## Bachelor's thesis at the Lucerne School of Engineering and Architecture

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| **Title** | **Heating Solution Analysis of Gasthaus Göscheneralp** |
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**Abstract German**

Das Gasthaus Göscheneralp, ein Familienbetrieb im Göscheneralptal bei Göschenen, Uri, ist als Testumgebung für die Anwendung von verbesserten Heizsystemtechnologien analysiert worden. Das Ziel ist eine vergleichbare Analyse verschiedener Heizsysteme als mögliche klimaneutrale Lösungen zu entwicklen, um den Elektrizitätsverbrauch und die Energiekosten zu reduzieren.

Die aktuelle Situation des Gasthauses Göscheneralp wurde analysiert und drei Technologien wurden als mögliche Varianten gewählt: eine Sole/Wasser- Wärmepumpe, ein Vakuum Rohr Kollektor System, und eine verbesserte Wärmedämmung in der Gebäudehülle. Diese drei Technologien wurden auf der ersten Ebene in Bezug auf die Nachhaltigkeit im wirtschaftlichen, ökologischen und gesellschaftlichen Umfeld bewertet. Auf der zweiten Ebene wurde der Nettobuchwert im wirtschaftlichen Bereich, das Potential der globalen Erwärmung sowie die Ästhetik und der Komfort im sozialen Bereich als endgültige Werte bestimmt. Die Technologien und die definierten Kriterien sind mittels einer Kosten-Nutzen Analyse, einer Ökobilanz, und einer Multikriterien-Entscheidungsanalysemulti-Kriterien auswertet worden.

Auf Grund der ausgewerteten Ergebnisse der verschiedenen Methoden wird die Anwendung einen Vakuum Rohr Systems vorgeschlagen. Diese Variante hat bezüglich ökologischer und wirtschaftlicher Nachhaltigkeit die höchste und bezüglich gesellschaftlichem Umfeld die zweithöchste Gesamtpunktzahl erreicht. Eine zusätzliche Verbesserung könnte mit der Verstärkung der Wärmedämmung in der Gebäudehülle erzielt werden. Zu Erwähnen ist noch, dass die Variante Sole/Wasser-Wärmepumpe wohl die nachhaltigste aber auch teuerste Lösung darstellt. Der derzeitige tiefe Strompreis in der Göscheneralp sprechen gegen diese Variante. Sollte der Strompreis jedoch stark steigen, könnte die Installation einer Sole/WasserWärmepumpe eine plausible Lösung werden.

**Abstract English**

Gasthaus Göscheneralp, a family-run hotel/restaurant business in central Switzerland, was analysed as a testbed for the application of improved heating system technologies. The aim of this report is to develop a comparative analysis of various heating systems as a possible climate-neutral solution to reduce electricity consumption and cut energy costs.

The current situation of the Gasthaus Göscheneralp was evaluated, then three technologies were considered as possible heating alternatives: a ground-sourced heat pump, an evacuated tube collector solar system, and

improved building insulation. The technologies were evaluated using the first level criteria of economic, environmental, and social sustainability. Then, the second level criteria of net present value (economic), global warming potential (environmental), and aesthetics and comfort (social) were established as final indicator values. The technologies and the established criteria were evaluated using the techniques of a cost/benefit analysis, a life cycle assessment, and a multi-criteria decision analysis.
Given the results of these evaluation techniques, it is recommended to implement the evacuated tube collector solar system. This technology scored highest in environmental and economic sustainability categories and second in the social category. Additional improvement could be made with stepwise measures to increase the thermal resistance of the building envelope with improved building insulation. It is also notable that although the ground source heat pump is the most cost effective solution during the operating phase, it is not recommended given the current energy tariffs of the Gasthaus Göscheneralp. However, if energy prices increase significantly, the low energy demand of the ground-sourced heat pump could prove to be a feasible option.

Place, date Horw, 08.06.2020

# Contents

# Figures

# Tables

# Equations

# Abbreviations and acronyms

| | |
|---|---|
| a | Annum |
| CBA | Cost/Benefit Analysis |
| CHF | Swiss Frank |
| DHW | Domestic Hot Water |
| ETC | Evacuated Tube Collector |
| FU | Functional Unit |
| GSHP | Ground-Source Heat Pump |
| GVA | Gross Value Added |
| GWP | Global Warming Potential |
| HDD | Heating Degree Days |
| HSLU | Hochschule Luzern |
| K | Kelvin |
| kWh | Kilowatt-hour |
| LCA | Life Cycle Assessment |
| MCDA | Mult-Criteria Decision Analysis |
| NPV | Net Present Value |
| Rp | Rappen |
| SC | Solar Coverage |

# 1 Introduction

The Swiss federal government's energy strategy provides for a reduction in energy consumption in the building sector of -43% by 2035 compared with 2000 in the Energy Act 2050 (FOEN 2018). The CO2 Act aims to reduce domestic greenhouse gas emissions by 20% by 2020 compared with 1990 (Swiss Federal Office of Energy SFOE 1/18/2018). Both targets can only be achieved if new buildings are exemplary in terms of energy efficiency, and existing buildings, in particular, are also renovated in terms of energy efficiency. Total energy consumption can be reduced primarily by insulating the building envelope. A reduction in greenhouse gas emissions can be further promoted by substituting fossil fuels for the provision of space heating and hot water to renewable sources. One sector to be considered is tourism.

The tourism sector is not only a major contributor to CO2 emissions, but is also directly and indirectly affected by them. As anthropogenic induced climate change increases with higher levels of CO2 emissions, winters in the alpine regions are becoming more erratic and glaciers are receding. This negatively impacts tourism in these alpine areas as winter sport enthusiasts are forced to recreate less due to less snow in the winter. Sightseeing tourists also come less if glaciers recede and become less awe-inspiring. In this paper, the "Gasthaus Göscheneralp" is used as a case study framed in the context of climate change.

## 1.1 Background

The building, Gasthaus Göscheneralp, was constructed in 1956 and has since been used as a bed & breakfast (Gasthaus). The heating system consisted purely of a wood stove with a direct connection to a heat distribution system feeding to wall radiators throughout the building. Water was the heating medium. There was no domestic hot water production.

In 1983, a wing of two stories was added towards the west for an additional eating and sleeping capacity of 110.74 m². Space heating was supplied in the annex with rudimentary electric heating elements that utilized bricks as thermal mass for heat storage throughout the nights. Domestic hot water was added to the existing pluming infrastructure using an electric heating element connected to the fresh water supply.

The building changed ownership in 2015 with new appliances being added in the kitchen, as well as cosmetic work being done to both the interior and exterior of the house. Additionally, in 2018, a space heating storage tank of 697.1 liters, and a DHW storage tank of 749.8 liters were added, each having an integrated electric resistance heater of 6.0 kW and 10.0 kW respectively. The existing wood stove has been refurbished and hydraulically connected to the space heating storage tank. It is currently fired primarily with dried beech wood, and the stoves exact heating power is unknown. The electric heating elements in the annex have been replaced with six modern electric resistance radiators. The radiators in the original building vary in type and efficiency from modern ceramic wall radiators to original cast iron wall radiators installed in 1954.

## 1.2 Current situation

The electricity demand for an aged Gasthaus in the Göscheneralp is large due to electrical resistance radiators being the primary means of heating, for both domestic hot water and space heating. A secondary heat production method exists in the form of a wood-burning oven to cover peaks in the heat demand of space heating. The potential of renewable energy production exists to cover a base heat demand by means of solar energy for roughly 8 months of the year, when the sun is not at its lowest.

Gasthaus Göscheneralp provides lodging and dining from March to October depending on the weather, as the tourism industry in the swiss alps positively correlates with sunny weather (Scott and

Lemieuw 2010). In the remaining three months during the peak of winter, the road to the Gasthaus is closed due to excessive snow. The Gasthaus offers its services even before the road opens to the public in order to accommodate skitourers and snowshoers.

The peak demand for domestic hot water tends to be in the mid-summer months when families are typically on vacation. Domestic hot water is not used at all November through February when the Gasthaus is closed. Energy is supplied by the local utility, Elektrizitätswerk Göschenen, or EWG.

Space heating is required year-round, even when closed in order to keep a minimum of 10°C in the pipes to avoid freezing. Space heating demand sees peaks in the spring and autumn months when temperatures are lower and guests' numbers reach capacity. However, in the summer months, space heating is seldomly used, typically only on cold nights.

**Problem description**

Although electrical energy prices in the Göscheneralp are extremely low compared to the rest of Switzerland at just 9.69 Rp/kWh (summer tariffs) compared to 20.7 Rp/kWh, a higher degree of autarky is desired. (Statistica Research Department 2019) (Elektrizitätswerk Göschenen 2019). This desire for autarky is rooted primarily in financial reasons of cost savings, but also in environmental reasons of sustainability.

The swiss government is fostering renewable technologies and energy reduction within the building sector. The Swiss Energy Act 2050 has set the goal for 11,400 GWh of average domestic production of renewable energy as well as a decrease of average per capita energy consumption of 43% in 2035 (versus the level in 200) (Swiss Federal Office of Energy SFOE 1/18/2018). To achieve this goal, the Swiss government is increasing the budget of subsidies towards the promotion of energy efficient buildings from 300 million to 450 million CHF/a. The old infrastructure of the Gasthaus Göscheneralp, and buildings like it, are hampering the environmental goals of the Swiss Government by having a large energy demand due to poor heating systems. The refurbishment of buildings with high heat demand is essential to environmental sustainability.

With help from the above-mentioned subsidies, the Gasthaus Göscheneralp could support Switzerland's energy goals while also improving the business' financial position. The heat demand of the bed & breakfast accounts for the majority of the electricity costs due to the inefficient existing electricity-to-heat conversion technologies. Despite high investment costs, a switch to a renewable heat source could be profitable due to the lower marginal cost of heat production.

## 1.3 Project aim and objectives

The technical and financial feasibility of implementing a new heating system with at least two variations will be analysed as a possible climate-neutral solution to reduce electricity consumption and cut energy costs.

# 2 Methodology

In this section, the research approach and the underlying methodology (qualitative, quantitative methods) are described. A "process-interim result" structure was used throughout this report. The "process-interim result" methodology defines processes to complete intermediate objectives, which build up to achieve the overall aim of this project: to recommend an optimal heating solution based on both technical and financial aspects. This goal has many facets, which does not fit with a rigid methodology. Therefore, this general methodology of "process-interim result" was chosen based on its simplicity and its ease to implement in various work packages of a project. The interim results align with the chapters of this report, whereas the processes align with the methods used. A schematic of the general methodology can be seen in Figure 1. The processes, or methods used, are outlined in this chapter. The application of the methods can be found in their respective chapters within this report.

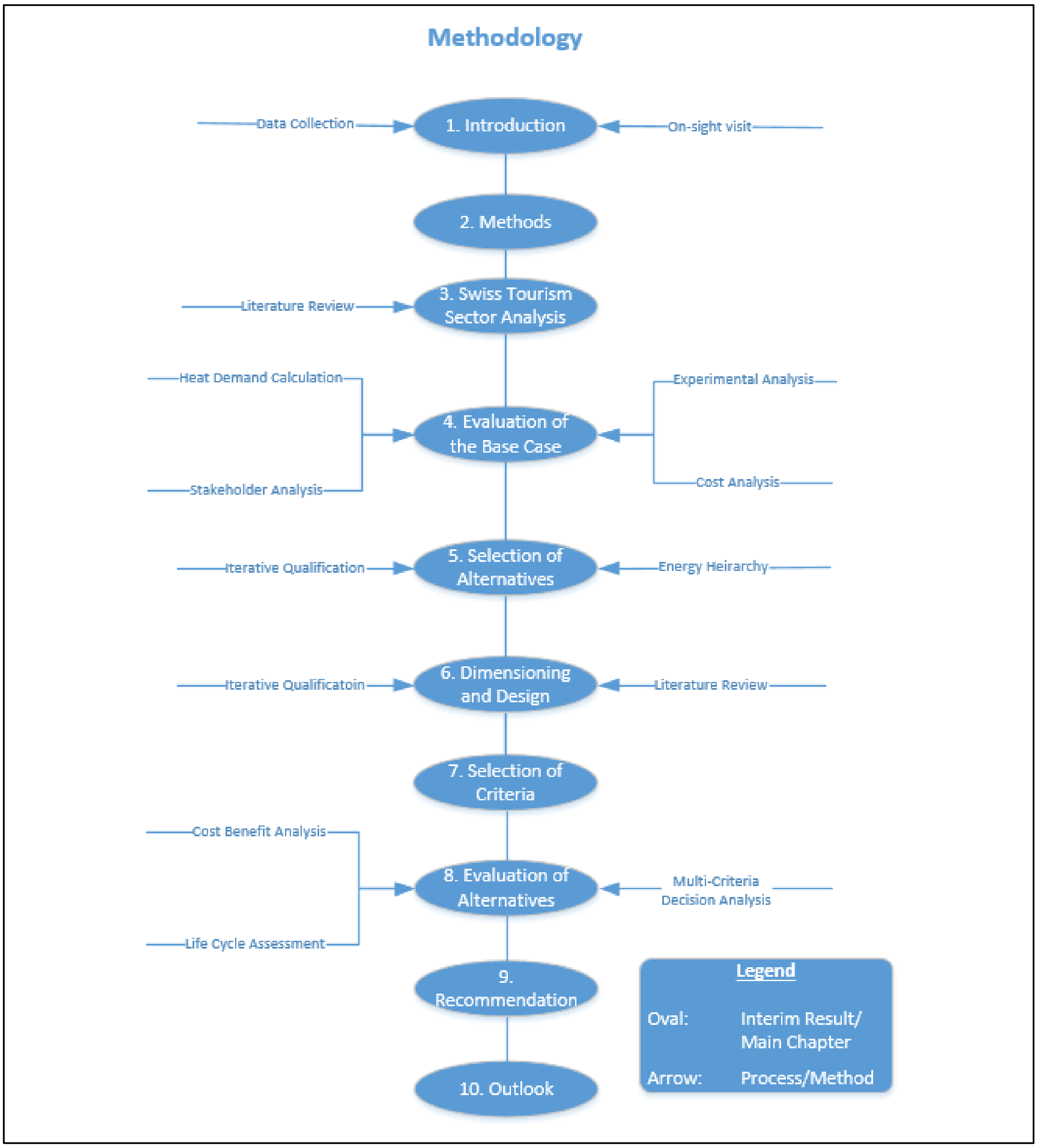



*Figure 1: Process-interim result methodology diagram*
*Source: Own illustration*

## 2.1 Literature review

Literature review throughout this study is a tool to gather information that builds upon prior knowledge. Academic papers, scientific articles, government reports, and other sources were used to provide relevant information for this report. The sources of selected literature were carefully assessed for their credibility such that reliable information is provided. The analysis of the Swiss tourism sector and the dimensioning and designing of heating alternatives were the interim results that primarily required literature review, yet all other interim results required a certain degree of literary research and review as well. Even specific methods listed in this chapter required research of existing literature to support the steps taken as viable process to determine an end result.

