Factory energy consumption and energy improvement recommendations

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Sammandrag:

Detta slutarbete är ett beställningsarbete från Engel Austria GmbH. Engel planerar göra energiinbesparingar åtgärder på fabriksorten i St.Valentin och ville utreda hur den sammanlagda energiförbrukningen fördelas. Utöver det, skulle de årliga kostnaderna för samtliga byggnadstekniska installationer beräknas. Baserat på detta kan en årlig energibesparningspotetial beräknas. Arbetet belyser hur distributionen är fördelad i dom befintliga systemen- dvs, ventilation, belysning, uppvärmning samt nedkylning. För varje byggnads tekniska system finns det beräkningar hur mycket moderniserande av diverse system skulle kosta, samt årliga potentiella besparingar jämfört med det befintliga läget. Den årliga elförbrukningen i fabriken är 23 202 MWh, varav 25 % (5 800 MWh) används av byggnadstekniska system. Målet är att reducera den årliga elförbrukningen för byggnadsteknik med 5% av den totala elanvändningen, motsvarande 20% av byggnadsteknikens specifika konsumtion, dvs en årlig minskning på 1 160 MWh

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Abstract:

This degree thesis is commissioned by Engel Austria GmbH. Engel is planning reduce energy consumption in their factory in St. Valentin, and therefore needs more detailed information regarding how the energy consumption is currently distributed. The thesis also studies the annual cost for specific building technology systems, as well as the energy savings potential. It is important to analyze how the energy consumption is distributed in the different building technology system. Namely, ventilation, lighting, heating and cooling. For each building technology system, there are calculations on how much an update of various systems would cost, as well as the savings of the systems. The annual electricity consumption in the factory is 23 202 MWh, of which 25 % (5 800 MWh) is used in building technology systems. The target is to reduce the annual electricity consumption of building technology systems by 5 % of total electricity usage, i.e. an annual decrease on 1 160 MWh. This corresponds to 20% savings on current building technology systems' annual energy consumption.

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Yhteenveto:

Tämä opinnäytetyö on tilaustyö Engel Austria GmbH:lta. Engel suunnittelee energiasäästöjä tehtallaan St. Valentinissa, ja haluaa analysoitavan miten energiankulutus jakautuu eri taloteknisten järjestelmien kesken. Eriteltävänä on myös talotekniikan vuosittainen sähkön kulutus ja mahdolliset säästämismahdollisuudet. Työ analysoi sähkönkulutuksen hajautumista taloteknisissä järjestelmissä, eli ilmanvaihdossa, valaistuksessa, lämmitys- ja jäähdytysjärjestelmissä. Jokaisessa taloteknisessä järjestelmässä on laskelmia siitä, kuinka paljon eri järjestelmien päivitys maksaa, sekä uusien järjestelmien mahdolliset säästöt. Tehtaan vuosittainen sähkönkulutus on 23 202 MWh, josta 25% (5 800 MWh) on tarkoitettu talotekniikkajärjestelmille. Tavoitteena on vähentää taloteknisten järjestelmien vuosittaista energiankulutusta viidellä prosentilla tehtaan kokonaiskulutuksesta, vastaten 20% talotekniikan osuudesta, vuosittainen energiansäästön ollen tuolloin 1 160 MWh.

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1 JOBB TASK AND AIMS

The aim is to reduce the energy consumption for base load system and sustaining comfortable working conditions in the facility. The facility consists mainly of factory area, but also has office spaces.

The information provided, is that the base load (ventilation, lighting and cooling) energy use is 25% of the total electricity consumption. The aim is to have the electricity for the building service systems reduced to below 20% of the total energy consumption.

In the year 2015 Engel St.Valentin used 23 202MWh. Of that, 25% or 5 800MWh was used for building service systems. The aim is to get the base power consumption down to 4 640MWh, which equals a 1 160 MWh reduction in building technology systems electricity usage.

The factory consists of six different parts that all have been built in different stages, the oldest being from the year 1987. All the halls are constructed a bit differently from each other, which means that all proposed solutions will differ for each area.

Since exact electricity consumption distribution information was not available, the calculations are theoretical and based on estimates.

2 ENERGY CONSUMPTION

There has been a steady increase in power usage since 2005. With an estimated cost of 105€/MWh , the years from 2005-2015 would look close to the table below. [1]

Table 1 Overview of annual energy consumption

Year	Energy, MWh	€
2005	17 375	1 824 375
2006	16 120	1 692 600
2007	17 175	1 803 375
2008	17 010	1 786 050
2009	14 040	1 474 200

2010	18 460	1 938 300
2011	21 100	2 215 500
2012	21 650	2 273 250
2013	13 940	1 463 700
2015	23 200	2 436 000

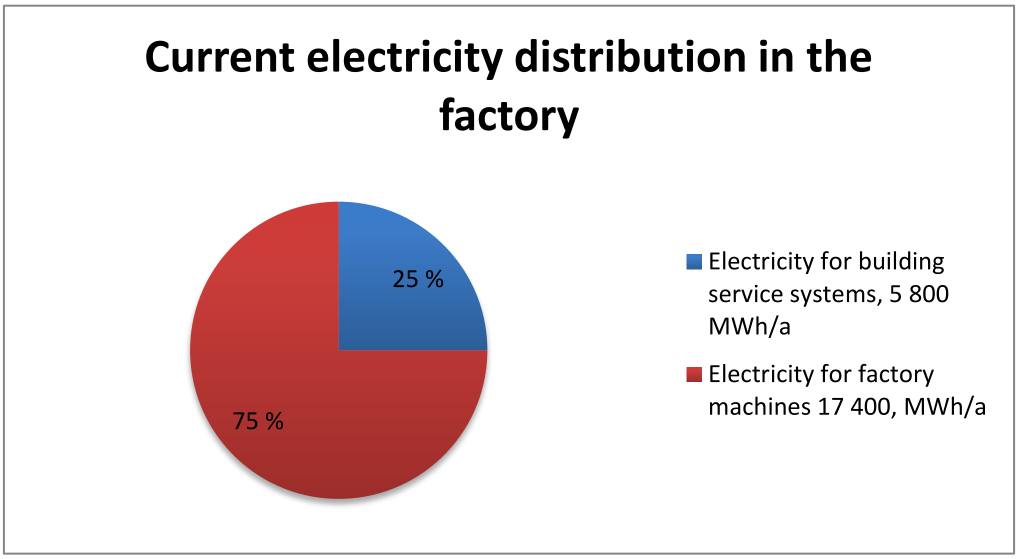

Figure 1 Current electricity distribution in the factory

Now, the total electricity consumption for base load is 5 800 MWh, and spread over 51 275 m² equaling to 113 kWh/m². The target is to lower the annual energy use to 4 640 MWh or to 90 kWh/m².

A major part of the heating is from the district heating network, as well as from the heat load that the factory's production machines are generating.

The electricity usage can further be divided with in the building service systems to their own functional groups.

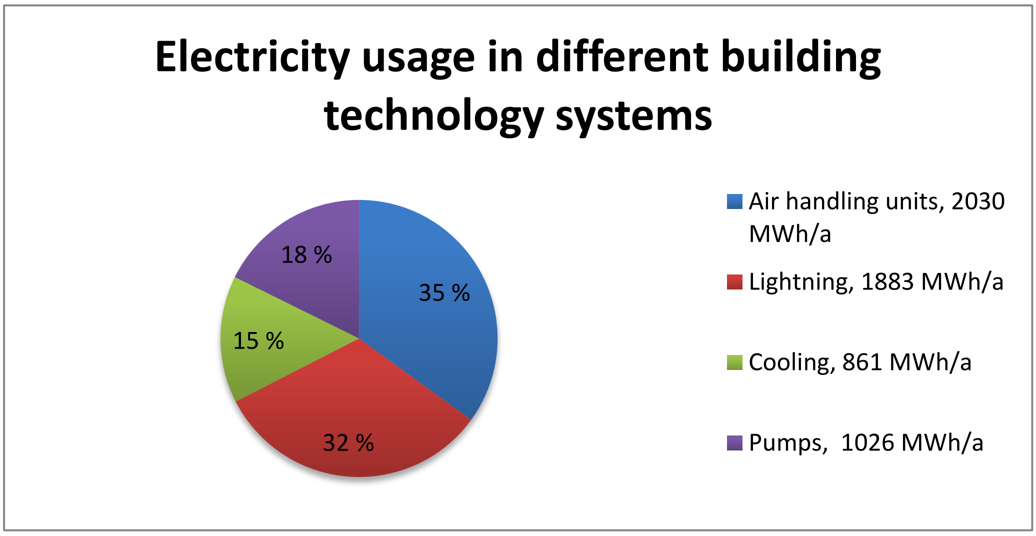

Figure2 Electricity usage in different building technology systems

Heating demand is not included in this thesis, as relevant data for district heating was not available.

In later chapters, different solutions for heating and heat loss minimization are discussed.

The calculations with electricity prices are based on Austrian electricity cost in year 2016, which is 0,105 €/kWh of which 0,025 €/kWh is network cost and 0,032 €/kWh is taxes and levies. District heating prices are 0,056 €/kWh Transmission fees and taxes was not available

3 VENTILATION

The air distribution system has the important part of making the indoor environment as thermally comfortable as possible, to achieve the highest productivity from. A successful air distribution, air exchange and a ventilation system goes without notice. Meaning that there is no feeling of draft, the temperature stays the same and that the noise from the ventilation system stays within set values.

In planning ventilation for different areas, the area specific demands should be taken in consideration, so that the values used for planning gives as high efficiency as possible. [2]

3.1 Ducts, air terminal devices and air distribution

Currently the air terminal units are mainly equipped with connection boxes, which give the possibility to adjust the air flow and to even out the air flow so that the air terminal units can work at their optimal capacity.

When planning ventilation for a specific area, it is worth making the system as adaptable as possible for future area purpose changes. This will limit the amount of installation work that must be done, if the purpose of the area is changed. Below is a list of things to consider for each area.

-The target room condition (room temperature, the maximum air flow and air quality)

-Room dimensions (width, length and height)

-Heat loads and their location

-The sources of impurities

-Heat losses; especially windows and doors

-The needed pressurization in the surrounding areas

-Total air flow

Most of the existing air terminal units are from when the factory first was built in 1987. The newest units are from 1990. Since majority of the equipment is from 1987, the calculations are done with the year 1987. This means that the understanding of different ventilation units and technology development have developed quite a bit.

The pictures below demonstrate that difference. To the left is an air terminal unit that is from 1987, which is designed to distribute air in different directions. The picture to the right is an example of a modern air terminal unit, which is designed to give maximum coverage while still giving a smooth airflow. [3]

Figure 3 Existing air diffuser

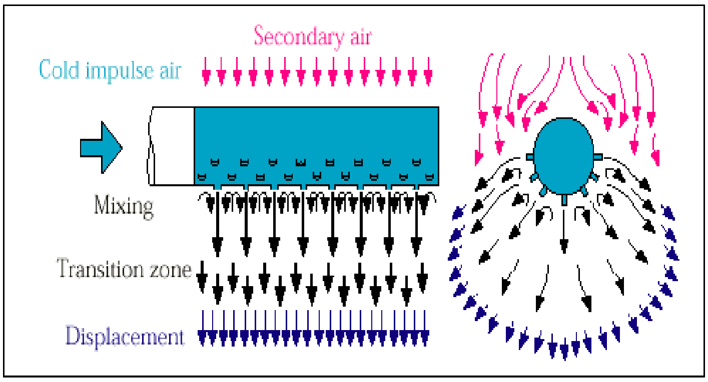

Figure 4 Schematics over how the cold impulse work

A modern perforated duct can provide correct supply of air flow exactly where it is desired. Cold air impulses are mixed with ambient temperature in a short turbulence zone. And this results in a smooth air distribution with the optimum flow for thermal air displacement.

