Energy Supply & Optimization of New Tannery in Bangladesh

Carl Ekberg
Gabriel Åkerling

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Luleå University of Technology
Department of Engineering Sciences and Mathematics
Abstract

Böle Garveri is a tannery located outside Piteå with a long history of leather production. They are planning a new tannery in Bangladesh as a step in their ongoing expansion of their business. The leather industry in Bangladesh is currently chemically heavy and in many cases highly toxic to the environment. Böle Garveri intends to change the view of the leather industry with their green tanning process and commissioned this project to energy map the tannery, optimize their production and investigate the possibilities of becoming self sustaining with power production. The investigated parts of the production was transport and cooling of hides, drying of the tanned leather and the supply of heat and electricity. The tannery will be situated in the Bagatipara region of Bangladesh, occupy an area of 1500 m² and have an annual capacity of 20 tonnes finished leather. It will employ 42 people directly and up to 5000 farmers indirectly.

As the hides are delivered raw, there is need for cooling both during transport and in the tanneries storage facility. The recommended transportation option is to use an insulated truck without active cooling. The recommended cold storage solution is a cold room of 4.2x3.4 m, insulated with 200 mm polyurethane boards which results in a capacity of 103 hides. The room will be cooled with a compressor driven heat pump with an effect of 2 kW, operating with air on both condenser and evaporator side.

The recommended dryer is a hot air dryer with a heat-exchanger between ingoing and outgoing air, which is heated by the outgoing stream from the power production. It has a capacity to dry 31 hides in 36 hours and has a required power of 4.1kW which yield a theoretical efficiency of 50 %.

Results from the energy mapping shows that the tannery will need 190 MWh thermal energy and 62 MWh electrical energy annually. To cover this demand the recommendation is to invest in a 130 m³, plug-flow type digester operating with co-digestion of manure and bagasse. The annual substrate demand of the biogas plant will be 100 tonnes of bagasse and 343 tonnes of manure. The total investment cost for the recommended biogas plant will be 149 kSEK and it will have a pay-back time of 3 years.

Analysis of process streams indicated that the process water can be used as mixing water for the biogas plant, but further analysis of the impact of contaminants on the bacteria is required.
Acknowledgements

It shall be specified that Gabriel Åkerling is responsible for sections 4.1 - 4.3, 5.2 - 5.5 and 6.1 - 6.3, specifically all parts regarding cooling, drying and transportations. Carl Ekberg is responsible for sections 4.4 - 4.7, 5.6 - 5.9 and 6.4 - 6.5, specifically power production and the economical aspects for the report.

Furthermore we would like to thank Professor Marcus Öhman, our examiner at Luleå University of Technology for his help with technicalities regarding our project as well as questions about the overall structure for the report and presentation.

We would also like to thank Jan Sandlund at Böle Garveri AB and Imrul Ahmed Tulin at Sustainably Yours who have acted as supervisors at the company. They have given a lot of insights into the everyday dealings at a tannery, how the tanning process works and input about our thoughts and solutions regarding the optimization and efficiency-work that has been done throughout this report.
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<tr>
<td>$H$</td>
<td>Heating Value</td>
<td>MJ/kg</td>
</tr>
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<td>Specific Heat</td>
<td>kJ/kg, K</td>
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<td>$\rho$</td>
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<td>Volatile Dry Matter</td>
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<td>Organic Loading Rate</td>
<td>kg VDM/m$^3$ day</td>
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<tr>
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<td>Volume</td>
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<td>$NCF$</td>
<td>Net Cash Flow</td>
<td>kSEK/year</td>
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<tr>
<td>$NIC$</td>
<td>Net Income</td>
<td>kSEK/year</td>
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<tr>
<td>$C, D$</td>
<td>Write-Off</td>
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<tr>
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<td>years</td>
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<td>$NPV$</td>
<td>Net Present Value</td>
<td>kSEK</td>
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</table>
1 Introduction

1.1 Background

Tanning and leather production is declared by the Bangladeshi government to be a priority industry with large investment and growth potential, with a reported profit of $1.12 billion in 2015. Export goals is set as $5 billion in 2020. [27]

The leather industry in Bangladesh is chemically intensive and lacking in enforced regulations regarding work-safety and waste-treatment. It is impacting the surrounding communities negatively due to releasing large amounts of toxic, untreated waste into the environment on a daily basis. The leather-district in Dhaka alone releases 122 000 liters of toxic water into the Buriganga River each day. The Bangladeshi government has since 2005 been cracking down on leather manufacturers to force a change. In 2010 a new district for leather manufacturing with better conditions for sustainable tanning was completed and factories has started to be moved. [17] The tanneries will still be using highly toxic chromium for tanning, due to the lower cost and higher production speed, but there is possibilities for green tanning.

Böle Garveri AB is a leather and tannery-goods producer with its roots in Sweden and over 100 years of experience with leather. They use a 100 % sustainable and environmentally friendly vegetable-tanning process. They have longstanding business-connections and personal ties to Bangladesh, with part of their production already being located in the capital city of Dhaka. They want to cut transportation and ensure good quality hides for their leather-goods and is therefore opening a new tannery in the Bagatipara region. Their vision is a sustainable, completely green tannery which produces high-quality goods as well as gives back to the local community in the form of employment and necessities such as a steady electricity delivery and availability of cooking gas.

The tannery will be a 1500 m² facility with the production capacity of 20 tonnes of high quality hides annually. It will employ 42 persons directly and up to 5000 farmers indirectly for the supply of hides. The goal is to begin production in August of 2018 and to be at full capacity at the end of the year.

1.2 Purpose & Goal

The purpose of this master thesis is to optimize the processes of the planned tannery that will be located in Bangladesh, as well as providing energy-efficient solutions for the power production to ensure that Böle Garveri AB’s vision of a sustainable and environmentally friendly tannery is achieved.

The main goal is to suggest energy efficient and optimized sub-processes as well as power production. To reach the main goal, sub-goals where outlined as following:
• Energy map the tannery
• Analyze the hide-transport solution
• Compare and optimize cooling and drying processes in the tannery
• Analyze process streams to investigate the possibility of re-circulation
• Design a power production plant
• Carry out a techno-economical analysis of the suggested power production plant

1.3 Limitations

The quality, nutrient content and contaminant levels of the substrates available in Bangladesh is unknown and will not be considered for the calculations. Only commercially available technology is considered for the project. The implemented solutions should not disturb or alter the tannery process.
2 Tanning of Hides

The process of leather manufacturing are divided into three different unit operations which are the same regardless of the tanning process used. Pre-tanning operations, the tanning process and post-tanning operations. The process flow is simplified in Figure 1. [6]

![Figure 1: Simplified flowchart for the tannery](image-url)
2.1 Pre-Tanning Operations

The first operation is commonly called soaking. The purpose of this operation is to restore the hides to its original state, or as close as possible. In practice this means that the hides are re-hydrated and cleaned. This operation differs depending on which condition the hides currently have when they are delivered to the tannery. If the hides have been preserved using salt, or dried, more water has to be used, compared to if the hides are delivered fresh. The process is often carried out in pits, paddles or low speed rotating drums. To improve the efficiency of the soaking process, alkalies, surfactants and enzymes may be added. [6][26]

Fleshing is the process of removing excessive flesh from the hide with the help of a fleshing machine, consisting of knife cylinders and several pressure rolls. This process can remove as much as 40% wb of the hides total weight depending on the type of animal it originated from. If the operation is performed during or after the soaking stage or directly on fresh or chilled hides, it is called green fleshing. If the operation is performed after the liming stage, it is called lime fleshing. The latter is more commonly chosen as it makes the process much easier to perform.[6]

Removal of hair and the outer skin layer, is done during a process known as liming. This operation also opens up the fiber structure which makes it easier for the chemicals in later stages to enter the hides. To do this the hair fiber is firstly immunized by the lime(alkali) and can then be removed with the help of sulphide. The hair which has been removed from the hides, then has to be filtrated and removed from the liquid to decrease the risk of pollution. The hides are thereafter re-limed with a weaker solution.[6]

To further increase the quality of the hide, it is split in a splitting machine. This device divides the hide in a top part called the grain split and a bottom part called flesh split. This procedure are most commonly done after the liming process or after the tanning process.[26]

Before the prepared hides enters the tanning process, chemicals used in earlier stages has to be removed. This is done during the deliming process. During this operation, a number of different chemicals can be used to achieve the wanted result, but the most prominent are ammonium sulphate. It is also important to lower the pH of the hide from a previous level of 12.5. This new level has to be monitored closely as it could possibly damage the hides. Bating is the process in which the partially degraded proteins and fibres are removed with the help of specialized enzymes. [6][26]
2.2 The Tanning Process

When the hides are prepared, the main tanning process can commence. This process produces leather from the prepared hides which are more durable and more resistant to both heat and degradation. This can be done in many different ways. The most common are chrome tannage or vegetable tannage, which will be briefly explained.[6][26]

2.2.1 Chrome Tanning

Commonly this process consists of mainly three steps, pickling, tanning and basification. In the pickling operation, the hide is prepared for tanning by acidification with sulphuric and formic acid. A catonic or multi-charged fatliquor together with basic chromium sulphate is used in the actual tanning process. The pH level is often started at around 2.8 and raised to 3.8. Thereafter a mixture of sodium formate and bicarbonate is used to basify after the tanning process.[6][26]

2.2.2 Vegetable Tanning

This type of tanning can be done using bark, nuts, leaves or a number of other natural tanning agents. The traditional method of vegetable tanning is done by having several pits with the tanning liquid with increasing concentration. The hides rests in each of these pits for several days, or even weeks, depending on what method and tanning agent is in use. To speed up this process, many tanners uses pre-tanning for about a week after which the hides are tanned using rotating drums with the tanning agent in high concentration. [6]

2.3 Post Tanning Operations

After the tanning process, the hides has been converted into a stable material that could be used. But to achieve a finished product that has the desired properties, such as color, hardness and water resistance, additional steps are conducted during the post tanning operations. As the desired properties vary extensively, so does the steps taken during post tanning.

Neutralization is often one of the first steps taken and is done to remove free acids from the leather arriving from the tanning process and thereby prepare the product for the following operations. [6]

Re-tanning is done to make the leather more uniform, improve its general feel and increase resistance to perspiration. It is done with a tanning agent, but not always the same used for the main tanning process.
Thereafter the leather is dyed to the desired color in rotating wooden drums or dyeing machines. The type of dye used vary depending on if the leather had been tanned using vegetable tanning or chrome tanning but the method is the same. Generally the range of different colors is greater for chrome tanning than vegetable tanning.[6][26]

To replace the natural fat removed during earlier processes, a operation known as fat-liquoring is used. This lubricates the hides to a level that is sufficient for the finished product.[26]

3 Electricity Production & Distribution In Bangladesh

Bangladesh is a country with a large population of 160 million people and the economy of the country is on the rise. Despite this, their demand for electricity is quite low for a country of that size. In fact, Bangladesh have one of the lowest electricity demands per capita in the world, 310 kWh/capita.[2] This is partially due to the fact that a big part of the population is yet to connect to the grid. It is estimated that around 76% of the Bangladeshi people have access to electricity today. In the nineties, this number was as low as 7%.

The electricity production today is mainly sustained by natural gas, which accounts for around 60% of the countries total electricity production. 20% is covered by coal and oil. The remaining percentages is covered by bio power and waste. The government in Bangladesh sees a problem with the low rate of connectivity and the low production...
and is therefore planning to expand the countries energy production in the future. The bulk of this expansion will still be based on fossil powered alternatives such as gas and coal. Investments will also be made in two nuclear reactors that is planned to be in use by 2024. Aside from this, the government is pushing for fossil free solutions, mainly solar photo voltaics. One of the upside with these alternative is that panels can be placed off-grid in rural areas where delivery of electricity otherwise would be a problem.[2]

The availability of power and the possibility to connect to the grid is often not the problem for bigger plants and industries in Bangladesh. The issues revolve around the frequent blackouts which causes production stops and creates demands for additional electricity production by internal generation. Of all the electrical power needed by the industries in Bangladesh, only 86.4 % was delivered. Approximately 94 % of the time that power was not provided, it was due to unplanned stops which resulted in an average cost of 0.83 US$/kWh, lost. This is also a deterrent factor for companies planning to start up industries or other energy dependent operations in Bangladesh.[2]
4 Theory

Figure 3 shows a simplification of the studied tannery’s tanning process, where the raw hides is made into commercial leather. The arrow indicates the hides way through the tannery. The required energy carrier for each process-step is shown. The report structure will also follow the flow of the hides, where transportation will be examined firstly, followed by cooling, tanning, drying and lastly power production.

![Diagram of the tannery process](image)

**Figure 3:** Simple process chart of the studied tannery with incoming process streams.

4.1 Heat Transfer

To solve problems regarding heating and cooling, methods to calculate the heat transfer rate will be required.
4.1.1 Conductive Heat Transfer

One-dimensional calculations will be seen as sufficient to calculate the heat rate $q_x$, due to conduction. Where $k$ is the thermal conductivity of the material.[14]

$$q_x = -kA\frac{\Delta T}{\Delta x}$$  \hspace{1cm} (1)

$$q''_x = \frac{q_x}{A}$$  \hspace{1cm} (2)

Many building components that are purchased have an overall heating coefficient $U$ ($W/m^2, K$) that is marked for the product. It can be derived from the thermal conductivity and the thickness of the material in Equation 3. If $n$ materials are combined in an element, Equation 4 is used. $q_x$ can then be rewritten, as shown in Equation 5.[14]

$$U = \frac{k}{\Delta x}$$  \hspace{1cm} (3)

$$U_{\text{tot}} = \frac{1}{\frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} \ldots \frac{1}{k_n}}$$  \hspace{1cm} (4)

$$q_x = UA\Delta T$$  \hspace{1cm} (5)

The overall heating coefficient can also be calculated from the thermal resistance $R$, as shown in Equation 6.

$$U = \frac{1}{R_{\text{tot}}}$$  \hspace{1cm} (6)

4.1.2 Convective Heat Transfer

The convection heat rate can be compromised as the conduction constant ($h$) for the fluid and the temperature difference between the surface ($T_s$) and the fluid ($T_\infty$).

$$q_{\text{conv}} = h(T_s - T_\infty)$$  \hspace{1cm} (7)
Questions regarding heat transfer during transient conditions will be handled with the lumped capacitance method. The assumption is made that the temperature gradients in the hides are small enough to be negligible, and that the surrounding temperature \( T_\infty \) is constant. The hide can then be seen as a solid with a boundary layer to the surrounding medium, where the change in internal energy of the hide is equal to the heat loss at the surface, due to convection. With Equation (8), the cooling time and temperature at a specific time can be calculated.\[14\]

\[
\frac{T - T_\infty}{T_i - T_\infty} = \exp \left[ - \left( \frac{h \cdot A_s}{\rho \cdot V \cdot C_p} \right) \cdot t \right]
\]  

(8)

\( T \) is the temperature of the object at a time \( t \). \( h \) is the convection coefficient of the object, \( \rho \) is the density, \( V \) the volume and \( C_p \) the specific heat.\[14\]

To validate that the lumped capacitance method can be used with big enough precision, the following condition must be met:

\[
Bi = \frac{h \cdot L_c}{k} < 0.1
\]

(9)

Where \( Bi \) is called the biot number, \( k \) is the thermal conductivity and \( L_c \) is the characteristic length of the object.\[14\]

\[
L_c = \frac{V}{A_s}
\]

(10)

**Free Convection**

The convection coefficient \( h \) can be calculated in the following way if the assumption is made that there is no forced convection. Therefore \( h \) will only depend on natural convection where a buoyancy force is created due to the density gradients in the fluid. For the case of free convection, Equation (11) can be used.\[14\]

\[
\overline{h} = \frac{\overline{Nu}_L \cdot k}{L}
\]

(11)

Where \( L \) is the height of the hide, \( k \) is the thermal conductivity and \( \overline{Nu}_L \) is Nusselt number, which is a dimensionless number that describes the temperature gradient at the surface. For a vertical plate, Equation (12) can be used, if \( Ra_L \leq 10^9 \), which indicated laminar flow. \( Ra_L \) is called the Rayleigh number and is calculated with Equation (13).\[14\]

\[
\overline{Nu}_L = 0.68 + \frac{0.67 \cdot Ra_L^{1/4}}{[1 + (0.492/Pr)^{9/16}]^{4/9}}
\]

(12)
\[ Ra_L = \frac{g \cdot \beta \cdot (T_s - T_\infty) \cdot L^3}{\nu \cdot \alpha} \] (13)

\[ \alpha = \frac{k}{\rho \cdot C_p} \] (14)

Where \( Pr \) is the dimensionless Prandtl number, \( g \) the gravity constant, \( \alpha \) the thermal diffusivity, \( \nu \) the kinematic viscosity and \( \beta \) the expansion coefficient for the boundary layer which can be written as \( \beta = 1/T \) for ideal gases.[14]

All properties are taken from table at the film temperature \( (T_f) \). When the table values do not correlate exactly, linear interpolation with Equation 16 is used.[15]

\[ T_f = \frac{(T_s + T_\infty)}{2} \] (15)

\[ y = y_0 + (x - x_0) \frac{y_1 - y_0}{x_1 - x_0} \] (16)

**Forced Convection**

Equation (12) can no longer be used when an external flow is applied. Therefore Equation (17) is used instead. Although Equation (11) is still viable.[14]

\[ Nu_L = 0.680 \cdot Re_L^{1/2} \cdot Pr^{1/3} \] (17)

\[ Re_L = \frac{V_\infty \cdot L}{\nu} \] (18)

**4.1.3 Radiative Heat Transfer**

In lower temperature cases as the ones that will be studied in this report, the heat transfer from radiation is often neglected but will be explained briefly in this section. The simplifications made are that the surfaces are opaque (\( \tau = 0 \)). The surfaces are also considered gray which means that they are independent of wavelength. Lastly the surfaces as considered diffuse, which means that the emissivities, absorptivity and reflectivity are independent of direction.[14]

\[ E = \epsilon \sigma T^4 \] (19)

\[ q_{12} = \sigma A_1 \epsilon (T_1^4 - T_2^4) \] (20)
Where $\sigma$ is called Stefan-Boltzmanns constant and has a value of $\sigma = 5.670*10^{-7} W/M^2*K^4$. The index 1 and 2 represent the 2 analyzed surfaces. Under the stated conditions the emissivity can be set to be equal to the absorptivity.[14]

$$\epsilon = \alpha$$

(21)

### 4.1.4 Annual Temperature Difference in Bangladesh

In many of the calculation used throughout the report, the ambient air temperature is needed. It will be taken from Figure 4 which shows the average temperature for each month.[42] The measuring location is Dhaka. The yearly average temperature is 26°C.

