81.38	0.8
Energy glass (U=1.3)	11.1	0.6
Strong glass (U=2.9)	24.56	0.4

Using the data provide above and eq. 3, the total sun irradiation is going to be calculated for the different wall orientations. In June, July, August and half of May and September the days have been stated to "0" since there is no need for heating input. The next tables show the calculated results.

Table 14: Sun irradiation for -120N wall.

Month	"-120 N" [Wh/m^{2}day]	Cloud factor [-]	Window Type 2-pane (U=4)		Days	Sun Irradiation [kWh]
			Area [m^2]	Sun Factor [-]		
January	160	0.45	12.8	0.8	31	22.86
February	640	0.49	12.8	0.8	28	89.92
March	1720	0.58	12.8	0.8	31	316.68
April	3320	0.58	12.8	0.8	30	591.54
May	4460	0.63	12.8	0.8	15.5	445.97
June	5230	0.61	12.8	0.8	0	0.00
July	4910	0.61	12.8	0.8	0	0.00
August	3720	0.59	12.8	0.8	0	0.00
September	2200	0.58	12.8	0.8	15	195.99
October	1010	0.51	12.8	0.8	31	163.51
November	270	0.42	12.8	0.8	30	34.84
December	90	0.43	12.8	0.8	31	12.28
					TOTAL	1873.59

Table 15: Sun irradiation for -30E wall.

Month	"-30 E" [Wh/m^{2}day]	Cloud factor [-]	Window Type: 2-pane (U=4) Area [m^2]	Window Type: 2-pane (U=4) Sun Factor [-]	Energy glass (U=0.6) Area [m^2]	Energy glass (U=0.6) Sun Factor [-]	Strong glass (U=6) Area [m^2]	Strong glass (U=6) Sun Factor [-]	Days	Sun Irradiation [kWh]
January	2360	0.45	55.5	0.8	11.1	0.6	21.06	0.4	31	1958.33
February	4280	0.49	55.5	0.8	11.1	0.6	21.06	0.4	28	3493.00
March	5740	0.58	55.5	0.8	11.1	0.6	21.06	0.4	31	6139.06
April	6370	0.58	55.5	0.8	11.1	0.6	21.06	0.4	30	6593.09
May	5980	0.63	55.5	0.8	11.1	0.6	21.06	0.4	15.5	3473.55
June	5820	0.61	55.5	0.8	11.1	0.6	21.06	0.4	0	0.00
July	5820	0.61	55.5	0.8	11.1	0.6	21.06	0.4	0	0.00
August	6070	0.59	55.5	0.8	11.1	0.6	21.06	0.4	0	0.00
September	5760	0.58	55.5	0.8	11.1	0.6	21.06	0.4	15	2980.86
October	4960	0.51	55.5	0.8	11.1	0.6	21.06	0.4	31	4664.59
November	3040	0.42	55.5	0.8	11.1	0.6	21.06	0.4	30	2278.48
December	1770	0.43	55.5	0.8	11.1	0.6	21.06	0.4	31	1403.47
									TOTAL	32984.43

Table 16: Sun irradiation for 60S wall.

Month	"60 S" [Wh/m^{2}day]	Cloud factor [-]	Window Type				Days	Sun Irradiation [kWh]
			2-pane (U=4)		Strong glass (U=6)			
			Area [m^2]	Sun Factor [-]	Area [m^2]	Sun Factor [-]		
January	1440	0.45	13.08	0.8	3.5	0.4	31	238.32
February	2900	0.49	13.08	0.8	3.5	0.4	28	472.04
March	4520	0.58	13.08	0.8	3.5	0.4	31	964.18
April	5850	0.58	13.08	0.8	3.5	0.4	30	1207.64
May	6150	0.63	13.08	0.8	3.5	0.4	15.5	712.49
June	6350	0.61	13.08	0.8	3.5	0.4	0	0.00
July	6280	0.61	13.08	0.8	3.5	0.4	0	0.00
August	5850	0.59	13.08	0.8	3.5	0.4	0	0.00
September	4820	0.58	13.08	0.8	3.5	0.4	15	497.50
October	3570	0.51	13.08	0.8	3.5	0.4	31	669.62
November	1910	0.42	13.08	0.8	3.5	0.4	30	285.52
December	1060	0.43	13.08	0.8	3.5	0.4	31	167.64
							TOTAL	5214.96

As it can be seen in the next table [Table 17] there are no windows in that side of the building.