The more modern air diffusers have a more efficient way of adjusting the airflows to gain optimal airflow. A perforated air diffuser as seen above to the right will ensure optimal efficiency.

3.2 Demand controlled ventilations systems

The principle of demand controlled ventilation is to optimize air flow and pressure drop. It has the potential to lower energy consumption by over 30-70% in a facility, depending on the situation. However, demand controlled ventilation is best suited for areas where the “demand” varies a lot. Demand controlled ventilation system solution offers system parts that are calibrated to fit a new system or existing one. It communicates between a central computer, air handling unit and dampers via a control unit. It does real time adjustments on connected dampers and/or and units to optimize the position and balancing the whole system. The fans themselves are not able to react as quick and constant rpm changing leads to more energy consumption, quick reaction by the automation system means that the air handling units does not worn out as much. In addition to lowering pressure drops, it makes the unit quieter. [4]

3.3 AC-motors & EC-integral motors

A clear majority of older asynchronous motors (AC-motors) use a pulley system.

A normal AC-motor is powered by AC-current that causes variations in the magnetic field in the motor that makes the rotor turn in relation to the stator.

A part of the input energy dissipates as heat in form of friction from the pulley drive.

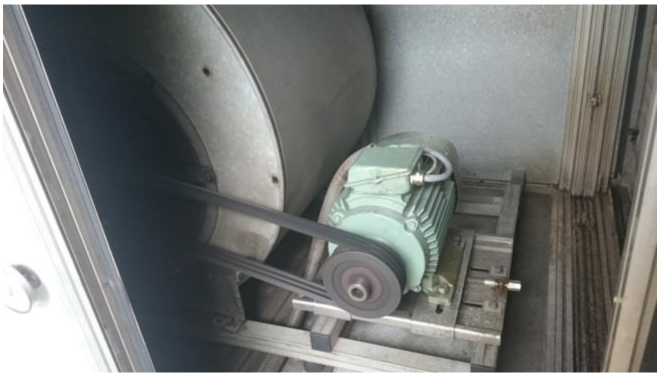

Figure 5 AC motor with a pulley system at Engel

An easy solution is to change the motors that are AC-powered with a pulley, to brushless motors (EC-integral motors) with direct drive.

EC-integral motors have permanent magnets that create a magnetic field and DC to create rotation. This construction means that a bigger part of the input energy creates rotation and a smaller part dissipates as heat, which in turn leads to higher motor efficiency.

The EC-integral motors have a higher motor efficiency and are more consistent over the whole rpm field 10-100%. [4]

Currently the motors that handle’s the ventilation, have a combined nominal power of 676, 9 kW.

Since the oldest ones are almost 30 years old, the time is advantageous to change the old motors to newer EC-integral motors.

Below is a chart that compares the AC and EC motors input power at any given rpm.

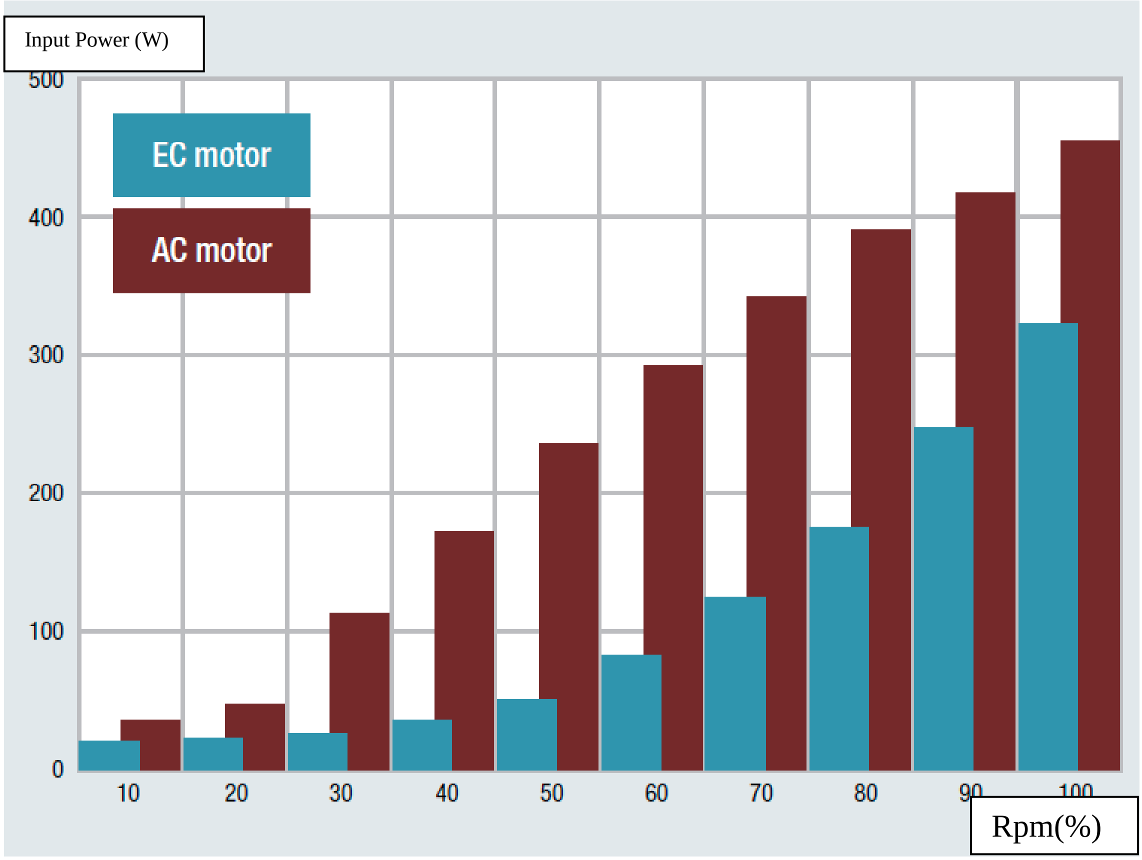

Figure 6 AC and EC motor comparison [4]

As shown in the graph above, the general energy needed for EC-motors are substantially lower, than for AC-motors. Thou, the chart is showing the difference between a 500 W AC and EC motor, the same relation persists when scaled up.

If we estimate that the motors are running in operation 5000h/annually, and that they operate at an average 60% of their total capacity, and if EC motors are 30% more energy efficient than AC motors. The installed fans have a total combined power of 677 kW. By using EC motors, with a 30 % reduction of the AC-motors total capacity, the value would be 473 kW. Using 105 €/MWh, we get the result in the table below.

Table 2 AC versus EC comparison

Motor	Power, (kW)	Time on,(h/a)	%	MWh/a	€/a
AC	677	5000	60%	2 030	213 150 €
EC	473	5000	60%	1 540	161 700 €

The annual potential reduction is 490 MWh, which results in savings of 51 450€. Estimated replacement cost for one motor (installation not included) is 6 650€, and replacing every motor makes an approximated total investment cost of 272 650 €.
With yearly savings of an estimated 51 450€, it puts the payback time at 5,3 years.

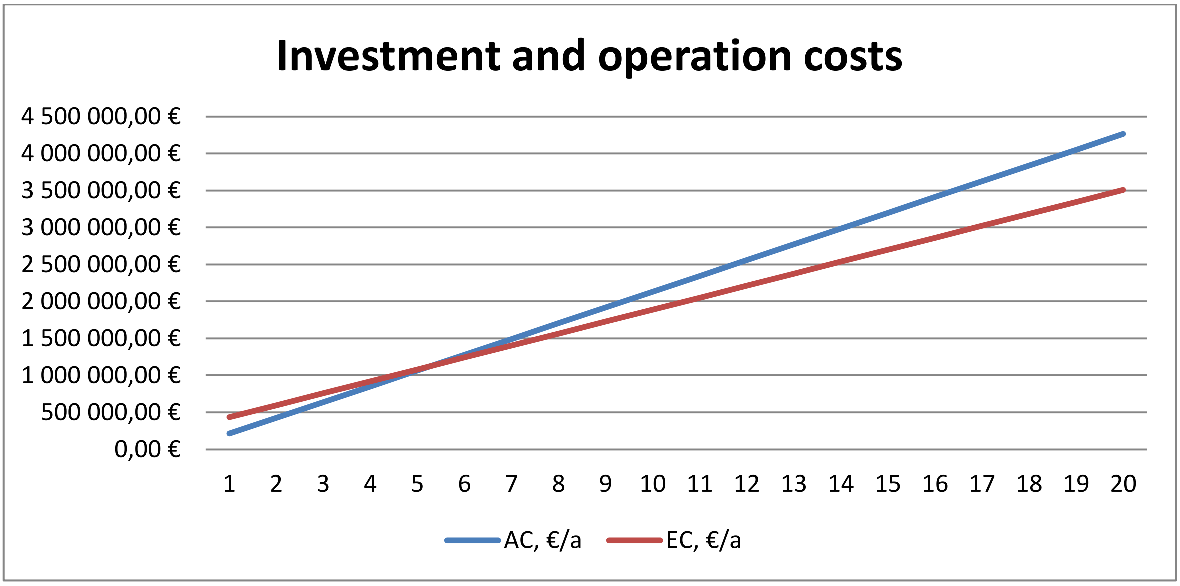

Figure 7 Investment and operation costs

The figure above shows the difference between AC and EC motors over a 20-year period. Even if the EC motors have a higher initial cost, the annual savings makes the investment cost worth it due to its payback time.

3.4 New air handling units

Ventilation causes a huge energy need in facilities, due to the demand of good indoor climate.
The heat loss via ventilation is dependent on the air-change ratio.
When dimensioning the airflow, either the floor area is used as a reference point, or number of persons occupying the respective area at any given time.
Per Finland's building code D2, the airflow is under normal conditions between 1-5 (l/s)/m² or 6-15 l/s per person. The airflow can be higher in special cases.
The air change rate for any given area should be more than 0,5 times the area's air volume per hour. [5]

The heat loss caused by ventilation can be calculated with the following formula. [6]

$$Hiv = \rho i * \text{Cpi} * \text{q}v, \text{poisto} * td * tv\ (1 - \eta a)$$

where

H_{iv}	specific heat loss due to ventilation, W/K
ρi	air density, 1,2 kg/m³
C_{pi}	air specific heat capacity, 1000 Ws/(kgK)
$q_{v,poisto}$	calculated exhaust air in normal use, m³/s
t_d	average time the air handling unit is in operation per day, h/24
t_v	time the air handling unit is operating per week, days/ 7 days
η_a	yearly efficiency for heat recovery from exhaust air, the relation between the energy that is recovered with heat recovery unit annually and the energy that is needed to heat the ventilation air when no heat is recovered.