## 2.2 On-site visit and data collection

Initially, little definitive data was known about the existing heating system. Prior knowledge of the heating system was established by the Gasthaus owner which formed the starting point for this project. In order to perform a deeper analysis, further data collection methods were required.

An on-sight visit was conducted and photos were taken of relevant heating components; namely the heat storage tanks, wood stove, radiators, windows, and heat distribution piping (see On-site photos in the appendix). This gave knowledge of the model and make of the various components as well as the interconnectivity between the constituents of the heating system. From this information, further important factors such as primary energy sources, performance of installed technologies, and the current heat demand could be deduced. Needs and interests of the Gasthaus Göscheneralp owner/manager were also clarified.

The original building plans were retrieved which provided information of the building dimensions as well as some limited information of the construction materials (see Building plans in the appendix). Furthermore, the biannual (spring-summer and autumn-winter) energy bills of 2018-2019 were verbally provided to aid in the calculation of the heating costs. The total cost of all electricity consumption for both heating and general utility was provided by means of a testimony from the Gasthaus Göscheneralp owner, and the price per kilowatt-hour was given by the local utility provider (Elektrizitätswerk Göschenen 2019).

## 2.3 Experimental analysis

The main features of the existing heating system were known from the collection of nameplates of the appliances such as the storage tanks, integrated electric heaters, and so on. However, the wood stove posed a large unknown factor in the base case heating system. The model and make was unknown because the nameplate of the stove was missing, therefore making researching the technical data not possible. An experimental analysis was undertaken to understand the average heating power, mass flow of the wood, efficiency, and cost per kWh. The system boundary of the experiment was defined, an experimental procedure was executed, and observations were recorded. The result could then be used to evaluate the base case heating system. A deeper analysis and a step-by-step procedure can be seen in section 4.3 of this report.

## 2.4 Heat demand calculation

A crucial aspect to a heating system analysis is a deep understanding of the heat demand of the building. An accurate heat demand estimate allows for an optimal coupling of heat production with demand. This includes the demand from heat losses through the building envelope, infiltration loss through air leakage, and the use of domestic hot water.

Space heat losses were calculated by finding the specific transmission and infiltration losses in terms of Watt per Kelvin. This could then be multiplied by derived Heating Degree Day values for various time intervals. The Heating Degree Days were weighted based on seasonal heat demand information. This yielded an estimated annual space heat energy demand for the building site.

To find the heat energy required for the domestic hot water demand, estimates of daily demand curves were necessary. These demand curves were then extrapolated over the appropriate seasonal demand pattern to yield the seasonal heat energy demand for domestic hot water. The seasonal demands were then summed to give the yearly domestic hot water energy demand.

The complete process necessitates many mathematical formulas and interim steps. The analysis is unique to the application of the building in question due to factors such as the heating system configuration, building type, and demand patterns. An in-depth explanation specific to the Gasthaus Göscheneralp can be seen in section 4.4.

### 2.5 Stakeholder analysis

A method for assessing all parties impacted by the projected renovation the heating system was necessary in order to better understand the effects of making a certain decision. This enables better strategic decision-making. To this end, a stakeholder analysis was used. A stakeholder analysis considers all parties affected by the system in question. The applicable parties are then placed on a spatial matrix to be rated in terms of how much power they have over the system and how much interest they have in the system. An example of a stakeholder analysis is depicted below in Figure 2:


*Figure 2: Stakeholder analysis template*
*Source: (Mugridge et al. 2019)*

This matrix allows for a qualitative comparison of the stakeholders affected by the system. The most import stakeholders can be determined thus allowing future decisions to be made to meet their needs (Leventon et al. 2016).

As applied to the Gasthaus Göscheneralp case, the stakeholders were assessed on a fluid scale of low-high interest, and low-high power. Low interest and low power stakeholders should be monitored at minimum effort in case their position may develop and gain importance. High-interest and low-power stake holders should be kept informed of the decision, yet do not have a strong influence on the results of the decision. High-power and low-interest stakeholders should be kept satisfied because these plays can impact the results of the decision. Finally, stakeholders that enter the high-interest and high-power area must be managed closely, and criteria should be set to reflect their interests.

The completed stakeholder analysis was presented to the owner/manager for validation.

## 2.6 Iterative qualification

An iterative process of qualification, rejection, and adaptation was carried out until only the most technically and financially feasible options for a heating system renovation remained. Throughout the development of the project, this method allowed the selection of heating system alternatives to remain agile and further adaptations could be made. A flow diagram of this process can be seen below in Figure 3:

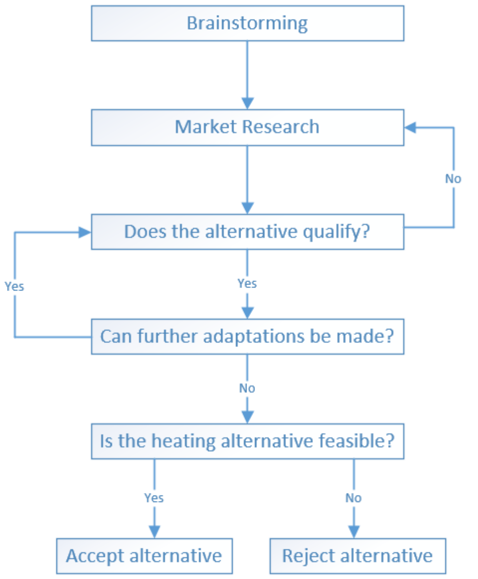



*Figure 3: Interactive qualification flow chart*
Source: own illustration

This method is applied and further discussed in both the "Selection of Alternatives" and "Dimensioning and Design" chapters of this study.

## 2.7 Energy hierarchy pyramid

The diagram in Figure 4 was used as a tool to prioritize various energy-improvement measures of buildings. It illustrates the most basic and cost-effective measures at the foundation of the triangle, with less cost-effective and exorbitant measures at the top of the triangle. This method of assigning effectiveness to building renovation measures was used in conjunction with the iterative qualification method throughout the qualification, adaption, and accept/reject phases of the selection process for heating system solutions.

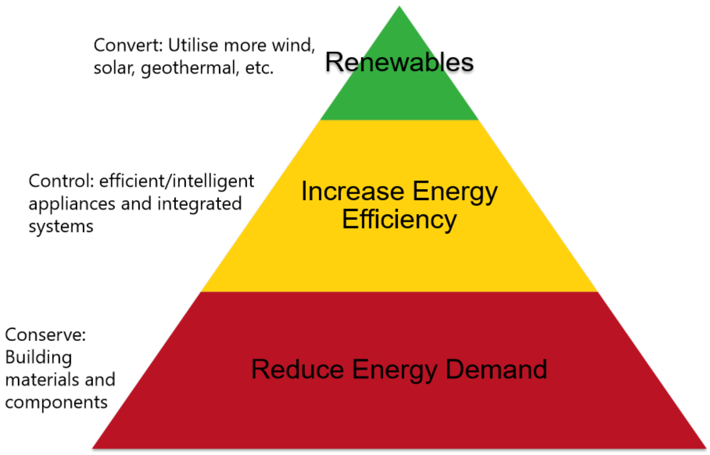



*Figure 4: Energy hierarchy of buildings*
*Source: (Bollinger 4/23/2020)*

## 2.8 Cost/benefit analysis

A Cost/Benefit Analysis was conducted in this project to attempt to address the economic sustainability of the selected heating alternatives. A cost benefit analysis consists of the following basic components (Layard and Glaister 2005):

1. Definition of scope and assumptions
2. Identification of alternatives and quantification of costs/benefits for each alternative
3. Selection of appropriate discount rate and calculation of present value of costs/benefits
4. Selection and application of measure for comparing alternatives
5. Discussion of uncertainties

This method highlights the temporal difference of the cash flow and Net Present Value, or NPV, of the heating system alternatives. This term attempts to define the profitability of an investment by evaluating the worth of cashflows in the future which are adjusted to consider the time value of money. The formula for the net present value is shown below:

*Equation 1: Net Present Value*
*Source: (Arnaboldi et al. 2015)*

$$NPV = \sum_{i=1}^{n} \frac{Cashflow_i}{(1+r)^i} - initial\ investment$$

$r$ is the discount rate and $i$ is the time unit of the investment. It also reveals the sensitivity of the results when assuming different input parameters.

## 2.9 Life cycle assessment

When evaluating the heating alternatives, environmental sustainability was also considered. For this purpose, and Life Cycle Assessment was employed. Products or services, in this case a heating system, that are to be evaluated in terms of environment impact can be done so by means of a Life Cycle Assessment, or LCA (Muralikrishna and Manickam 2017). An effective LCA focuses on process that stress the environment over the entire life cycle of the product. This typically includes processes of extraction of raw materials, manufacturing, transportation and distribution, use and maintenance phase, and the final disposal. The ISO 14040 and 14044 standards define four phases of an LCA (Principles and framework 14040)(Requirements and guidelines 14044):

1. Goal and scope definition
2. Inventory analysis: compiling relevant inputs and outputs
3. Impact assessment: evaluating potential environmental impacts associated with inputs and outputs
4. Interpretation: evaluation of results (inventory analysis and impact assessment) in relation to objectives of LCA

There have been extensive studies done and LCAs conducted on various heating system alternatives (Aquino et al. 2017) (Greening and Adisa Azapagic 2014) (Flury and Frischknecht 2012). Therefore, this project considers existing LCAs on the selected heating system alternatives and compares the results qualitatively. LCAs with similar parameters to that of the selected heating alternatives were chosen. However, some fundamental differences remained prevalent. These parameters and inconsistencies are highlighted and discussed in the LCA section of the evaluation of results (see section 7.2).

A complete ground-up approach to producing new LCAs tailored to the parameters of this project would include the purchase of licensing of a capable LCA software, access to applicable databases for the respective heating alternatives, and expertise in the use of the selected software. Although this approach would better represent the environmental impact of the alternatives, this exceeds the financial and temporal scope of this project. Therefore, a qualitative comparison of the results from the LCAs of the selected heating alternatives was thought to be sufficient for the scope of this project.

### 2.10 Multi-criteria decision analysis

A multi-criteria decision analysis, or MCDA, is a means to assess the impacts of a decision using several factors over a comparable basis. This tool can be effective when making complex decisions that involve various metrics. By assigning weighted values to a criterion bases on the decision makers preferences, a decision can reached that is scientifically defensible. This method is especially effective when evaluating social factors of which their impacts are otherwise difficult to quantify. The following steps comprise a MCDA (Angelis and Kanavos 2017):

1. Problem identification
2. Problem structuring
3. Assessment
4. Initial results and sensitivity analysis
5. Decision/planning

The first step, problem identification, aligns with the project aim of this report. The second step is comprised of the "Selection of criteria" section in the beginning of chapter 7. Therefore, the MCDA section 7.3 in this report addresses steps 3 and 4, and step 5 (Decision/planning) is applied in the recommendation chapter.

The MCDA was used to compare the results of the CBA and LCA of the heating system alternatives. Additionally, social criteria were introduced in this evaluation method to cover the social pillar of sustainability thus giving a holistic assessment of the relative sustainability of the heating alternatives.

Microsoft Excel was used to tabulate and to calculate the total sustainability score of each purposed heating solution. Then, a more detailed analysis was made using the MCDA software Decerns (Dee & Soft 2017). This software was chosen because it is open source and user friendly. Other MCDA software provide the evaluator with more functions and control over the MCDA process. However, for the scope of this report, the Decerns framework proved to be sufficient in that the tools of problem structuring and modelling (Value Tree and Performance Table), weighting criteria, sensitivity analysis and uncertainty treatment could all be implemented (Linkov and Mober 2012).

# 3 Analysis of Swiss Tourism Sector

As mentioned in the introduction of this report, the building sector is an important consumer of energy, which must be addressed when formulating measures to meet environmental goals. The Gasthaus Göscheneralp is a building of generally outdated and inefficient infrastructure. Therefore, it is applicable to the measures discussed in the Swiss Energy Strategy 2050 (FOEN 2018). However, when one considers the “bed and breakfast” business function of this building, the Gasthaus Göscheneralp also falls into the energy measures applied to the swiss tourism sector. To formulate a complete analysis of the buildings heating system, it is important to view the building within the context of the swiss tourism sector, which also plays a major role in the economic, social, and environmental aspects of Switzerland.

When looking at the statistics, it indicates tourism having a large economic role in Switzerland. According to Hueber at the FDFA, “tourism is one of Switzerland’s most important economic sectors” (Hueber 2020). In 2017, the swiss tourism sector generated a total revenue of 44.7 billion CHF, and 18.7 billion CHF of Gross Value Added (GVA) (STF 2019). It is one of the largest export industries in Switzerland at 4.4% at 16.6 billion CHF (STF 2019). Despite an already large demand in tourism, the number of overnight stays continues to modestly increase by +5.2% from 2016-17, and +3.8% from 2017-2018. These figures are especially relevant for the Gasthaus Göscheneralp in that it belongs to the accommodation and food and beverage services within tourism, which makes up the majority of tourism industry at about 30%.