![Figure 4: The average monthly temperature in Dhaka, Bangladesh.](image)

### 4.2 Cooling Systems

Systems that are relevant and viable for implementation for cooling will be explained in this section, and the different variations of these systems.
4.2.1 Compressor Driven Heat Pump

A heat pump operates by using the thermal energy stored in the ground, water or air to use as a driving force. The pump operates within the confound of the first and second law of thermodynamics.

*First law of thermodynamics:* The increase in the amount of energy stored in a control volume must equal to the amount for energy that enters the control volume, minus the amount of energy that leaves the control volume. Energy can neither be created or destroyed.[5]

The law is stated in Equation (22), where $\Delta E_{tot}$ is the change in the total energy stored in the system, $Q$ is the net heat transferred to the system, and $W$ is the net work done by the system.[5]

$$\Delta E_{tot} = Q - W$$  \hspace{1cm} (22)

*Second law of thermodynamics:* It is impossible for any system to operate in a thermodynamic cycle and deliver a net amount of work to its surroundings while receiving energy by heat transfer from a single thermal reservoir. [5]

From the second law, many different important equations can be derived, many regarding the efficiency of the heat pump cycle. The one needed for further calculation is stated in Equation (23), where $\eta_m$ is the efficiency of the irreversible heat transfer process, $q_{out}$ and $q_{in}$ is the heat transfer rate of the system and $T_{c,i}$ and $T_{h,i}$ is the internal temperature of the cold and the hot side.[5]

$$\eta_m = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_{c,i}}{T_{h,i}}$$  \hspace{1cm} (23)

In practice this means that work has to be added to a system to transfer heat against the natural flow. In the case of cooling, heat will be transferred from low temperature to high temperature with the use of a pressure regulated cycle with cooling medium. The concept are the same for cooling and heating. To be able to transfer heat the pump utilizes the phase change of the working medium which depends on the pressure and enthalpy.
In general, the heat pump process can be broken down to the components seen in Figure 5. A visualization of the change in pressure, temperature and enthalpy of the cycle with R134a as working medium can be seen in Figure 6. The pressure of the working medium is increased with a compressor as the temperature simultaneously rises, the working medium is superheated during this stage. After the compressor, the working medium reaches the condenser, a heat exchanger which is connected to an external stream, in which the phase change takes place as the water condenses, transferring heat to the external stream in the process which leads to lowered enthalpy. In a non-ideal cycle the working medium is often sub cooled. The pressure is thereafter lowered by a valve as the temperature simultaneously decrease. In the evaporator, which is also a heat exchanger connected to an external stream, the enthalpy of the working medium increases as a result of heat transfer from the external stream. Thereafter the cycle begins all over again.[5]
Coefficient of Performance

To determine the effectiveness of the heat pump, the coefficient of performance (COP) of the pump, is considered. It specifies the ratio of work required (W) to the requested cooling or heating output. In the case of cooling, Q is the amount of heat removed and for heating, Q is the amount of heat supplied.\[5\]

\[ COP = \frac{Q}{W} \]  \hspace{1cm} (24)

4.2.2 Absorption Heat Pump

The absorption heat pump is very similar to the compressor driven heat pump, but differs in the way that the gas is compressed after the evaporator. The absorption cycle uses an ammonia cycle powered by added heat, instead of a compressor powered by electricity which mechanically compresses the gas.\[5\]
An overview of the internal parts in heat pump driven by an ammonia absorption refrigeration cycle can be seen in Figure 7. The dotted line indicated the components which have replaced the mechanical compressor. A solution of ammonia and water is used as the working medium in the cycle. The low pressurized ammonia is in gas state after the evaporator after which it enters the absorber, where it is absorbed into the weak water-ammonia solution. Heat will be transferred to the surrounding during this process as the temperature of the absorber is higher than the ambient air. From the absorber the now strong ammonia solution is pumped via a heat exchanger to a boiler, also called the engine. Heat is added from an external stream to the boiler, with high enough temperature and pressure to boil the ammonia. 100°C–200°C is often required. As the ammonia has such low boiling point, some of the ammonia will vaporize and be transferred to the condenser, while the water remains in liquid state. Heat is transferred to the surrounding medium in the condenser while the ammonia simultaneously condenses. The pressure is then decreased through an expansion valve and the ammonia vaporizes in the evaporator while absorbing heat. Thereafter the cycle begins again. The part of the solution which did not evaporate in the engine is transferred back to the absorber via the heat exchanger.[5]
The only electrical input to the ammonia absorption cycle is to the pump, which requires less electricity than the mechanical compressor as the medium pumped is a liquid instead of a gas. The COP of an absorption heat pump is often lower than a compressor driven heat pump. The COP of a pump with one cycle averages around 0.6–0.7.[20] But the exergy, which is the quality of energy required, is also lower, as it uses a majority of heat instead of electricity. An absorption heat pump also has more parts and is therefore more expensive than the compressor driven heat pump.

The COP for the heat pump can be increased if the number of engines and condensers increases. An absorption heat pump with two engines and condensers is called a double-effect system and has a COP averaging around 1.0–1.2.[20] This system operates at a higher temperature and pressure level, usually around 200–600°C.[20] The initial cost for the system is more expensive than the single-effect system.

The total work input for the cycle ($W_{tot}$) is calculated in Equation 25 and can be seen as the sum of the work of the pump ($W_p$) and the added heat to the engine ($Q_H$).

\[ W_{tot} = W_p + Q_H \eta_{HE} \]  

(25)

The absorption cycle that replaces the compressor can be seen as a heat engine with efficiency $\eta_{HE}$. The COP of the system is calculated with Equation 24, which is rewritten in Equation 26 with the work taken from Equation 25.[5]

\[ COP = \frac{Q_L}{W_p + Q_H \eta_{HE}} \]  

(26)

4.2.3 Medium of the Connecting Streams for a Heat Pump

There are several ways to distribute the heat that is transferred by the heat pump. It is done by changing the working medium of the connecting streams in both the evaporator and the condenser. The most common medium is water and air. Depending on this choice, and if the aim is to cool or heat, the setup of the pump will look different.

**Geothermal Cooling**

A geothermal heat pump system utilize the fact that temperatures deep in the ground stays constant during the year. A water-mixture is pumped through pipes, buried in the ground, that works as a heat exchanger. Warmer water is pumped into the ground and the heat is taken up by the cold earth. There is often need to drill deep into the ground as the temperature decrease with depth. The depth needed varies with the geological properties of the local area, but are commonly 18-130 m deep.[22] If multiple holes are bored they need to be placed with 5-6 m of space between so they do not effect the ground temperature in adjacent holes.[22] The depth and number of drill holes is decided by the cooling need.
The ground properties of the area of implementation must be known before drilling the geothermal holes. Unfortunately the geothermal recourses of Bangladesh is to date not properly explored. This means that the implementation of a geothermal cooling system may come with a high price and unpredictability in the case of the temperature gradient of the local area. An estimation of the national varieties of the temperature gradient \( T_g \) can be seen in Appendix 75. The temperature \( T_z \) at a depth of \( Z \)m can then be estimated with Equation 27, where \( T_0 \) is the average surface temperature.[23].

\[
T_z = T_0 + T_g \times \frac{Z}{100}
\]  

(27)

River Cooling

A river with flowing water will have a lower temperature than the surrounding air through a large portion of the year. The river temperature will not change when a system of moderate size is implemented. In the same manor as geothermal cooling, the river can be used as a heat sink and will increase the efficiency of the heat pump by lowering the temperature of the stream on the condenser side. A river has the added benefit of a flowing medium which will further increase heat transfer. The simplest way of doing this is by pumping river water through an open loop to the condenser where it is heated. The warmer water which has absorbed heat from the condenser is then pumped back into the river. This means that an additional pump for the river water has to be added in addition to drawn piping for the water. The depth of the river is of importance when analyzing a potential system. A deeper river or lake has a more constant temperature at the bottom. The ideal depth required is usually 60-70 m.[20]

As can be seen in figure 8, the distance from the tannery to the adjacent Baral river is approximately 113 m. The average depth of the Baral river is 6m. There is little to no data regarding the water temperature of the river.[36]
Air Cooling

In the case of cooling, the condenser can be placed outside to transfer heat to the surrounding air. This is easily implemented and a cheaper alternative, but often not as effective as the options previously mentioned. This is due to the high temperature of the surrounding air, and the lower thermal conductivity of the medium. This solution is often chosen as it is the easiest and cheapest to implement. However, the efficiency of this system will be lower than the previously mentioned methods.

Comparison of the Systems

An estimate of average COP during a year, or SCOP, will be presented in Table 1 to validate the difference in efficiency between the different methods.\cite{20}\cite{22}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
\textbf{System} & \textbf{SCOP} \\
\hline
Geothermal & 2.4-5 \\
Water coupled & 4 \\
Air to Air & 1-3 \\
\hline
\end{tabular}
\caption{Difference in Average COP between systems}
\end{table}
4.3 Drying of Leather

The hides keep a high moisture content during the entire tanning process, as can be seen in Table 2.[16] There is therefore a need for drying at the final stages of the process before the dry finish. This drying process has to be controlled as the finished product may take damage if the drying is carried out too quickly.

<table>
<thead>
<tr>
<th>Process Stage</th>
<th>Moisture Content [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before dewatering</td>
<td>70</td>
</tr>
<tr>
<td>After dewatering</td>
<td>30-45</td>
</tr>
<tr>
<td>After drying</td>
<td>8-15</td>
</tr>
<tr>
<td>After conditioning</td>
<td>20-30</td>
</tr>
</tbody>
</table>

The drying process is one of the more energy intensive processes in the tannery, as can be seen in Figure 9.[6] Therefore the dimensioning of the dryer and the choice of drying method is very important as it will highly effect the overall energy requirement of the tannery.

Figure 9: Energy usage of individual processes for a tannery in Europe [%].
The humidity of the ambient air is a contributing factor to an increased drying time, as an air stream with high humidity can absorb less water. The humidity in Bangladesh is very high due to the country’s location near the equator, as can be seen in Figure 10.[42]

![Figure 10: Average monthly humidity of Dhaka, Bangladesh.](image)

**Dewatering**

Before the main drying, the hides go through a process stage called dewatering, where the moister content are lowered. During this step the hides go through the sammying machine, which mechanically presses the water out of the hides. In combination with this, the process makes the leather completely flat, by removing pockets, flattening out folds and wrinkles and smooth out coarse grains. A simplification of the machine can be seen in Figure 11.[6][41]

![Figure 11: Simplified explanation of the sammying machine.](image)

The energy requirement for this process can simply be acquired through Equation 28 where $P_{sam}$ is the power requirement for the sammying machine and $h$ its operating hours in a week, which gives the energy requirement $P'_{sam}$ for each hide in [MJ/kg].
\[ P'_{\text{sam}} = \frac{P_{\text{sam}} \cdot h \cdot 3600}{n_{\text{week}} \cdot m_{\text{hides}}} \]  \hspace{1cm} (28)

### Main Drying

The general methods involved in drying are basically the same for all methods. Enough heat has to be transferred for the latent heat of vaporization. For water at atmospheric pressure this value is \( (h_v = 2257 \text{kJ/kg}) \).[14] The change in evaporation enthalpy as function of pressure is plotted in Figure 12 and is utilized in certain drying methods to lower the input energy required. In general the water has to firstly be transported through the material and thereafter away from the item that is dried.[16]

![Figure 12: Evaporation enthalpy and temperature as function of pressure][35].

The theoretical amount of energy required to lower the moisture content of a hide with initial moisture content of \( M_1 \) to \( M_2 \) is calculated with Equation 30.[16] The simplification is made that the water stays as a film on the surface of the hide, calculations regarding diffusion through the hide is therefore neglected. The moisture content will be seen as constant until the hide and the water is heated to the evaporation temperature \( (T_{ev}) \). This time is called the pre-heating period.

\[
m_{ev} = M_1 \cdot m_{\text{hide}} - \frac{M_2 \cdot (1 - M_1) \cdot m_{\text{hide}}}{1 - M_2} \]  \hspace{1cm} (29)

\[
Q_{\text{dry}} = (T_{ev} - T_i) \cdot C_p_{\text{hide}} \cdot m_{\text{hide}} + m_{ev} \cdot h_v \]  \hspace{1cm} (30)

Where \( T_{ev} \) is the temperature of evaporation for water in atmospheric pressure, which is 100°C and \( m_{ev} \) is the mass of water that need to be evaporated.
The relative humidity (RH) can be calculated as the fraction between the partial pressure of water vapor ($p_w$) and the saturation vapor pressure at dry bulb temperature ($p_{ws}$). \[15\]

$$RH = \frac{p_w}{p_{ws}} \times 100 \quad (31)$$

The humidity ratio ($Y$) is the mass of water per unit mass of dry air $[kg/kg]$ and is calculated in equation 32.\[15\] $m_w$ and $m_a$ are the mass of water vapor and dry air respectively.

$$Y_a = \frac{m_w}{m_a} = \frac{p_w}{p_a} \times 0.622 \quad (32)$$

To be able to calculate the change in enthalpy, temperature, relative humidity, absolute humidity and dew point, the Molier-diagram is used. It can be seen in Appendix 79.\[35\]

### 4.3.1 Drying Methods

There are several commercial viable ways of drying leather in modern tanneries. The most common methods are hot air-drying, toggling, vacuum drying and pasting. The output properties of the leather might vary depending on the method used.

#### Hot Air Drying

The most basic iteration of this method is shown in Figure 13. Where the outdoor air is heated in a heat exchanger. If the outgoing air is not hot enough it will be heated in an electric heater. Hot, dry air is thereafter blown over the hides which causes the water to evaporate. The vapor is then transported with the now moist air out of the dryer. The drying chamber can vary extensively in its design but the overall method stays the same. The hides can be put into the dryer as a batch or can be fed as a continuous flow, for example on a conveyor belt.
Toggling

Toggling is when the hides are suspended on a board with clamps or nails, called toggles. The board in question is often filled with holes so that air and moisture can easily pass through it. The area of the hides increases when stretched in combination with decreased thickness. This also speeds up the drying process. This method can be used in combination with previously mentioned alternatives, but can also be used as a standalone system to let the hides dry in the ambient air.[34]

Vacuum Drying

Vacuum drying is working within the same methodology as hot air drying but takes advantage of the fact that evaporation occurs during lower temperatures when the pressure is lowered, as is visualized in Figure 12. The hide is placed in a chamber in which the pressure is lowered to a suitable level. The thermal energy required for the evaporation process is thereby decreased. Additional energy is required to power the vacuum pump, however the overall energy requirement is often still considerably lower for a vacuum dryer than a conventional forced air dryer. The heat is often supplied through conduction or radiation, instead of convection, which is the case for a forced air dryer.[24]

Pasting

The hides are fasten or pasted to plates, made of glass, ceramic or steel. This is done with a paste, made up of a starch-like substance that works as a glue for the hides. The technique requires less manual work than toggling, but is more expensive. This method is often used in combination with hot air drying or vacuum drying.[34]
4.4 Biogas Production

Biogas is mainly composed of methane (CH₄) and carbon dioxide (CO₂) and forms when organic material is digested by micro-organism in an oxygen-deprived atmosphere. This process is called anaerobic digestion (AD). Commonly used feed-stock is organic waste from households and industry, energy crops such as maize and farming residues such as slaughter offal and manure.[3]

Production of biogas is done in digesters, where the feed stock usually is introduced continuously to the digestion process under stirring to ensure a homogenized slurry. [40]

The production-process can be divided into two steps:

The cellulose, hemi-cellulose, protein and fat breaks down into simple sugars, amino acids and longer fatty-chains due to hydrolyzing bacteria.

These components breaks down further into short, organic acids such as acetic (CH₃COOH) and formic (HCOOH) acid. At the same time hydrogen (H₂), CO₂ and water (H₂O) is formed.

In the next step, CH₄ is formed from the reaction of H₂ with CO₂ and from the break down of the organic acids by the bacteria.

The chemical reactions into CH₄ can be seen below:

\[ 4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \]

\[ CH_3COOH \rightarrow CH_4 + CO_2 \]

The ratio (C:N) between carbon (C) and nitrogen (N₂) in the feed-stock is important for the biogas yield. Experiments has shown that a C:N between 15-30:1 is preferred and between 25-30:1 is optimal for maximum methane yield. [40]

If the ratio is lower than 15:1 the excess nitrogen will not be digested by the bacteria resulting in the forming of ammonia. On the opposite, if the ratio is too high there will not be enough nitrogen for the bacteria to digest leading to a decreased methane production.
4.4.1 Important Parameters

Hydraulic Retention Time

The hydraulic retention time (HRT) is usually the determining factor for the volume as the substrate will have a physical maximum capacity of produced CH$_4$ and the longer time it is left for digestion the more CH$_4$ can be produced. Typically, 100 days is the maximum time for full CH$_4$ release, but depending on the temperature range chosen for the digester the HRT is decided as a compromise between gas yield and economical profitability. [40]

Typically 30-50 days will yield approximately 80% of maximum CH$_4$.[3]

Organic Loading Rate

The organic loading rate (OLR) is the amount of organic dry matter loaded into the digester that can be digested by the bacteria each day. It is suggested that a lower OLR is desired as an increase in OLR will result in a decreased production of CH$_4$.[1]

Temperature Range

The AD usually takes place in three different ranges of temperatures, which can be seen in Table 3 below.

Table 3: Temperature range for anaerobic digestion including minimum HRT for the range.