3.5 Fans

The fans have a significant role in the power consumption. The electricity for a fan or the air handling unit is calculated with specific electricity, air flow and the operation time with the formula below [7]

$$W\ air\ exchange = \sum SFP *\ qv *\ \Delta t + W\ iv, muu$$

$W_{air\ exchange}$	Energy consumption
SFP	The air handling unit's specific energy consumption, kW/(m³/s)
q_v	The fans or the air handling unit's airflow, m³/s
Δt	The air handling unit's operation time during calculation period, h
$W_{iv,\ muu}$	Other energy consumption, kWh

Demand controlled ventilations effect is calculated separately. Per Finland's building code, the ventilation system should be designed so that the unit's specific energy consumption does not go above the value of 2 kW/ (m³/s) for fan driven supply air, and exhaust air and 1 kW/(m³/s) for mechanical exhaust air.

Specific fan power for the whole ventilation system is the sum of all the fans consumed electricity in kW, divided with the planned supply and exhaust air flow m³/s. [8]

$$SFP = \frac{Psupply\ fan. + P\ exhaust\ fan.}{qmax}$$

SFP	The fans or the air handling unit's specific electricity consumption, kW/(m³/s)
$P_{supply\ fan.}$	The power for the supply air fan or air handling unit with power adjustment device, kW
$P_{exhaust\ fan.}$	The power for the exhaust air fan or air handling unit with power adjustment device, kW
q_{max}	The fans or the air handling unit's airflow, m³/s

The electricity consumption consists of the electricity that is consumed by all fans and any accessories, such as pumps. In case the ideal fan power cannot be seen from blueprints or from inspection, the values given in the table below is to be used.

Table 3 Ventilation associated demand for electric power

Ventilationsystem	**-2012**	**2012-**
Natural ventilation	0,0 kW/m³/s	0,0 kW/m³/s
Fan controlled exhaust air	1,5 kW/m³/s	1,0 kW/m³/s
Fan driven supply-/exhaust air	2,5 kW/m³/s	2,0 kW/m³/s

The energy consumption in a single air handling unit, or process, can be noticed in the enthalpy's change over time. [9]

$$Qp = (\Sigma\, qm) * (h2 - h1) * \Delta t$$

Q_p The amount of heat needed during the process, kWh

q_m The mass flow, dry air, kg/s

h_1 The entering air enthalpy, kj/kg

h_2 The leaving air's enthalpy, kj/kg

Δ_t Change in time, h.

When the electricity consumption of the process is calculated, it can be divided in to three energy categories. Electricity needed for the air handling unit (the fans), energy needed for heating and energy needed for cooling.
Energy consumption is the amount of energy the supply system must produce to order to achieve the desired effect and outcome.

The purchased energy is the energy that is, for example, bought from the electrical network, district heating network, district cooling network and the energy contained in renewable or fossil fuel.

To calculate the cooling need for ventilation, the COP (coefficient of performance) must be calculated. The formula takes in consideration all cooling appliances electrical consumption, not only the compressors electricity need. The formula is: [10]

$$COP = \frac{Qc}{\sum Pi}$$

Qc Cooling power (evaporator's power), W

$\sum P_i$ Total consumed power

3.6 Energy calculation for new air handling units

The facility has 33 air handling units with a capacity with at least 5 m³/s. Several these are original that have been modernized with a frequency converter. Since the machines are added as the different factory parts have been built, the gap between the age of the units are not that great, even if all the units are old. Of the 33 air handling units, 21 are from 1987, the rest are added over the course of 3 years. The systems are either without or with inefficient heat recovery.

The options are, to either keep using the system as it is, change the fan and the motor or change the air handling units all together.

The values used in calculations are founded on the values of air density of 1,2 kg/m³, indoor temperature of 22°C , -and as the air handling units are set to blow in 18°C air. The air handling units are approximately on 4 000h/a.

The heat recovery is calculated with 80%, and the pressure raise is calculated with 830 Pa.

The heating coefficient used for calculating the new AHUs values, is 0,5.

The following part will use the formulas from earlier, to calculate the different options.

The calculations will be founded on the heating degree day value of value of 3 300 Kd which is the value measured at the nearly located airport in Linz from the last year. [11]

3.6.1 Existing air handling units

The air handling units that have a airflow of 8,3 m³/s, the majority are from 1987. The fan efficiency is expected to be 55,1% and the fans are expected to have a SFP value of 1,74 kW/(m³/s).

Electricity

To calculate the power needed for one air handling unit we use the following calculation:

$$Pel = \frac{qv * \Delta Pfan}{\eta}$$

$$\frac{8{,}3\,\frac{m^3}{s} * 0{,}83\ kPa}{55{,}1\%} = 12{,}5\ kW$$

Pel	The electrical power supplied from the mains, kW

qv	Volume flow rate, m³/s

$\Delta Pfan$ Pressure drop occurred in the AHU, kPa

η	Overall efficiency of the fan, motor and drives

Calculating the annual energy need for the AHU motor with the following formula:

$$Eel/a = \frac{\frac{qv * Pa * h}{\eta}}{1\,000\,000}$$

Adding the numbers from earlier, the calculation gives the result:

$$\frac{\frac{8{,}3m^3}{s} * 830\ Pa * 4\ 069\ h}{\frac{55{,}1\%}{1\,000\,000}} = 50{,}9\ MWh/a$$

The annual electrical consumption is 50 MWh/a [11]

Heating

Once the electricity for the fan is known, the heating of the supply air is calculated for each hour of the year when the temperature is under 17°C, i.e. the air temperature difference between the outside air temperature and the wanted supply air temperature, divided by number of hours per day.

Take for example the coldest outside temperature, which is -19,9°C, the ΔT is 36,9°C. The formula for calculating the heat need is:

$$Pheating = (\Delta T * qv * \rho * Cp) - P\text{el}$$

Calculating the heating power needed for the coldest hour:

$$\left(36{,}9°C * 8{,}3\frac{m^3}{s} * 1{,}2\frac{Kg}{m^3} * 1{,}006\frac{Kj}{Kg} * K\right) - 12{,}5\text{ kW} = 357{,}2\text{ kW}$$

ρ	Density of air, kg/m³

Cp Specific heat, KJ/Kg*K

Calculating for the coldest hour of the year which was -19,9 °C, the calculation takes every degree that is below 17°C and subtracts the outside temperature, and divides it with hours a day, 24. For the coldest hour, the calculation looks like;

$$\frac{17°C - (-19{,}9°C)}{24} = 1{,}53°C$$

The annual heating need is 365 MWh/a.

Cooling

Calculating the cooling need can be done with the same formula as with heating, with the small adjustment of calculating every hour when the temperature is over 17 °C, and adding the adding the motor to the heat load.

Considering the heat load that occurs in the AHU, the following formula is used:

$$\frac{P}{qv * \rho * Cp} = T\ ahu$$

$$\frac{12{,}5\ kW}{8{,}3\frac{m^3}{s} * 1{,}2\frac{Kg}{m^3} * 1{,}005\frac{Kj}{Kg} * K} = 1{,}25°C$$

The warmest day, it was 31, 36°C and adding T ahu, gives an ΔT of 15,61°C.

$$Pcooling = \left((\Delta T) * Q * \rho * Cp\right) + P\text{el}$$

Calculating the heating power needed for the warmest hour:

$$\left(15{,}61\ °C * 8{,}3\frac{m^3}{s} * 1{,}2\frac{Kg}{m^3} * 1{,}006\frac{Kj}{Kg} * K\right) + 12{,}5\ \text{kW} = 168\ \text{kW}$$

Calculating for the warmest hour of the year which was 31,36°C. The calculation takes every degree that is above 17°C and subtracts the it from the outside temperature, and divides it with hours a day, 24. For the warmest hour, the calculation looks like;

$$\frac{17°C - 31{,}36°C}{24} = -0{,}598°C$$

Doing so for each hour of the year the system is on, gives an annual heating need of 55,4 MWh/a.

By using a COP value of 3,0 the annual cooling need can be calculated $\frac{Pcooling}{COP} = Pel$ which gives the electricity needed to achieve the cooling needed:

$$\frac{55{,}4\ MWh/a}{3{,}0} = 18{,}46\ MWh/a$$

Table 4 Energy consumption of current AHU system, per unit

Energy category	Power, kW	Energy, MWh/a	Annual cost, €/a
Electricity	12,5	50	5 250
Heat	360	360	20 440
Cooling	170	18,5	1 945
Sum:			**27 635 €/a**

3.6.2 New units

A modern air handling unit from 2017 with an airflow of 8, 3 m³/s, is expected to have a fan with an efficiency of 72, 6% and a SFP value of 1, 38 kW/(m³/s).

Electricity, new AHU

Using the same formulas as with the existing system, the calculation would look like the following:

$$Pel = \frac{qv * \Delta Pfan}{\eta}$$

And adding the values:

$$\frac{8{,}3\,\frac{m^3}{s} * 0{,}83\ kPa}{72{,}6\%} = 9{,}48\ kW$$

Calculating the annual energy need for the AHU motor with the following formula:

$$Eel/a = \frac{\frac{qv * Pa * h}{\eta}}{1\ 000\ 000}$$

Adding the numbers from earlier, the calculation gives the result:

$$\frac{\frac{8{,}3m^3}{s} * 830\ Pa * 4\ 069\ h}{\frac{72{,}6\%}{1\ 000\ 000}} = 38{,}6\ \ MWh/a$$

Heating, new AHU

Since the new AHU system has heat recovery, this section takes into account that 80% of the supply air is already heated exhaust air.

In order to calculate the heating need of a new AHU, the new theoretical exhaust air is to be calculated:

$$Tex = -\eta\ h.rec * \left(\frac{qv\ new}{qv\ old}\right) * (Tin - Tout) + Tin$$

η h.rec Heat recovery, %

Calculating for the coldest hour with -19,9 °C:

$$-0{,}8\% * \left(\frac{6{,}64\frac{m^3}{s}}{8{,}3\frac{m^3}{s}}\right) * \big(22℃ - (-19{,}9℃)\big) + 22℃ = -4{,}8\ ℃$$

The next step is to calculate the theoretical supply air after the AHU.

$$Tsu = (Tex * Heating\ coefficient) + \left(\eta\ h.rec * \left(\frac{qv\ new}{qv\ old}\right)\right) * (Tin.room - Tout) + Tout$$

Adding the values gives:

$$(-4{,}8\ ℃ * 0{,}5) + (0{,}8\ \% * \left(\frac{6{,}64\frac{m^3}{s}}{8{,}3\frac{m^3}{s}}\right) + \big(18℃ - (-19{,}9℃)\big) + (-19{,}9℃) = 3℃$$

The air after the AHU is 3°C. Since the target indoor temperature is 18°C, it means that 15°C is to be heated with other means. To calculate the energy needed to heat the air to its desired temperature, the same formula is used as when calculating heating need for the existing units. The ΔT of 15°C is used:

$$\left(15°C * 8{,}3\frac{m^3}{s} * 1{,}2\frac{Kg}{m^3} * 1{,}006\frac{Kj}{Kg}\right) - 9{,}48\text{kW} \; = \; 140 \text{ kW}$$

Calculating for the coldest hour of the year which was -19,9 °C, the calculation takes every degree that is below 17°C and subtracts the outside temperature, and divides it with hours a day, 24. For the coldest hour, the calculation looks like;

$$\frac{17℃ - (-19{,}9℃)}{24} = 1{,}53℃$$

Doing so for each hour the system is on, gives an annual heating need of 65 MWh/a.