The social aspects of the tourism in Switzerland are also impactful and widespread. This is evident when looking at the employment numbers of tourism, which employs around 4% of the working population. Moreover, the alpine regions of Switzerland stand to benefit the most from tourism. In some tourist destinations in the alps, value added of tourism amounts to more than 80% of the regional GDP (Müller et al. 2007). Large cities have other industries such as pharmaceuticals and banking to promote social stability, whereas many rural mountain towns depend primarily on tourism as the main source of income. A major contributor to the Swiss tourism industry is hiking and skiing, two activities that stimulate social well-being. Switzerland offers more than 65,000 kilometres of hiking trails, which is unrivalled by any other country in the world. Hiking is the most popular leisure and sporting activity in Switzerland, of which 2.7 million swiss and 300,000 tourists from aboard are active hikers (STF 2019). Skiing is also a favourite leisure pursuit for many Swiss people, and Switzerland is the fifth most popular ski destination in the world (Hueber 2017). The Gasthaus Göscheneralp, as it is located in the midst of the central alps, supports both hiking and skiing activities by offering accommodation and food and beverage services.

It is beyond dispute that tourism positively affects both social and economic aspects of Switzerland. However, the tourism and its relationship with the environment is more complicated. Tourism causes both direct and indirect effects on the environment. Directly, the tourism sector leads to more land usage in areas that would otherwise support untampered ecosystems, especially in sensitive areas such as the alpine regions. Also, energy is consumed, and greenhouse gases are emitted from tourism infrastructure and activities, mainly due to an estimated 5% increase of mobility stemming from tourism (Federal Department of Economic Affairs, Education and Research 4/22/2009). People travel by fossil fuel modes of transportation to pursue touristic activities. In 2018, inland travel for tourism purposed used 3.7 PJ of energy (Strauss et al. 2020). This shows the significant negative impact tourism has on the environment. On the other hand, tourism has the potential to create beneficial effects on the environment by contributing to environmental protection and conservation. It is a way to raise awareness of environmental values and it can serve as a tool to finance protection of natural areas and increase their economic importance (Sunlu 2003).

Above it is mentioned how tourism affects the environment. However, the environment, specifically the threat of climate change, affects tourism as well. In many places, the first effects of warmer temperatures, higher snow lines, or more frequent extreme events have already been noticeable (Müller et al. 2007). The increasing instability of winters can lead to less snow reliability in alpine regions. Tourism in these areas can expect changes in the landscape due to receding glaciers and the melting of permafrost. This will strongly affect the attractiveness of alpine tourism regions and change the degree of danger associated with rockslides and avalanches from the melting of permafrost. However, the accommodation sector in these regions could benefit from these areas being more easily accessible throughout the year. The ramifications of climate change are difficult to predict, but it is certain that the tourism sector must continually adapt to the new challenges.

The tourism sector plays an important role in many lives throughout Switzerland and considering all implications of future change is important for its progress. Preventative measures should be taken against climate change to foster the success of tourism services. Additionally, service providers should develop adaptation strategies for diversifying offerings and improving infrastructure. Energy efficient practices such as the installation of renewable and energy efficient technologies can minimize the negative impacts of tourism on the environment, as well as strengthen societal belief in conserving natural areas. Measures to improve the energy systems of buildings, and tourism facilities in general, are key steps towards a more sustainable future.

# 4 Evaluation of the base case

To improve upon the heating system of the Gasthaus Göscheneralp, the current heating system must first be understood. Only then can adaptations be made in areas of inefficiencies thereby creating a cost-effective and adept heating solution. The interim result of the evaluation of the base case system was achieved through a stakeholder analysis and an in-depth analysis of the current heat demand. These steps provide both a qualitative and quantitative means for evaluation.

## 4.1 Stakeholder analysis

A deeper understanding of the players involved in the projected renovation of the heating system was necessary to frame future decisions in this study. This can be done qualitatively using a stakeholder analysis as mentioned in the methodology section 2.5. The results of the stakeholder analysis are outlined below in Figure 5.

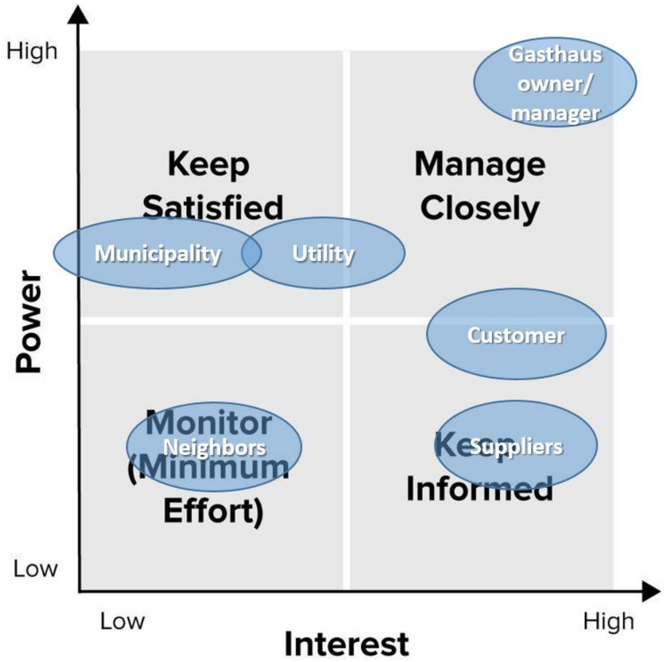



*Figure 5: Applied stakeholder analysis*
*Source: Adapted from (Mugridge et al. 2019)*

The following stakeholders were considered and positioned on the matrix:

**Gasthaus owner/manager**: manage closely- the owner and manager of the Gasthaus ultimately has the final say of the heating system and is impacted the most by the results. If the heating system does not meet thermal comfort standards or malfunctions, then the owner/manager will be greatly financially affected in both repair costs and loss of customers due to dissatisfaction.

**Municipality**: keep satisfied- the municipality has the power to create and enforce policy at a local level. However, the heating system of a local business is not of high interest from the municipality's perspective.

**Utility**: keep satisfied- the local utility provider has the power to adjust prices for both the grid usage and energy supplied. This could affect the decision making when considering heating system alternatives. Unlike the municipality, the local utility company is slightly more affected by the heating system because the Gasthaus is a mid-level consumer of their product- electricity.

**Suppliers**: keep informed- the suppliers of heating system components have an interest to sell their product to the Gasthaus owner/manager, therefore it is important to keep them informed. Also, they control the prices of their products, which is a degree of power from the suppliers, even though the Gasthaus owner could select a product from a supplier's competitor.

**Customers**: keep informed- the customers desire a certain level of thermal comfort. The customers would like to sleep and eat in a building with a properly designed and operating heating system. Beyond this, the customer base of this particular Gasthaus, as it is located in the mountains, could be attracted to the outdoors, and therefore they would value an energy efficient heating solution. If demand from the customer increases, this could directly influence the decision of implementing a heating system solution and ultimately shows a presence of some power.

**Neighbours**: monitor (minimum effort)- the residents within close proximity to the Gasthaus would have both little power and little interest in the implementation of a heating system alternative. Some effects of specific alternatives could displease neighbours such as noise during the construction phase, noise of the operation of an outdoor heat pump, or having a negative disposition to the aesthetics of a solar collector; but neighbours must first go through a formal process by means of the municipality to have any influence over the heating solution.

This analysis results in the Gasthaus Owner/Manager being the most important stakeholder in the context of the heating system renovation. This is to be expected given that the owner/manager's livelihood is at stake if the business is affected, and a heating system affects cost of the business, as well as customer satisfaction due to thermal comfort or lack thereof. Customer satisfaction also implies the customer is an important stakeholder in this decision process. The interests, needs, and position of the utility should also be strongly considered as they have a large degree of power. The importance of the other stakeholders is relatively peripheral.

### 4.2 Site data

The location of the Gasthaus Göscheneralp plays a major role in assessing the current heating system parameters, as well as defining potential alternatives for improvement. The collection of the building plans and the on-site visit were then initial the steps taken to collect reliable data of the current situation (see appendix: Building plans, and On-site photos). The exact material layering of the roof, and angle of the roof was not known. This information was inferred based on industry standards at the time of construction as well as verbal confirmation from the Gasthaus owner (Brody 2017).The relevant figures derived from the building plans are outlined below in Table 1:

*Table 1: Building part areas*
*Source: Building plans (see appendix: Building plans)*

| Building Part | Surface Area [m²] | U-Value [W/m²K] |
|---|---|---|
| Walls | 122 | 0.35 |
| Windows | 34 | 3.00 |
| Ground | 96 | 0.54 |
| Roof* | 115 | 1.00 |
| Heating Reference Area | 287 | 1.08 |
| Total area | 398.17 | - |

**a tilt of 30° was assumed*

Subsequently, meteorological data was extracted using the PVGIS tool, which interpolates weather data for a given location from nearby weather stations. The values for 2016 were used to model the typical climate conditions of the Gasthaus Göscheneralp. This provided values for monthly averages of temperature and irradiation, as well the yearly averages and totals. These values can be seen in Table 2. Heating Degree Days, or HDD were established in a later stage, then added to this table for a complete meteorological overview of the site. The factor of HDD was used to find the space heat demand that is outline in section 4.4.

*Table 2: Site data*
*Source: (Europa Analytics 2019)*

**Site Data**

| | | | |
|---|---|---|---|
| ***Street:*** | Gwüest 5 | ***Elevation:*** | 1564 meters |
| ***Area Code:*** | 6487 | ***Owner/ Manager:*** | Seraina Wicki |
| ***City:*** | Göschenen | ***Data Source:*** | PVGIS |

| Season Type | Month | Irradiation* [kWh/m²] | Average Temperature [°C] | Heating Degree Days |
|---|---|---|---|---|
| Winter Season | January | 8.15 | -3.9 | 267 |
| | February | 21.76 | -2.6 | 228 |
| Middle Season | March | 68.48 | -1.2 | 636 |
| | April | 78.87 | 2.1 | 537 |
| Summer Season | May | 78.58 | 6.7 | 0 |
| | June | 67.09 | 11.4 | 0 |
| | July | 84.96 | 14.2 | 0 |
| | August | 102.25 | 13.8 | 0 |
| Middle Season | September | 101.5 | 11.1 | 267 |
| | October | 45.98 | 3.5 | 495 |
| Winter Season | November | 11.88 | -0.8 | 174 |
| | December | 7.9 | -2.1 | 213 |
| | **Total:** | **677.4** | **4.35** | **2817** |

*irradiation derived from a vertical south orientation

## 4.3 Wood stove analysis

The unknown parameters of the wood stove were the heating power and efficiency. The heating power of the wood logs, $h_v$, which are a semi-dried beech, was assumed to be 4.15 kWh/kg at 15% moisture content from information using the Wood Fuels Handbook (Francescato et al. 2008). This allowed for the theoretical heating power of the wood stove, $P_t$, to be calculated given a certain mass flow of wood, $\dot{m}$, using the Equation 2. The theoretical heating power can be compared to the real heating power to find the efficiency of the wood stove:

*Equation 2: Bio-mass heating power*
*Source: (Nussbaumer and Schumacher 2019b)*

$$P_t = \dot{m} \times h_v$$

Then, the experimental procedure was as follows:

1. Collect enough wood to fill up the burning chamber.
2. Weigh the amount of wood from step 1

3. Record starting temperature of space heating storage tank
4. Fire the wood stove with the established amount of wood from step 1. Tend to the wood as needed such that the fire burns constantly.
5. Measure and record the temperature of the heat storage tank every 15 min until the wood is completely combusted. Make notes of observations, as necessary.

This procedure yielded roughly a 20-minute heating profile of the charging of the space heating storage tank by means of the wood stove. This allowed the finding of the average heating power and its efficiency of the wood stove. Now the current heating system production data was known for all heating system components. The wood stove analysis gave the following results in Table 3:

*Table 3: Wood stove analysis parameters and results (derived from appendix: Wood stove experiment)*

| **Parameters** | **Values** | **Definition** |
|---|---|---|
| Change of time deltat [hr] | 3 | deltat= total elapsed time |
| Change of temp deltaT [K] | 68 | deltaT=starting temp-ending temp |
| Buchenholz Hv [kWh/kg] | 4.15 | Source: (Hahn et al. 2014) |
| Mass flow= m' [kg/h] | 10.33 | m'= mass/deltat |
| Theo. heating power Pt [kW] | 43 | Pt = m'*Hv* |
| Real heating power Pr [kW] | 18 | Pr = E/deltat |
| Efficiency N [-] | 0.43 | N = Pr/Pn |
| Heat energy in tank E [kWh] | 55 | E = rho*V*Cp*deltaT |
| Variable cost of wood Cv [CHF/kg]* | 0.15 | Cv = (CHF/Klafter)*(Klafter/V)*(1/rho of Klafter) = 320CHF*(1/3m3)*(1/700kg/m3) |
| Annual cost of wood Ca [CHF/yr]* | 320 | Ca = (1 Klafter /year)*(CHF/Klafter) |
| Yearly Energy Ey [kWh/yr] | 3740 | Ey = Ca*(1/Cv)*E*(1/mtot) |
| Price per KWh Ce [CHF/kWh] | 0.086 | Ce = Ca/Ey |

**Klafter is a unit of volume for measuring a stack of chopped wood logs. 1 Klafter is roughly 3 $m^3$*

## 4.4 Heat demand

From the on-sight visit, the building plans, and further values collected from secondary research, the heat demand calculations could be made. The heat demand is an important parameter when dimensioning an adequate heat production technology, and it provides insight to the cost drivers of the heating system.

### Transmission losses

The transmission heat loss calculation requires the layering data of the wall, floor, and roof. The material type and layer thickness are required. Once this is collected from the building plans (see appendix: Building plans), research was conducted to find the heat conductance (lambda-value) of each layer. The material values can be seen below in Tables 4 and 5.