<table>
<thead>
<tr>
<th>Type</th>
<th>Range[°C]</th>
<th>Minimum HRT[days]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Termophilic</td>
<td>55-60</td>
<td>15-20</td>
</tr>
<tr>
<td>Mesophilic</td>
<td>35-40</td>
<td>30-40</td>
</tr>
<tr>
<td>Phsycrophilic</td>
<td>&lt;20</td>
<td>70-80</td>
</tr>
</tbody>
</table>

At 43°C in the mesophilic range, inhibition of the microbial digestion sets in and gas production decreases. Similar occurrence can be observed in the termophilic at 63°C. It is recommended to not allow fluctuations of ±1°C or more for the termophilic range as to not unsettle the microbial activity. For mesophilic fluctuations of ±3°C is allowed, without any change in gas production. [40]

Dry matter & Volatile Solids

The gas exchange is dependent on the dry matter(DM) and the volatile solids(VS) of the substrate. In Figure 14 a more detailed explanation of the DM and VS in the wet weight is illustrated.
In Table 4 the values for three possible feed-stocks for Bangladesh is seen.

### Table 4: Specifications for three commonly available feed-stocks in Bangladesh

<table>
<thead>
<tr>
<th>Feed stock</th>
<th>DM[%]</th>
<th>VS[% of DM]</th>
<th>Nm\textsubscript{CH\textsubscript{4}}/VS[tonne]</th>
<th>E\textsubscript{d}[kWh/Nm\textsuperscript{3}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow Manure</td>
<td>10-16</td>
<td>80</td>
<td>213</td>
<td>9.97</td>
</tr>
<tr>
<td>Slaughter Waste(Cow)</td>
<td>16</td>
<td>83</td>
<td>434</td>
<td>9.97</td>
</tr>
<tr>
<td>Sugar Cane</td>
<td>25</td>
<td>94</td>
<td>413</td>
<td>9.97</td>
</tr>
</tbody>
</table>

#### 4.4.2 Co-digestion

**Manure**

Due to the composition of manure, with a high water content and it being already digested anaerobically in the stomach of the cow, it has a low potential for CH\textsubscript{4}-production but is a very stable base-substrate.[3]

A problem with manure is that it contains ligno-cellulose, which is difficult to break down for the bacteria. This will affect the time of production for the methane making it so that the manure will have to be digested for a longer period of time to achieve maximum biogas yield. Manure is also nitrogen-rich which affects the C:N ratio.
When using manure as a base-substrate in the digester, co-digestion of another feedstock is often done as to decrease the HRT and increase CH$_4$-yield as well as balancing the C:N ratio. \[40\]

**Bagasse**

One type of possible co-digestion substrate that is abundant in Bangladesh is Bagasse. Bagasse is the fibrous matter left as residue after crushing sugar cane to extract the juices. The bagasse has a high carbon content which makes it an attractive co-substrate when using manure as a base-substrate.

**4.4.3 Digesters**

There is a range of different digesters to consider. Intended area, availability and composition of feed stock as well as if the substrate will be delivered dry or wet will be deciding in the choice of digester.

Typically the digestion chamber is constructed with concrete or steel, regardless of type. If concrete is chosen as the material, the inside of the chamber needs to be treated before production is initiated to prevent the biogas from breaking down the walls. \[40\]

**Batch Digester**

The batch process is commonly used for dry, 30-40% solids content, substrates. The feedstock is fed in batches to the digester where the gas production initiates. The gas production will increase, peak, decrease and finally cease. At this stage the digester is opened and approximately half of the batch is removed. The remaining substrate is left as inoculum for the next batch of feed stock. Liquor formed from the substrate is typically extracted and recirculated in closed loop to shower the batch repeatedly so acclimated bacteria is introduced to the batch. \[3\]

Due to this process the effective retention time of substrate is twice the period between feedings. The advantage of this process is the simplicity. Due to the high solids content only a small amount of thermal energy is needed for heating. Contaminants are a small problem as there is no moving parts in the digester to be obstructed. The feeding system is simple and often existing equipment at the site is possible for insertion and extraction of feedstock.

The main disadvantage is that, due to the simplicity, the methane production of CH$_4$ per kg feed stock may not be maximized.
This type of digester might be operated as a single step with only one digester, but commercially a multi-step process is usually employed to achieve homogeneous production of gas. An illustration of both a single- and multi-step process is shown in Figure 15.

The most common type of batch digester is the dome-type, which is used extensively in countries such as India and China.

Figure 15: I). A single stage digester with recirculation of substrate liquor. II). A multi-step digester system with recirculation of substrate liquor.
Continuous Digester

As opposed to the batch digester, the continuous flow digester (CF) has a constant flow without any process interference for extraction of the batch. This type of digester is the most experimented type of AD-digester and allows for much more control of digestion in the form of temperature, volume-flow and retention time. It is more technically advanced and sensitive than the dry-batch digester, but allows for more maximized biogas production due to the possibility of process-control.

There is two main types of operating CF, dry continuous and wet continuous.

**Wet Continuous.** Substrate with solids contents between 2%-12% is considered wet and is used in continuously stirred tank reactors (CSTR). The substrate is fed into the digestion chamber where it is stirred to ensure a homogenized slurry as well as preventing sedimentation or floats on the surface. The retention time in the reactor has to be higher than the doubling time of the bacteria to prevent washout in the reactor. [40]

This system may be operated as a single step but it is more common to employ a two-step system where all bacterial groups are present in each step. A two-step system allows for recycling of liquid digestrate from the second vessel which helps with the dilution of the feed stock as well as balancing the bacteria concentration. Generally, most of the bio gas is produced in the first step. [40][3]

A wet continuous plant may also employ two-phase systems, where the bacteria groups is separated in different vessels and introduced along the way. This type of reactor is seldom used at commercial scale due to its experimental status.

**Dry Continuous.** The dry continuous digester, where substrate with solids content typically between 12%-15% is fed to the digester, is usually done via plug flow. [40]

The reactor can be either horizontal or vertical, and is typically heated with hot water pipes which runs on the inside of the digester tank. One example of such a digester can be seen in Figure 16.

The substrate is first transported to a tank where it is mixed with water to homogenize and obtain optimal consistency before feeding in to the digester. The substrate is then fed from the inlet of the digester, pushing older substrate towards the outlet and digesting at the same time, forming "plugs" in the digester. Typically effluent will be recirculated to inoculate the fresh substrate. The digester will have a digestion gradient, and theoretically if the tube is long enough all the VS will be degraded when reaching the outlet. [40]
This would result in a less contaminated effluent than for a completely mixed digester, but in practice the friction of the walls and convection currents will result in mixing of new and old substrate.

Figure 16: A vertical plug flow digester with effluent reintroduction.

4.4.4 Hygienization

Depending on the utilization of the effluent, if it is to be sold as fertilizer, run through a waste treatment plant or in a compost, the substrate might need to be sanitized before final storage. The need for hygienization is mainly dependent on the concentration of contaminants in the substrate. The regulations for hygienization is different for different countries.

Hygienization is usually done by pasteurizing the substrate by heating it up to 70°C in a separate chamber and cooling it down to the desired temperature before feeding it into the digester. [40]

If the goal is to remove pathogens from the substrate, raising the temperature of the digestion chamber above the mesophilic range will serve the same purpose, eliminating the need for a separate hygienization chamber but increasing the overall retention time of the substrate.

4.4.5 Heat Losses Through Chamber Walls

The chamber walls and floor of the biogas chamber will conduct heat from the substrate to the surrounding, and to minimize these losses it is recommended to insulate the walls.

These losses is illustrated in Figure 17 and Figure 18 below.
Studies have shown that the losses only accounts for 2-8% of the total energy demand of the biogas plant.[29]

4.4.6 Slurry as Fertilizer

The effluent from the digester, called slurry, contains easily accessible macro-and micro-nutrients and is suitable as fertilizer if sufficient quality is reached. The quality and composition of the slurry is dependent on the type of the composition and type of the feed-stock used for the biogas-production.

The three most important features of fertilizer-grade slurry is:

- Purity. The slurry must be free of physical impurities
- Sanitation. The slurry must be free of pathogens and other undesired biological contents
• Safety. The slurry must be non-toxic for living organisms and the environment.

The slurry can be used directly as fertilizer, if sufficient quality, but it can be upgraded to increase concentration and transportability.

There is many technologies for upgrading slurry to fertilizer-grade, but the most common and simple way is to separate the solids and liquids. The solids can then be used directly or composted and dried to ease transportation. The liquids can be used directly as fertilizer as well, but a more common utilization is re-feeding it to innoculate the ingoing feedstock in the digester.[40]

4.5 Power Production

The main power components needed in the tannery is heat and electricity. The Bangladeshi national grid is very unstable and a industry connected to the power grid will need extensive sectioning of important and heavy duty machinery as well as installing back-up power, usually in the form of diesel engine.

Böle Garveri AB wants their new tannery to be as environmentally friendly as possible and to depend on the national grid as little as possible. Alternatives to diesel engines and the national grid was therefore examined.

4.6 Electricity

Biogas

Production of electricity with biogas is done either via a combustion engine or in a gas turbine. The type of machine used is depending on the scale of the biogas plant, where a gas turbine would be used for a medium to large scale plant as opposed to the engine which would be used in small to medium scale.

Typically, a gas turbine will have a higher efficiency at 35-40 % on average compared to a combustion engine which only has an average of 18-20 %. The choice of machine used for electricity production is dependent on the economy as well as the size of the plant.[40] [30]

Solar Power

With an average of 177 of sun hours per month across the year Bangladesh has a high potential for solar power and sun produced electricity is responsible for almost 10% of Bangladesh’s total electricity production. [12]
The most common way to harness the sun is to install solar panels on the roof or other large, unshaded areas. On average, a commercially available solar panel has an efficiency of 15-25% at optimal angle. The optimal angle of the solar panel is different during the year, and to optimize the power production a solar tracking panel might be installed. These are more expensive than standard, immobile solar panels but ensures a more steady supply throughout the year.

4.6.1 Heat

Biogas

It is possible to provide space heating with biogas by combustion of the gas in a furnace to heat water which is then lead into the building.

Solar Power

Another applications for solar power is solar collectors, which coupled with an accumulator tank provides a steady supply of hot water throughout the year. There is several different types of solar collectors, but the most common type is flat plate collectors. These consists of a insulated container with a dark absorber plate bottom and a flat, transparent top to allow the solar rays to hit the absorber. Inside the absorber there are fluid passage ways where the fluid is circulated to be heated.

The efficiency of a solar collector system is between 60-80%.

4.7 Co-Production

There is also a possibility of co-producing electricity and heat. The waste heat from the combustion of gases can be harnessed to heat water, usually by running water through pipes constructed on the outside of the machine used for combustion. This is the most efficient way of harnessing the energy from the combustion increasing the overall efficiency of the plant to up to 90%. [30]

Solar collectors and solar panels can be combined to produce both heat and electricity when installed on the same roof, but choosing either heat or electricity is more preferable as to optimize the installed area when available area is a limiting factor.

4.8 Micro-Grid

Böle-Garver AB has the ambition to distribute the excess power to nearby communities. One way to do this is to generate abundant amount of electricity which can be distributed via power-lines to villages and thereby ensure that their electrical demands are met. To distribute the electrical power generated from the biogas plant and solar
panels, a transmission system needs to be built. This grid will be isolated from the national grid and will therefore be unaffected by the frequent blackouts, but will in turn be unable to rely on the national grid for backup power if something were to happen to their own generation.\cite{2}\cite{18}
5 Method

5.1 Energy Mapping of Tannery

In Figure 19 below the energy map of the tannery is presented with prospective sources of process streams.

Figure 19: Energy map of Böle Garveri’s new tannery in Bangladesh

A compilation of the most important energy demands can be seen in Table 5.
Table 5: Energy demand of tannery

<table>
<thead>
<tr>
<th>Unit</th>
<th>Energy per tone product [MWh/t]</th>
<th>Energy per year [MWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal</td>
<td>2</td>
<td>166</td>
</tr>
<tr>
<td>Electrical</td>
<td>0,8</td>
<td>60</td>
</tr>
</tbody>
</table>

5.1.1 Expected Energy Requirement of Sewing-Compound

A sewing factory might be built in the vicinity of the tannery, and it is therefore of interest to know the need for electricity and heat, which might be taken into account when the power production is dimensioned.

5.1.2 Electricity Requirement

The electrical power and operating hours for all equipment with electrical demand are noted to estimate the amount of electricity needed for the entire sewing compound. This can be seen in Table 6. The values from the machines are taken from Appendix 77.

Table 6: Electrical demand per unit

<table>
<thead>
<tr>
<th>Unit</th>
<th>Quantity</th>
<th>Total demand[kW]</th>
<th>Daily demand[kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>20</td>
<td>1,2</td>
<td>14,4</td>
</tr>
<tr>
<td>Fans</td>
<td>5</td>
<td>0,75</td>
<td>9</td>
</tr>
<tr>
<td>Sewing Machines</td>
<td>40</td>
<td>20</td>
<td>301</td>
</tr>
<tr>
<td>Other Machines</td>
<td>31</td>
<td>17,62</td>
<td>141</td>
</tr>
</tbody>
</table>

5.1.3 Heating & Cooling

The factory will only be cooled by fans and will not have any air-conditioning. Heating of the factory will therefore not be considered.

5.2 Composition of the Hides

Information regarding the hides is necessary in many of the calculations that will be carried out throughout the report and will be presented here. The measurement of hides differs, the approximation that will be used are \(1,50 \times 1,4m\) or \(2,8m^2\). The thickness varies between \(0,004 - 0,008m\) but the higher value of \(0,008m\) will be used in calculations. The raw hide weights 20\(kg\) when it is delivered to the tannery.[36]
5.2.1 Calculation of CP

The raw hides can be divided into skin, meat and fat. The specific heat for these individual components, seen in Table 7 are used in Equation (33) to calculate the approximate specific heat of the hide.[39]

Table 7: The basic components of raw hides and their specific heat

<table>
<thead>
<tr>
<th>Component</th>
<th>Fraction[%]</th>
<th>Specific Heat[kJ/kg,K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin and Hair</td>
<td>20</td>
<td>1.30</td>
</tr>
<tr>
<td>Meat</td>
<td>60</td>
<td>3</td>
</tr>
<tr>
<td>Fat</td>
<td>20</td>
<td>2.5</td>
</tr>
</tbody>
</table>

\[
C_{p_{hide}} = \left( C_{p_{skin}} \times \%_{skin} + C_{p_{meat}} \times \%_{meat} + C_{p_{fat}} \times \%_{fat} \right)/100 \tag{33}
\]

5.3 Transportation of the Raw Hides

The livestock will be slaughtered and processed in Padma and then transported to the tannery located in the Bagatipara municipally. This route, which can be seen in Figure 20 is approximately 60km, and will take up to 2hours to travel.[36]
The transportation will be done by truck, running on diesel. Böle Garveri AB is currently looking at the truck *Tata Super Ace*. This model is available as an insulated truck, or with built in refrigeration. The questions handled in this section is listed below.

- What temperature will the hides reach during transport with the different options?
- What is the fuel consumption of the truck and how big are the resulting emissions?
- What is the required power from the heat pump and is it necessary?
5.3.1 Fuel Consumption & Emissions

Calculations are carried out to estimate the emission and fuel consumption the transport will contribute with. The fuel consumption and emissions of the truck is summarized in Table 8.[25][33]

<table>
<thead>
<tr>
<th>Model</th>
<th>Consumption [l/mile]</th>
<th>CO₂ [g/l]</th>
<th>NOₓ [mg/km]</th>
<th>CO [mg/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tata Super Ace</td>
<td>0.56</td>
<td>2640</td>
<td>180</td>
<td>500</td>
</tr>
</tbody>
</table>

The total distance \((D_{\text{month}})\) and \((D_{\text{year}})\), must be calculated to be able to analyze the emissions and energy requirement for the truck. The truck must drive back and forth between the tannery and the slaughter house each delivery, a distance which is equal to \(2 \times D = 120\, \text{km}\). There will be approximately 52 deliveries in a year.[36] Which gives \(D_{\text{month}} = 1000\, \text{km}\) and \(D_{\text{year}} = 12500\, \text{km}\). The energy density of diesel, used to calculate the energy requirement of the truck, is approximately \(M_{\text{diesel}} = 35.8\, \text{MJ/L}\). The cost of diesel in Bangladesh is approximately 65 taka/L or 6.5 kr/L.[21] The increase in fuel consumption as an increase in payload will be estimated as an linear increase, as can be seen in Equation 34. This will only be applied on the way to the tannery and not on the drive back. The weight of the truck is \(m_{\text{truck}} = 1700\, \text{kg}\).[25]

\[
m_{\text{increase}} = \frac{N_{\text{hide}} \times m_{\text{hide}} + m_{\text{truck}}}{m_{\text{truck}}} \tag{34}\]

When the total consumption of fuel has been calculated the resulting transportation cost, required energy and the total emissions can be acquired.