Cooling

Calculating the cooling need can be done with the same formula as with heating, with the small adjustment of calculating every hour when the temperature is over 17 °C, and adding the adding the motor to the heat load.

Taking into account the heat load that occurs in the AHU, the following formula is used:

$$\frac{Pfan}{qv * \rho * Cp} = T\ ahu$$

$$\frac{9{,}48\ kW}{8{,}3\frac{m^3}{s} * 1{,}2\frac{Kg}{m^3} * 1{,}005\frac{KJ}{Kg} * K} = 0{,}95℃$$

The warmest day, it was 31,36°C and adding T ahu, gives an ΔT of 15,31°C.

$$Pcooling = (\Delta T * Q * \rho * Cp) + P\text{el}$$

Calculating the power required for achieving the cooling needed:

$$\left(15{,}31℃ * 8{,}3\frac{m^3}{s} * 1{,}2\frac{Kg}{m^3} * 1{,}005\frac{Kj}{Kg}\right) + 12{,}5 \text{ kW} = 153{,}25 \text{ kW}$$

Calculating for every hour when the outside air temperature is over 17 °C, gives an annual cooling need of 52,4MWh/a. By using a COP value of 3,0 the annual cooling need can be calculated $\frac{Pcooling}{COP} = Pel$ which gives the electricity needed to achieve the cooling needed:

$$\frac{52{,}4\ MWh/a}{3{,}0} = 17{,}5\ MWh/$$

Table 5 Energy consumption for new AHU system, per unit

Energy category	Power, kW	Energy, MWh/a	Annual cost, €/a
Electricity	9,5	40	4 200
Heat	140	65	3 640
Cooling	155	17,5	1 840
Sum:			**9 680 €/a**

3.6.3 The difference between existing and replacement units

The difference on an annual level per unit would be: annual energy savings obtainable with modernized ventilation system

Table 6 Energy savings, per unit

Energy category	Energy, MWh/a	Annual savings, €/a
Electricity	10	1 050
Heat	295	16 500
Cooling	1	105
Sum:	**306 MWh/a**	**17 655 €/a**

That means that one new unit, compared to an existing air handling unit, would annually save 17 655 €/a.If all the existing 21 air handling units were changed to modern ones, the estimated result would be:

Table 7 Total saving potential

Energy category	Energy, MWh/a	Annual savings, €/a
Electricity	210	22 050
Heat	6 200	347 000
Cooling	20	1 500
Sum:	**6 430 MWh/a**	**463 050 €/a**

Estimating that one new air handling unit costs around 60 000€, it would mean that 21 new units would be an estimated 1, 22 million €. Having an estimated annual saving of 463 050 €, would mean that the pay-back time would be 2,6 years.

3.7 Conclusion

Below is a comparison of the different options.

Table 8 Comparison between different options

	Changing motor + fan	New air handling units
Investment	272 650 €	1,22 million €
Annual savings	490 MWh	6 430 MWh
Annual savings	51 450 €	463 050 €
Payback time	5,3 Years	2,6 Years

The investment and time to install a new fan and motor is much faster than having to install a new air handling unit. By installing new air handling units, a rearrangement of the exciting ductwork is needed to get the system as optimized as possible

By investing in new air handling units, the annual energy savings would by more than then times higher and would pay itself back in half the time.

Noteworthy is that by converting the existing ventilation system to a system with heat recovery, the factory's own heat load can produce the necessary heat needed in the winter.

Since the AHU are near their end of the lifecycle, the preferred option would be to change the AHU than replacing the existing fans and motors.

4 COOLING AND HEATING

A facility that has a volume of 667 967, 5 m³ need a system that provides cooling and heating. Since the temperature can vary from -15°C to +35 °C, the cooling and heating powers needed to reach target indoor climate can at times be very high.

One way to provide the facility with cooling in the summer and potentially heating in the winter would be with geothermal. The soil at the location is unknown, which means that an exact calculation is not possible.

4.1 Geothermal

Geothermal energy would be an optimal source for providing heating and cooling, since it has a very low annual operating cost, whilst being able to provide constant cooling or heating effect around the year. And since the wells can be operated for many decades, it is one of the most long lasting systems that have a very low annual operating cost. It is also can be a very flexible system. The idea of geothermal power is that the earth is at a constant temperature of 6-8 °C (depending on soil). It gives the ideal opportunity to have a cooling circuit in the summer and a heating circuit in the winter. [12] [13][14]

The chart below shows monthly day degree days. The blue area indicates months when heating is needed and red indicates a month when cooling is needed.

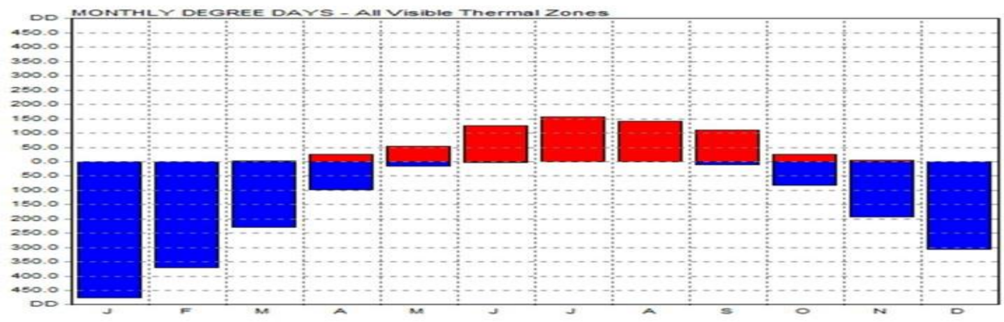

Figure 8 Heating and cooling demand during the year[15]

4.1.1 Cooling

Cooling of the facility is needed for about 5 month of the year, and at its peak the indoor climate must be cooled down by 15 °C. The cooling need is mainly from the factory's own heat load.

Now, the facility has 4 cooling machines installed, which has a combined cooling power of 4 150 kW and a power consumption of 1 160 kW. Which means for each input kW it produces 3,6 kW cooling power. Since the property has limited space and the wells should be placed a minimum of 15 m of each other, the number of wells that estimated that could fit is 35 wells

As stated, the soil at the location is unknown; an estimated theoretical value of 44 W/m is used in the calculations. This means, that for every meter drilled, the geothermal system can provide 44 W cooling power. Calculating with 300 m well, would mean that, one well has the capacity (44W/m *300 m=) 13,2 kW. Estimating that the max well capacity at the premises is 35 wells, which would make the total cooling effect of the wells at 462 kW.

Calculating with a simultaneity factor of 75% and hours of top effect 1 000h, we get that it produces an estimated 460 MWh of cooling energy.

The soil circuit is calculated to have a ΔT of 4 °C on the return and supply line.

To calculate the effect of the pump needed to the system, the flow in the system is to be calculated. For the calculations, the value of water is used:

$$qv = \frac{Pgeo}{(\Delta T * Cp * \rho) * 1000}$$

$$\frac{630\ kW}{\left(4°C * 4{,}18\frac{KJ}{Kg} * k * 1000\frac{Kg}{m^3}\right) * 1000} = 37{,}7\ dm^3/s$$

It is estimated that the system has a drop of 800 kPa, and the motor to have an effect of 45 kW. Calculating with an on time of 1000h/a, the energy needed for the pump would be 45 MWh/a.The annual electricity for the pump would be 3 240€.

Having 35 wells with 300 m per well, gives a total length of 10 500 m, that must be drilled. Given an estimation that drilling one meter costs 25 €, with provided pipe, the total investment for the infrastructure would be:

$$10\ 500m * \frac{25€}{m} = 262\ 500\ €$$

Addition to the wells, a conveyor is needed, and is estimated to cost 21 000€.

The total investment for the system would be 283 500€, with an annual electricity cost of 4 700 €. In return the geothermal system can provide 462 MWh/a.

The estimated payback time is around 16 years.

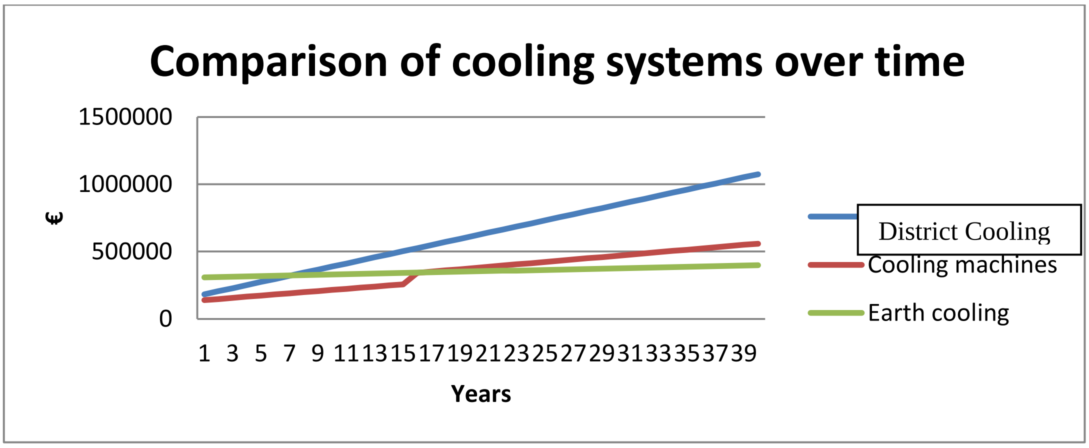

Figure 9 Comparison of cooling system over time

As illustrated in the diagram above, even if the geothermal cooling has the highest initial cost, the yearly operating cost make it the most efficient system in the length.

The cooling machine would be a good solution if the time frame is 15 years. It irregularity in the cooling machines line is that, it is calculated that they are changed after 15 years of usage.

It is a system well suited for providing steady and cheap cooling and heating energy continuously and can easily be regulated. It would lower the usage of the existing cooling machines, which reduces energy consumption, and lowers the need from district heating. The amount of cooling hour can be increased if needed, thus also increasing annual cooling energy gained from geothermal cooling.

4.1.2 Heating

Geothermal heating might not be necessary, since the factory itself produces massive heat load around the year, that, combined with new a AHU system makes a huge impact in the facility's heating need.

Heating and cooling

Since heating and cooling use the same wells, to combine them into one system is an optimal solution. The total infrastructure is 262 000€, since the heating circuit uses the same wells as the cooling circuit. Additional investments must be done to have a functioning heating circuit. A heat pump is around 180 000€. The total installation cost would be 442 000€, and an annual operating cost of 41 000 €/a with 105 €/MWh.

This means an annual 1 125 MWh for heating, 460 MWh for cooling, and an annual production of 1 585 MWh/a. The whole system would have a payback time of 3,5 years**.**

However, in this situation, the cooling aspect of geothermal energy is of more interest.

5 LIGHTING

The factory's lights consist of linear fluorescent lights (LFL). The LFL are using much of the electricity in the factory

Now, there are 7980 T5 fluorescent tubes, consuming 80W each for 126h/week, 52 weeks/a. Since they are connected to a light sensor, it is assumed that on a yearly average they use about 45% of their max power.

One solution is to change the fluorescent tubes to LED tubes. They use on an average a third to half of what a LFL. In this case a 37W LED has almost the same lighting properties.