*Table 4: Material values of the walls*
*Source: (Marti and Di Paolantonio 2014)*

| | **Material** | **(English)** | **Thickness [cm]** | **Lambda-Value [W/mK]** |
|---|---|---|---|---|
| **1** | Eternitverkleidung | Cement asbestos | 2.0 | 0.560 |
| **2** | Lattung | Battens | 2.0 | 0.130 |
| **3** | Kraftpapier | Kraft Paper | 0.5 | Negligible |
| **4** | Schalung | Formwork | 2.5 | 0.130 |
| **5** | Vertoflex | Vetroflex | 8.0 | 0.040 |
| **6** | Lattung | Battens | 2.0 | 0.130 |
| **7** | Täfer-Verkleidung | Paneling | 2.0 | 0.130 |

*Table 5: Material properties of flooring*
*Source: (Marti and Di Paolantonio 2014)*

| | **Material** | **(English)** | **Thickness [cm]** | **Lamba-Value [W/mK]** |
|---|---|---|---|---|
| **1** | Betonbodenplatte | Concrete Flooring | 18.0 | 2.100 |
| **2** | Hartschamstoffplatte | Styrofoam | 2.0 | 0.025 |
| **3** | Holz | Wood | 5.0 | 0.130 |
| **4** | Isotex | Wood/Concrete | 0.5 | 0.050 |

The building materials and their heat conductivity for the windows and doors were not given in detail in the building plans, but a testimony from the Gasthaus owner as well as observed data from the on-site visit revealed poor insulation of the doors, and the windows were of double-, and sometimes only single-pane glazing. A general lambda-value of 3.0 W/mK was defined for all windows and doors on the facade based on established norms in the building sector (Aspire Bifolds 2019).

Additionally, material data for the roof was not provided in the building plans, therefore an assumption of the lambda-value was made based on the conditions of the roof. One relevant aspect is that the space directly below the roof is inhabited by hotel guests, therefore the space cannot provide additional insulation as would, for example, an unheated storage space. In addition, the roofing does have an insulation layer; however, it dates to the original building construction of 1954. Based on empirically tested lambda-values of roofs with similar construction years and building types, a lambda value of 1.0 W/mK was assumed (Baker 2011).

Once the complete data of the building envelope was established, the serial heat transfer equation was applied to find the thermal transmittance (U-value) over the respective surfaces. Thermal bridges and planer inhomogeneities were neglected. The thermal transmittance equation is shown in Equation 3.

*Equation 3: Thermal transmittance*
*Source: (Weigland et al. 2016)*

$$U_{TR} = \frac{1}{\frac{1}{h_i} + \frac{d_1}{\lambda_1} + \cdots + \frac{d_n}{\lambda_n} + \frac{1}{h_e}} \quad [W/m^2]$$

The variable $h_i$ is the heat transfer coefficient of the interior wall side, $h_e$ is the heat transfer coefficient of the exterior wall, $d$ is the layer thickness, and $\lambda$ is the heat conductance.

The thermal transmittance, $U_{TR}$, was then multiplied by the area of the buildings to yield the specific U-value with respect to Kelvin as see in Equation 4.

*Equation 4: Specific U-value for transmission losses*
*Source: (2028)*

$$U_{specific,TR} = \sum U \times A \quad [W/K]$$

This was conducted separately for the walls, windows, roofing, and flooring with their respective surface areas, then summed to receive the overall transmission heat flow per Kelvin [W/K]. This yielded a result of 300 W/K. The specific thermal transmittance could later be applied directly to find the HDD to find the annual heating energy, or it could be factored with the change of temperature that the heating system must produce to supply the transmission heating power demand seen in Table 6. The change of temperature was considered for the peak demand, which is defined to be 20 Kelvin in the spring/autumn months from approximately 0°C ambient temperature to a room temperature of 20°C.

**Infiltration losses**

Infiltration losses are prevalent in older buildings, such as this Gasthaus, due to outdated building technologies being used with little or no standardization with respect to the building envelope (Baker 2011). This results in large air leakages that must be accounted for with a large heating power supply. Calculation for the dimensioning of this output with respect to Kelvin can be done with the following equation (Equation 6):

*Equation 5: Specific U-value for infiltration losses*
*Source: (Owen and Kennedy 2011)*

$$U_{specific,AE} = AE \times V_B \times \rho \times C_p \quad [\mathrm{W/K}]$$

In this specific case, the building is constructed without mechanical ventilation thus relying on natural air leakage through joints in the construction, and cracks between door and window frames to supply clean air. For passive ventilation of this nature, the air exchange rate, $AE$, is assumed to be 1.2 1/hr (Owen and Kennedy 2011). Additionally, although the density and heat capacity of air varies with a change in temperature, the factor of density times specific heat capacity, $\rho \times C_p$, can be simplified as a fixed value of 0.33 Wh/m²K based on the sources (Klems 1983; Hall 1994). (Hall 1994; Klems 1983)The building volume, $V_B$, has been derived from the building plans. The result of the infiltration heat loss is 240 W/K. Like the transmission losses, the specific U-value for infiltration losses could be used to find the annual heating energy, or the infiltration heating power demand seen in Table 6. The temperature change, $\Delta T$, used to find the infiltration heating power demand is defined as the same value as the transmission heat losses of 20 Kelvin.

**Heating degree days**

Now that the heat flow per Kelvin for both transmission and infiltration losses was found, the missing factor of Heating Degree Days was necessary to calculate the energy demand on the scale of months, seasons, and finally of one year. Heating Degree Days, or HDD, is a metric used to quantify the demand of energy needed to heat a building in a certain location over a certain period of time. HDD takes into account the amount of temperature change must made over a period of time. Then, this term can be factored with the heating power demand to estimate the energy demand over a given time period.

To calculate HDD, a threshold is defined for the minimum temperature inside the building to meet comfort standards. Then the difference of the threshold temperature to the outside temperature is found and multiplied with the amount of days when this occurs. The resulting unit is [days x Kelvin]. The threshold for Switzerland is defined at 12°C and can be seen mathematically in the following formula (Equation 6) from the SIA 2028 norm:

*Equation 6: Heating degree days*
*Source: (2028)*

$$HDD = \sum_{j=1}^{n}\left(20 - \theta_{am;j}\right) \quad \text{for all outdoor daily average temperatures } \theta_{am;j} \leq 12°C$$

The average monthly temperatures in the year 2016 for the building site in Göscheneralp were derived from the PVGIS weather tool (Figure 6). The comfort threshold for the Gasthaus Göscheneralp differs from the Swiss SIA standard in that the building is not inhabited in the winter months (November through February), and therefore it is not heated to 20° celsius. During this period, a temperature threshold of 5°C was assumed because the water inside of the heat storage tanks should be kept at this temperature in order to prevent the hydraulic heat distribution system from freezing. In the summer months (May through August), the Gasthaus owner/manager has claimed that space heat production is not required. Therefore, zero HHD was assumed for summer. The temperature threshold of the remaining months of the year were assumed to follow the SIA 2028 norm mentioned above. The result of the HDD calculations is 2817 [days x Kelvin] and can be seen in the Site Data Table 2.

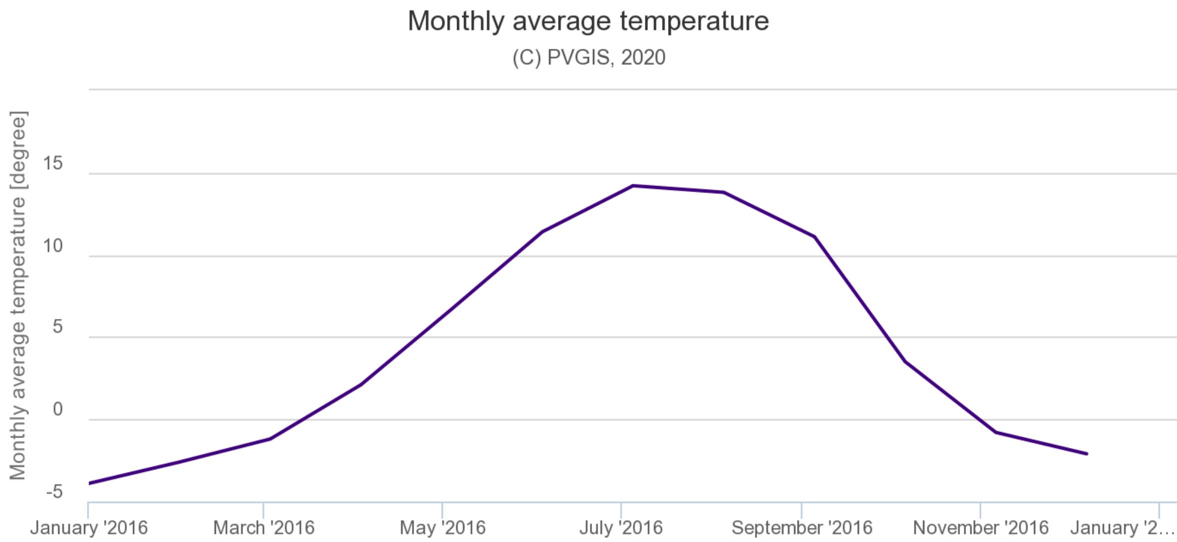



*Figure 6: Average monthly temperatures in the year of 2016 for Gwüest 5, Göschenen*
*Source: (Europa Analytics 2019)*

To apply the HDD to find the space heat energy [kWh/a] over a specific time period, the following formula (Equation 7) is used:

*Equation 7: HDD factored with time scalars to yield annual space heat energy*
*Source: (Füssel 2019)*

$$E_{SH} = HDD \times .001 \times 24 \times \sum U_{specific} \quad [kWh]$$

The scalars 0.001 and 24 are used to yield the desired units from watts to kilowatts and day to hours, respectively. The results of the annual space heat energy demand can be seen in the following section, 4.4.1.1 Domestic hot water demand, in Table 6.

#### 4.4.1.1 Domestic hot water demand

The third and final aspect of the heat demand calculation is the domestic hot water, or DHW, demand. The daily energy demand can be modelled with the following equation:

*Equation 8: Domestic hot water energy demand per day*
*Source: (Hildebrand and Alimpic 2012)*

$$E_{DHW} = \mathrm{V} \times \rho \times C_p \times \Delta T \qquad [\mathrm{kWh/day}]$$

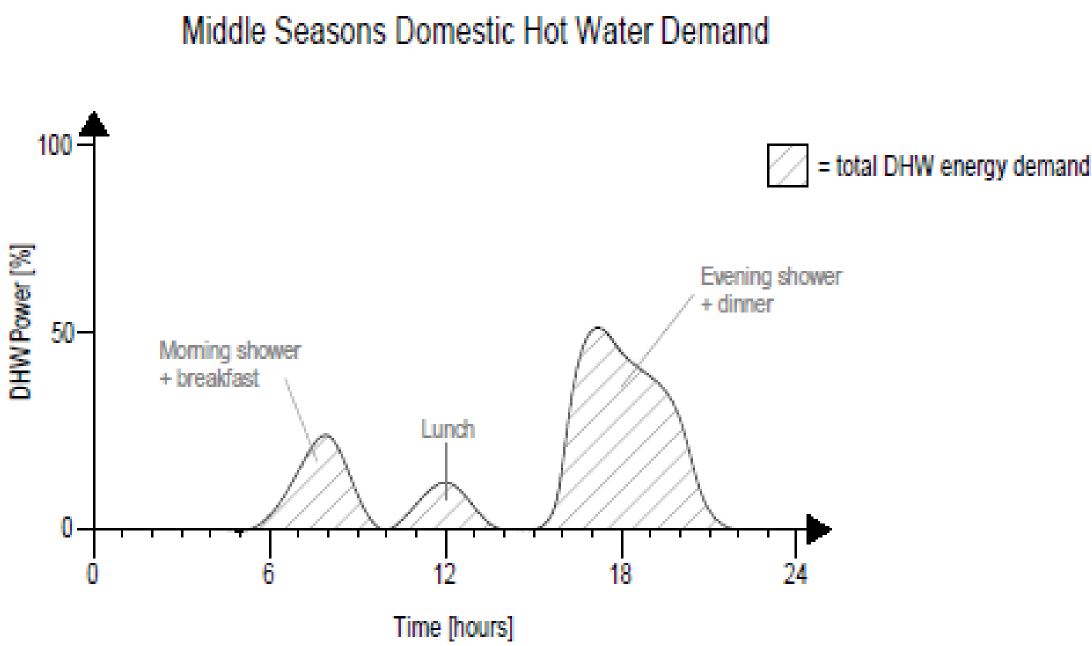
The change of temperature, $\Delta T$, is defined as the freshwater inlet of 10°C (Osmancevic et al. 2018) being heated up to 60°C for a hygienic storage condition mitigating the production of legionella (Hildebrand and Alimpic 2012). Empirical values of the density, $\rho$, and specific heat capacity, $C_p$, for water are used.

The volume of water required, V, can vary greatly depending on the function of the building. In the hotel sector, the use of hot water applies to many processes, specifically showering, dishwashing, laundering, cooking, and drinking. According to Weber, a building used as a restaurant should provide 25 liters per person per day of DHW (Weber 2010). A hotel operation should provide 50 liters per person per day (Weber 2010). The Gasthaus Göscheneralp has a capacity of 50 people in the restaurant, and 17 beds for overnight guests (verbal testimony from the Gasthaus owner/manager). Combining these numbers, the volume flow for DHW can be calculated with the following formula:

*Equation 9: DHW daily volume flow*

$$\mathrm{V} = \frac{liters}{person \times day} \times number\ of\ people \qquad [liters/day]$$

Once the daily energy demand for DHW, $E_{DHW}$, was estimated, an hourly demand profile was necessary to understand the how the current heating system operates on a daily level. Then given approximations of seasonal demand patterns, the hourly demand could be extrapolated over a season, and eventually over the entire year. An hourly demand was developed and presented to the Gasthaus owner for validation. Important peaks resulted from morning and evening showering times, and from cooking times during breakfast, lunch, and dinner. A schematic of the demand profiles can be seen in Figure 7.