5.3.2 Temperature Rise During Transportation Without Additional Cooling in Uninsulated Truck

To make sure that the hides reaches the tannery in acceptable condition, it is of interest to know what temperature the hides will obtain during transport, when there is no additional cooling in the truck. The temperature change of the hide will be calculated with Equation (8) for each minute of travel. The surrounding temperature will be decided by the mean temperature during 3 different periods of the year, to see when additional cooling might be needed. It is assumed that the hides are cooled when they leave the slaughterhouse, and the initial temperature will therefore be set to 4°C. The area of the hide will be simplified as a rectangle with measurements taken from Section 5.2. The specific heat is calculated in Equation (33). The average weight of the hide is used as \(M = \rho \times V\). The convection coefficient \(h\) is calculated each minute from the film temperature with Equation 11, 12, 13 and 14. The temperature change over the time of transport can then be plotted.
5.3.3 Temperature Rise During Transportation Without Additional Cooling in Insulated truck

To calculate the temperature rise inside the insulated truck during transport, the heat rate into the truck needs to be known. It is calculated with Equation 5 in the same manner as for the case of the cooled truck, but the inside temperature is varied as a result of the heat transfer. The simplification made are that the temperature of the ambient air in the truck and the hides rises simultaneously, and that the specific heat for the hides and the ambient air is kept constant. The temperature can then be plotted with the linear relationship seen in Equation 35 for each hour. The specific heat and density of the ambient air at atmospheric pressure is $C_{p_{\text{air}}}$ = 1,0035 and $\rho_{\text{air}}$ = 1,225.

\[
T = T_0 + \frac{\dot{Q}_{\text{trans}} \times 3600}{m_{\text{hide}} \times N_{\text{hide}} \times C_{p_{\text{hide}}} + (V_{\text{truck}} - V_{\text{hide}} \times N_{\text{hide}}) \times C_{p_{\text{air}}}}
\] (35)

5.3.4 Active Cooling During Transport

As the distance between the tannery and the slaughterhouse is great, there might be a requirement to apply cooling during transportation to avoid damage to the product. The proposed truck model has a built in air to air heat pump to accommodate for the cooling requirement. To calculate the energy required to keep the hides cool, the assumption is that the hides are 4°C when they enter the truck. The surrounding temperature ($T_{\infty}$) is taken for each month. No regards will be taken to the forced convection on the outside of the truck as it is driving. The dimension of the truck are shown in Table 9, the walls are 0,104m thick and consists of 0,096m polyurethane foam with a thermal conductivity of $k$ = 0,026W/m, K in between 2 sheets of panel, each 0,004m and a conductivity of $k$ = 121W/m, K.[25] The transmission into the truck can then be calculated with Equation 5.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>2,42</td>
<td>m</td>
</tr>
<tr>
<td>Width</td>
<td>1,25</td>
<td>m</td>
</tr>
<tr>
<td>Height</td>
<td>1,66</td>
<td>m</td>
</tr>
<tr>
<td>Walls</td>
<td>6,09</td>
<td>m²</td>
</tr>
<tr>
<td>Roof</td>
<td>3,01</td>
<td>m²</td>
</tr>
<tr>
<td>Floor</td>
<td>3,01</td>
<td>m²</td>
</tr>
<tr>
<td>Volume</td>
<td>5</td>
<td>m³</td>
</tr>
</tbody>
</table>
The installed cooling pump is engine driven. The coefficient of performance is not specified, but heat pumps of similar model does have a coefficient of performance of $COP = 1.8$, and this value will therefore be used in the calculations.[22] The power required for the cooling pump each month can be calculated with Equation 24. The total increased in required energy will be added to the total energy requirement for the truck. This in turn will result in an increased fuel consumption as the pump gets the required power from the alternator. The alternator efficiency will be estimated to a value of $\eta_{alt}$. The increase in fuel consumption can then be estimated with Equation 37.

\[
P_{\text{cooling}} = \frac{W_{\text{cooling}}}{\eta_{\text{alt}}} \tag{36}
\]

\[
V_{\text{cooling}} = \frac{P_{\text{cooling}} \times 3600}{m_{\text{diesel}}} \tag{37}
\]

5.4 Cooling and Storage of Raw Hides

The fresh hides will be transported directly from the slaughterhouse and will therefore not be conserved in salt or other preservatives. The hides mainly consists of water and protein, and will decompose if left untreated.[36][26] This process is sped up in Bangladesh due to the high temperature and moisture content in which microorganism thrive. This means that they will have to be cooled until they enter the first stage of the tannery process. To keep the hides from sustaining damage, a temperature of 0-4 degrees will have to be kept.[36]

Two different methods will be analyzed in this section, the cooling of hides in a cold room and in a water cooling tank. Firstly the common problems with the two methods will be discussed after which the design of the individual solutions will be done. Lastly the method of deciding and dimensioning the cooling system will be analyzed. The questions handled in this section is listed below.

- What is the optimal design for each of the analyzed options in terms of energy efficiency, storage capacity and cost?
- How big is the required cooling effect for the different alternatives?
- What is the cost for the analyzed options?
- Which of the two options is recommended?
Cooling Capacity

The hides will be supplied to the tannery from the slaughterhouse by truck. One truckload will in average contain 36 hides, with a 5% deviation. The tannery process will require a steady flow of hides and the need will therefore be seen as constant throughout the year, with a value of $N_{\text{min}} = 72$. This will be seen as the minimal storage capacity that the storage solution should have.[36]

It is important that hides are available in the storage at all times so that the process stops as a result of storage shortage are eliminated. A buffer might therefore be required. The buffer ($N_{\text{buffer}}$) will account for $N$ number of batches, each containing 31 hides.

As Böle Garveri AB will own their own cows, the availability of hides will not be dependent on the external market. But there is a big increase in demand for meat during seasons with big religious festivities, which occurs in intervals of about 2.5 month.[36] This means that the company will benefit from slaughtering cows during these periods. As the hides are delivered to the tannery shortly after the slaughter process is done, the amount transported might increase during these periods. In practice this means that the amount of hides stored in the cold storage will also increase. The allocated buffer space will also cover this increase.

$$N_{\text{dim}} = N_{\text{buffer}} + N_{\text{min}}$$  \hspace{1cm} (38)

Initial cooling requirement and cooling time for the hides

The assumption is that the fresh hides are cooled to the final temperature $T_c$ when delivered to the tannery. But if the hides instead have an initial temperature of $T_i$ when placed into the cooling room or tank, additional cooling will be required, equal $Q_{\text{hide}}$, which is calculated in Equation (39). This scenario is seen as plausible and will therefore be examined.

$$Q_{\text{hide}} = m_{\text{hide}} \cdot C_{p_{\text{hide}}} \cdot (T_c - T_i)$$  \hspace{1cm} (39)

The cooling time for the hide will differ if it is placed in water with 2°C or air with 2°C. The temperature change of the hide will be calculated with Equation (8). The surrounding temperature ($T_\infty$) are set to be constant and the initial temperature of the hides will be varied to see how that effect the cooling time. The convection coefficient $h$ is calculated each minute from the film temperature with Equation 11, 12, 13 and 14. The properties will also vary between water and air. The temperature change can then be plotted.
For the case of air, the temperature change will also be calculated if the air is blown over the hides, in other words, when forced convection is applied. This is done to visualize the decreased cooling time as a function of airflow. The same methodology will be used as in the case of free convection, but the Nusselts number will instead be calculated with Equation 17 and 18.

Maximizing Heat Transfer

To maximize heat transfer between the cooling medium and the hides, Equation 7 is studied. If the area of contact \( A \), between the hides and the cooling medium increases, the heat transfer will increase linearly. In practice this means that touching between the hides though folding or wrinkling during cooling should be avoided. This can be done by suspending the hides. The natural convection is higher from a vertical surface than a horizontal, as seen in Equation 11. The hides should therefore be hanged vertically.

The cooling process can also be sped up by increasing the convective heat transfer coefficient. This can be done by not letting the water or air around the hides stagnate, as this medium will warm up and lessen the temperature difference between the hide and the medium in close proximity and thereby lower the heat transfer rate. As can be seen in Equation 18 and 17, an increase in the velocity of the medium will increase the Nusselts number and thereby the heat transfer coefficient. This can be solved either by keeping the water in motion with the help of a pump or actively moving the hides around. In the case of air, a fan can be easily implemented.

5.4.1 Water Cooling

The concept of the method is simple. The raw hides are kept in a chilled tank, filled with water that have a low enough temperature to keep the hides from decaying. Although the simplicity of the method, there are several questions that has to be taken into consideration.

- What is the optimal dimensions for the tank?
- What insulating material should be used and how thick should it be?
- How should the tank be cooled?
- What is the cost for the analyzed options?
Tank Size and Design

The size of the tank ($V_{tank}$) has to be dimensioned properly to make it sufficient for the task but still energy efficient. If the tank is too small, the hides may not have enough space. Large tanks lead to a higher cooling requirement as the cooled volume of water and transmission area increases.

There can be assumed that every hide will be of similar size. The dimensions for the hide width ($W_{hide}$), thickness ($T_{hide}$) and height ($H_{hide}$) are given in Section 5.2. The distance between each hide and the distance from the hide to the tank wall will be set to $f = 0.03$ m, as requested. In the first design it is assumed that the hides are not folded, but hanged vertically in the tank. The distance from the hide to the tank lid and from the hide to the bottom of the tank will be summed to $f_h = 0.13$ m. This horizontal buffer distance is there to make room for the rack on which the hides will be suspended and to keep the hides from touching the tank bottom. The number of rows ($N_{row}$) of hides in the tank will decide how long and wide it will become. The parameters of the basic tank design can be seen in figure 21.

![Figure 21: The dimensioning parameters of the tank](image)

The volume of the tank will then depend on the dimensioned number of hides $N_{dim}$ and the number of rows chosen and is calculated with Equation (43).

$$W_{tank} = N_{row} * W_{hide} + f * (N_{row} + 1)$$ (40)
\[ L_{tank} = 2f + T_{hide} \times \frac{N_{dim}}{N_{row}} + f \times \left( \frac{N_{dim}}{N_{row}} - 1 \right) \]  \hspace{1cm} (41)

\[ H_{tank} = H_{hide} + f_h \]  \hspace{1cm} (42)

\[ V_{tank} = L_{tank} \times H_{tank} \times W_{tank} \]  \hspace{1cm} (43)

If the hides instead are folded over a rack in the tank, the dimensions for \( L_{tank} \) and \( H_{tank} \) will be calculated with Equation 44 and 45 instead.

\[ L_{tank} = 2f + 2T_{hide} \times \frac{N_{dim}}{N_{row}} + 2f \times \left( \frac{N_{dim}}{N_{row}} - 1 \right) \]  \hspace{1cm} (44)

\[ H_{tank} = \frac{H_{hide}}{2} + f_h \]  \hspace{1cm} (45)

The volume of the tank will be plotted as a function of the number of stored hides, for both folded and unfolded hides.

**Insulation of Tank**

As it is assumed that the tannery will not be actively cooled, the air outside of the tank will be \( T_\infty \), which is the same temperature as the air outside the tannery. To avoid heat transfer from the surroundings the tank must be properly insulated. The important parameters are the overall thermal conductivity (\( U \)) of the tank elements, and the element thickness (\( t \)). The choice of material will highly effect these parameters.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity [W/m, K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyurethane</td>
<td>0.024</td>
</tr>
<tr>
<td>Phenolic Foam</td>
<td>0.02</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>16</td>
</tr>
<tr>
<td>Concrete Slab</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Table 10: Thermal Conductivity for different materials

When the size of the tank has been dimensioned, different materials from Table 10 with varying thickness will be tested to see how they effect the cooling requirement of the tank. This will be done with Equation 5. The surrounding walls of the tank will be made up of insulation between two layers of stainless steel. The overall heat transfer
The coefficient of the building elements is calculated with Equation 4. The thickness of the surrounding steel frame of the elements and the concrete slab below the tank will be kept constant, as shown in Table 11. The thickness of the steel are taken from analyses of commercially used tanks.

**Table 11: Thickness of steel frame and concrete slab**

<table>
<thead>
<tr>
<th>Element</th>
<th>Thickness [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>0.01</td>
</tr>
<tr>
<td>Lid</td>
<td>0.005</td>
</tr>
<tr>
<td>Floor</td>
<td>0.01</td>
</tr>
<tr>
<td>Concrete Slab</td>
<td>0.3</td>
</tr>
</tbody>
</table>

The tank lid will not be completely designed but the weight of the lid might have to be taken into consideration, as it should be possible for 1 person to operate the tank. The resulting weight of the lid as a function of insulation thickness will therefore be plotted with Equation 46.

\[ m_{lid} = \rho_{steel} \times V_{frame} + \rho_{insulation} \times V_{insulation} \] (46)

The top part of the tank does not need to be filled with water as this is where the suspension rig will be located. This will result in an air pocket that will insulate the tank further. This installation layer will be estimated to \( H_{ins} = 0.1 \) m. This means that a lessened insulation thickness for the lid is acceptable. The thermal conductivity of air is \( k_{air} = 24.74 \times 10^{-3} W/m, K \) which will be added as an insulating layer in the transmission calculations.

**Cleansing of Cooling Water**

As the hides are transported directly from the slaughterhouse, they will be polluted with unwanted byproducts from the process. This will mean that the cooling water becomes contaminated with time. This contamination can be minimized by moving the first washing stage before storage.

Another precautionary step is to continuously clean the water with the help of a pump and filtration-system. This system will pump the water out of the tank, filtrate it and then pump it back in. This solution will also make sure that the water inside the tank does not stagnate as the pump will keep the liquid in motion.

Even if this is done, the risk of water pollution with time is still almost certain. This means that clean water has to be added to the tank to keep the pollution level at a reasonable level. The energy required for a complete change of water can be calculated with Equation 47. If the choice is made not to use a filtration system, the number of changes in a month will increase.
\[ Q_{\text{change}} = V_{\text{tank}} \times \rho_{\text{water}} \times C_{p\text{Water}} \times (T_{\text{in}} - T_{\text{final}}) \] (47)

Depending on the time \((t_{\text{cooling}})\) that the volume of water needs to be cooled, the additional power-requirement of the cooling system can be calculated in Equation 48. The power needed for an complete change of water will be plotted as a function of the cooling time.

\[
P_{\text{change}} = \frac{Q_{\text{change}}}{t_{\text{cooling}}} \] (48)

If the change is done as a continuous flow of water in and out of the tank, the volume flow of water in \(l/h\) can be calculated with Equation 49, where \(n_{\text{change}}\) is the number of changes in a month. The corresponding energy flow is calculated with 50. If this is done instead of a change of the entire mass of water, the cooling tank will still be operational during the change. If all water is changed in one instance, the tank will be unusable for a time equal to \(t_{\text{cooling}}\).

\[
\dot{V}_{\text{change}} = \frac{V_{\text{tank}} \times n_{\text{change}}}{0.72} \] (49)

\[
q_{\text{change}} = \dot{V}_{\text{change}} \times \rho_{\text{water}} \times \Delta T \] (50)

**Cooling requirement of the tank**

The cooling requirement for the tank will be a sum of the heat flows into the tank that have been shown in this section, as can be seen in Figure 22. The total equation for the heat rate can be seen in Equation 51.
Cooling With Heat Pump

A heat pump can be implemented to efficiently transport the excess heat away from the tank. This will provide an energy efficient and reliant method of cooling the water. The basic principle of the heat pumped is explained in Section 4.2.1. The medium of the stream connected to the the evaporation-side of the heat pump will be water, but the medium on the condensing side may be either air or water. As the heat transfer into the tank is known, the effect of the cooling system can be dimensioned. The dimensioning factors are the following:

1. \( P_{\text{cooling}} > q_{\text{tank}} \)
2. The initial cooling time of the hides must be shorter than \( t_{\text{dim,hide}} \)
3. Lowest possible cost
4. The initial cooling time of the water must be shorter than \( t_{\text{dim,water}} \)

Where the dimensioning cooling time \( t_{\text{dim}} \) will be evaluated with Equation 52 for both cases. \( Q_{\text{initial}} \) is the initial amount of heat that has to be removed from the mass of water or the hides.

\[
t_{\text{dim}} = \frac{Q_{\text{initial}}}{P_{\text{cooling}} - q_{\text{tank}}}
\]  

\( q_{\text{tank}} = q_{\text{transmission}} + q_{\text{initial}} + q_{\text{change}} \)  

(51)
The cooling will be done by coils, which can be positioned either in the tank itself, on the outside of the tank or in a smaller external tank, which will cool the water that can then be pumped into the main tank.

**Cooling With Added Ice**

An alternative to the heat pump is to cool the tank by adding ice. The ice will continuously melt and cool the tank. Enough ice has to be added in intervals to keep the tank cool. The method is simpler but less energy efficient. The mass flow of ice \( \dot{m}_{\text{ice}} \), that has to be put into the tank must be calculated before the ice-machine can be dimensioned and chosen.

\[
Q_{\text{ice}} = m(C_{P_{\text{ice}}}(T_1 - 0) + L_t + C_{P_{\text{water}}}(0 - T_2))
\]

Where \( L_t \) is the latent heat for ice and are given in kJ/kg. \( T_1 \) and \( T_2 \) are the starting temperature of the ice and the final temperature of the water. In equation 54 \( Q_{\text{ice}} \) is substituted by \( q_{\text{tank}} \), which is calculated in Equation 51.

\[
\dot{m}_{\text{ice}} = \frac{q_{\text{tank}}}{C_{P_{\text{ice}}}(T_1 - 0) + L_t + C_{P_{\text{water}}}(0 - T_2)}
\]

The power requirement \( (P_{\text{ice}}) \) from the ice-machine can be calculated in Equation 55 with the known mass flow of ice \( (\dot{m}_{\text{ice}}) \) needed for the tank and the efficiency of conversion for the machine \( (\eta_{\text{machine}}) \).

\[
P_{\text{ice}} = \eta_{\text{machine}}\dot{m}_{\text{ice}}
\]

Additional mass flow out of the tank is required as the addition of ice will lead to an increase in water level.

**5.4.2 Cold Room**

The basic concept of the cold room is a simple insulated and refrigerated chamber with easy access to the hides. Heat transfer to the room will occur through transmission from the surroundings and infiltration, as can be seen in Figure 23.
Firstly the cooling power needed will be calculated for the refrigerated room in its most basic design, to get a reference case, after which energy-efficient solutions will be implemented and analyzed. The cooling system can thereafter be chosen and dimensioned. The questions that will be answered in this section is presented below.

- What is the optimal dimensions for the tank?
- What insulating material should be used and how thick should it be?
- How should the tank be cooled?
- What is the cost for the analyzed options?

**Cooling Required**

As can be seen in Figure 23, the cooling need for the room is the summation of all transmission heat flows and the heat flow from infiltration. It is assumed that the hides will arrive pre-chilled, but the case where it is not will also be studied. The internal gain of equipment and humans in the rooms will be neglected.

\[ q_{\text{cooling}} = q_{\text{transmission}} + q_{\text{infiltration}} + q_{\text{hides}} \]  

The amount of heat transferred will be directly correlated to the surrounding temperature. As the tannery will not be cooled, it is assumed that the air surrounding the cold room has the same temperature as outside the tannery.