Table 17: Sun irradiation for 150W wall.

Month	"150 W" [Wh/m^{2}day]	Cloud factor [-]	Window Type 2-pane (U=4) Area [m^2]	Sun Factor [-]	Days	Sun Irradiation [kWh]
January	130	0.45	0	0.8	31	0.00
February	370	0.49	0	0.8	28	0.00
March	900	0.58	0	0.8	31	0.00
April	1990	0.58	0	0.8	30	0.00
May	3050	0.63	0	0.8	15.5	0.00
June	3870	0.61	0	0.8	0	0.00
July	3510	0.61	0	0.8	0	0.00
August	2380	0.59	0	0.8	0	0.00
September	1230	0.58	0	0.8	15	0.00
October	530	0.51	0	0.8	31	0.00
November	200	0.42	0	0.8	30	0.00
December	80	0.43	0	0.8	31	0.00
					TOTAL	0.00

Appendix III: Data sheet of the ventilation system

Aggregates of the mechanical balanced ventilation system.

WOLF

Luftbehandlingsaggregat

Order O-14162 / 001

Kund	**Greiff Industrimiljö AB**
Projekt	Tunnplåt i Gävle AB
Vår handläggare	Kenneth Löf
Projektnummer	
Er handläggare	Kristjan Geirsson
Beteckning	TA/FA1
Antal	1
Aggregatstorlek tilluft	**KG Top 260**
Aggregatstorlek frånluft	**KG Top 260**
Prestanda	DIN EN 13053 02/2012
Värmeåtervinning	KVS
Luftmängd tilluft	5.69 m³/s
Luftmängd frånluft	5.69 m³/s
Aggregattyp	Till- och frånluft Liggande
Höljesvariant	50 mm
Lufthastighet	Tilluft:2.55 m/s Klass: V6
Lufthastighet	Frånluft:2.55 m/s Klass: V6

Tilluft:

(1) Påsfilter lång F7

Begynnelstryckfall	129	Pa
Dimensionerande tryckfall	164	Pa
Rekommenderat sluttryckfall	200	Pa
Filterarea	37.44	m²

filterkassett F7
Påsfilterramar,filterkassetter utdragbar
spjäll täthetsklass 2 enligt DIN EN 1751,Q utsida,1222 x 1832 / 13 Nm Vridmoment / axeldim 15 x 15 mm
För att undvika skador på spjällen använd motor med max drivmooment på max 20Nm
Inspektionsdörr

(2) KVS Batterivärmeväxlare tilluft (lång) Outside air

Luftvärmare typ	IV Cu/Al	LT
Anslutning (in-utlopp)	2 0/0 " (tum)	
Lufttemperatur in	-20.0	°C
Lufttemperatur ut	2.8	°C
Effekt (totalt)	179.8	kW
Mediatemp in	14.6	°C
Mediatemp. ut	-0.8	°C
Mediaflöde	11.70	m³/h
Frostskyddsprocent	34	%
Tryckfall luft	252	Pa
Tryckfall media	66.4	kPa
Temperaturverkningsgrad	0.46	
Lufthastighet	2.9	m/s
Mediavolym	84.0	l

Dränerings- och luftningsmuff,T-stycke 2 "
skena för uttagbarhet värmare

(3) Värmesektion Heating (from the paint oven.

Luftvärmare typ	1 Cu/Al LT	
Anslutning (in-utlopp)	1 1/2 " (tum) - 1 1/2 " (tum)	
Lufttemperatur in	0.0	°C
Lufttemperatur ut	20.0	°C
Effekt (totalt)	146.0	kW
Mediatemp in	100.0	°C
Mediatemp. ut	80.0	°C
Mediaflöde	6.47	m³/h

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WOLF

Frostskyddsprocent	0 %
Tryckfall luft	44 Pa
Tryckfall media	11.1 kPa
Lufthastighet	2.9 m/s
Mediavolym	13.7 l

Dränerings- och luftningsmuff,T-stycke 1 1/2 "
skena för uttagbarhet värmare

(4) Tomdel 407

(5) Fläkt, Axiradiell Fan.