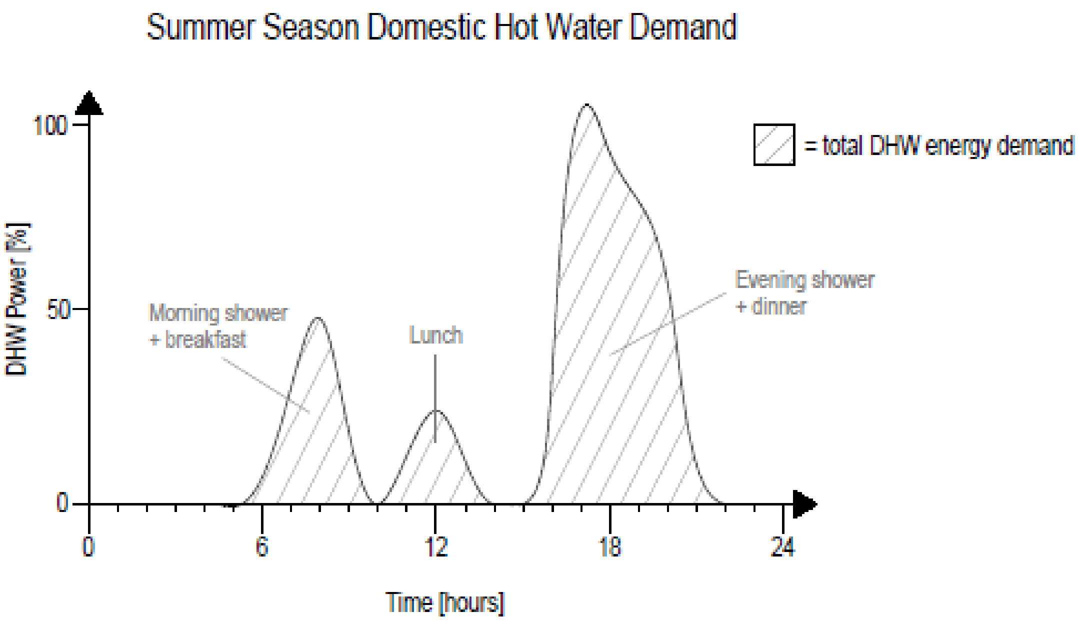



*Figure 7: Daily demand profiles for DHW*
*Source: Own illustrations*

Seasonal demand was assumed based on seasonal customer patterns outlined below (sourced from verbal testimony from the Gasthaus owner/manager):

Summer months: May-August at an average of 90% capacity
Middle months: March-April and September-October at an average of 45% capacity
Winter months: November-February at 0% capacity (operation suspended)

The final heat demand results for the thermal transmittance, the infiltration losses, and domestic hot water demand are outlined below in Table 6. The full load hours were not used in the calculation process. Rather, the full load hours are the quotient of power and energy and are shown to gain a sense of time usage for the heating system.

*Table 6: Heat demand calculation results*

| | **Power [kW]** | **Full Load Hours [hr/a]** | **Energy [kWh/a]** |
|---|---|---|---|
| **Infiltration losses** | 5 | 3400 | 17,000 |
| **Transmission losses** | 6 | 3400 | 20,300 |
| **Domestic hot water demand** | 10 | 1980 | 19,800 |
| **Total Heating Demand** | 21 | 2714 | 57,000 |

| | | | |
|---|---|---|---|
| **Space heat wood stove (production)** | 18 | 206 | 3,700 |
| **Electric heat (DHW+SH-Wood Stove)** | 11 | 4855 | 53,400 |

**Current costs**

Now that the annual heat energy was calculated for the DHW demand, space heat demand, and wood stove usage, the financial drivers of the base case heating system could be found. The electric energy used to power both DHW and space heat of 53,400 kWh/a was multiplied by the variable price for electricity at 10 Rp/kWh. The listed electricity rates from local utility provider are given for summer as 9.69 Rp/kWh and in winter as 13.69 Rp/kWh (Elektrizitätswerk Göschenen 2019). The simplification of 10 Rp/kWh was assumed because the majority of electric energy is consumed in the summer months of the year, seen from the DHW demand profiles and heating degree days in Figure 7 and Table 2. This gives the estimated annual cost of 5,340 CHF for converting electric energy from the grid to heat energy that is used for space heating and DHW. The amount of 5,340 CHF is omitting the additional costs of the woodstove, which are described later. When compared to the overall electricity expense of 5,800 CHF for all utilities, the electric sourced heating cost amounts to 92% of the total. Although this is a large proportion of the total electricity cost, it is plausible given the poor insulation of the building and high demand of DHW inherent in both the restaurant and hotel industries.

Annual fixed costs were considered such as the cost of wood for the wood stove of 320 CHF/a given by verbal confirmation from the owner/manager, and a yearly maintenance cost estimated at 300 CHF/a to clean the chimney of the wood stove (Eidgenössisches Department für Wirtschaft, Bildung und Forschung WBF 2014). It is also assumed that the woodstove has 5 more years of expected operating time due to its age and maintenance history. This is assumed based on the owner/manager's verbal testimony of previous problems of the wood stove. At year five, a new woodstove of similar heating power would be installed costing an estimated 3,000 CHF (Kanuk Turbo 2 Holzofen 2013).

The current costs are outlined below:

*Table 7: Current Costs*

| **Current Costs** | **Unit** | **Base Case** |
|---|---|---:|
| Electric-Heat energy consumption | kWh/a | 53400 |
| Energy price | CHF/kWh | 0.10 |
| Energy cost | CHF/a | 5340 |
| New stove cost at year 5 | CHF | 3000 |
| Annual fixed cost, wood | CHF/a | 320 |
| Annual fixed cost, maintenance | CHF/a | 300 |

# 5 Selection of Alternatives

Once the base case had been defined both qualitatively and quantitatively, the consideration of more effective heating system alternatives could be made. Pre-emptive criteria were defined in order to give direction and to establish some bounds to the initial selection phase. Subsequently, the iterative qualification method of brainstorming and market research was used. General brainstorming was used to gather a wide range of possible heating alternatives. Then market research was employed in order to understand what products or techniques are currently applied in the industry. Furthermore, market research uncovers even more alternatives that may have been overlooked in the brainstorming phase that sparks further idea generation. This stepwise process makes up the iterative qualification method described in the methodology section 2.6.

## 5.1 Pre-emptive criteria

The pre-emptive criteria were defined to give bounds to the overall selection process. The criteria for the novel heating system are the following:

- The heating alternative should fit with the existing heating system such that integration with the recently renovated storage tanks is possible and the alternative could be connected with the current heat distribution system. Failure to meet this criterion would undermine the recent investment of the modern storage tanks and greatly increase investment costs of modifying or even replacing the heat distribution piping.
- The heating alternative should not consist of a fossil fuel-based heating. This conflicts with the swiss energy strategy 2050 and is against the desires of the Gasthaus owner.
- The heating alternative should be an automatically operated system. During the winter months, the Gasthaus is uninhabited yet demands space heat. A manually operated solution, such as a new wood stove, would not be able to cover this seasonal demand as no one would operate the heating system. Therefore, a self-regulating, automatic system is a pre-emptive criterion

With these bounds defined, the selection process has been framed and further progress towards establishing feasible alternatives can proceed.

## 5.2 Iterative qualification

The next step to selecting viable heating solutions was taken by means of the iterative qualification method outlined in the methodology chapter 2.6. First, brainstorming was used, and then market research was conducted to deepen the understanding of the possibilities. Next, a qualification process of listing the pros and contras of each alternative narrowed the focus further. Market research could be made again to find possible adaptations to the heating technologies such that the technologies could be more effective. Finally, the hierarchy of building energy was used to assess the purposed solutions effectiveness and feasibility. This follows the flow chart of Figure 3 in the methodology chapter.

#### 5.2.1.1 Brainstorming

The geographical, political, and technical position of the Gasthaus Göscheneralp lays the framework for the brainstorming process. For example, because the Gasthaus is geographically situated near a river, micro hydropower could be an option. Also, it is known that a political notion was voted upon and approved to expand a district heating grid to the municipality of Göschenen. Therefore a grid connection of the Gasthaus could be considered. All possible alternatives are listed below without critical reflection:

- micro wind generation
- micro hydropower
- connection to a district heating grid

- renovation of space heating radiators
- geothermal heat pump
- groundwater heat pump
- Ambient air heat pump
- Photovoltaic powered electric heating
- Solar thermal collectors
- Automated ventilation system

#### 5.2.1.2 Market research

In a second step, market research was conducted to verify the feasibility of the various alternatives. For example, to build upon the pervious example of a connection to a district heating network, the cantonal department for energy was contacted to find more information about the district heating network expansion in Göschenen. The department of energy confirmed that the expansion of the district heating grid to the town of Göschenen will be realised in the next 10 years. However, the expansion to the valley of the Göscheneralp will not be realised due to the long distance of connection resulting in a low line density of thermal power. This indicates a low economic profitability (Ködel 02/2020). Further market research steps of all heating system alternatives can be seen in Table 8.

A table of all considered alternatives are listed along with a description of plausibility stemming from market research:

*Table 8: Considered heating alternatives*

| Alternative | Pros | Cons | Energy hierarchy level |
|---|---|---|---|
| **Ground-source heat pump*** | • Capable of yearly heat supply, independent of outside environment<br>• 3-5 times more efficient than existing system | • Mid-high investment costs | Convert and control- renewable and integrated to both RH and DHW |
| **Air-sourced heat pump** | • Cheaper investment costs than ground-sourced heat pump | • Lower seasonal COP due to cold temperatures in winter | Convert and control- renewable and integrated to both RH and DHW |
| **District heating connection** | • High efficiency<br>• Lower heating costs | • Confirmation that network will **not** extend to Göscheneralp | Control- large scale integrated and efficient system |
| **Automated ventilation system** | • Better air quality<br>• Heat recovery possible | • Infiltration losses must first be addressed<br>• Heat recovery would not cover enough of heat demand | Control- efficient and integrated system |
| **Photo voltaic panels** | • The existing heating system, including western annex, runs on electricity with peaks covered by the wood stove. | • Partial shading from a tree makes installation on the facade not possible | Convert – renewable solar radiation |

| | | | |
|---|---|---|---|
| | • Feed in tariff of 0.06 CHF/kWh | • Snow covers roof in winter | |
| **Solar thermal collectors*** | • Shading and diffused light is less of a factor than PV<br>• Direct use for heating is advantageous<br>• Space for 2mx14m on the façade (partial shading)<br>• Recommended by Gasthaus owner/manager | • Not a consistent heat supply throughout the year (large daily and seasonal oscillations)<br>• No direct radiation from the sun Dec-Feb | Convert and control- renewable and integrated to both RH and DHW |
| **Micro-hydropower** | • river located close to building<br>• green alternative<br>• The existing heating system, including western annex, runs on electricity with peaks covered by the wood stove. | • disrupt flow of river<br>• policy could forbid installation<br>• supply subject to variances in streamflow (controlled by upstream hydropower plant) | Convert- renewable hydropower |
| **Renovation of space heaters (floor heating)** | • Increased efficiency<br>• lower supply temperature with increased surface area of floor radiators | • high investment costs<br>• intrusive installation (must suspend service of the Gasthaus) | Control- efficient and intelligent heaters |
| **Building envelope refurbishment to increase insulation*** | • Existing insulation has low heat resistance<br>• The windows are at the end of their lifetimes<br>• Potential for reducing demand<br>• easily combined with new heat supply technology | • Intrusive installation (must suspend service of Gasthaus) | Conserve- new building materials to reduce energy demand |

*Selected alternatives

#### 5.2.1.3 Energy Hierarchy Qualification

After a qualitative assessment of the pros and contras of the considered heating system solutions, the possible solutions were then compared with the energy hierarchy of buildings (see Figure 4 in the methodology chapter). Given this hierarchy, the following three alternatives were accepted for further design and evaluation:

- Improved insulation of building envelope
- Ground-source heat pump
- Solar thermal collectors

The improved insulation of the building envelope is prioritized as the most effective measure covering the base of the energy triangle. If the proposed alternative energy conversion technologies (solar collectors and ground-source heat pump) would supply both space heat and domestic hot water demands, then these alternatives would cover both the conversion and control of energy within the building. This would address the upper two levels of the energy hierarchy of buildings.

# 6 Dimensioning and Design

To achieve the interim result of dimensioning the alternatives, a further feasibility assessment in conjunction with product research was made. This method follows the iterative qualification approach used in the selection phase. However, now the focus is narrowed, and the three selected alternatives of a ground-source heat pump, solar thermal collectors, and improved building insulation are further analysed. Literature review into each technology also laid the foundation of knowledge upon which this dimensioning and design process could be built.

The three alternatives varied greatly in this process, as each alternative has different plausibility factors and different technical specifications to consider. In this chapter, the purposed heating solution technology is briefly introduced, and then the process to design and dimension each heating system solution is explained.

## 6.1 Ground-source heat pump

Ground-source heat pumps, or GSHPs, extract heat from below the earth's surface by means of boreholes, typically at depths of 150-250 meters (384/6). A water/brine mixture is passed through these boreholes to warm the mixture to the desired temperature change using the heat from the soil. This temperature change can then be exploited to operate a heat pump at a high efficiency. The main advantage of this technology is that the efficiency remains constant irrespective to the ambient conditions. On the other hand, when one considers air sourced heat pumps, it is evident that they are subject to lower seasonal efficiencies due to the intake of cold, sometimes sub-zero, air in the winter. This increases the temperature gap which the heat pump must overcome thus limiting its heating output greatly. However, a ground-source heat pump was selected specifically to avoid this negative effect in the harsh climate of the Göscheneralp. A deeper description of GSHPs can be found in book "Ground-Source Heat Pumps" by Sarbu and Sebarchievici (Sarbu and Sebarchievici 2016).