The calculation procedure for the heat flows will firstly be explained, after which they will be applied to the different cases.
Transmission

As seen in Figure 23, different heat transfer rates has been labeled for each building element. This is due to the change in thermal conductivity between the different materials. This can be seen in Table 12. The contribution of convection to the heat transfer rate is simplified with a thermal resistance of \( R_{\text{tot}} = 0.17 \, m^2, K/W \) which is the sum of the thermal resistance on the inside wall \( R_{\text{inside}} = 0.04 \, m^2, K/W \) and on the outside \( R_{\text{outside}} = 0.13 \, m^2, K/W \), which in turn are set as an overall heating coefficient \( U \) in Table 12 with Equation (6).[15]

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity ([W/m, K])</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyurethane</td>
<td>0.024</td>
</tr>
<tr>
<td>Mineral Wool</td>
<td>0.036</td>
</tr>
<tr>
<td>Phenolic Foam</td>
<td>0.02</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>16</td>
</tr>
<tr>
<td>Aluminum</td>
<td>204</td>
</tr>
</tbody>
</table>

The walls and roof of the room is delivered as panels with variable thickness and a aluminum exterior frame. The doors are delivered with a polyurethane foam core of varying thickness and stainless steel exterior frame. The floor is made out of a coated concrete slab which can be insulated. A simplified view of the building elements can be seen in figure 24.

\[
q_{\text{trans}} = (T_{\text{in}} - T_{\infty}) \times ((U_{\text{wall}} + U_{\text{Conv}}) \times A_{\text{wall}} + U_{\text{roof}} \times A_{\text{roof}} + U_{\text{floor}} \times A_{\text{floor}} + U_{\text{door}} \times A_{\text{door}})
\]

\( (57) \)
Infiltration

Infiltration through the walls of a structure depends on the pressure difference between the inside and outside. This pressure difference is induced by the wind and the stack effect. The stack effect, is the pressure change that is created by the difference in density between the cold and hot air.[4]

Exchange of air will occur due to infiltration through the building elements and when the door is opened. The number of times that the air in the room changes in an hour \((N)\), is used to measure the flow of air into the room.[15]

\[
\dot{V}_{tot} = \dot{V}_{leakage} + \dot{V}_{door} \quad (58)
\]

\[
N = \frac{\dot{V}_{tot}}{V_{tot}} \ast 3600 \quad (59)
\]

For a modern residential building, the infiltration rate is approximately \(0.1 l/s\).[15] The cold room is located within the tannery and will therefore not directly be effected by the wind that cause increased infiltration. The cold room is also better insulated than a normal building. An estimation of the infiltration due to leakage will therefore set to \(\dot{V}_{leakage} = 0.01 l/s\). As 2 batches starts each week and 2 deliveries are made each week, the assumption is that the door into the cooling room will be opened 4 times for longer periods of times. The assumption is that one complete air change happens during this time. This is then calculated to an average volume flow in \(l/s\). The total heat transfer rate as a result of infiltration to the room can therefore be calculated.

\[
q_{infiltration} = \rho_{air} \ast \dot{V}_{tot} \ast C_{p,air} \ast (T_{in} - T_{\infty}) \quad (60)
\]

Simulation in IDA-ICE

The calculations explained in Equation 57 and 56 will be carried out by the software IDA-ICE, which is a simulation program for simulating energy flows and energy demands in buildings. The reason for this is that changes of parameters can easily be done and comparisons between cases are effective. No data is provided for Bangladesh by the program, therefore data will be taken from the city of Patna in India, which is close to the Bangladeshi border. The entire tannery will not be simulated and the cooling room will be seen as a stand alone building, with total cover from the sun. This is done as the assumption is that the temperature of the tannery will be the same as the surrounding air.
**The Basic Case**

To have a case to compare values towards, a basic case of the cooling room will be created. In this case, the measurements will be taken directly from the blueprints of the tannery provided by Böle Garveri AB, seen in Appendix 76. Not all measurements are given and the individual lengths are therefore taken out with the software *imageJ* from the two given lengths. The measurements are summarized in Table 13.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Dimensions [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>6.06</td>
</tr>
<tr>
<td>Width</td>
<td>3.18</td>
</tr>
<tr>
<td>Height</td>
<td>2.20</td>
</tr>
</tbody>
</table>

The wall and roof insulation-thickness is set to 50mm and *Mineral Wool* is chosen as the insulating material. For the door, the insulation thickness of the polyurethane core is set to 40 mm with 2 mm thick stainless steel exterior frame. The floor is left uninsulated. The cooling requirement can thereafter be simulated in IDA-ICE.

### 5.4.3 Energy Optimization

When the values for the basic case i acquired, the resulting difference in price, cooling requirement and storage capacity can be analyzed as changes are made in room dimensions, insulation thickness and insulation material.

**Change in Insulation Thickness and Material**

The 3 different materials from Table 12 will be analyzed in separate cases to see the resulting change in cooling requirement. The thickness of the insulating layer of the panels will be set to 50, 80, 100, 120, 150 and 200 mm, as these are common dimensions that are available by suppliers. The floor will also be insulated to see the effect.

**Maximizing the usage of space**

In the basic case, the measurements for the cooling room was taken directly from the blueprint. This design might not use the space optimally or might not accommodate enough space for all the hides to be stored. Calculation will therefore be carried out to optimize the use of space in the cooling room. The same methodology will be used as in Section 5.4.1. The difference in the cold room is that the entire height of the room can be utilized, and folded hides can therefore be placed above each other. Space also
needs to be allocated within the room for workers to move around. In addition to this all the hides much be easily accessible by the workers. A proposed simple design can be seen in Figure 25 and is variable with the number of hides in storage as well as the space allocated for the worker.

**Figure 25:** The design and dimensioning parameters of the cold room

The length and width of the room can be calculated with an Equation 61 and 62.

\[ L_{\text{room}} = \frac{N_L}{2} \ast (T_{\text{hide}} + f) + W_{\text{hide}} + 3f + L_{\text{extra}} \]  
\[ (61) \]

\[ W_{\text{room}} = N_L \ast (T_{\text{hide}} + f) + 2(W_{\text{hide}} + 2f) + W_{\text{extra}} \]  
\[ (62) \]

Where \( N_L \) and \( N_W \) is the number of hides placed along the length of the room and width of the room respectively. \( N_W \) is chosen as the dimensioning parameter while the corresponding number of hides placed along the length of the room i simply calculated as the difference \( N_L = N_{\text{tot}} - N_W \). If extra space is needed, it is added as \( W_{\text{extra}} \) and \( L_{\text{extra}} \). The resulting space not occupied by the hides is calculated with Equation 63 and 64.

\[ W_{\text{move}} = W_{\text{room}} - 2(w_{\text{hide}} + f) \]  
\[ (63) \]
\[ L_{\text{move}} = L_{\text{room}} - (w\text{hide} + f) \] (64)

The room can thereafter be dimensioned by varying the number of hides. The desired results can be calculated in both directions the hides are placed. The desired proportions of the room can then be calculated with the goal-seek function in Excel.

**Sectioning for Increased Efficiency**

If the demand for cooling space differs during a year, it might be a good idea to have the ability to change the volume of the room to accommodate this change. The theory is that the transmission-area decreases when one part is no longer actively cooled and therefore the heat transfer rate into the room decreases. The part of the room that is not actively cooled can also work as an entrance chamber. This will lessen the heat transfer rate through infiltration, as the temperature difference, which can be seen in Equation (60), decreases. This solution will require two separate heat pumps.

**Cooling Solution**

The cold room will be cooled with a compressor driven heat pump. The evaporator will be placed inside the room, preferably above the door. Integrated fans will increase the heat transfer through convection between the evaporator and the surrounding air in addition to mixing the air in the room. The stream connecting to the condenser can be chosen differently, as will be discussed in Section 5.4.5.

**5.4.4 Decision of Final Design**

When the different design options of the cooling room and the cooling tank have been analyzed, the final design will be decided through discussion in the form of a summarized table. The *Cost initial* of the solution is compared as *Taka/ stored hide* to get an estimation of how much each hide cost to cool. The same unit will be used for the moving costs, that are a sum of the cost of electricity and maintenance. The *Energy Efficiency* of the solution will be decided as the total amount of cooling required in a year per stored hide. The *Buffer Space* is the amount of space not dedicated to the hides or the movement of the workers, and can be used to store hides during an increase in transport or if the production capacity of the tannery increases.
5.4.5 Cooling Solution

As mentioned in section 4.2.3 the condenser side of the heat pump can be connected to a colder stream to increase efficiency. This can in practice be done in many different ways. The choice of geothermal cooling, river cooling or air cooling will be reached though discussion in the Result section, based on the facts listed in Section 4.2.3. The same methodology will be used to decide between the absorption heat pump and the compressor-driven heat pump.

5.5 Drying

The method for the dimensioning of the dryer will be explained in this section. As was explained in Section 4.3, the hot air dryer is one of the cheapest options and, after discussion with Böle Garveri AB, is the one that will most likely be implemented. Therefore calculations have only been done on this type of dryer.[36]

The questions that will be handled in this section is listed below.

- What is the dimensioned effect of the dryer?
- What is the theoretical efficiency of the dryer?
- What is the cost of the dryer?

Hot Air Dryer

Equation 30 and 29 can be used to calculate the theoretical energy requirement to evaporate the water of the hide. To see the effect of the dewatering process the moisture content before the main drying stage \( M_1 \) will be varied. There is also of interest to learn how much the final moisture content of the hides will effect the energy requirement and therefore the moisture content after the process \( M_2 \) will be varied.

When the energy required for the evaporation of water is known, the energy required for the dryer can be calculated. An energy balance was set up for the dryer as can be seen in 26.
The ingoing ambient air was set to the yearly average which is $T_1 = 26^\circ C$ and $RH_1 = 74\%$. The enthalpy ($h_1$) and absolute humidity ($Y_1$) was thereafter read from the molier diagram seen in Appendix 79, with the computer software Computer-aided Thermodynamic Tables 3 which is a software tool for thermodynamic calculations. The temperature ($T_2$) was calculated by interpolating the specific heat and the density. The absolute humidity was set to be constant $Y_2 = Y_1$. The enthalpy $h_2$ and the relative humidity $RH_2$ could then be calculated with Thermodynamic Tables. The temperature $T_3$ will initially be set to 150$^\circ C$. The absolute humidity will still be constant $Y_3 = Y_2 = Y_1$. The enthalpy $h_3$ and the relative humidity $RH_3$ could then be calculated with Thermodynamic Tables. The relative humidity of the wet air out of the dryer was approximated to $RH_4 = 90\%$ as the ideal humidity of 100% seldom occurs in real dryers.[16] The outgoing temperature was set to $T_4 = 55^\circ C$. The enthalpy $h_4$ and the absolute humidity $Y_4$ could then be calculated with Thermodynamic Tables. The difference in absolute humidity over the dryer, is the amount of water that has been taken up by the air per kilo air. The mass of water that has to evaporate is calculated with Equation 29. The mass flow of air needed into the dryer can then be calculated with Equation 65, where $t_{dry}$ is the dimensioned drying time.

$$\dot{m}_{air} = \frac{m_{ev}}{(Y_4 - Y_3) \ast t_{dry}}$$  \hspace{1cm} (65)

The heat requirement of the dryer can then be calculated with Equation 66. The dryer effect will be evaluated by changing the drying time $t_{dry}$.

$$P_{dryer} = (h_3 - h_2) \ast \dot{m}_{air}$$  \hspace{1cm} (66)

The efficiency of the dryer will be calculated with Equation 70 to see how much of the energy into the dryer is used for evaporation of water. The evaporation energy ($Q_{ev}$) and the initial heating of the hides $Q_{heat}$ is calculated with Equation 30 and is multiplied with the number of dried hides. The heat losses from the exhaust air out of the dryer ($Q_{ex}$) will be calculated with Equation 67 where it is compared to the ideal conditions of ambient air temperature of 26$^\circ C$ and a relative humidity of 100%.
The heat transferred in the first heat exchanger \( Q_{re} \) is subtracted from \( Q_{ex} \) as it is used to pre-heat the incoming ambient air. \( Q_{re} \) is calculated in Equation 68. The losses through the chamber walls and from infiltration \( Q_{loss} \) is estimated to 10% of the total input and is rewritten in Equation 69.

\[
Q_{ex} = (h_4 - h_{ideal}) \times (m_{air} + m_{ev}) \quad (67)
\]

\[
Q_{re} = (T_2 - T_1) \times m_{air} \times C_{p_{air}} \quad (68)
\]

\[
Q_{loss} = \frac{0.1 (Q_{ex} + Q_{heat} + Q_{ev} - Q_{re})}{1 - 0.1} \quad (69)
\]

\[
\eta_{dryer} = \frac{Q_{ev}}{Q_{ev} + Q_{heat} + Q_{ex} + Q_{loss} - Q_{re}} \quad (70)
\]

5.6 Power Production

5.6.1 Biogas

To estimate the possible biogas production the biogas plant was first designed to meet the total energy demand, i.e. both thermal and electrical, for the tannery. After this, the production was calculated as scaled up to sell electricity or gas directly to nearby communities. The type of digester considered was of plug-flow type at mesophilic temperature range.

5.6.2 Substrate Mass Flow

The mass of substrate needed on a daily basis was calculated from the needed volume of \( CH_4 \), given from Equation 71. below where the energy demand was given from Jan Sandlund and the energy density for \( CH_4 \) from Table 4.

\[
V_{CH_4} = P_{annual} \times E_{dCH_4} \quad (71)
\]

Equation 71 with the amount of \( CH_4 \) in VS of cow manure, also given from Table 4 gives Equation 72 from which the mass of substrate in tonnes VS is calculated.

\[
\dot{m}_{VS} = V_{CH_4} \times [m^3CH_4/VS[tonne]] \quad (72)
\]

For the total mass of manure needed, Equation 72 is multiplied with the percentage of VS and DM in given from Table 4.
The cow dung is assumed to be supplied to the plant via cart or truck, and is collected during the week from the farmers.

5.6.3 Co-Digestion With Alternative Feed-Stock

The possibility of co-digesting the manure with alternative feed-stock to maximize the methane-yield was examined. The co-substrates considered were slaughter-waste from cattle and sugar cane residues.

5.6.4 Digester

**Volume of Digestion Chamber**

For the effective volume of the digestion chamber the HRT was assumed to be 30 days, and from equation 74 the effective volume was calculated.

\[
HRT = \frac{V_{eff}}{V_{substrate}} \quad (74)
\]

With the effective volume the OLR is calculated with equation 73 and equation 75.

\[
OLR = \frac{\dot{m}_{VS}}{V_{eff}} \quad (75)
\]

The effective volume is not taking the volume of gas storage in consideration, so for the total volume of the digester equation 76 was used.

\[
Volume_{total} = Volume_{eff} + Volume_{CH_4} \quad (76)
\]

5.6.5 Energy Demand & Hygienization

The digester will have a demand for energy in the hygienization(if implemented) as well as losses to the surrounding.

To calculate this energy demand for heating the slurry as well as for the hygienization, the specific heat for the slurry was assumed to be the same as for water due to the low solids content.

Then equation 77 below was used.

\[
P = \dot{m}_{slurry} \times C_{p_{slurry}} \times (T_{in} - T_{out}) \quad (77)
\]
Heat Loss Through Chamber Walls

Due to uncertain digestion gradients and internal substrate flows, the heat losses from the digestion chamber could not be calculated accurately. Instead, a value of 5 % was assumed from theory on heat losses in biogas plants. [29]

5.6.6 Production Potential

To calculate the potential electricity production, assumptions for methane-yield and efficiency of engine was made. Then through Equation 78 the potential per day was given.

\[ P_{\text{daily}} = E_{\text{dCH}_4} \cdot V_{\text{slurry}} \cdot \eta_{\text{CH}_4} \cdot \eta_{\text{el}} \]  

(78)

The efficiency of the engine was assumed to be 30% and the methane-yield for the determined retention time was assumed to be at least 80 % of the total methane potential.

5.6.7 Solar Power

The solar panel system was calculated to supplement the biogas production and designed to allow for maximum distribution of biogas to surrounding communities while still maintaining profitability of the solar cell investment.

The needed area of solar cells to meet the demand is calculated from Equation 79 where \( \dot{q}_{\text{solar}} \) is given from manufacturer.

\[ A_{\text{solar}} = \frac{P_{\text{need}}}{\dot{q}_{\text{solar}}} \]  

(79)

Calculations for a solar collector system was also carried out in case the waste heat from the gas engine would not be enough to cover the thermal energy demand. To determine the area of the system Equation 80 was used.

\[ A_{\text{solar}} = \frac{Q_{\text{demand}}}{\dot{q}_{\text{sun}} \cdot \eta_{\text{solar collector}}} \]  

(80)

5.6.8 Water Consumption

Knowing the water consumption for the tannery and for the biogas plant is important as fresh water is not abundant and is rather used as drinking water than process-water.
To evaluate the possibility of re-circulation, the volume flows and temperature of the process water was analyzed to investigate the impact on the system and the digestion process in the biogas plant.

5.7 Economy of Power Production

When evaluating the process techno-economically, the investment (CAPEX) and capital gain (Revenue) is compared to gage if the project is feasible. To compare this some economical parameters are considered.

The main parameter is the net cash flow (NCF), given from Equation 81.

\[ \text{NetCashFlow} = \text{Netincome} - \text{Grossincome} \]  

(81)

When calculating the gross income, the write-off \((C_cD)\) has to be considered. This is the depreciated value of the investment each year. This is given from Equation 82.

\[ C_cD = a \times CAPEX \]  

(82)

Where \(a\) is

\[ a = \frac{i(1 + i)^n}{(1 + i)^n - 1} \]  

(83)

and \(n\) is the economical lifespan and \(i\) is the real interest rate. The pay-back time (PBT) was then calculated with Equation 84

\[ PBT = \frac{CAPEX}{NetCashFlow} \]  

(84)

Then, to gage the value of the investment after the economical life span, the net present value (NPV) was calculated with Equation 85

\[ NPV = \sum \left( \frac{(R_j - C_{opex,j}) \times (1 - (1 + r)^j)}{r} \right) C_{CAPEX,j} \]  

(85)

To analyze the economy of the biogas plant, four cases where considered. As the technical life-span for the equipment and the chamber differ with 10 years, at 10 respectively 20 years, two separate depreciation calculations where carried out.