Table 9 Difference between T5 fluorescent tubes and LED tubes in annual cost

	W	%	Tubes/lamp	Lamps	h/week	Weeks/a	MWh/a	€/a
LFL	80	45%	6	1 330	126	52	1880	197 400
LED	37	45%	6	1 330	126	52	870	91 350

Above is a table that compares annual energy consumption between fluorescent tubes and LED tubes:

On an annual level, the difference is 1 010 MWh. With an energy price of 105 €/MWh, it means annual savings in 106 050 €.

Taking in to consideration that the life-time of a traditional fluorescent tube is proximately 20 000h, whereas the LED tube has a life-time of 50 000h. Furthermore, the fluorescent tubes tend not to have a shorter life-time when they are used with a dimmable system. [16][17]

Table 10 The lifetime of the lamps and their cost.

	Lifetime, h	h/a (on)	€/tube	all lights	1 year
LFL	20 000	6552	3,00€	23 940 €	159 500 €
LED	50 000	6552	32,00€	255 360 €	318 000 €

Below is a chart, which compares the both systems over a time of 21 years, using the data from the table above. The cost of the tubes is an estimation based on what is available in hardware stores.

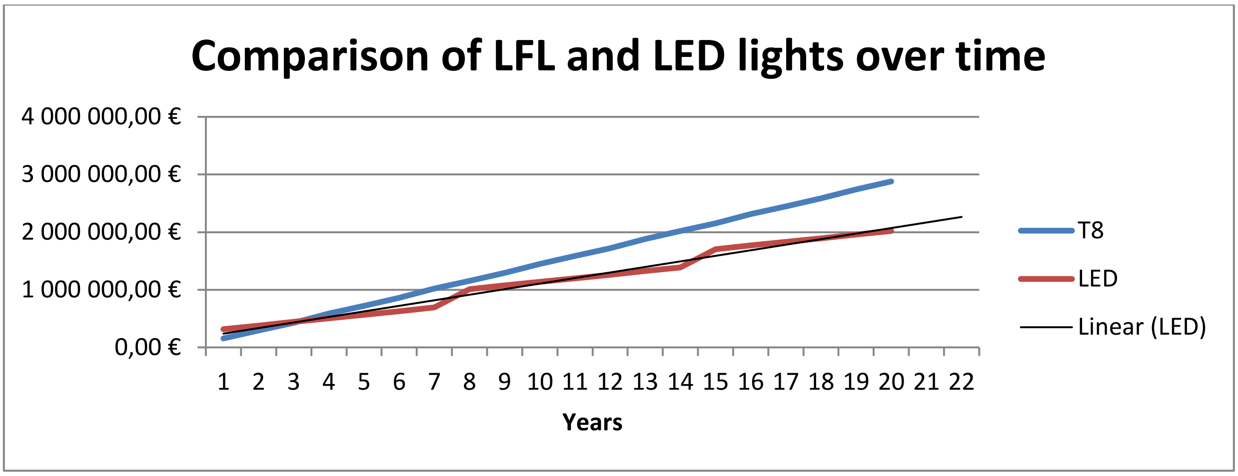

Figure 10 Comparison of LFL and LED lights over time

The chart above shows that the initial investment for the LED lights is higher, and does not include installation cost. However, the annual energy consumption of the fluorescent light makes it more expensive solution over time. Even if the LEDs have to be changed with an approximated 7 years' interval, they are a more energy- and cost effectively alternative. Another advantage with the LED lights, it is that heat load will be decreased, and therefore also the cooling need will decrease.

6 PUMPS

There are 113 pumps in the factory for various purposes. The total capacity is 1 450 m³/s and annual use of the pumps is 569 880 h. Depending on the pump, they work between 6 000 and 8760h/a. Changing all pumps would reduce noise and consumption of electricity.

An offer from the pump manufacturer Wilo is used as a base for calculations.

The calculations are done with an energy price of 105€/MWh (0,105 €/kWh).

6.1 "Calculations for the pumps

To begin the calculations, the offer report from Wilo is used. The table below illustrates the comparison between the existing pumps and the potential savings with the new ones.

Table 11 Annual difference between existing and modern system

	Existing	New	Existing	New	Savings/a	Savings/a
	MWh/a	MWh/a	€/a	€/a	MWh/a	€/a
Sum	1 025	615	107 625	64 575	410	**43 050**

By changing the pumps, annual energy savings would be 43 050 €, and total energy reduction would be 40 % compared to the existing pumps

6.2 Summary pumps

The investment cost for the pumps is 253 000€. With a estimated annual savings of 43 050 € it would put the payback time at 5,9 years.

The potential electricity savings for replacing the pumps are 410 MWh/a.

By replacing the pumps to more energy efficient ones, it also lowers the heat load in the factory, which in turns lowers the cooling demand.

One thing that is worth examining closer is the pressure control. It can have huge saving potentials.

7 PREVENTING UNNECCESARY HEAT GAIN

The aim is to reduce heat gains and losses, as it reduces the cooling and heating needed and in return reduces electricity consumption. In this chapter, there are some suggestions on how to reduce unwanted heat gain and losses.

7.1 Night Solar

NightSolar is a relative new system on the market that uses solar energy to pre-heat the incoming air or to cool the roof by using an effect called nocturnal radiation, and lowers heat gain through shading

Since Engel in St.Valentin is at an location that both needs cooling and heating.

Engel in St.Valentin has on the roof many rows of so-called pyramid sky-lights that have the window facing either north or west. This makes it so that the larger surface area of the “sky-light pyramid” faces the sun for majority of the day.

Figure 11 The Engel factory in St.Valentin

It gives a total sloped roof are facing the sun of 19 900 m².

The NightSolar concept is an all-round system that can provide year around insulation in the form of air pockets between the original roof and the NightSolar installment. And it can provide night time cooling in the summer and in the winter time preheated air for ventilation.

As well does virtually hinder direct heat gain from the roof while it protects the original roof. The NightSolar panels can be fitted on existing roofs, and on these panels, can be fitted with solar panels, if so should desire. [18] [19]

7.1.1 Conduction

The roof construction has now a theoretical calculated U-value of 0, 3 W/m².K. With the NightSolar, it would have a theoretical calculated U-value of 0,185 W/m².K. Calculating heat loss through the roof of conditions of Tin= 20 °C, Tout, a/avg. = 14 °C and with are of 19 900m², we can use the formula: [20]

$$Q = U(Tin - Tout.) * A$$

And we get the theoretical heat loss values as following:

$$Qexisting = 0{,}3\,\frac{\mathrm{W}}{\mathrm{m}^2}.\mathrm{K.}* (20\ °\mathrm{C} - 14\ °\mathrm{C}) * 19\ 900\ m^2 = 35\ 820\ W$$

$$QNightSolar = 0{,}185\,\frac{\mathrm{W}}{\mathrm{m}^2}.\mathrm{K.}* (20\ °\mathrm{C} - 14\ °\mathrm{C}) * 19\ 900\ m^2 = 22\ 089\ W$$

And on an annual level it would mean:

$$Qexisting = 35\,820\ W * 8760\ \mathrm{h} * 10^{-6} = \ 313,78\ \mathrm{MWh/a} =$$

$$QNightSolar = 22\,089\ W * 8760\ \mathrm{h} * 10^{-6} = \ 193{,}5\ \mathrm{MWh/a}$$

That would mean a decrease in conduction heat loss of 120 MWh/a or 6 720 €/a.

Table 12 Saving from NightSolar.

	Existing	NightSolar	Saving tot
Conduction	315 MWh/a	190 MWh/a	120 MWh
Capital cost		**≈ 65 000 €**	
SUM:			**120 MWh/a**

The total annual savings would be 6 720 € and the payback time would be 9,6 Years. Area of heating in the winter is not included, since there was not enough data for making calculations.

8 WINDOWS

In the chapter windows is a short explanation on how different windows and their values contribute to energy efficiency. In the oldest part is a window area of 3 684 m².

8.1.1 Windows U-value

The most notable area of interest is the windows in area BS1.
They are from the time when BS1 was built, year 1987, and would mean that there were no U-value (overall heat transfer coefficient, W/m². K) restrictions in Austria. Exact theoretical U-value is unknown; however, an estimated theoretical U-value can be done. Since the windows are single glazed, the normal U-value is 5, 8 W/m².K.
There are many modern-day windows that offer insulation of different degrees, from high insulation windows with argon filled windows with values of 0, 6 W/m². K to more commonly used windows with U-values of 1-2 W/m².K. Requirements in Finland are

that if the area is supposed to be warm the year around, the highest allowed value is 1 W/m². K, and for a half-warm area the highest value is 1,4 W/m².K.
Calculations are done with theoretical U-values of 5, 8 W/m². K and 1, 4 W/m².K. [21][22][23][24]

Calculating total heat loss through the windows in Area1, following values can be used: [25]

$$Q = U * (Tin - Tout) * A$$

Existing windows U-value: 5, 8 W/m². K

Replacement window U-value: 1, 4 W/m². K

Tin: 20 °C

Tout.avg/a: 14 °C

Window area: 3 684 m², 1 632 windows

Hours annually: 8760 h

$$Qexisting = 5{,}8 \frac{\mathrm{W}}{\mathrm{m^2.K}} * (20\ ^\circ\mathrm{C} - 14\ ^\circ\mathrm{C}) * \ 3\ 684\ \mathrm{m}^2 = 128\ 203\ \mathrm{W} * 10^{-3}$$
$$= 128{,}2\ \mathrm{kW}$$

$$Qreplacment = 1{,}4 \frac{\mathrm{W}}{\mathrm{m^2.K}} * (20\ ^\circ\mathrm{C} - 14\ ^\circ\mathrm{C}) * \ 3\ 684\ \mathrm{m}^2 = 30\ 945{,}6\ \mathrm{W} * 10^{-3}$$
$$= 30{,}95\ \mathrm{kW}$$

And adding hours annually we get:

$$Qexisting = 128{,}2\ kW * 8\ 760 \frac{h}{a} = 1\ 123\ 030\ kWh * 10^{-3} = 1\ 123\ \ MWh/\mathrm{a}$$

$$Qreplacment = 30{,}95\ kW * 8\ 760 \frac{h}{a} = 271\ 122\ kWh * 10^{-3} = 271{,}1\ MWh/a$$

And the annual difference would be 852 MWh or 47 712€ in heating cost.

8.1.2 Windows g-value

The g-value is total solar energy transmittance of a window.

It composes of direct transmitted energy and the dispersion of heat from the glazed surface due to absorption of solar radiation in the glass.

Reducing the transmission (g-value) of the window reduces the solar irradiation of the interior of the building

Below is an example of calculating total irradiance for a window. The example is using irradiance data from Stockholm in Sweden for south facing windows in Stockholm 1986. Same irradiance data was not available for Austria. The data is to get an indicative estimation of the irradiance for the window.: [25]

Irradiance Gb,n = 634 W/m²

Gd = 226 W/m²

albedo = 0,2

Solar income angle = 46, 4°

$$Direct\text{: } 634\frac{\mathrm{W}}{\mathrm{m}^2} * \cos(46{,}4°) = 437\ \mathrm{W/m^2}$$

$$Diffuse\text{: } \frac{1+\cos(90°)}{2} * 226\frac{W}{m^2} = 113\ W/m^2$$

$$Ground\ reflected\text{: } \rho\frac{1-\cos(\beta)}{2} = Iglob = 0{,}2\frac{1-\cos(90)}{2} * 676 = 67\ W/m^2$$

$$Gtot = 437\frac{W}{m^2} + 113\frac{W}{m^2} + 67\frac{W}{m^2} = 617\ W/m^2$$

Total calculated irradiance that hits the window is 617 W/m². The next step is to calculate how much of the total irradiance reaches the inside of the window.