#### 6.1.1.1 Site feasibility

A critical factor when considering this type of energy conversion technology is the geology of the desired site. This gives an idea for how many boreholes must be drilled for a desired heating power, which is an important cost driver for this heating alternative. For the Gasthaus Göscheneralp, the geological strata of the surrounding area can be found on map.geo.admin.ch (COGIS 2020). From this source, a rough estimate of rock layering can be inferred and used to calculate the heating power in terms of W/m for the rock layers. Then, the number of boreholes and their length can be estimated to satisfy the heating power required for the evaporator side of the ground-source heat pump. "The simplified calculation process for simple sites" in section D.3 of SIA 384/6 was used (384/6). The following assumptions were made, and then applied to Equation 10.

Assumptions:

- Homogeneous geologic layer of granite (COGIS 2020).
- Duplex piping (Figure 7 SIA)
- Limit of 250 m probes (SIA)
- Specific power per meter, $L_{sp}$ = 42 W/m (Figure 7 SIA)
- Correction factor, $CF$ = 1.25 %
  at 2700 full load hours (Table 6), 2.8 heat conductivity (Table 6 SIA), 5m probe spacing (figure 14 SIA)
- COP of 4 (Schütz 2010)
- $Q_a$ = 57,000 (Table 6)

*Equation 10: Length of geothermal probes*
*Source: Adapted from the SIA standard (384/6)*

$$L = \frac{Q_a}{COP \times L_{sp}} \times (1 + CF)$$

If L is greater than 250 m, then the result must be divided by the smallest whole number such that L fulfils the assumed limit of 250 m. The whole number used is the number of probes. After, applying the figures of the Gasthaus Göscheneralp, the result is 235 m x two probes to fill the heat demand of the evaporator side of the heat pump. This parameter allows for a more accurate estimate of GSHP costs seen later in the section 6.1.1.2 Ground-source heat pump costs.

Another important factor to consider is the policy surrounding drilling for geothermal energy at the location of the Gasthaus. The canton of Uri, to which Göschenen belongs, provides an online platform to visualize the feasibility of drilling for geothermal heat (Karten-Werk GmbH 2019). Water catchments, wildlife zones, and other spatial conditions limit the area of drilling possibilities. In the case of the Gasthaus Göscheneralp, the ground in close proximity to the building proves plausible for geothermal drilling as seen in Figure 8.

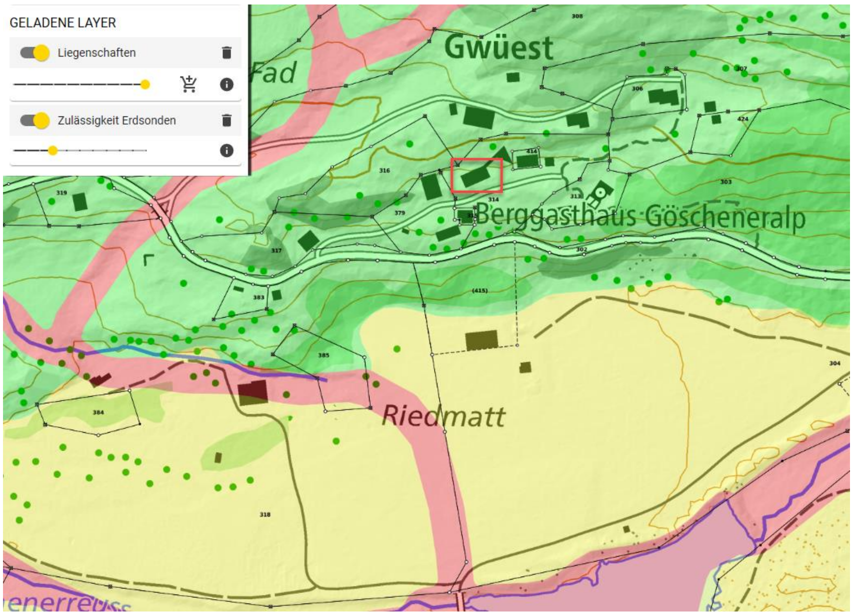



*Figure 8: The permissibility of geothermal probing*
*Source: (Karten-Werk GmbH 2019)*
*Red zones indicate no permissibility, yellow possible permissibility, and green in high permissibility. The Gasthaus Göscheneralp is indicated within the red box.*

Further installation steps were considered by establishing a general site plan and creating a hydraulic schematic. Due to the location of the heating system center existing in the ground floor towards the west side of the building, it was decided the heat pump and boreholes should be also located towards the west side of the building to reduce piping material and installation costs. This can be seen in Figure 9.

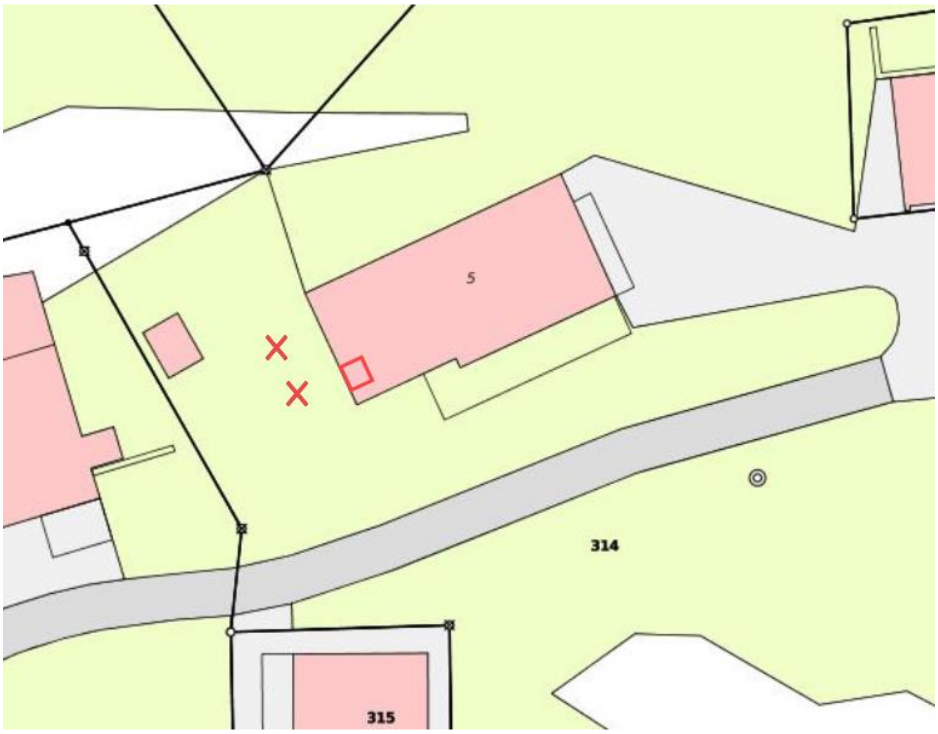


*Figure 9: General site plan of GSHP*
*Source: Adapted from (Karten-Werk GmbH 2019)*
*Boreholes (red Xs) and positioning of the heat pump (red rectangle)*

Additionally, a hydraulic schematic of the proposed heating system illustrates a proposed connection of the heat pump to the existing heating system (see appendix: Hydraulic schematics). Currently the DHW and space heating storage tanks are completely separated with no way to load both tanks with one heat source. For maximum utilization of the projected heat pump, a connection is proposed to regulate the temperatures of both tanks with the GSHP. The configuration is possible with a three-way valve that is electrically controlled based on temperature sensors in both tanks. Furthermore, the existing wood stove is to be uninstalled because the GSHP is capable of covering the complete heating demand for both space heat and DHW. As a result, the wood stove could be uninstalled thereby saving the annual costs incurred by the woodstove.

#### 6.1.1.2 Ground-source heat pump costs

Once the required number of probes and their length was estimated (see section 6.1.1.1) and a rough depiction of the site plan was made, this information could be supplemented with the heat demand calculations to establish a cost estimate of the heat pump and its installation. Possible suppliers for ground-source heat pumps were contacted via telephone to present products meeting the technical requirements at an estimated price. The cost estimates included the product and a rough estimate of additional materials needed for system installation and operation, for example: installation materials, sensors, valves, pumps, piping, wiring, and so on. In the planning phase of a project, an error of estimated costs of +/- 15% is to be expected (Müller et al. 2016). These rough estimates were then averaged to get the price of 50,000 CHF for the purchase and installation of a GSHP (full table of costs can be seen in the appendix: Product comparison).

The canton of Uri, in which Göschenen is located, has a subsidy program in place to support the installation of heat pumps that replace electric heating systems. Given the current heating system of the Gasthaus Göscheneralp, it would qualify for the following subsides (see Table 9) under the "Harmonisiertes Fördermodell der Kantone" (HFM), in addition to supplemental measures by canton Uri (Kantonale Verwaltung Uri 2020; Sigrist, Donald; Kessler, Stefan 8/21/2015):

*Table 9: GSHP subsidies*

| Subsidy | Amount [CHF] |
|---|---|
| Flat rate for installation | 1,600 |
| Connection of DHW to the heat pump | 500 |
| Variable rate per kW until the 50 W/m² limit | 60 |
| Total | 2,960 |
| Net total installation cost | 47,000 |

Next, annual costs must be considered. The annual costs are comprised of the annual energy costs of heating and maintenance. The annual energy cost of heating can be derived from the Base Case cost structure. The Coefficient of Performance, or COP, of a GSHP can be estimated to be a value of four (Schütz 2010). This means the electric energy consumed in a GSHP is one-fourth to that of the currently installed immersion and flanged heating elements, which are assumed to have an efficiency ratio of one (Sarkis 2017). The total annual energy of 57,000 kWh/a would then be divided by the COP of 4 to yield about 14,300 CHF. Then, multiplying that by the variable energy cost of 0.10 CHF/kWh results in an annual electricity cost for heating of approximately 1,400 CHF. Additionally, heat pumps require a maintenance cost of 1% of the overall cost of heat pump resulting in a 470 CHF per year fixed maintenance cost (384/6). The total annual costs sum to about 1,900 CHF.

## 6.2 Solar Thermal Collectors

The sun is a central source of energy for life on earth, yet efficient energy conversion from solar radiation to the desired form of energy poses a large issue within the energy sector today (Fedkin and Dutton 2018). Solar radiation can be converted into electricity using photovoltaic panels, into bio-chemical energy using concentrating reflectors, or into heat energy by means of solar thermal collectors. This study is concerned with the latter due the application of energy to be heating the building of Gasthaus Göscheneralp. For this application, Evacuated Tube Collectors, or ETC, were chosen. These solar collectors allow a high efficiency of solar radiation to heat energy by not having to make an additional intermediate energy conversion process, contrasting that of a photo voltaic panel. For the application of the Gasthaus Göscheneralp, the photo voltaic panels would convert solar radiation to electric energy, then finally to heat energy. Each extra conversion step has an inherent loss of efficiency. The book “Solar Heating and Cooling Systems” allows for further reading on the intricacies of solar collector technology (Sarbu and Sebarchievici 2017).

Evacuated tube collectors were chosen over flat plate collectors due to the ETCs capability of producing a higher temperature change over the collector surface (Nussbaumer and Schumacher 2019a). This is particularly relevant in the mountain climate of the Göscheneralp, where thermal losses from the collector to the cold ambient air are considerable. Also, similar to the GSHP, the collectors are to feed heat energy to both the DHW and space heating storage tanks. This increases the utilization time throughout the year by being capable of loading the space heating storage in the winter and middle season, and then loading the domestic hot water in the middle season and summer seasons when more guests fill the Gasthaus Göscheneralp. Moreover, the annual costs of fuel and maintenance for wood stove can be neglected, as it is assumed that the additional heating power of the ETCs would render the woodstove obsolete for peak covering.

#### 6.2.1.1 Positioning

The positioning of the panels was selected based on various factors: protection from snowfall, ease of mounting and maintenance, and orientation to the sun. Throughout the winter, snow accumulates on the roof, sometimes in quantities of 2 meters in height. If the panels were to be mounted on the roof, they would be inoperative throughout the majority of the winter months due to snow piling on top and blocking direct exposure to the sun. Uncovering the snow would be too time intensive and unsafe. Therefore, a vertical facade mounting style was deemed more fitting thus allowing the panels to have direct exposure to the sun throughout the year. However, if the panels are to be mounted high on the facade, several windows would be blocked, and maintenance and mounting would prove be difficult. For this reason, the panels were selected to be mounted on the facade below the balcony, approximately two meters above the ground (see Figure 10). This is just above the average snow height in winter, yet it allows accessibility for mounting and maintenance. This section of the building provides a surface area of 2 meters in height, and 14 meters in length to be available for the positioning of the collectors. Moreover, this location is on the same level as the storage tanks thus reducing hydrostatic pressure that a pump would need to overcome, and it reduces the piping material required for the connection. This ultimately reduces installation costs.

*Figure 10: Positioning of solar thermal solar system on south façade*
*Source: Adapted from (Gerardi 2018)*
*The orange highlighted area signifies the purposed positioning of the ETC system with dimensions of 14m x 2m (length x height)*

The final decisive factor for designing the solar collector site was the orientation towards the sun. The afore mentioned location on the lower facade is southerly oriented, which is ideal for capturing the maximum yearly radiation at the latitude of the Gasthaus Göscheneralp (46.65°). The proposed location was therefore taken to be well suited for the mounting of the solar collectors.

#### 6.2.1.2 Solar yield

Subsequently, the panels must be properly dimensioned. In the end of the dimensioning phase, the yearly heating energy of the projected solar collectors, or solar yield, is necessary to evaluate the energy costs saved. The tool PVGIS was used to extract daily, monthly and yearly irradiation data for this location, assuming a vertical, south orientation. The irradiation values can be seen above in the "Site Data" section of this study in Table 2. This data was then used to find the temperature dependent efficiency of the panels, which was then multiplied with the summed yearly radiation and the surface area of the panels. The Equation 10 for the temperature dependent efficiency is given by empirical results from the SPF (Höberle 2007).