Luftmängd	5.69 m³/s
Externt tryck	586 Pa
Pressung Ventilatorteil	52 Pa
Internt tryck	460 Pa
Dynamiskt tryck	136 Pa
Totalt tryck	1234 Pa
Fläktsektion	FE630C - 11 - 1500 IE2 RML
Fläkteffekt	8.79 kW
Fläktvarvtal	1850 1/min
Verkningsgrad	79.9 %
Frekvens vid nominell driftpunkt	63 Hz
Byggstorlek	160
Effekt	11.00 kW
Motorvarvtal	1470 1/min
Motorspänning	3*400 V
Motorström	21.00 A
Maxvarvtal vid frekvensomformardrift	1985 1/min
Maxfrekvens vid frekvensomformardrift	68 Hz
uppskattad eleffekt	**9.64 KW**
SFP enl. EN 13779	1.65 kW/(m³/s)
	0.458 W/(m³/h)
SFP Klass (EN 13779)	SFP4
P-Klass (EN 13053)	P1

Nach EU-Verordnung Nr. 327/2011, gestützt auf die Richtlinie 2009/125/EC übertrifft die erreichte Gesamteffizienz der Ventilator-Motor-Einheit die ErP Stufe 2015
Tryckuttag för flödesmätning, utsida aggregat
Skyddsgaller för dörr
Motorskydd,Termisk brytare
Inspektionsdörr ,Inspektionsdörr på trycksidan

Frånluft:

(6) Påsfilter lång F5

Begynnelstryckfall	64 Pa
Dimensionerande tryckfall	132 Pa
Rekommenderat sluttryckfall	200 Pa
Filterarea	29.16 m²

filterkassett F5
Påsfilterramar,filterkassetter utdragbar
utan anslutning (öppen)
Inspektionsdörr

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WOLF

(7) KVS Batterivärmeväxlare frånluft (lång)

Luftvärmare typ	IV Cu/Al	LT
Anslutning (In/Ut)	2 0/0 " (tum)	
Lufttemperatur in	30.0	°C
Relativ fukt	50.0	%
Lufttemperatur ut	13.7	°C
Relativ fukt	87.7	%
Effekt (totalt)	-179.8	kW
Tryckfall (droppavskiljare)	32	Pa
Tryckfall luft	229	Pa
Mediatemp in	-0.8	°C
Mediatemp. ut	14.6	°C
Mediaflöde	11.70	m³/h
Frostskyddsprocent	34	%
Tryckfall media	66.4	kPa
Temperaturverkningsgrad	0.46	
Lufthastighet	2.9	m/s
Mediavolym	84.0	l

Dränerings- och luftningsmuff,T-stycke 2 "
Glidskenor
Droppavskiljare,Droppavskiljare, plast (PP),T 400
Glidskenor
Dräneringstråg 1908 KGT
Dräneringsmuff: 1 1/4 " (tum)
utan anslutning (öppen)

(8) Tomdel 407

(9) Fläkt, Axiradiell

Luftmängd	5.69	m³/s
Externt tryck	586	Pa
Pressung Ventilatorteil	52	Pa
Internt tryck	393	Pa
Dynamiskt tryck	136	Pa
Totalt tryck	1167	Pa
Fläktsektion	FE630C - 11 - 1500 IE2 RML	
Fläkteffekt	8.36	kW
Fläktvarvtal	1827	1/min
Verkningsgrad	79.5	%
Frekvens vid nominell driftpunkt	62	Hz
Byggstorlek	160	
Effekt	11.00	kW
Motorvarvtal	1470	1/min
Motorspänning	3*400	V
Motorström	21.00	A
Maxvarvtal vid frekvensomformardrift	1985	1/min
Maxfrekvens vid frekvensomformardrift	68	Hz
uppskattad eleffekt	**9.15**	**KW**
SFP enl. EN 13779	1.53	kW/(m³/s)
	0.424	W/(m³/h)
SFP Klass (EN 13779)	SFP4	
P-Klass (EN 13053)	P1	

Nach EU-Verordnung Nr. 327/2011, gestützt auf die Richtlinie 2009/125/EC übertrifft die erreichte Gesamteffizienz der Ventilator-Motor-Einheit die ErP Stufe 2015
Tryckuttag för flödesmätning, utsida aggregat
Skyddsgaller för dörr
Motorskydd,Termisk brytare
Inspektionsdörr ,Inspektionsdörr på trycksidan

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