Every case is calculated with 6 different pricing models, one base case and 5 alternatives. The base case uses prices and costs cited by Böle Garveri and literature. [37] [8]

The 5 alternatives uses prices and costs found in literature or providers. [38] [37] [31]
The four cases are designed with Bøle Garveri’s wishes in mind. For the first case the biogas plant was designed to cover the internal electricity need for the tanning process so the need for back-up diesel generators is eliminated. Both single and co-digestion was considered for this case.

In the second case the biogas plant was scaled up to allow for distribution of either gas or electricity. To allow for maximum distribution, two identical digesters where determined to be most effective. One which covers the internal demand of the tannery and one which is used for the distribution to the local community.

The third case was calculated with solar power in mind. A solar power system was designed to cover at least half of the tannery’s internal electricity demand with a biogas plant identical to the one in case one and two.

A fourth case, where all the positive aspects of the three base cases, where also considered. For this case, a solar power system was designed and co-digestion of was assumed in the biogas plant.

5.7.1 Investment Costs

In Table 14 the equipment and operational costs used for the bio gas plant as well as the costs for distributional infrastructure and solar panels is presented.

Table 14: Investment Costs & Operational Costs for Bio Gas Plant & Distribution

<table>
<thead>
<tr>
<th>Investment Costs [kSEK]</th>
<th>Operational Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Utility</strong></td>
<td><strong>Annual Cost</strong></td>
</tr>
<tr>
<td>Hygienization Chamber [pcs]</td>
<td>3</td>
</tr>
<tr>
<td>Water Pump [pcs]</td>
<td>1.88</td>
</tr>
<tr>
<td>Digestion Chamber [m^3]</td>
<td>0.458</td>
</tr>
<tr>
<td>Piping &amp; Valves [pcs]</td>
<td>4.38</td>
</tr>
<tr>
<td>Heat Exchanger [pcs]</td>
<td>7.95</td>
</tr>
<tr>
<td>Gas Engine [pcs]</td>
<td>67.50</td>
</tr>
<tr>
<td>Scrubber [pcs]</td>
<td>1.50</td>
</tr>
<tr>
<td>Installation [pcs]</td>
<td>4.63</td>
</tr>
<tr>
<td><strong>Distribution Equipment [kSEK]</strong></td>
<td><strong>5% of capital investment</strong></td>
</tr>
<tr>
<td>Distribution line, el</td>
<td>3.25 kSEK/km</td>
</tr>
<tr>
<td>Extra Equipment, el</td>
<td>7.00 kSEK</td>
</tr>
<tr>
<td>Installation &amp; Transport,el</td>
<td>35% of investment</td>
</tr>
<tr>
<td>Gas pipeline</td>
<td>0.35 kSEK per household</td>
</tr>
<tr>
<td>Installation &amp; Transport, gas</td>
<td>10% of investment</td>
</tr>
<tr>
<td><strong>Solar Panels &amp; collector [kSEK]</strong></td>
<td><strong>11%</strong></td>
</tr>
<tr>
<td>Solar Panel</td>
<td>1.12 kSEK/unit</td>
</tr>
<tr>
<td>Solar Collector</td>
<td>1.05 kSEK/unit</td>
</tr>
<tr>
<td>Extra Equipment</td>
<td>30% of solar unit cost</td>
</tr>
<tr>
<td>Installation Cost</td>
<td>15% of solar unit cost</td>
</tr>
</tbody>
</table>

Table 15 show the sales prices and costs of different products used for the biogas plant.
Table 15: Sales Prices

<table>
<thead>
<tr>
<th>Utility</th>
<th>Sales Prices</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas [38]</td>
<td>1,84 SEK/m³</td>
<td>0.015 SEK/m³</td>
</tr>
<tr>
<td>Electricity [38]</td>
<td>0.73 SEK/kWh</td>
<td>0.42 SEK/kWh</td>
</tr>
<tr>
<td>Cow Dung [36][38]</td>
<td>-</td>
<td>95-10 SEK/tonne</td>
</tr>
<tr>
<td>Fertilizer Slurry [37][8]</td>
<td>50 - 200 SEK/tonne</td>
<td>-</td>
</tr>
</tbody>
</table>

5.7.2 Governmental Financial Aid & Subsidies

There is currently no governmental subsidies or funding for industrial-scale biogas plants or micro-grids available in Bangladesh but the Infrastructure Development Company Limited (IDCOL), which is a governmentally owned company, provides loans of up to 80% of the investment costs. This loan must be paid back in full in 7 years at a interest rate of 6%.

IDCOL also provides loans for solar-power projects with 40% of the investment cost at a maximum of 10 years pay-back time and a interest rate of 6%

Böle Garveri AB intends to take advantage of these loan and the interest rate and pay-back time was used in the economical calculations.[36]

5.7.3 Sensitivity Analysis

Due to uncertain parameters in the calculations, a sensitivity analysis of these parameters where carried out to determine the severity of change in them.

The parameters considered was:

1. Cost of electricity
2. Cost of substrate
3. Pricing for fertilizer slurry
6 Results & Discussion

6.0.1 Energy Mapping

The results of the energy mapping can be seen in Figure 27 below.

![Figure 27: Final chart of the energy flows in the studied tannery.](image)

Figure 28 and Figure 29 show a more detailed description of the energy demand and power production.
Figure 28: The energy demand of the tannery. [MWh/year]

Figure 29: The delivered energy to the tannery with the recommended solutions. [MWh/year]
6.1 Transport

6.1.1 Emissions During Transport

With the values given in Section 5.3 the emission and consumption during transport was compiled in Table 16. The total weight of the 31 delivered hides was $m_{hides} = 620 \text{kg}$ and accounted for an increase in weight of 36.5%.

<table>
<thead>
<tr>
<th>Property</th>
<th>Moth</th>
<th>Year</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Consumption</td>
<td>69</td>
<td>824</td>
<td>L</td>
</tr>
<tr>
<td>Correlated Energy</td>
<td>0.7</td>
<td>8.</td>
<td>MWh</td>
</tr>
<tr>
<td>Fuel Cost</td>
<td>4500</td>
<td>53600</td>
<td>taka</td>
</tr>
<tr>
<td>Fuel Cost</td>
<td>450</td>
<td>5360</td>
<td>kr</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>180</td>
<td>2180</td>
<td>kg</td>
</tr>
<tr>
<td>CO</td>
<td>0.3</td>
<td>3</td>
<td>kg</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>0.1</td>
<td>1</td>
<td>kg</td>
</tr>
</tbody>
</table>

The calculations has entirely been based on the mileage of the truck, which is a value that can not be decided with absolute certainty. A sensitivity analysis was therefore carried out with an increase in mileage. The mileage was changed with a factor ranging from 0.6 to 1.6 as it is more likely for the mileage to increase than decrease. The result can be seen in Figure 30, 31 and 32.
**Figure 30:** The difference in the yearly energy requirement for transportation as a result of changing fuel consumption.

**Figure 31:** The difference in the yearly fuel cost for transportation as a result of changing fuel consumption.
Figure 32: The difference in the yearly emission of carbon dioxide as a result of changing fuel consumption.

It can be seen that every parameter will increase linearly with the increase in fuel consumption. Due to the big amount of traffic, the substandard roads and the chance for extra weight in the truck, the case with an increase of at least a factor 1.2 should be accounted for.

6.1.2 Transportation Without Insulation or Additional Cooling

The temperature change of the hides during transport was plotted in Figure 34 for three different temperatures, the yearly average of 26°C, the yearly minimum of 12°C and the yearly maximum of 33°C. The initial temperature of the hides are set to 2°C. The critical temperature of 4°C is highlighted as a black line.
Figure 33: Temperature change of the hides during transport without additional cooling in a uninsulated truck.

The temperature the hides reach during the transportation time is unacceptable and shows that additional cooling or increased insulation is required during all parts of the year.

### 6.1.3 Transportation With Insulated Truck Without Additional Cooling

The insulated truck will keep a more steady temperature than a truck without insulation, but will still allow the temperature of the truck interior to rise. Equation 35 was used to plot the temperature each hour as can be seen in Figure 34. Three temperature was examined, the yearly average of 26°C, the yearly minimum of 12°C and the yearly maximum of 33°C. The initial temperature of the hides are set to 2°C. The critical temperature of 4°C is highlighted as a black line.
Figure 34: Temperature change of the hides during transport with insulated truck without cooling.

It can be seen that the temperature of the hides stays below the critical temperature during every part of the year. It should be said that this assumes that the initial temperature of the hides are 2°C. The maximum initial temperature that the hides can have to not reach the critical temperature before the end of the transport can be seen in Table 17. They are calculated with Equation 35 and the built in goal seek function in Microsoft Excel. The temperature change with these initial temperatures can be seen in Figure 35.

Table 17: The critical initial temperature for the hides during different surrounding temperatures.

<table>
<thead>
<tr>
<th>Surrounding temperature [°C]</th>
<th>Initial temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>3,5</td>
</tr>
<tr>
<td>26</td>
<td>3,3</td>
</tr>
<tr>
<td>33</td>
<td>3,1</td>
</tr>
</tbody>
</table>
The maximum initial temperature can be high and still allow the hides to reach the tannery in acceptable condition, although it is not recommended. If these initial conditions are met there should theoretically not be any requirement for additional cooling.

### 6.1.4 Transportation With Active Cooling

The energy required to keep the storage unit of the truck at 4°C each month is presented in Figure 36. The assumption is made that the hides enter the truck at 4°C and are kept at this temperature during the entire distance.
Figure 36: Temperature change of the hides during transport without additional cooling.

The cooling requirement needed during transport is not negligible and will add to the total energy used by the tannery. This amount could also be lessen with the decrease in distance between the tannery and the slaughter house.

6.2 Cooling

In this section the alternatives for the storage and cooling of hides will be examined. The result for each individual option will firstly be presented after which both options will be compared.

6.2.1 Water Cooling

The analyzed option for water cooling is a simple water filled tank in which the hides are lowered into. Results will firstly be presented for the different parameters analyzed to get a better understanding how they effect the final design. The studied parameters are the cooling time of the hides, the dimensions of the tank, insulation thickness and the cleansing of the tank. The effected parameters analyzed are the storage capacity, required cooling effect and initial and operational costs.

After this is done, case studies will be done on a number of different constellations to more clearly visualize which option should be chosen.
Cooling Time of the Hides

The cooling time for hides if the water temperature in the tank is kept constant at 2°C are shown in Figure 37. Three different initial temperatures are analyzed, 5°C, 10°C and 15°C.

![Figure 37: Temperature change for the hides in the cooled tank.](image)

It can be seen in Figure 37 that the cooling time is very short regardless of the initial temperature. This is due to the high thermal conductivity of water. The simplification done during these calculations is that the water keeps a constant temperature. This assumption can be made when only one hide is lowered into the tank. But when entire truckload will be stored, the assumption can be made that the temperature would increase slightly which in turn would lead to a longer cooling time. This assumption is made as the required cooling effect would be larger than the one that in practice would be installed. As the cooling time are so short when calculating on the optimal case, the actual time would not increase long enough for it to become a problem.
**Tank Size and Design**

The tank size is analyzed by varying the number of hides in storage \( N_{dim} \), the number of rows in the tank \( N_{rows} \) and if the hides are folded or not. The number of rows will affect the tank width, which is the same if the hides are folded or not and can be seen in Table 18.

**Table 18:** Width of the tank for different number of rows

<table>
<thead>
<tr>
<th>Number of rows</th>
<th>Tank Width [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,5</td>
</tr>
<tr>
<td>2</td>
<td>2,9</td>
</tr>
<tr>
<td>3</td>
<td>4,3</td>
</tr>
<tr>
<td>4</td>
<td>5,7</td>
</tr>
</tbody>
</table>

The tank length will directly be affected by the number of hides in storage. The length was plotted separately for unfolded hides in Figure 38 and folded hides in Figure 39. The length of the tank should not surpass the length allocated for the cooling solution in the blueprint. This value is 6,06 m and is marked in the figures as a black line.

**Figure 38:** Variation in tank length for unfolded hides.
Figure 39: Variation in tank length for Folded hides.

The number of rows chosen will effect the overall look of the tank, if it is long and thin, or more square in its design. In coming decisions the tank will be kept as a square when possible, meaning that the difference between the length and width will be as small as possible.

The resulting volume of the tank was also studied as a function of the number of hides. The volume was plotted for both folded and unfolded hides, which can be seen in Figure 40.
It can be seen in Figure 40 that the unfolded option is more efficient in the use of space. It will require a smaller floor-area but might be harder to operate as the distance to the factory ceiling is smaller. The option to overcome this problem would be to build the tank into the floor. This would in turn lead to an increase in installation cost and could complicate the working procedure for the pump and the changing of water.

**Insulation of Tank**

The thickness of the insulation material was changed to see the resulting change in required energy during the hottest month of the year. The wall and floor thickness was set to be equal and the lid thickness 50% of that value. The material used is polyurethane. The plotted values are seen in Figure 41.
Figure 41: The transmission heat transfer rate into the tank as a function of element thickness.

The effectiveness of increasing insulating is lowered as the insulation gets thicker, which can be seen in 41. Increased insulation therefore needs to be compared with the investment cost to see when it is still worth to insulate further.

The change of material was then analyzed in combination with a variation of element thickness, which can be seen in Figure 42. The analyzed materials were polyurethane and phenolic foam.
Figure 42: Cooling required as a function of insulation material and thickness.

It can be seen that the percentual difference in kWh are constant between the two materials but the absolute amount of usage in kWh decreases. This means that a change in material would be less economically viable if the tank were insulated further, as phenolic foam is more expansive than polyurethane.

The weight of the lid was plotted in Figure 43 as function of lid insulation thickness. The frame material and thickness was varied to visualize the difference.
Figure 43: The weight of the lid as function of insulation thickness.

It can be seen that the weight of the lid is high even with thinner insulation thickness. The stainless steel lid can be ruled out due to its extremely high weight, as it will not be able to operate in an easy way. The high weight of the lid suggest that a solution such as a sliding lid on rails should be implemented for one person to operate the tank. It should be said that the importance of the lid is smaller for cooling purposes than heating as the evaporating water will cause additional heat transfer out of the tank top. This will not be the case for cooling in the same extent.

Cleansing of Water

The energy required to initially cool the entire body of water can be seen in Figure 44.
Figure 44: The initial, total cooling required for the entire mass of water as a function of tank size.

The corresponding cooling requirement for one complete change of water was plotted in Figure 45 as function of the tank volume and studied for 4 different cooling times.
It can be seen that the effect of the cooling pump must be greatly increased if the entire body of water need to be cooled in a short time. The change will also lead to bigger losses if the tank is emptied often.

It is not certain how often the water might have to be changed. The volume flow of water is therefore represented in Table 19 as a function of the number of changes in a month. The additional energy required to cool this amount for water each month is thereafter shown in Figure 20.

**Table 19:** Volume flow out of the tank as a function of the number of water changes in a month.

<table>
<thead>
<tr>
<th>Storage capacity</th>
<th>Changes/month:</th>
<th>0.2</th>
<th>0.6</th>
<th>1</th>
<th>1.4</th>
<th>1.8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>72 <em>hides</em></td>
<td>Volume flow [l/h]</td>
<td>1.9</td>
<td>5.6</td>
<td>9.3</td>
<td>13.0</td>
<td>16.7</td>
</tr>
<tr>
<td>103 <em>hides</em></td>
<td>Volume flow [l/h]</td>
<td>2.7</td>
<td>8.0</td>
<td>13.3</td>
<td>18.6</td>
<td>24.0</td>
</tr>
<tr>
<td>134 <em>hides</em></td>
<td>Volume flow [l/h]</td>
<td>3.4</td>
<td>10.4</td>
<td>17.3</td>
<td>24.2</td>
<td>31.0</td>
</tr>
</tbody>
</table>
Table 20: Corresponding required cooling as a function of the number of water changes in a month.

<table>
<thead>
<tr>
<th>Storage capacity</th>
<th>Changes/month:</th>
<th>0,2</th>
<th>0,6</th>
<th>1</th>
<th>1,4</th>
<th>1,8</th>
</tr>
</thead>
<tbody>
<tr>
<td>72</td>
<td>Cooling effect [W]</td>
<td>21.60</td>
<td>64.8</td>
<td>108.0</td>
<td>151.2</td>
<td>194.4</td>
</tr>
<tr>
<td>103</td>
<td>Cooling effect [W]</td>
<td>31.0</td>
<td>92.7</td>
<td>154.5</td>
<td>216.3</td>
<td>278.0</td>
</tr>
<tr>
<td>134</td>
<td>Cooling effect [W]</td>
<td>40.0</td>
<td>120.6</td>
<td>201.0</td>
<td>281.4</td>
<td>361.8</td>
</tr>
</tbody>
</table>

The additional cooling requirement for the tank as a result of the mass flow in and out is not insignificant and will effect the overall efficiency of the tank, as can be seen in Table 20. As the number of changes required is not known, the median of 1 change/month will be used in future calculations.

6.2.2 Overall Efficiency for Ice-Cooling

As requested by Böle Garveri AB, the alternative to cool the tank with ice was examined. The mass flow of ice needed for a specific cooling requirement from the tank is visualized in Table 21. The energy required for the ice-machine was thereafter examined for the different mass-flows. The corresponding efficiency could thereafter be calculated.

Table 21: The mass flow of ice into the tank and efficiency for a specific cooling requirement.

<table>
<thead>
<tr>
<th>Cooling requirement kW</th>
<th>Mass-flow kg/h</th>
<th>Energy requirement kWh/kg</th>
<th>Energy efficiency kWh/kWh, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>1.0</td>
<td>0.26</td>
<td>16.4</td>
</tr>
<tr>
<td>0.3</td>
<td>3.1</td>
<td>0.20</td>
<td>21.6</td>
</tr>
<tr>
<td>0.5</td>
<td>5.2</td>
<td>0.16</td>
<td>26.6</td>
</tr>
<tr>
<td>1</td>
<td>10.4</td>
<td>0.14</td>
<td>31.2</td>
</tr>
<tr>
<td>2</td>
<td>20.9</td>
<td>0.12</td>
<td>37.8</td>
</tr>
<tr>
<td>4</td>
<td>41.8</td>
<td>0.10</td>
<td>46.8</td>
</tr>
</tbody>
</table>

The ice machine must first lower the temperature of the incoming water to 0°C and thereafter remove enough latent heat for the water to freeze. The ice must be stored as it will not be directly be put into the water tank. This means that the transmission heat into the ice storage must be removed. This is what resulting the low efficiency of the machine. It can be seen that larger machines have better efficiency than smaller.