Since it is the windows g-value that determines the transmittance, we can calculate the total transmitted radiation for different g-values.

Assuming a g-value of 0.8 for the existing single glazing, 0,55 for new double glazed windows, IAM for one glazing 0,94 and for two (0,94*0,94=) ,0,88. Effective incidence angle for Id and Ig: 59°.

Transmittance for diffusion 0, 86*0, 86 = 0, 74,

Total transmitted radiation:

$$Qexisting = 0,8 * \left(0,88 * 437\frac{W}{m^2}\right) + 0,74 * \left(113\frac{W}{m^2} + 68\frac{W}{m^2}\right) = 441,6\ W/m^2$$

This is 67 % of total transmittance heat gain.

$$Qnew = 0,55 * \left(0,88 * 437\frac{W}{m^2}\right) + 0,74 * \left(113\frac{W}{m^2} + 68\frac{W}{m^2}\right) = 345,5\ W/m^2$$

This is 46% of total transmittance heat gain.

That means a transmittance gain trough solar irradiation of 96 W/m². And since there is 3 684 m² in BS1, it would put the total solar irradiation at 353 kW.

Calculating with 10 h of daylight each day, 5 days a week during a 4-month summer period gives 800 h of sun, resulting in energy savings of 282 MWh/a. Or 282 MWh in cooling needed.

Note that this is an example calculation on how much solar irradiation and a windows g-value matter on energy efficiency, and that the g-value example is from Stockholm Sweden. Similar calculations can be done at Engel St.Valentin with the correct data.

8.1.1 Window films

An alternative to changing all the windows would be to use a film that has the potential to be installed without removing the existing windows.

There are window films that can reduce both conductivity and solar heat gain through radiation.

The windows at the factory are single paned, and the goal is to achieve as much natural light as possible.

The film chosen is 3M PR20 which has the following properties: [26]

U-value	5,8 W/m². K
g-value	0,38

Since the U-value is the inverse of R, the values are converted to R to be added together, before summing it up to a new U-value.

Calculating the conduction for the window the total resistance would be:

$$\frac{1}{5{,}8\frac{W}{m^2}.K}+\frac{1}{5{,}8\frac{W}{m^2}.K}=0{,}345\frac{m^2}{W}.K$$

Converting back to U-value:

$$\frac{1}{0{,}345\frac{m^2}{W}.K}=2{,}9\frac{W}{m^2}.K$$

Adding the solar film would increase the U-value of the window to 2,9 W/m². K
Calculating the heat loss from the window with the film:

$$Qreplacment = 2{,}9\frac{\mathrm{W}}{\mathrm{m^2.K}} * (20\ °\mathrm{C} - 14\ °\mathrm{C}) *\ 3\ 684\ \mathrm{m}^2 = 64\ 101{,}6\ \mathrm{W} * 10^{-3}$$
$$= 64{,}1\ \mathrm{kW}$$

And adding hours annually we get:

$$Qexisting = 58{,}1\ kW * 8\ 760\frac{h}{a} = 561\ 515\ kWh * 10^{-3} = 561{,}5\ MWh/\mathrm{a}$$

This result in an annual 561, 5 MWh reduction, and annual savings in 58 960€.

Calculating the solar energy transmittance of a window with the film:

$$Qfilm = 0{,}345 * \left(0{,}88 * 437\frac{W}{m^2}\right) + 0{,}74 * \left(113\frac{W}{m^2} + 68\frac{W}{m^2}\right) = 266{,}6\ W/m^2$$

That makes the transmittance difference through the window with the film 175 W/m². With a window area of 3 684 m², it makes the total solar radiation 644,7 kW and an annual energy saving and cooling reduction of 515,7 MWh.

The window film has the potential to reduce the cooling needed with 1 032 MWh/a, or 108 360 €/a.

And with an estimated installation cost of 130 €/m² the total investment cost would be 480 000€ with a payback time of 4,4 years.

8.2 Window summary

Changing all the windows in BS1 would be an expensive investment that would pay itself back in 10-15 years. It would not only reduce heat loss and gain through window; it would also provide the area with more natural light and a more controllable indoor climate.

Using the window film has the potential of lowering cooling needed in the summer, and is easy to install, with a relatively fast payback time.

9 OPTIMIZATION OF CURRENT SYSTEMS

A big part of lowering energy consumption comes down to how optimized the current systems are. Changing units to newer and more energy efficient also reduces energy efficiency, but using the units outside their "comfort zone" has a huge impact.

9.1 Ventilation

Optimizing current systems will also reduce energy consumption. For example, by reducing the air handling unit's motor rpm by 20% can there be a 50% reduction in energy usage. Therefor it is never suggested that the motors should use 100% of their capacity.

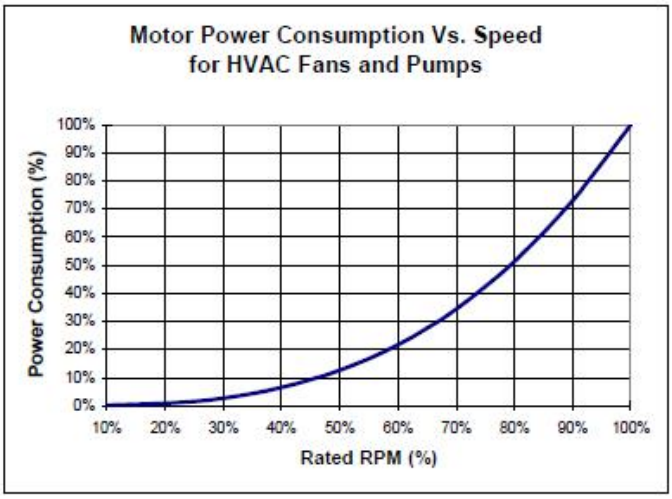

Figure12 Motor rpm versus power consumption [27]

The airflow capacity is enough to change the factory's air volume 1,77 (Air handling unit's capacity: 1 183 000 m³/s, 667 968 m³ facility's volume) times an hour and, so it is not an case of for little ventilation, most likely the current system is designed so that excess heat is "cooled" by having full ventilation on. And by having an optimized heat recovery for the air handling units, will reduce needed heating and cooling. An rpm "stopper" could be used to regulate the maximum rpm to 80-90 %

10 SUMMARY

In each of the analyzed areas are improvements that can be done and that potentially can have huge impacts on the total energy consumption. Some of the areas are integrated in other areas which mean that they might have a more positive effect than calculated. Note that in some cases the investment does not include installation cost of the product, since there none prices available. Below is a table summarizing the results from the different energy areas.

Table 15. Potential energy savings

System	Area	Investment	Savings MWh/a	Savings €/a	Payback-time
Ventilation					
	1) Motors and fan	272 650 €	490 MWh	51 450 €	5,3 years
	2) AHU	1 220 000 €			
	Electricity		210 MWh	22 050 €	
	Heating		6 200 MWh	322 400 €	
	Cooling		20 MWh	2 100 €	
	Tot		6 430 MWh	346 550 €	3,5 Years
Lights					
	LED	255 360 €	1 010 MWh	106 050 €	2,4 Years
Geothermal					

	Cooling	283 500 €	460 MWh	22 300 €	7,7 Years
Pumps					
	Pumps	253 000 €	410 MWh	43 050 €	5,9 Years
NightSolar					
	NightSolar, Conduction	65 000 €	120 MWh	6 720 €	9,7 Years
Windows					
	1)Windows	-	852 MWh	47 710 €	-
			282 MWh	29 610 €	
	Tot		**1 134 MWh**	**77 320 €**	
	2)Window film	480 000 €	1 032 MWh	108 360 €	4,4 Years
SUM:	1) With motors and fans and film	**1 609 510 €**	**3 473 MWh**	**337 930 €**	4,7 Years
	or				
	2) With AHU and film	**2 557 000 €**	**9 462 MWh**	**632 190 €**	**4 years**

There are a couple of possibilities to choose from within the ventilation and window section, that effects the outcome. The first one being to replace the existing fans and motors, the other option being to change the entire unit. This option requires a reconstruction of the current ventilation system.

All in all there are improvements to be made and the improvements mentioned would get below the target reduction of 5% in demand for electricity.

The electricity savings adds up to 1 910 MWh/a with ventilation option 1). With ventilation option 2, the electricity savings would be 1 630 MWh/a. Both options are over the target annual reduction of 1 160MWh/a.

In heating and cooling there is a potential to save 8 575 MWh/a, however, it would include more work and investment to achieve the goal.

The reduction in annual energy use is also a significant reduction in the factory's heat load.

With the changes, the total electricity usage would be distributed:

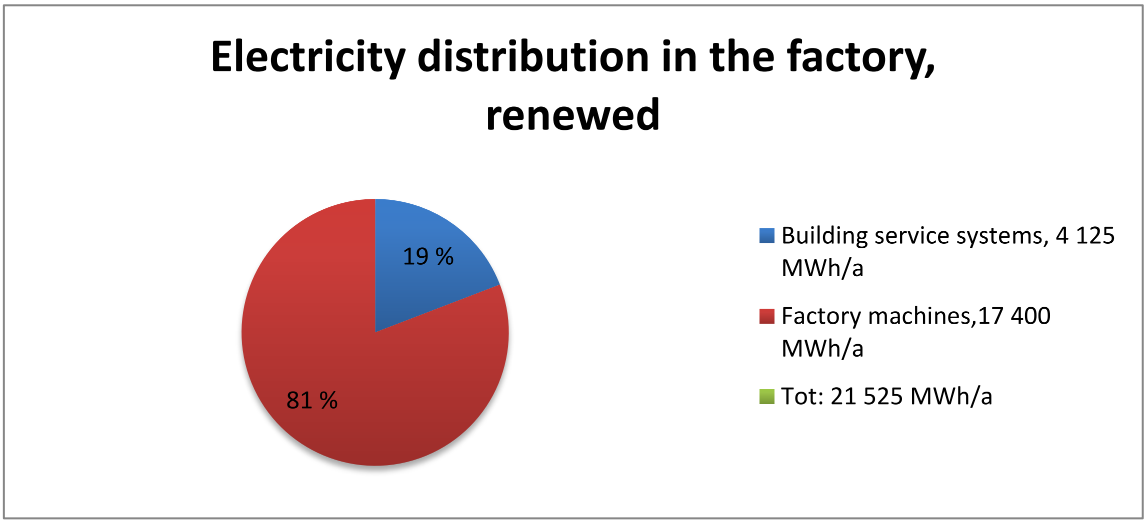

Figure 13 Electricity distributions in the factory, renewed

And within the building service system:

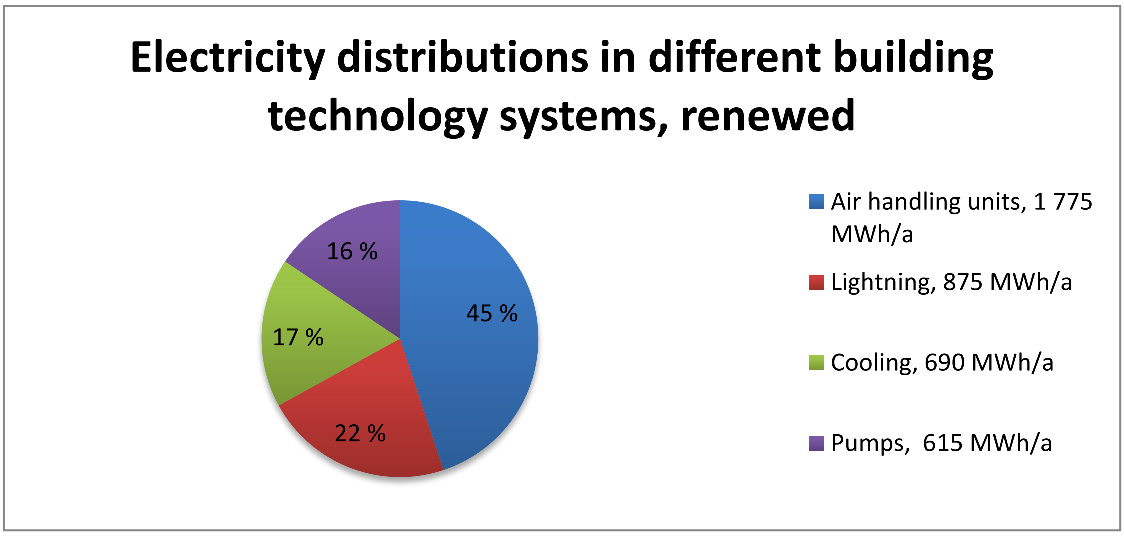

Figure 14 Electricity distributions in different building technology systems, renewed

11 CONCLUSION

This thesis focuses on the energy consumption in the Engel factory in St.Valentin. The target was to lower the electricity consumption for building technology system by 1 160 MWh/a,

After the comparison between the existing systems and the new system, the result was that the annual electricity savings would be 1 630 MWh with updating the AHU units pumps and LED-lights. As for the heating and cooling, the new systems could have an annual energy savings potential of 8 575 MWh. The annual electricity savings translates to 117 360 €, with and energy price of 105 €/MWh.

Table 13Potential savings

System	Area	Investment	Savings MWh/a	Savings €/a	Payback-time
Ventilation					
	1) Motors and fan	272 650 €	490 MWh	51 450 €	5,3 Years
	or				
	2) AHU	1 220 000 €			
	Electricity		210 MWh	22 050 €	
	Heating		6 200 MWh	322 400 €	
	Cooling		20 MWh	2 100 €	
	Tot		**6 430 MWh**	346 550 €	3,5 Years
Lights					
	LED	255 360 €	1 010 MWh	106 050 €	2,4 Years
Geothermal					
	Cooling	283 500 €	460 MWh	22 300 €	7,7 Years
Pumps					
	Pumps	253 000 €	410 MWh	43 050 €	5,9 Years
NightSolar					
	NightSolar, Conduction	65 000 €	120 MWh	6 720 €	9,7 Years
Windows					

	Windows	-	852 MWh	47 710 €	-
			282 MWh	29 610 €	
	Tot		**1 134 MWh**	**77 320 €**	
	Window film	480 000 €	1 032 MWh	108 360 €	4,4 Years
SUM:	1) With motors and_fans	**1 603 000 €**	**3 473 MWh**	**337 930 €**	4,7 Years
	or				
	2) With AHU	**2 557 000 €**	**9 462 MWh**	**632 190 €**	**4 Years**

As seen in the table above, the different areas all have huge saving potentials. They all have a rather pricy investment cost, but considering the annual savings and the low pay-back time, the investments are attractive.

The fastest area to improve would be the lights, since they are quite easy to install and they have the shortest payback time.

The improvement that would have the biggest impact would be the AHU system. A new AHU system has the possibility to reduce electricity, heating and cooling need. Also, would the system be quieter. The replacement of the AHU would be accompanied by an improvement to the indoor climate.

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13 APPENDICES

Appendix 1 Calculations of old and new pumps

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Used energy price, €/MWh:	105
Energy price €/kWh:	0,105

Bezeichnung	Pump, Old	Pump, New			Energy consumption,kWh/a		Energy cost €/a		Energy Savings			Worktime	Price-brutto, €		Payback time
Baustufe 1			Anzah pumpen	Q, m³/h	Pump ,Old	Pump, New	Pump ,Old	Pump, New	kWh/a	€/a	%	h/a	1 Unit	Unit-sum	Years
Heizregister	Top-S 40/a 1~	Stratos 40/1-6	1	6,9	998,00	238,00	104,79	24,99	760,00	79,80	76,15	6 000,00	1 062,00 €	1 062,00 €	13,31
Heizregister	S 40/80r 1~	Stratos 25/1-6	1	4	1 167,00	145,00	122,54	15,23	1 022,00	107,31	87,57	6 000,00	871,00 €	871,00 €	8,12
Heizregister	S 40/80r 3~	Stratos 25/1-6	1	4,5	946,00	184,00	99,33	19,32	762,00	80,01	80,55	6 000,00	871,00 €	871,00 €	10,89
Heizregister	S 40/80r 3~	Stratos 25/1-6	1	4,5	946,00	184,00	99,33	19,32	762,00	80,01	80,55	6 000,00	871,00 €	871,00 €	10,89
Heizregister	S 40/80r 3~	Stratos 25/1-6	1	4,5	946,00	184,00	99,33	19,32	762,00	80,01	80,55	6 000,00	871,00 €	871,00 €	10,89
Heizregister	Rp 25/80r 3	Stratos PICO 25/1-6	1	1,7	601,00	41,00	63,11	4,31	560,00	58,80	93,18	6 000,00	423,00 €	423,00 €	7,19
Heizregister	S 40/80r 3~	Stratos 25/1-6	1	4,5	946,00	184,00	99,33	19,32	762,00	80,01	80,55	6 000,00	871,00 €	871,00 €	10,89
Heizregister	Top-s 40/4r 3~	Stratos 25/1-8	1	5,7	976,00	146,00	102,48	15,33	830,00	87,15	85,04	6 000,00	910,00 €	910,00 €	10,44
Heizregister	S 40/80r 3~	Stratos 25/1-6	1	4,5	946,00	184,00	99,33	19,32	762,00	80,01	80,55	6 000,00	871,00 €	871,00 €	10,89
Heizregister	S 65/80r 3~	Stratos 65/1-9	1	12,2	2 842,00	675,00	298,41	70,88	2 167,00	227,54	76,25	6 000,00	2 743,00 €	2 743,00 €	12,06
Lackierbox 2	Top-s 40/4r 3~	Stratos 25-/1-8	1	6,4	1 426,00	267,00	149,73	28,04	1 159,00	121,70	81,28	8 760,00	910,00 €	910,00 €	7,48
Lackierbox 1	S 40/80r 3~	Stratos 40/1-4	1	5	1 382,00	406,00	145,11	42,63	976,00	102,48	70,62	8 760,00	1 062,00 €	1 062,00 €	10,36
-	Top-s 25/7 3~	Stratos 25/1-6	1	3,3	892,00	180,00	93,66	18,90	712,00	74,76	79,82	6 000,00	871,00 €	871,00 €	11,65
Heizung, tür 19	Top-s 40/7 3~	Stratos 40/1-8	1	7,8	1 634,00	379,00	171,57	39,80	1 255,00	131,78	76,81	6 000,00	1 749,00 €	1 749,00 €	13,27
Maschinentest Vorwart	Ipn 65/150-4/2~	Stratis Giga 65/1-38/3,8	2	40	54 312,00	24 528,00	5 702,76	2 575,44	29 784,00	3127,32	54,84	8 760,00	5 758,00 €	11 516,00 €	3,68
			n	Q, m³/h	kWh/a	kWh/a	€/a	€/a	kWh/a	Savings €/a	% less energy		Price- Brutto, €	All units	Payback time, Years
is not included in calculations			16	115,5	70 960,00	27 925,00	7 450,80	2 932,13	43 035,00	4 518,68 €	60,65		20 714,00 €	26 472,00 €	5,86

Bezeichnung	Pump, Old	Pump, New			Energy consumption,kWh/a		Energy cost €/a		Energy Savings			Worktime	Price-brutto, €		Payback time
Baustufe 2			Anzah pumpen	Q, m³/h	Pump ,Old	Pump, New	Pump ,Old	Pump, New	kWh/a	€/a	%	h/a	1 Unit	Unit-sum	Years
Radiatoren	TOP-S 25/7 3~	Stratos 25/1-6	1	3,3	892	180	93,66	18,90	712,00	74,76 €	79,82	6 000,00	871,00 €	871,00 €	11,65
Heizung Meisterkabine	RS 25/60r	Stratos PICO 25/1-6	1	1,6	416	54	43,68	5,67	362,00	38,01 €	87,02	6 000,00	423,00 €	423,00 €	11,13
Heizregister	S 65/80r 3	Stratos 65/1-9	1	12,2	2842	675	298,41	70,88	2 167,00	227,54 €	76,25	6 000,00	2 743,00 €	2 743,00 €	12,06
			n	Q, m³/h	kWh/a	kWh/a	€/a	€/a	kWh/a	Savings €/a	% less energy		Price- Brutto, €	All units	Payback time, Years
is not included in calculations			3	17,1	4 150,00	909,00	435,75	95,45	3 241,00	340,31 €	78,10		4 037,00 €	4 037,00 €	11,86

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Baustufe 3			Anzahl pumpen	Q, m³/h	Pump ,Old	Pump, New	Pump ,Old	Pump, New	kWh/a	€/a	%	h/a	1 Unit	Unit-sum	Years
Heizreg. Lüftung	Smart 25/6	Stratos PICO 25/1-6	1	1,8	515	83	54,08	8,72	432,00	45,36 €	83,88	6 000,00	423,00 €	423,00 €	9,33
Mischkreis-Versorung	TOP-S 30/7 1	Stratos 30/1-6	1	3,4	927	175	97,34	18,38	752,00	78,96 €	81,12	6 000,00	924,00 €	924,00 €	11,70
Heizreg. Lüftung	RS 25/60r	Stratos PICO 25/1-6	1	1,8	416	64	43,68	6,72	352,00	36,96 €	84,62	6 000,00	423,00 €	423,00 €	11,44
Kälte Deckenstrahlplatten	Rp 30/100r 1	Stratos 30/ 1-6	1	3	906	125	95,13	13,13	781,00	82,01 €	86,20	6 000,00	924,00 €	924,00 €	11,27
			n	Q, m³/h	kWh/a	kWh/a	€/a	€/a	kWh/a	Savings €/a	% less energy		Price- Brutto, €	All units	Payback time, Years
is not included in calculations			4	10	2 764,00	447,00	290,22	46,94	2 317,00	243,29 €	83,83		2 694,00 €	2 694,00 €	11,07