*Equation 11: Solar temperature dependent efficiency*
*Source: (Höberle 2007)*

$$\eta = \eta_0 - \frac{a_1 \times \Delta T}{\epsilon_e} - \frac{a_2 \times \Delta T^2}{\epsilon_e}$$

The optical efficiency, $\eta_0$, was taken from the ETC Xinox HP30 by Conergy to be 0.576. $a_1$ and $a_2$ are the temperature dependent coefficients of 1.21 and 0.0008 represented in W/K*m² and W/K²m², respectively. The Irradiation, $\epsilon_e$, during the test was taken to be 1000 W/m² and the $\Delta T$ was derived from the Site Data (Table 2) and the over-temperature Equation 12:

*Equation 12: Over-temperature equation*
*Source: (Nussbaumer and Schumacher 2019a)*

$$\Delta T = T_m - T_a$$

where $T_a$ is the yearly average ambient temperature of 4.35°C for the Gasthaus Göscheneralp, and $T_m$ is the middle temperature of the solar collector of the inlet and outlet of 55°C [0.5*(70°C-40°C)]. The upper temperature of 70°C was assumed based on the required temperature to heat both the DHW and space heating storage tanks.

Finally, the overall efficiency of 52% ($\eta$), the summed yearly irradiance of 680 kWh/m² ($\epsilon_{tot}$), and the total projected gross surface area of the ETCs at 28 m were multiplied together to give the solar yield from the collectors given by the following equation.

*Equation 13: Annual solar yield*
*Source: (Nussbaumer and Schumacher 2019a)*

$$Q_s = \eta \times \epsilon_{tot} \times A_{ETC}$$

From this equation, the approximate annual solar yield, $Q_s$, is 10,000 kWh/a.

#### 6.2.1.3 Utilization calculation

In the next phase of the dimensioning process, two operating points of the solar panel were evaluated to assess if the capability of the solar system to meet both the yearly and daily demands of the Gasthaus Göscheneralp. This can be shown using the Solar Coverage, or SC, term, displayed in Equation 14. This term displays the ratio of annual solar yield, $Q_s$, with respect to the energy demand, $Q_{Ref}$. If the energy of the solar collectors can fully supply the heat energy demand of the building, then the SC ratio is 1.

*Equation 14: Solar coverage*
*Source: (Nussbaumer and Schumacher 2019a)*

$$SC = \frac{Q_s}{Q_{Ref}}$$

Two operating points for the solar collectors were taken to represent the annual SC, and the max daily SC. The annual SC considers the total annual energy supply of the ETC relative to the annual energy demand. These values have been calculated in previous sections of this report, and simply require the application of the SC formula. The $Q_s$ of 10,000 kWh/a divided by total heat energy demand of 57,000 kWh/a and results in an annual solar coverage of 18%.

The calculation of the daily SC is a more involved process. However, it sheds light on the effectiveness of the existing heat storage capacity relative to the daily output of the purposed solar collector. The daily SC considers the max daily operating point, which is assumed be an average day in August, where the monthly irradiation total is at a max. Additionally, space heat demand is assumed to be zero, as the heating is not required on such warm days. This means that only the DHW storage tank would be charged. The total capacity of heat energy of the DHW tank was calculated by applying the first law of thermodynamics to this situation. The formula is the following:

*Equation 15: First law of thermodynamics in terms of heat energy*
*Source: (Weigland et al. 2016)*

$$Q_{Ref} = V \times \rho \times C_p \times \Delta T$$

Where the volume, $V$, is given as 0.7 m³; the density of water, $\rho$, as 998 kg/m³; the heat capacity of water, $C_p$, as 0.00116 kWh/kg*K; and a change of temperature, $\Delta T$, of 50 K (see section 4.4 Heat demand for reasoning of temperature change assumption). The storage capacity of the DHW tank is 44 kWh.

Next, the maximum heat energy that the solar collector can supply in one day, or daily solar yield, was calculated on the same premise of the total solar yield employing Equation 13. The input parameters were taken as the daily averages for the month of August resulting an irradiation of 102 kWh/m², an efficiency of 52%, and the fixed gross collector area of 28 m². The energy output of the ETC system in one day is 48 kWh.

As a result, it can be approximated that, during the max operating point, the max daily SC is 110%. In other words, the ETC supply 110% of the storage capacity. This means that roughly 10% of the produced energy could not be stored, and therefore wasted. On the other hand, if a smaller ETC surface area would be installed to address this excess energy, the overall affect would be a more significant net loss of annual energy. Therefore, if the dimensioning of the solar system were to be improved to an increased annual solar yield, the surface area should increase. However, the spatial constraints of the facade do not allow a larger surface area to be installed.

#### 6.2.1.4 Evacuated tube collector costs

The technical aspects of the solar collector system have been established. However, the cost of the collectors and their installation have yet to be determined. To obtain the costs, two regional suppliers of ETCs were contacted. After providing all the relevant technical parameters and a hydraulic schematic of the planned installation, the suppliers could estimate the costs in the form of a quote (see appendix: Product offers). An average of the two quotes were taken, yielding the estimated cost of 26,500 CHF for the purchase of the solar collectors plus their installation.

Similar to the GSHP, solar thermal systems also qualify for subsidies from Uri's government (Kantonale Verwaltung Uri 2020).The applicable subsidies are shown in Table 10 below:

*Table 10: GSHP subsidies*

| Subsidy | Amount [CHF] |
|---|---:|
| Flat rate for installation | 8000 |
| Connection of DHW to the heat source | 500 |
| Variable rate per kW over the 4 kW threshold | 4800 |
| Gross total subsidies | 13300 |
| Net total installation cost | 13200 |

The ETCs annual cost consists solely of the electrical energy cost of the current immersion and flanged heating elements integrated into the heat storage tanks. The total annual solar yield of the ETCs was estimated at 10,000 kWh. The yearly heat energy demand would be 10,000 kWh/a less, resulting in a total yearly demand of 47,000 kWh/a. At a rate of 10 Rp/kWh, the cost energy consumption for heating would be now be 4700 CHF/a. The maintenance cost was assumed negligible and therefore taken as zero.

With the total costs and technical aspects known for the solar collector heating system alternative, the sustainability of this heating option could be evaluated and compared with the other alternatives.

## 6.3 Building insulation

The design and dimensioning of the building insulation alternative was less demanding than that of the GSHP and the ETC as it simply requires the replacement of existing windows with windows of increased thermal resistance, and the removal of outer-panelling to add insulation on the walls and roofing. The heating system solution of improving the thermal transmittance of the building envelope differs from the other two considered alternatives in that it is a passive measure that reduces heat demand rather than actively changing the heat supply technology. Although passive in nature, its effectiveness in reducing energy consumption and lowering costs is affirmed in the Building Energy Pyramid (Figure 4). In this section, the exact type of technology and how it is implemented in the case of the Gasthaus Göscheneralp is explained.

#### 6.3.1.1 Extent of insulation

Building insulation materials can vary widely within the construction industry from conventional materials (e.g. rock wool and wood fibers), to alternative materials (e.g. sheep wool and flax), to advanced materials (e.g. vacuum insulation panels and aerogel) (Schiavoni et al. 2016). For the application of the Gasthaus Göscheneralp, a conventional insulating material with a high thermal resistance-to-cost ratio was desired. This insulation material would be implemented throughout the facade and the roofing to cover a total surface area of 333 m² (result from Table 1). Mineral wool, sometimes referred to as rock wool or stone wool, was chosen for this purpose as it quite cheap, can be handle easily without losing thermal performance, and is a good sound absorber. It also has good fire resistant properties (Schiavoni et al. 2016).

This study assumes the improvement of the building's thermal resistance would fulfil the conditions of the Swiss "Gebäudeprogramm" measure of building insulation. This measure subsidizes the renovation of the building envelope to improve thermal resistance, and ultimately to reduce the environmental impact in the building sector. To receive the subsidy, the following conditions must be fulfilled (Sigrist, Donald; Kessler, Stefan 8/21/2015):

- Buildings must be built before year 2000
- Building components that are to receive the subsidy must be currently heated
- The limit of the improved U-Value of subsidized building components: U ≤ 0.25 W/m²K
- For protected buildings, a higher U-Value can be allowed
- GEAK Plus service is required for subsidy amounts above 10,000 CHF

Given these conditions, the costs of renovation of the building envelope can be variably reduced by 80 CHF per m² of improved building insulation. The walls and roofing of the Gasthaus Göscheneralp are assumed to fulfil the above criteria given the installation of mineral wool insulation.

The existing windows of the Gasthaus Göscheneralp have varying thermal resistance, however, the oldest are of single glassing with significant air-leakage through the window frame. The overall thermal transmittance was estimated at 3 W/m²K (see section 4.4 Heat demand). Replacing the windows to the Gebäudeprogramm standard of 0.7 W/m²K would lower the glazing's U-Value by 76.7%. Furthermore, by applying the U-value Equation 3, transmission losses are estimated to be reduced to half of the current estimated value given modern, better sealed window framing.

The total improvement of the building envelope insulation is estimated to decrease the transmission losses by 60.5% given the standards seen in Table 10. Overall, when including the reduction of infiltration losses, the space heat power demand is projected to decrease from 11.0 kW to 5.2 kW, which is a reduction of 52% from the current space heat demand. Then, one can apply this reduction to the yearly energy savings. The yearly transmission losses of 17,000 kWh/a summed with the infiltration losses of 20,300 kWh/a (see Table 6) gives 37,300 kWh/a of space heat losses. The savings of the total space heat losses is $37{,}300 \cdot (1 - 0.52) = 17900$ kWh/a.

#### 6.3.1.2 Building insulation costs

The yearly electricity cost is now lower when considering the space heat savings of 52% from the purposed building insultation measure. This translates to a decrease in space heat energy from 37,300 kWh (derived from Table 6) to 19,400 kWh. It is also assumed that the wood heating would remain constant and therefore further reducing the electrically sourced space heating demand to 15,700 kWh. The improved building insulation would have no effect on the domestic hot water demand so the electric energy used is the sum of the reduced space heat demand and the existing domestic hot water demand: 15,700 kWh + 19,800 kWh = 35,500 kWh. When multiplying this with the variable electricity cost of 0.10 CHF/kWh this results in a total electricity cost of 3,550 CHF.

Next, the installation costs of the building insulation must be calculated. This process was based on product catalogues from Flumroc, a rock wool producer in Switzerland, and Ofri, a window manufacturer in Switzerland. The rock wool insulation material costs 30 CHF/m² at 0.1 m of thickness (Flumroc AG 2020). However, installation costs for insulation materials are 90 CHF/m² for the roofing and 60 CHF/m² for the facade (Energieheld 2020). This totals to 120 CHF/m² for the roofing and 90 CHF/m² for the facade. Then, the refurbished windows are assumed to have wooden frames and openable, similar the current windows. The cost for windows of this type with triple glazing of high insulation cost approximately 1200 CHF/m² (Ofri 2020). Labour costs are assumed to be between 800 CHF and 1,500 for windows (Ofri 2020). An average value of 1,150 CHF was taken. The estimated costs and measures taken were then be applied to the scenario of the Gasthaus seen in Table 11.

*Table 11: Insulation costs*

| | |
|---|---|
| **Area of Walls [m²]** | 122 |
| **Area of Windows [m²]** | 34 |
| **Area of Roof [m²]** | 115 |

| | **Façade** | **Roof** | **Windows** |
|---|---|---|---|
| **Gebäudeprogramm standards (U-Value)** | 0.2 | 0.2 | 0.7 |
| **Price for renovation [CHF/m2]** | 90 | 120 | 1,200 |
| **Labor cost [CHF]** | 80 | 80 | 80 |
| **Subsidies [CHF/m2]** | - | - | 800 |
| **Gross cost [CHF]** | 10,980 | 13,800 | 41,600 |
| **total subsidies [CHF]** | 9,760 | 9,200 | 2,720 |
| **Net cost [CHF]** | 1,220 | 4,600 | 38,880 |
| **Total [CHF]** **44700** | | | |

Inherent errors of accuracy do exist in these estimation techniques. However, costs that are more exact could only be known if a professional installer visits the building site. This extended degree of accuracy is beyond the scope of this report.

# 7 Selection of Criteria

The next step in this project's methodology is to select criteria to form a basis for evaluation. The criteria can be grouped to reflect the three pillars of sustainability: economic viability, social equity, and environmental protection (see Figure 11). Economic viability encompasses long term financial stability such that the object in question (in this case a heating system) provides monetary benefit. Social equity addresses the value that the object can give to society to promote social well-being. Then, environmental protection aims to secure natural resources and preserve the natural world in general. Finally, balance in these three pillars ensures long term sustainability such the needs of the current generation can be met without sacrificing the needs of generations to come. This report addresses all three pillars using one criterion each for economic viability and environmental protection, and two criteria for social equity to provide a holistic evaluation of the heating system.

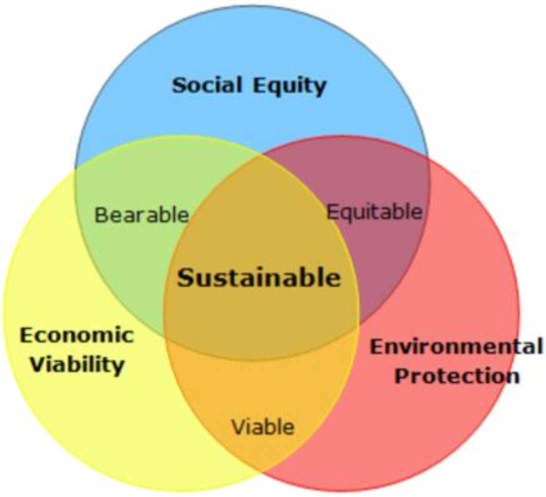



*Figure 11: Three pillars of sustainability*
*Source: (University of Nottingham 2016)*

The decision to install a new heating solution is made based on stakeholders' interests, and criteria must be chosen to reflect those interests. The criterion for economic viability has been defined and analysed from the perspective of the Gasthaus Göscheneralp owner/manager, as they are the primary stakeholder in this decision. The net present value of the investment of the heating solutions was chosen as the best metric to quantify and compare their economic viability. This shows the benefit of lowering heating costs relative to the base case scenario. The value of the benefit is quantified in terms of savings that are adjusted using a predetermined discount rate. By adjusting the savings to account for the time value of money, a more accurate economic evaluation can be made to decide in which potential heating solution to invest.