6.2.3 Cooling Required of Heat Pump

The transmission heat transfer to the tank and the minimum power required from the cooling pump to keep the tank at at constant temperature of 2°C are shown in Figure 53.
Cost of Individual Components

The price for different components used in the tank are presented in Table 22. The costs are estimated from market analyses and may vary greatly between suppliers. The installation cost is estimated to 30% of the total investment cost.

Table 22: The mass flow of ice into the tank and efficiency for a specific cooling requirement.

<table>
<thead>
<tr>
<th>Component</th>
<th>Price</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel</td>
<td>798</td>
<td>kr/m²</td>
</tr>
<tr>
<td>Electricity price</td>
<td>0.56</td>
<td>kr/kWh</td>
</tr>
<tr>
<td>Suspension rig</td>
<td>1000</td>
<td>kr</td>
</tr>
<tr>
<td>Heat pump (3kW)</td>
<td>10000</td>
<td>kr</td>
</tr>
<tr>
<td>Filtration system</td>
<td>2300</td>
<td>kr</td>
</tr>
<tr>
<td>Circulation pump</td>
<td>1200</td>
<td>kr</td>
</tr>
</tbody>
</table>

The cost of the insulation will be estimated through interpolation between the known prices. The result is presented in Figure 47.
Decision of Final Design

As has been seen the tank design can vary depending on choices made. The different options will therefore be compared in a decision matrix to estimate the best options that will later be compared with the options for the cooling room. It can be seen in Appendix 78 The insulation thickness, storage capacity and cooling method is varied to see the resulting changes in cost, cooling requirement and energy efficiency.

6.2.4 Cold Room

Results from calculations regarding the cold room will be presented in this section. Firstly the basic case will be presented after which changes in size, insulation material and insulation thickness are made. Lastly, the final design is decided.

Cooling Time for Hides

The cooling time for hides if the air temperature in the room is kept constant at 2°C are shown in Figure 48. An initial temperature of the hides of 5°C, 10°C and 15°C are analyzed.
Figure 48: Temperature change for the hides in the cooled room

If the forced convection of the fans inside the cooling room is taken into account, the cooling time can be plotted with Equation 18 and 17 instead. The result can be seen in Figure 49 for 4 different air velocities. The temperature of air in the room is kept at 2°C and the initial temperature of the hides are 10°C.
A big difference can be seen between Figure 49 and Figure 48. The cooling time is almost halved when forced convection is used instead of free convection. This shows that the airflow in the cooling room has a big impact on the cooling time and that the flow of air should be increased if fast cooling is required.

When the cooling time in Figure 49 is compared with Figure 37, it can be seen that there is a big discrepancy of almost 10 times the cooling time. This is due to the difference in thermal conductivity of the medium. This could be of importance when the hides need to be cooled quickly, if they for example have reached high temperature before storage.

**Basic Case**

The cooling requirement for the basic case of the cooling room is presented in Figure 53. The material used are mineral wool with a thickness of 50 mm. The dimensions and thermal conductivity of the different building elements are shown in Table 23.
Table 23: Thermal conductivity and measurements for the different building elements.

<table>
<thead>
<tr>
<th>Element</th>
<th>Dimensions [m²]</th>
<th>Thermal Conductivity [W/m².K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>20.3</td>
<td>0.64</td>
</tr>
<tr>
<td>Roof</td>
<td>19.3</td>
<td>0.64</td>
</tr>
<tr>
<td>Floor</td>
<td>19.3</td>
<td>2.9</td>
</tr>
<tr>
<td>Door</td>
<td>2.4</td>
<td>0.64</td>
</tr>
</tbody>
</table>

The required cooling effect of the room was simulated over a year in IDA-ICE. The result can be seen in Figure 50.

As expected the required cooling effect will vary with the changing temperature. The effect will peak at 1.8kW.

The amount of energy transferred through each building element is visualized in Figure 51.
Even though the floors are uninsulated it can be seen that only a small part of the overall transmission heat transfer occurs through the ground. This infers that the focus should be made on the walls and the roof.

The monthly temperature kept in the cold room can be seen in Figure 52. The temperature is fairly constant during the year and is below the lowest limit of the hide of 2°C. The yearly mean temperature of the room 1,4°C, the yearly minimum temperature 1,3°C and the yearly maximum temperature 1,5°C.
Change in Insulation

The dimensions from the basic case was kept but the insulation material and thickness was changed. The resulting cooling requirement can be seen in Figure 53. "Mineral Wool 50 mm" is the cooling requirement for the basic case.
The change in the required cooling is fairly linear. It can be seen that mineral wool is significantly worse than the two other options. The difference between the phenolic foam and the polyurethane are seen as small enough to choose polyurethane for the final design as it costs considerably less. This will be seen in the cost comparison in Appendix 80.

The effect of an insulated floor can be seen when comparing Figure 54 which is uninsulated and 55 which is insulated with 0.1m thick polyurethane boards. Where Blue = Floor, Red = Roof and Brown = Walls. The walls and roof are insulated with 0.2m thick polyurethane boards.
There is a clear difference when the floor is insulated, which means that the floors should be insulated if thicker insulation is used for the walls and roof, as the percentage of leakage from the uninsulated floor increases with increased insulation thickness of the walls and roof.
Sectioning of the Room

If the room in section in 2 separate rooms, they can be driven individually when the need for additional space rises. This is done by simply dividing the cooling room in two parts. Calculations are then carried out as before, with the addition of a 3 m layer of air for the wall facing the other section of the cooling room.

![Figure 56: The cooling requirement for the sectioned room and the entire room.](image)

The sectioning of the room will as expected approximate half the required cooling, but will increase the cost of the room in form of an extra wall, an extra door and an extra heat pump. The additional cost will have to be weighted towards how much use the tannery will get out of the solution.

Optimal Size of the Room

The storing-capacity for the basic case of the cooling room, with dimensions according to the provided blueprints can be seen in Table 24. Table 24 shows the theoretical storing capacity of the room.
Table 24: Storing-capacity for basic case

<table>
<thead>
<tr>
<th>Storage Capacity</th>
<th>Total Volume [m$^3$]</th>
<th>Working Area [m$^2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>171</td>
<td>42.0</td>
<td>5.6</td>
</tr>
</tbody>
</table>

The basic room is over dimensioned as the storage capacity is 171 hides. This would mean that the room has a buffer of 99 hides. This would lead to a higher required effect of the cooling system and an overall increase in energy usage.

The room dimensions was then plotted as a function of the number of hides. The result can be seen in Figure 57.

![Figure 57: The dimensions of the room as function of the number of stored hides.](image)

The energy requirement for a room with a storage capacity of 72 hides, 103 hides and 134 hides was studied, as can be seen in Figure 58, 59 and 60.
Figure 58: Cooling required for the room dimensioned for 72 hides.

Figure 59: Cooling required for the room dimensioned for 103 hides.
Figure 60: Cooling required for the room dimensioned for 134 hides.

**Decision of Final Design**

The different options for the cold room was compared in a decision matrix to estimate the best options. It can be seen in Appendix 80. The insulation thickness and storage capacity is varied to see the resulting changes in cost, cooling requirement and energy efficiency.

### 6.2.5 Cooling Solution

The different solutions to cool the cold room and the tank will be discussed in this section.

**Connecting Stream for Condenser**

As could be seen in Section 4.2.3 that the geothermal resources of Bangladesh have not yet been fully explored. Therefore the geological conditions are not known which makes it difficult to estimate the cost and time needed to implement such a system. Implementation of geothermal cooling will be expensive as the number of companies working with it are few, and the experience is limited. Therefore the option of geothermal cooling will not be recommended.
River cooling could be an option if more data could be obtained from the Baral river. But as the cooling requirement of the different options are relatively small, there is no economic incentives to use a more expensive alternative such as river cooling. If the cooling requirement of the tannery would increase, the solution might required to be studied more carefully. But for this report, the option of river cooling will not be recommended.

Absorption or Compressor-driven Heat Pump

As stated in Section 4.2.2, the absorption heat pump is most efficiently used when there is a big surplus of heat in the range of 100 – 200°C. This will not be the fact for the studied tannery. The produced heat from the biogas-plant will be required to heat other processes. The choice could be made to use the excess heat from the electricity production to the absorption pump instead of the drying process. The reason that it will not is the big cost difference it would make. The comparison in price between a heat exchanger, an absorption heat pump and a compressor driven heat pump is made in Table 25. As a result of this, the choice is made to utilize a compressor driven heat pump to delivered the required cooling effect.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Investment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorption heat pump</td>
<td>30000-50000</td>
</tr>
<tr>
<td>Compressor driven heat pump</td>
<td>5000-20000</td>
</tr>
<tr>
<td>Heat exchanger</td>
<td>3000-8000</td>
</tr>
</tbody>
</table>

6.2.6 Comparison Between the Alternatives and Final Recommendation

The difference between the cold room and the cooling tank was compared in Appendix 81 to see which alternative that should be chosen. It can be seen that the cold room is cheaper and more energy efficient for the majority of the constellations. It is therefore our recommendation that this option is chosen for the cooling storage.

As previously mentioned, buffer space will be needed for a variety of reasons. It is therefore recommended that a cooling room with at least room for 103 hides is implemented. The difference in cost when increasing the insulation from 50 mm to 200 mm, is 12300 kr, which will be seen as a small amount. The reduction in the yearly energy requirement accounts for 3140 kWh/year. Therefore the recommendation is that 200 mm polyurethane boards are used for wall and ceiling insulation. For this an air to air heat pump will be used to cool the room with an effect of 2 kW.

Depending on the COP of the heat pump, the yearly requirement of electricity will differ, as can be seen in Table 26, where the requirement is calculated with Equation 24.
### Table 26: Yearly requirement of electricity to the heat pump.

<table>
<thead>
<tr>
<th>COP</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required electricity kWh</td>
<td>1600</td>
<td>1050</td>
<td>790</td>
<td>630</td>
<td>530</td>
</tr>
</tbody>
</table>

#### 6.3 Drying

**Theoretical Energy Requirement**

The theoretical energy requirement to dry the hides was calculated with Equation 30 and is presented in Table 27. One batch contains 31 hides and the wet weight of the hides before dewatering is 15kg. After dewatering the weight was calculated to 8.2kg with Equation 29. The initial moisture content of the hides before and after the drying process was decided to 45% and 8% respectively, based on the values of Table 2.

### Table 27: Energy requirement for drying.

<table>
<thead>
<tr>
<th>kJ/hide</th>
<th>MJ/batch</th>
<th>kJ/kg, wet hides</th>
</tr>
</thead>
<tbody>
<tr>
<td>8500</td>
<td>610</td>
<td>1040</td>
</tr>
</tbody>
</table>

The energy requirement per kg hides was plotted as a function of the moisture content in Figure 61. Both the moisture content before the drying process ($M_1$) and after the drying process ($M_2$) was changed while the corresponding value shown in the legend was kept constant.
It can be seen in Figure 61 that the theoretical energy requirement of the dryer is greatly decreased by lowering the moisture content before the dryer. This can be done in multiple ways.

**Hot air drying**

The initial temperature was set to 150°C and the outgoing temperature 55°C with a relative humidity of 90%. The outgoing stream from the dryer was led through a heat exchanger in which the temperature of the ambient air, which initially had a temperature of 26°C and a relative humidity of 74%, which is the average during a year in Bangladesh. The temperature that the ambient had after the heat exchanger was analyzed and can be seen in Table 28.
Table 28: Temperature of ambient air after heat exchanger.

<table>
<thead>
<tr>
<th>$T_{\text{exhaust, before}}$ [°C]</th>
<th>$T_{\text{ambient, after}}$ [°C]</th>
<th>$T_{\text{exhaust, after}}$ [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>42.4</td>
<td>33.2</td>
</tr>
<tr>
<td>55</td>
<td>44.8</td>
<td>35.6</td>
</tr>
<tr>
<td>60</td>
<td>47.2</td>
<td>37.9</td>
</tr>
<tr>
<td>65</td>
<td>49.6</td>
<td>40.2</td>
</tr>
<tr>
<td>70</td>
<td>51.9</td>
<td>42.5</td>
</tr>
<tr>
<td>75</td>
<td>54.2</td>
<td>44.7</td>
</tr>
</tbody>
</table>

The temperature for the ambient heat after the first heat exchanger was taken from Table 28 corresponding to the exhaust temperature of 65°C. The supplied energy from the second heat exchanger was then calculated based on the drying time of the hides. The heat exchanger efficiency was set to 85%. The heat provided by the hot stream could then be estimated. The result can be seen in Table 29.

Table 29: Energy requirement for drying.

<table>
<thead>
<tr>
<th>Drying time [h]</th>
<th>Required dryer effect [kW]</th>
<th>Energy from hot stream [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>6.1</td>
<td>7.2</td>
</tr>
<tr>
<td>36</td>
<td>4.1</td>
<td>4.8</td>
</tr>
<tr>
<td>48</td>
<td>3.1</td>
<td>3.6</td>
</tr>
<tr>
<td>60</td>
<td>2.4</td>
<td>2.9</td>
</tr>
<tr>
<td>72</td>
<td>2.0</td>
<td>2.4</td>
</tr>
</tbody>
</table>

To evaluate the overall efficiency of the dryer, the pie diagram that is shown in Figure 62 was made which visualizes where the energy is used. Where Evaporation is the energy required to evaporate the excess water from the hides, Heating is the energy required to heat the hides and the water before the evaporation starts, Exhaust is the energy of the air leaving the dryer and Other losses includes losses though the chamber walls and infiltration.
It can be seen that the overall theoretical efficiency for the dryer is 50%.

6.4 Water Consumption

It was found that the waste streams could be used as mixing-water for the biogas plant, but further analysis of the contamination and how it would affect the bacteria in the substrate would be needed.

The waste-water would not be enough to cover the water demand for mixing the substrate if it is dry when it arrives to the plant, so extra water would be needed. River water could be used, but analysis of that water would also be needed.

It was assumed that the manure would be relatively fresh when supplied to the plant. If this is the case no mixing water would be needed as the manure would have a solid dry matter content of 16-20 % which is acceptable.

But for every percentage over 20 % mixing water would be needed at a 1:4 ratio. This effectively means that for each kilo completely dry manure it would need 4 liters of water to reach the sufficient moisture content.
6.5 Power Production

6.5.1 Type of Digester

A plug-flow type digester was chosen for the plant. This type allows for a higher control for methane-production, substrate-feed and slurry-production.

A batch-type digester is cheaper to build and maintain, but would need longer retention time and larger amount of substrate for the same amount of methane produced. A batch-type also need at least two larger production-stops each year to flush the slurry and refill with fresh substrate.

6.5.2 Biogas Production

The total annual electricity demand of the tannery was calculated to 62 MWh. In Table 30 below, the results from Equation 71 and Equation 72 can be seen.

<table>
<thead>
<tr>
<th>CH$_4$</th>
<th>Dung</th>
</tr>
</thead>
<tbody>
<tr>
<td>21,000 m$^3$/year</td>
<td>966 tonnes/year</td>
</tr>
<tr>
<td>58 m$^3$/day</td>
<td>3 tonnes/day</td>
</tr>
</tbody>
</table>

The daily amount of dung given from Table 30 and assumed HRT of 30 days, the volume as well as the OLR is calculated as 170,0 m$^3$ respectively 0,0043 kgVS/m$^3$.

The given amount of 3500 cows available for substrate extraction is more than enough to cover the annual demand, which would only need 894 cows to be satisfied. The problem is that the cows will be spread out over a large area for grazing, making collection of sufficient amounts each day hard if there is no proper infrastructure to do so.

6.5.3 Heat Demand for Digester

The total thermal energy for the flue gas stream was calculated to 146,0 MWh/year. As can be seen in Figure ??, the largest heat demand will be for the hygienization at 54,0 MWh/year. The flue gases will be able to cover this heat demand eliminating the need for external heating.
As the substrate will be heated to 70°C and the temperature in the digestion chamber will be between 35-37°C, the hygienized substrate can be utilized for heat exchanging with the other heat demanding processstreams in the tannery as well as the digestion chamber, effectively lowering the total heat demand of the digester to only 14.7 MWh/year which is the heat demand of holding the substrate at mesophillic conditions.

There might not be a need for hygienization. As this is done to kill off any harmful pathogens in the substrate so that the slurry can be utilized as a product, if the substrate is free from pathogens which would prevent that, the hygienization step can be eliminated completely. Further analysis of the substrate would be needed to determine the need for hygienization.

6.5.4 Alternative Feed-Stock

It was found that co-digesting with alternative feed-stocks would lower daily substrate demand substantially, as can be seen in Table 31 below. Choosing co-digestion for the biogas plant would also result in a significantly lower digestion chamber volume of 130 m³.
Table 31: Alternative feed-stock and daily demand of substrate [tonnes/day].

<table>
<thead>
<tr>
<th>Type</th>
<th>Total</th>
<th>Dung</th>
<th>Co-substrate</th>
<th>Decreased demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dung</td>
<td>2.45</td>
<td>2.45</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Slaughter Waste</td>
<td>1.8</td>
<td>1.2</td>
<td>0.60</td>
<td>26.3%</td>
</tr>
<tr>
<td>Bagasse</td>
<td>1.22</td>
<td>0.94</td>
<td>0.27</td>
<td>50.3%</td>
</tr>
</tbody>
</table>

The bagasse contains very high amounts of carbon, which could inhibit the digestion-process if the fraction of sugarcane to dung is higher than 1:1, but otherwise the co-digestion should not pose any problem. Sugarcane contains a higher amount of dry matter compared to dung or slaughter waste which would result in a higher demand for water when mixing, but due to the significantly lower total amount of substrate needed each day the water demand will remain largely unchanged.