Bezeichnung	Pump, Old	Pump, New			Energy consumption,kWh/a		Energy cost €/a		Energy Savings			Worktime	Price-brutto, €		Payback time
Baustufe 4			Anzahl pumpen	Q, m³/h	Pump ,Old	Pump, New	Pump ,Old	Pump, New	kWh/a	€/a	%	h/a	1 Unit	Unit-sum	Years
Machinentest Endmont	Ipn 65/150-4-/2	Stratis GIGA 65/1-38/3,8	2	40	54 312,00	24 528,00	5 702,76	2 575,44	29 784,00	3 127,32 €	54,84	8 760,00	5 758,00 €	11 516,00 €	3,68
Kondensator 1+2	Ipn 100/280-11/4	Stratos GIGA 100/1-33/5,6	2	90	78000	39600	8 190,00	4 158,00	38 400,00	4 032,00 €	49,23	6 000,00	6 342,00 €	12 684,00 €	3,15
Kältespeicher 1+2	Ipn 125/250-7,5/4	-	2	90	68400	31200	7 182,00	3 276,00	37 200,00	3 906,00 €	54,39	6 000,00		0,00 €	0,00
Lüftung	UPS 32-120 F 3	Stratos 32/1-10	1	6,5	1457	394	152,99	41,37	1 063,00	111,62 €	72,96	6 000,00	1 135,00 €	1 135,00 €	10,17
Gaskessel Ultrashall	UPS40-180 F 3	Stratos 40/1-12	1	9	2852	842	299,46	88,41	2 010,00	211,05 €	70,48	6 000,00	2 023,00 €	2 023,00 €	9,59
Heizregister	UPS 32-120 F 3	Stratos 32/1-10	1	6,5	1457	394	152,99	41,37	1 063,00	111,62 €	72,96	6 000,00	1 135,00 €	1 135,00 €	10,17
Heizreg. Induktionsofen	UPS 50-120 (F) 3	Stratos 50/1-12	1	14	4146	1978	435,33	207,69	2 168,00	227,64 €	52,29	8 760,00	2 789,00 €	2 789,00 €	12,25
GPN 650	IL 32/170-4/2	Stratos GIGA 40/1-45/3,8	2	17	49056	29784	5 150,88	3 127,32	19 272,00	2 023,56 €	39,29	8 760,00	5 032,00 €	10 064,00 €	4,97
GPN 550	IL 32/170-4/2	Stratos GIGA 40/1-45/3,8	2	17	49056	29784	5 150,88	3 127,32	19 272,00	2 023,56 €	39,29	8 760,00	5 032,00 €	10 064,00 €	4,97
GPN 750	IL 32/170-4/2	Stratos GIGA 40/1-45/3,8	2	17	49056	29784	5 150,88	3 127,32	19 272,00	2 023,56 €	39,29	8 760,00	5 032,00 €	10 064,00 €	4,97
GPN 450	IL 32/170-4/2	Stratos GIGA 40/1-45/3,8	2	17	49056	29784	5 150,88	3 127,32	19 272,00	2 023,56 €	39,29	8 760,00	5 032,00 €	10 064,00 €	4,97
is included, even <40%			n	Q, m³/h	kWh/a	kWh/a	€/a	€/a	kWh/a	Savings €/a	% less energy		1-unit, €	All units	Payback time, Years
is not included in calculations			18	324	406 848,00	218 072,00	42 719,04	22 897,56	188 776,00	19 821,48 €	46,40		39 310,00 €	71 538,00 €	3,61

Bezeichnung	Pump, Old	Pump, New			Energy consumption,kWh/a		Energy cost €/a		Energy Savings			Worktime	Price-brutto, €		Payback time
Baustufe 5			Anzahl pumpen	Q, m³/h	Pump, Old	Pump, New	Pump ,Old	Pump, New	kWh/a	€/a	%	h/a	1 Unit	Unit-sum	Years
Heizreg. Lüftung	UPS 32-120 F 3	Stratos 32/1-10	1	6,5	1 457,00	394,00	152,99	41,37	1 063,00	111,62 €	72,96	6 000,00	1 135,00 €	1 135,00 €	10,17
Heizreg. Lüftung	UPS 65-120 (F) 3	Stratos 65/1-12	1	22	4717	1907	495,29	200,24	2 810,00	295,05 €	59,57	6 000,00	3 051,00 €	3 051,00 €	10,34
Heizreg. Lüftung	UPS 32-120 F 3	Stratos 32/1-10	1	6,5	1457	394	152,99	41,37	1 063,00	111,62 €	72,96	6 000,00	1 135,00 €	1 135,00 €	10,17
Heizreg. Lüftung	UPS 32-120 F 4	Stratos 32/1-10	1	6,5	1457	394	152,99	41,37	1 063,00	111,62 €	72,96	6 000,00	1 135,00 €	1 135,00 €	10,17
Heizreg. Lüftung	UPS 65-120 (F) 3	Stratos65/1-12	1	22	4717	1907	495,29	200,24	2 810,00	295,05 €	59,57	6 000,00	3 051,00 €	3 051,00 €	10,34
Heizreg. Lüftung	UPS 32-120 F 3	Stratos 32/1-10	1	6,5	1 457,00	394,00	152,99	41,37	1 063,00	111,62 €	72,96	6 000,00	1 135,00 €	1 135,00 €	10,17
WW Bereitung	UPS 25-80 1	Stratos 25/1-8	1	3,8	1135	227	119,18	23,84	908,00	95,34 €	80,00	6 000,00	910,00 €	910,00 €	9,54
Maschinenkühlung Mac Pac	IL 65/270-5,5/4	Stratos GIGA 65/1-38/3,8	2	49	64824	28032	6 806,52	2 943,36	36 792,00	3 863,16 €	56,76	8 760,00	5 758,00 €	11 516,00 €	2,98

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Bezeichnung	Pump, Old	Pump, New			Energy consumption,kWh/a		Energy cost €/a		Energy Savings			Worktime	Price-brutto, €		Payback time
Baustufe 6			Anzah pumpen	Q, m³/h	Pump ,Old	Pump, New	Pump ,Old	Pump, New	kWh/a	€/a	%	h/a	1 Unit	Unit-sum	Years
Büro vorhiterpumpe	TOP-S 25/7 3	Stratos 25/1-8	1	3,7	892,00	229,00	93,66	24,05	663,00	69,62 €	74,33	6 000,00	910,00 €	910,00 €	13,07
DSP Heizkretspumpe	TOP-S 40/10 3	Stratos 40/1-12	1	10,4	2389	845	250,85	88,73	1 544,00	162,12 €	64,63	6 000,00	2 023,00 €	2 023,00 €	12,48
Heizkreis P7	TOP-S 40/10 3	Stratos 40/1-12	1	10,4	2389	845	250,85	88,73	1 544,00	162,12 €	64,63	6 000,00	2 023,00 €	2 023,00 €	12,48
Heizreg. Lüftung	TOP-S 40/10 3	Stratos 40/1-12	1	10,4	2389	845	250,85	88,73	1 544,00	162,12 €	64,63	6 000,00	2 023,00 €	2 023,00 €	12,48
Heizreg. Lüftung	TOP-S 40/10 3	Stratos 40/1-12	1	10,4	2389	845	250,85	88,73	1 544,00	162,12 €	64,63	6 000,00	2 023,00 €	2 023,00 €	12,48
			n	Q, m³/h	kWh/a	kWh/a	€/a	€/a	kWh/a	Savings €/a	% less energy		1-unit, €	All units	Payback time, Years
is not included in calculations			5	45,3	10 448,00	3 609,00	1 097,04	378,95	6 839,00	718,10 €	65,46		9 002,00 €	9 002,00 €	12,54

Bezeichnung	Pump, Old	Pump, New			Energy consumption,kWh/a		Energy cost €/a		Energy Savings			Worktime	Price-brutto, €		Payback time
Energiezentrale			Anzah pumpen	Q, m³/h	Pump ,Old	Pump, New	Pump ,Old	Pump, New	kWh/a	€/a	%	h/a	1 Unit	Unit-sum	Years
WRG Druckluft K2	RP 30/100r 1	Stratos 30/1-6	1	3	906,00	125,00	95,13	13,13	781,00	82,01 €	86,20	6 000,00	924,00 €	924,00 €	11,27
WRG Druckluft K1	RS 30/100 r 3	Stratos 30/1-6	1	2,7	1726	199	181,23	20,90	1 527,00	160,34 €	88,47	6 000,00	924,00 €	924,00 €	5,76
Wärmetauscherkreis 1	UPS 80-120 F 3	Stratos 80/1-12	1	31,5	6643	2295	697,52	240,98	4 348,00	456,54 €	65,45	6 000,00	4 868,00 €	4 868,00 €	10,66
Wärmetauscherkreis 1	UPS 80-120 F 3	Stratos 80/1-12	1	31,5	6643	2295	697,52	240,98	4 348,00	456,54 €	65,45	6 000,00	4 868,00 €	4 868,00 €	10,66
Wärmetauscherkreis 2	UPS 80-120 F 3	Stratos 80/1-12	1	31,5	6643	2295	697,52	240,98	4 348,00	456,54 €	65,45	6 000,00	4 868,00 €	4 868,00 €	10,66
Wärmetauscherkreis 2	UPS 80-120 F 3	Stratos 80/1-12	1	31,5	6643	2295	697,52	240,98	4 348,00	456,54 €	65,45	6 000,00	4 868,00 €	4 868,00 €	10,66
Versorgungspumpe HAT 1+2	IPL 65/140-4/2	Stratos GIGA 80/1-31/3,8	2	55	38400	15600	4 032,00	1 638,00	22 800,00	2 394,00 €	59,38	6 000,00	5 529,00 €	11 058,00 €	4,62
Versorgungspumpe NT 1	IP-E 65/130-3/2	Stratos GIGA 80/1-32/3,8	2	50	24000	12000	2 520,00	1 260,00	12 000,00	1 260,00 €	50,00	6 000,00	5 529,00 €	11 058,00 €	8,78
			n	Q, m³/h	kWh/a	kWh/a	€/a	€/a	kWh/a	Savings €/a	% less energy		1-unit, €	All units	Payback time, Years
is not included in calculations			10	236,7	91 604,00	37 104,00	9 618,42	3 895,92	54 500,00	5 722,50 €	59,50		32 378,00 €	43 436,00 €	7,59

Area	Amount	Energy consumption,kWh/a		Energy cost €/a		Energy Savings			All units	Payback time
	Pumps	Pumps, Old	Pump, New	Pump, Old	Pump, New	kWh/a	€/a	% Less energ	€	Years
Baustufe 1	18	70 960,00	27 925,00	7 450,80	2 932,13	43 035,00	4 518,68 €	60,65 %	26 472,00 €	5,86
Baustufe 2	3	4 150,00	909,00	435,75	95,45	3 241,00	340,31 €	78,10 %	4 037,00 €	11,86
Baustufe 3	4	2 764,00	447,00	290,22	46,94	2 317,00	243,29 €	83,83 %	2 694,00 €	11,07
Baustufe 4	18	406 848,00	218 072,00	42 719,04	22 897,56	188 776,00	19 821,48 €	46,40 %	71 538,00 €	3,61
Baustufe 5	9	81 221,00	33 649,00	8 528,21	3 533,15	47 572,00	4 995,06 €	58,57 %	23 068,00 €	4,62
Baustufe 6	5	10 448,00	3 609,00	1 097,04	378,95	6 839,00	718,10 €	65,46 %	9 002,00 €	12,54
Energiezentrale	10	91 604,00	37 104,00	9 618,42	3 895,92	54 500,00	5 722,50 €	59,50 %	43 436,00 €	7,59
SUM:	**67**	**667 995,00**	**321 715,00**	**70 139,48**	**33 780,08**	**346 280,00**	**36 359,40 €**	**51,84 %**	**180 247,00 €**	**4,96**