Choosing co-digestion for the biogas plant would result in a digestion chamber volume of 130m$^3$.

6.5.5 Solar Power

As can be seen in Figure 64 the maximum average solar irradiation, at annual optimal angle 28°, during the year is in February and March, and the minimum is in June and July.
Figure 64: Monthly irradiation in the Bagatipara region of Bangladesh.

Respective power per day can be seen in Table 32
Table 32: Solar Infraction in the Bagatipara region of Bangladesh.

<table>
<thead>
<tr>
<th>Month</th>
<th>( H_0 ) [kWh/m(^2),day]</th>
<th>( H_{opt} ) [kWh/m(^2),day]</th>
<th>( I_{opt} [\degree] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>4.13</td>
<td>5.53</td>
<td>51</td>
</tr>
<tr>
<td>February</td>
<td>5.19</td>
<td>6.43</td>
<td>42</td>
</tr>
<tr>
<td>March</td>
<td>6.08</td>
<td>6.69</td>
<td>28</td>
</tr>
<tr>
<td>April</td>
<td>6.25</td>
<td>6.15</td>
<td>11</td>
</tr>
<tr>
<td>May</td>
<td>6.01</td>
<td>5.51</td>
<td>-2</td>
</tr>
<tr>
<td>June</td>
<td>5.02</td>
<td>4.51</td>
<td>-7</td>
</tr>
<tr>
<td>July</td>
<td>4.86</td>
<td>4.43</td>
<td>-4</td>
</tr>
<tr>
<td>August</td>
<td>4.89</td>
<td>4.67</td>
<td>5</td>
</tr>
<tr>
<td>September</td>
<td>4.52</td>
<td>4.65</td>
<td>19</td>
</tr>
<tr>
<td>October</td>
<td>4.52</td>
<td>5.20</td>
<td>35</td>
</tr>
<tr>
<td>November</td>
<td>4.52</td>
<td>5.91</td>
<td>48</td>
</tr>
<tr>
<td>December</td>
<td>3.960</td>
<td>5.46</td>
<td>53</td>
</tr>
<tr>
<td>Annual</td>
<td>4.99</td>
<td>5.42</td>
<td>28</td>
</tr>
</tbody>
</table>

In Table 32 the horizontal irradiation is also shown, i.e the infraction when no tilt angle is present. On average the irradiation difference between horizontal and optimal angle is 7.1 %.

In Table 32 the respective optimal angles for each month can also be seen. Comparing the annual optimal angle with each months optimal angle, a difference in irradiation of only 3 % was found.

During July, an average of 13h per day is solar power producing, with an average irradiation of 0.20 kW/m\(^2\).

To cover half of the electricity demand of the tannery during the least sunny month of July, a total area of 116m\(^2\) solar cells would be needed.

As can be seen in the energy mapping, the total thermal energy demand of the tannery is 183 MWh/year. This demand is not covered by the 146 MWh/year from the gas generator and thus external heating is necessary. To cover the rest of the tannery’s heat demand a solar collector park with a total area of 46 m\(^2\) would be needed.

6.5.6 Distribution

There is some possibilities regarding distribution from the biogas plant and tannery processes.
Local Community

There are 5 educational institutes, and at least one of which is located only 500 m from the project site, as well as 100-150 household and a small shopping area in the immediate vicinity of the project area.

No further information about the small shopping area and educational institutes is available, but the household consumption was calculated to be 160.5 kWh/day in total for all 150 households.

Agricultural Industry

There is a lot of farms and agricultural industry in the proximity of the project area and a possible stream of revenue is the effluent slurry produced during the digestion. The slurry is a refined fertilizer and depending on the quality of the substrate used might be of very high quality.

6.6 Economy

6.6.1 Biogas Plant

Table 33 show a summary of the investment costs for the considered cases. The following sections will further break down the results of the economical calculations.

<table>
<thead>
<tr>
<th>Case</th>
<th>Plant Capital Investment [kSEK]</th>
<th>Distribution Capital Investment [kSEK]</th>
<th>Total Capital Investment [kSEK]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>159.1</td>
<td>0</td>
<td>159.1</td>
</tr>
<tr>
<td>B1</td>
<td>149.1</td>
<td>0</td>
<td>149.1</td>
</tr>
<tr>
<td>2</td>
<td>338.3</td>
<td>13 - 20</td>
<td>351.3 - 358.3</td>
</tr>
<tr>
<td>3</td>
<td>264.4</td>
<td>13 - 20</td>
<td>277.4 - 284.4</td>
</tr>
</tbody>
</table>

The differing costs in case 2 and 3 is due to the investment costs depending on if gas or electricity is to be sold. Case A1 and B1 is case 1 but with mono or co-digestion respectively.

Case 1

As can be seen in Table 34, the first case when only digesting manure, the bio gas plant is not profitable.
Table 34: Economical parameters for Case 1.

<table>
<thead>
<tr>
<th>Revenue kSEK/year</th>
<th>OPEX kSEK/year</th>
<th>( C_D ) kSEK/year</th>
<th>NIC kSEK/year</th>
<th>NCF kSEK/year</th>
<th>NVP kSEK/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>96,9</td>
<td>105,7</td>
<td>18,3</td>
<td>-21,2</td>
<td>-2,9</td>
<td>-261,2</td>
</tr>
</tbody>
</table>

This is in part due to the the high price, at 95 SEK/tonne, for the substrate cited to Böle Garveri. Looking at Figure 65 and Figure 66 below, where five alternatives with differing pricing for substrate and slurry is presented, it can clearly be seen that the profitability and feasibility can be increased with lower substrate cost.

Figure 65: Net income and cash flow for different pricing of substrate and slurry for Case 1.
Calculating with the substrate cost fixed at the given price of 95 SEK/tonne from Böle, the slurry would need to be sold at lowest at a price of 122.7 SEK/tonne for the plant to be feasible given the IDCOL mandate 7 years pay-back time. Conversely, if the slurry price is fixed at the lowest price of 50 SEK/tonne the substrate cost can not succeed 44.1 SEK/tonne.

Another reason for the negative results is the price of electricity. The energy demand of the tannery is not high enough to warrant the investment of alternative power production at the current price. According to Böle Garveri AB themselves the loss in production in case of a black-out is negligible as well.

In Figure 67 below an analysis of the PBT related to the energy price is presented. As can be seen, the price of electricity has to exceed 1.85 SEK/kWh for the plant to be profitable and 2 SEK/kWh for the investment to be recommendable.
If instead the decision to co-digest manure and bagasse is made, the feasibility for the plant is higher. The economical parameters for co-digestion is seen in Table 35 below.

**Table 35: Economical parameters for Case 1 with co-digestion.**

<table>
<thead>
<tr>
<th>CAPEX kSEK</th>
<th>Revenue kSEK/year</th>
<th>OPEX kSEK/year</th>
<th>NIC kSEK/year</th>
<th>NCF kSEK/year</th>
<th>NPV kSEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>149,2</td>
<td>79,5</td>
<td>26,3</td>
<td>16,2</td>
<td>27,9</td>
<td>45,4</td>
</tr>
</tbody>
</table>

In Figure 68, the economical analysis of the plant with different pricing of manure can be seen.
Figure 68: Net income and net cash flow for different pricing of substrate and slurry for Case 1 with co-digestion.

This shows that even for the base case of 95SEK/tonne for manure and a slurry price of 50SEK/tonne, the plant will be profitable. Figure 69 show the pay-back times for the different scenarios in Figure 68.

Figure 69: Net income and net cash flow for different pricing of substrate and slurry for Case 1 with co-digestion.
The co-digestion is much more preferable as the bagasse has twice the CH\textsubscript{4} potential as manure. The bagasse is more expensive than manure, but as the total mass flow into the digester is significantly decreased when co-digesting the operational costs is actually lower compared to when mono-digesting manure. This is further illustrated in Table 35 above.

Choosing to co-digest bagasse and manure also has the added benefit of lowering both transport costs and emissions from transport as the amount of substrate needed is cut in half.

These results indicates that single-digestion should not be considered at all if there is a possibility of buying bagasse for co-digestion.

**Case 2**

It was determined that it is more efficient to build two equal plants, one for the internal need and one for commercial purposes than scaling up. As can be seen in Table 36, selling gas is more profitable than selling electricity but is still not feasible for the base case.

<table>
<thead>
<tr>
<th>Revenue</th>
<th>Revenue</th>
<th>OPEX</th>
<th>NIC</th>
<th>NCF</th>
<th>NVP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>148,9</td>
<td>205,55</td>
<td>31,7</td>
<td>-72,4</td>
<td>-36,2</td>
</tr>
<tr>
<td>Gas</td>
<td>188,5</td>
<td>205,55</td>
<td>31,7</td>
<td>-41,1</td>
<td>-5,4</td>
</tr>
</tbody>
</table>

Selling gas have the added benefit of being more desirable for the local communities, as gas for cooking is more important than electricity for most Bangladeshis. Focus should lie on investing for gas distribution for maximum socioeconomic benefits.

In Figure 70 the analysis of different pricing for substrate and slurry is illustrated.
Figure 70: Net income and net cash flow for different pricing of substrate and slurry for Case 2.

The respective pay-back times can be seen in Figure 71

Figure 71: Pay-back time for different pricing of substrate and slurry for Case 2.
The breaking point for feasibility for this case can be seen in Table 37 below

**Table 37:** Breaking point for varying price of substrate and slurry with a maximum of 7 years pay-back time for Case 2.

<table>
<thead>
<tr>
<th>Utility</th>
<th>Parameter</th>
<th>Substrate Cost</th>
<th>Slurry Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>Fixed Substrate Cost</td>
<td>95.0</td>
<td>129.1</td>
</tr>
<tr>
<td></td>
<td>Fixed Slurry Price</td>
<td>39.6</td>
<td>50.0</td>
</tr>
<tr>
<td>Gas</td>
<td>Fixed Substrate Cost</td>
<td>95.0</td>
<td>93.8</td>
</tr>
<tr>
<td></td>
<td>Fixed Slurry Price</td>
<td>64.3</td>
<td>50.0</td>
</tr>
</tbody>
</table>

A more technical issue with this case is the increased work-load. Initially, there will only be one employee working with the bio gas plant.

Regardless of the type of digester chosen, even if the decision is to use a batch-digester instead of a continuous process, the work-load will most likely be too high for one worker. The distribution might therefore be something to consider for the future, when production and operations of the tannery is at full capacity.

**Case 3**

The solar power system is designed to be able to deliver at least 50% of the daily demand of the tannery during the least sunny month, July.

The economical parameters for the base case can be seen in Table 38 below.

**Table 38:** Base case parameters for Case 3.

<table>
<thead>
<tr>
<th>Utility</th>
<th>Revenue (kSEK/year)</th>
<th>OPEX (kSEK/year)</th>
<th>C_D (kSEK/year)</th>
<th>NIC (kSEK/year)</th>
<th>NCF (kSEK/year)</th>
<th>NVP (kSEK/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>El</td>
<td>112.1</td>
<td>107.4</td>
<td>23.4</td>
<td>-14.4</td>
<td>8.7</td>
<td>-107.0</td>
</tr>
<tr>
<td>Gas</td>
<td>130.4</td>
<td>107.4</td>
<td>21.3</td>
<td>1.3</td>
<td>22.6</td>
<td>47.9</td>
</tr>
</tbody>
</table>

The economical analysis of different pricing for slurry and substrate can be seen in Figure 72.
Figure 72: Net income and net cash flow for different pricing of substrate and slurry for Case 3.

Respective pay-back times can be seen in Figure 73 below.
In Table 39 below the breaking point of pricing for slurry and substrate can be seen.

**Table 39:** Breaking point for varying price of substrate and slurry with a maximum of 7 years pay-back time for Case 3.

<table>
<thead>
<tr>
<th>Utility</th>
<th>Parameter</th>
<th>Substrate Cost</th>
<th>Slurry Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>Fixed Substrate Cost</td>
<td>95,0</td>
<td>138,8</td>
</tr>
<tr>
<td></td>
<td>Fixed Slurry Price</td>
<td>33,1</td>
<td>50,0</td>
</tr>
<tr>
<td>Gas</td>
<td>Fixed Substrate Cost</td>
<td>95,0</td>
<td>102,6</td>
</tr>
<tr>
<td></td>
<td>Fixed Slurry Price</td>
<td>58,12</td>
<td>50,0</td>
</tr>
</tbody>
</table>

A problem with solar power is that it is sensitive to weather and clouding. Combining the solar power with the biogas production secures the plant from outages related to weather and clouding, and eliminates the need for back-up diesel generators as well when the plant is designed to fully support the tannery.

If it is decided to go with mono-digestion, this set-up is the most promising as it allows for moderate distribution of gas at a reasonable pay-back time and investment cost.
6.6.2 Sensitivity Analysis

A sensitivity analysis was carried out for revenue and operational costs, with an increase respectively decrease of 5% of the price for slurry, substrate and electricity. As can be seen in Figure 74 below, the pay-back time is most dependent on the price of slurry. The average decrease in pay-back time per 5% increase in sell-price is 20%.

![Figure 74: Pay-back time for different pricing of substrate and slurry.](image)

That the electricity price affects the pay-back time the least is not surprising as, which is show in Figure 67, the price of electricity needs to increase with about 100% from current levels to make the cost of investment worth the money saved from self-sufficiency.

6.6.3 Case Discussion

There is no significant difference between the economical feasibility of the dung-as-substrate scenarios. It is clear that the feasibility of the project is heavily dependent on being able to sell product in the form of gas or electricity and fertilizer because of the low energy demand and electricity prices.
Scaling up to increase distribution would of course generate more revenue but there is a clear problem with this. The water demand for the mixing will increase when the dry content of the substrate is high. Collecting fresh cow dung at the rate that would be needed to sufficiently feed two digesters at 150 m³ may simply not be possible with the current infrastructure in Bangladesh.

Would the cows have been milk-cows, which is gathered for milking at certain times each day, a way to solve the problem would be to build corrals close to the biogas plant where the milking could take place.

But as the cows for Bôle Garveri’s project will be meat-cows, no such gatherings will take place which means that collection of dung will be done over the total area for grazing.

Co-digestion would therefore be to prefer as the demand for fresh cow dung is remarkably lower because of the high methane-yield from sugar cane. This alternative would not only minimize the water consumption, but would also utilize a residual product of another industry.

For a project like this, the socioeconomic variables are as important as the technical. It is possible to consider a longer pay-back time if it means being able to provide stable energy for the local communities. Selling the gas directly to the communities instead of electricity is more beneficial as gas for cooking is the most important factor for most Bangladeshis. This is reflected in the economic calculations and the most profitable alternative is to sell the gas, when looking to sales prices.

But the infrastructure to sell the gas is more expensive and to reach a larger market a bottling plant would be needed. There is possible solutions with rubber-balloon containers that is implemented in African countries with success, but this method is not currently used in Bangladesh.

Selling electricity is currently only done back to the national grid, even though micro-grids are a feasible method. The issue with the micro-grids are that there is currently no subsidies or governmental financial aid for that kind of projects, making the construction rely solely on companies or communities willing to invest.

Possibility of building a pipe-line for gas-distribution is limited due to the cost of piping as well as the risk for natural disasters causing leaks.
7 Recommendation & Conclusions

An insulated truck without active cooling is recommended if the slaughterhouse can guarantee that the hides are delivered at acceptable temperatures.

It is recommended that a cooling room of 4.2*3.4 m, dimensioned for 103 hides is implemented, with 200 mm polyurethane boards as insulation for the walls and ceilings and 50mm polyurethane boards for the floor. For this option an air to air heat pump will be used to cool the room with an effect of 2kW.

The chosen dryer is a hot air dryer with heat exchanger for the exhaust air and the incoming ambient air. The overall efficiency of the dryer is 50%. It will be dimensioned to dry 1 batch of 31 hides in 36 hours, which will require a dryer effect of 4.1 kW. This heat will be supplied from the excess heat produced during electricity-generation.

The recommendation regarding the power production is to invest in a co-digestion, plug-flow biogas plant. It will give the most stable biogas production without any unnecessary production-stops and it will minimize the transport costs and emissions for substrate as the substrate demand is half of the demand if only digesting manure.

There is definitely an opportunity to distribute biogas to the local community and it is recommended to look into the possibility of expanding the biogas plant in the future to allow for distribution.

Testing both the waste-water and the water in the close-by river to see if it is possible to use this water as mixing water for the substrate should be done so that the consumption of clean ground-water is minimized.

8 Future Work

There is a lot of experiments and pilot-projects for bio-gas production. Commissioning a PhD-project looking into the possibility of using a two-phase digestion system, where the pH-levels in the substrate first is lowered so that the phosphates are precipitated, creating a high-quality, liquid manure and then digesting the remaining proteins and fats could lower the retention time and increase the yield of both fertilizer and biogas.

Experimenting on the waste-waters impact on the digestion is also something that should be done. An easy experiment that could be conducted on-site is simply filling a container with 1kg dry manure and 4l of waste-water and fresh water respectively and then covering the container with a balloon and see which container that produces the most biogas over 30 days.
References


Figure 75: The variation of the geothermal gradient ($T_g$) in Bangladesh [°C].[23]
Figure 76: The initial blueprint of the tannery.
## Electricity Demand

<table>
<thead>
<tr>
<th>Unit</th>
<th>Antal</th>
<th>W/styk</th>
<th>W</th>
<th>Operating Wh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>20</td>
<td>60</td>
<td>1200</td>
<td>12</td>
</tr>
<tr>
<td>Fans</td>
<td>5</td>
<td>150</td>
<td>750</td>
<td>12</td>
</tr>
<tr>
<td>Post bed sewing machine</td>
<td>10</td>
<td>400</td>
<td>4000</td>
<td>8</td>
</tr>
<tr>
<td>Cylinder bed sewing machine</td>
<td>10</td>
<td>800</td>
<td>8000</td>
<td>8</td>
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Figure 77: The electricity demand for machines in the planned sewing factory.
Figure 78: Summary of the different alternatives for the cooling tank.
Figure 79: Molier-diagram. [15]
Figure 80: Summary of the different alternatives for the cooling room.

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Figure 81: Comparison between the two different alternatives.

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