The second level criterion chosen to evaluate environmental protection was global warming potential (or GWP), which affects the customer, the owner/manager, the municipality, and the utility. GWP is the "an appraisal of greenhouse gas (for example, CO2, methane, nitrous oxide…) contribution to global warming" (Biron 2016). The various emissions of a product or process are calculated over a certain time horizon, commonly 20, 100, or 500 years, and expressed as a factor of CO2 whose GWP is standardized to 1. This impact category is the most pertinent to that of the Gasthaus Göscheneralp as GWP causes surrounding glaciers to melt at an alarming rate, and directly affects the customer base of skiers who need cold temperatures to enjoy their sport. Additionally, the Swiss government has prioritized mitigating the production of greenhouse gas emissions based on the Swiss Energy Strategy 2050 (Swiss Federal Office of Energy SFOE 1/18/2018). The federal government works in cooperation with the cantonal government to influence clean energy measures. This can be done at a local level via the municipality and the local utility. Therefore, both the municipality of Göschenen and the local utility provider of Elektrizitatswerk Göschenen have a stake in reducing the global warming potential of this heating system.

The social criteria were selected based on the ability to reflect the social impacts of implementing a heating solution. The social aspects relating to this decision were chosen to be the aesthetics of the heating technology and the physical comfort the technology can provide. These criteria mainly affect the customer base of the Gasthaus Göscheneralp, which directly relates to the success of the business. If a customer's comfort needs are not met, or the customer finds the appearance of the Gasthaus Göscheneralp to be unappealing, then they are less likely to return or to recommend it to other potential customers.

# 8 Evaluation of Alternatives

In the following stage, the dimensioned heating system alternatives must be analysed based on criteria mentioned in the previous chapter.

A financial Cost/Benefit Analysis, or CBA, considers monetary factors of economic sustainability; a Life Cycle Assessment, or LCA, considers ecological impacts in terms of environmental sustainability; and a Multi-Criteria Decision Analysis, or MCDA, considers soft factors of social sustainability and the MCDA weighs all three pillars of sustainability together to reflect the interests of the stakeholders defined in section 4.1.

## 8.1 Cost Benefit Analysis

A Cost Benefit Analysis method was used to evaluate the economic sustainability of the purposed heating solutions. The CBA is explained based on the same structure as mentioned in the methodology section 2.8 in this report. Each step of the analysis is outlined below.

### Definition of scope and assumptions

The costs of the current heating system were taken as the base-case scenario for comparison between the costs of the other heating alternatives. The time scope of the analysis is defined at 20 years, as that is the industry standard lifetime for both solar collectors and heat pumps (Sarbu and Sebarchievici 2017, 2016). The installation of insulation materials is assumed to have a longer duration of 25+ years (Tittarelli et al. 2013). However, a fixed time scope is important to effectively compare costs between the alternatives thereby defining a time scope of 20 years. Finally, a partial equilibrium analysis of the Gasthaus owner was chosen as opposed to a general equilibrium analysis of the entire market. This is because the Gasthaus owner is established as the most important stakeholder from the stakeholder analysis (see section 4.1) and can be assumed to be the only economic actor in this financial analysis.

### Identification of alternatives and quantification of costs/benefits for each alternative

No non-market costs or benefits were considered in this analysis, as these multiple benefits are then considered in the MCDA as comfort and aesthetics. Also, environmental externalities are not considered in this CBA, as they are considered in the LCA using global warming potential. The costs considered were all costs that are expected to be incurred within the defined time scope of 20 years. Below in Table 12 is the cost structure used in the CBA:

*Table 12: CBA cost structure*

| Scenario | Values | Unit | Base Case |
|---|---|---|---|
| Base Case | Elec. energy consumption | KWh/a | 53,400 |
| | Energy price | CHF/kWh | 0.10 |
| | Discount rate | % | 8% |
| | Construction cost | CHF | 0 |
| | New stove cost | CHF | 3,000 |
| | Annual fixed cost | CHF | 620 |
| GSHP | Energy consumption | KWh/a | 14,300 |
| | Energy price | CHF/kWh | 0.10 |
| | Discount rate | % | 8 |
| | Installation cost | CHF | 47,000 |
| | Maintenance cost | CHF/a | 500 |
| ETC | Energy consumption | KWh/a | 47,000 |
| | Energy price | CHF/kWh | 0.10 |
| | Discount rate | % | 8 |
| | Installation cost | CHF | 13,200 |
| Insulation | Energy consumption | KWh/a | 35,500 |
| | Energy price | CHF/kWh | 0.10 |
| | Discount rate | % | 8 |
| | Construction cost 1/2 | CHF | 22,350 |
| | New stove cost (year 5) | CHF | 3,000 |
| | Annual fixed cost | CHF | 620 |
| | Construction cost 2/2 | CHF | 22,350 |

The variable energy price and discount rate are held constant for all scenarios. Based on the current condition of the wood stove, it is assumed that it will break down in five years. In order to fulfil the peak demand of space heat, it is assumed a new stove of similar heating power will be installed at a cost of 3,000 CHF (Kanuk Turbo 2 Holzofen 2013). Both the Base Case and Insulation scenarios would incur this cost. However, GSHP and ETC would not rely on the wood stove after installation thus avoiding its cost of 3,000 CHF. Additionally, it is assumed that the installation cost of the insulation materials would be spread over two years as it takes more time to install than a GSHP or ETC. Reasoning of the remaining costs can be seen in the sections 6.1.1.2, 6.2.1.4, and 6.3.1.2 of this report.

**Selection of appropriate discount rate**

The selection of the discount rate for this investment was chosen based on the cost of capital for both the hotel and restaurant industry of 5-6% (Damodaran 2020). The discount rate of an investment should be greater than the cost of capital to deem an investment economically viable (Asdrubali and Desideri 2019). Therefore, a discount rate of 8% was chosen.

**Selection and application of measure for comparing alternatives**

The alternatives are compared based on their NPV, as mentioned in the methodology section 2.8. However, because the benefits of the alternatives exist in cost savings relative to the base-case scenario, the investment threshold is the NPV of the alternative minus NPV of the current situation must be greater than 0: NPV_alternative – NPV_basecase > 0

**Discussion of uncertainties**

A sensitivity analysis of two parameters was made to highlight the uncertainties. The discount rate was chosen as a parameter because the selection of the discount rate at 8% was rather trivial and difficult to justify. A variation +/- 6% from the standard 8% discount rate was chosen to show a wide range of possible outcomes. The second parameter that was selected to vary was the time scope of the CBA because there is large variability in the future of exactly how long the lifetime of an alternative would be. For example, a heat pump may last 25 years if maintained properly, whereas a solar collector may only last 15 years (Dott 2008).

**Initial results and sensitivity analysis**

The parameters of the CBA were inputted into Microsoft Excel to compute the results. The output values are summarized in Table 13, and the full table of results can be seen in the appendix: CBA full results. The evacuated tube collector had the lowest costs compared to the base case with a positive NPV difference of about 7,400 CHF, which implies this heating solution investment should be perused. The GSHP has also a positive NPV compared to the base case of 1,180 CHF. However, the building insulation solution has a negative difference of costs when compared to the base case at -19,600.

*Table 13: CBA results with the sensitivity analysis*

| Parameters | Values | GSHP | ETC | Insulation |
|---|---|---|---|---|
| **Time at 8% discount [years]** | 15 | -3,928 | 5,862 | -21,827 |
| | 20 | 1,180 | 7,440 | -19,582 |
| | 25 | 4,656 | 8,513 | -18,055 |
| **Discount rate at 20 years [%]** | 2 | 28,139 | 16,074 | -9,149 |
| | 8 | 1,180 | 7,440 | -19,582 |
| | 14 | -12,143 | 3,079 | -24,191 |

The first sensitivity analysis was performed by varying the time scope parameter +/- 5 years to 15 years then to 20 years. At 15 years, all solutions are financially less attractive. On the other hand, at 25 years, all heating solutions are more attractive. The economic position of the GSHP to invest or not to invest now changes to negative when a time scale of 15 years is assumed. The ETC remains in a net positive economic position throughout the sensitivity analysis, whereas the building insulation solution remains net negative.

The second sensitivity analysis considered a varied discount rate. The lower discount rate, set to 2%, caused a large increase in economic viability for all three heating solutions, yet all solutions have the same economic position of investment relative to the base case. Conversely, when a large discount rate was taken, all heating solutions become less financially attractive. This change even causes the GSHP solution to become a poor investment decision by changing it to a net negative economic position.

In the standard scenario of an 8% discount rate, the ETC is profitable after year 5. This can be accredited to a lower investment cost for the ETC compared to that of the other heating system alternatives. The GSHP only becomes net positive at year 20. The building insulation alternative fails to meet the threshold of a net positive NPV compared to the base case. When a lower discount rate is assumed, the GSHP surpasses the economic benefits of the ETC at year 14. This is due to a much lower variable energy costs for the GSHP compared to the other scenarios. When the cash flows are discounted less, the GSHP investment has considerably less impact compared to its cost savings per year. The low variable costs per year is also the reason behind the GSHP's benefit after the longer time scope of 25 years. The savings of low variable costs have time to build up to eventually shift the benefit to favour investing in a heat pump. The building insulation has large initial investment costs and a low impact on the variable costs per year. This is due to the insulation only addressing space heating costs, and DHW consists of roughly one-third of the total heating costs. When considering the financial sustainability of the investments to implement a new heating system solution, it can be concluded that the evacuated tube collector is the most robust and economically favourable solution.

## 8.2 Life cycle assessment

The pillar of environmental protection was addressed using the Life Cycle Assessment method. This study does not conduct the Life Cycle Assessments as primary information. Rather, the following sections draw upon secondary information of studies that have already been performed. This step required a Literature Review process to find existing LCAs that align with the characteristics to that of the proposed Gasthaus Göscheneralp heating system alternatives. The existing heating system was not evaluated by means of an LCA because it assumed there would be no environmental impact given the current operating conditions. The wood stove is a carbon neutral process and the integrated electric heaters are supplied with 100% renewable energy from the local utility of Elektrizitätswerk Göschenen (EWG 2019).

Studies were selected not only based on the assessed technology having similar dimensions and construction type as the proposed alternatives in this report, but also based on the comparability between the different heating systems. This comparability was addressed by ensuring the representative LCAs consider a cradle-to-grave analysis, and by holding the environmental impact category along with the functional unit, or FU, constant. The impact category that was considered was Global Warming Potential, or GWP, expressed in the total mass of carbon dioxide equivalent per 20 years [kg CO2(e)/20yrs] with “20yrs” being the FU.

The FU of “20yrs” is unique for the Gasthaus Göscheneralp case. It was chosen as it is a tangible unit for each heating solution. However, the LCAs used other FUs of kWh of thermal output (in a lifespan 20 years and 25 years), and in kg of rock wool (without a defined operating lifespan). Despite this difference, results of the representative LCAs could all be converted into the desired FU using the various conversion techniques. The conversion is explained in the results section of each LCA.

**Ground-sourced heat pump LCA**

When considering a GSHP, the heating power, number of boreholes drilled, and heating application constitute the critical parameters of comparability. A representative study has been published by ResearchGate, which parallels the proposed heating solution of the GSHP for the Gasthaus Göscheneralp (Aquino et al. 2017). Both heating systems have around 20 kW of thermal power, there are two boreholes drilled, and its heating application is for 150-200 m² of energy reference area. However, a notable discrepancy is the assumed an operational energy mix consists of the energy mix of central Italy, which is largely grey energy (CNPP 2018). This opposes the 100% green electrical energy mix of the municipality of Göschenen (EWG 2019). Moreover, this study considers an additional energy conversion application of cooling and omits the application of DHW, whereas the proposed GSHP for the Gasthaus Göscheneralp would be for both DHW and space heating, and no cooling. These inconsistences are hypothesized to result in a net increase of GWP per kWh due to more greenhouse gas emissions during the operation phase.

#### 8.2.1.1 Goal and scope definition

The scope of this study consists of the cradle to grave life of a GSHP: from raw material acquisition, processing, manufacturing, use, and finally its disposal. The lifetime considered is 20 years. No cutoff rules were used. This is a comparative LCA between three scenarios of a baseline, supplemental thermal energy storage, and improved heat exchangers. Only the result of the baseline is considered relevant for the application of the Gasthaus Göscheneralp as it mirrors the application closest.

The GSHP was analyzed by the ReCiPe 2008 method which uses 18 impact categories addressed at the each point of energy consumption throughout the life of the GSHP, and further converted and aggregated into four consumption categories of borehole drilling, heat pump construction, heating, and cooling. However, the impact category of total Climate Change is the only relevant value for the comparison of the three heating system solutions.

#### 8.2.1.2 Results

The total GWP, expressed here as Climate Change, is shown in Figure 10 for each consumption phase:

| Baseline scenario | | | | | | |
|---|---|---|---|---|---|---|
| **Impact category** | **Total** | | **Boreholes** | **Heat Pump** | **Heating** | **Cooling** |
| Climate Change | 3889.14 | kg $CO2_{eq}$ | 5.8% | 4.6% | 73.7% | 15.9% |

*Figure 12: The total GWP per consumption phase*
*Source: (Aquino et al. 2017)*

Then, the overall GWP, along with other impact categories, is expressed below (Figure 13) with respect to the FU of thermal energy produced.

| Impact category | Unit | Baseline |
|---|---|---|
| Climate Change | kg $CO2_{eq}/kWh_{th}$ | 0.156 |
| Ozone depletion | kg CFC-$11_{eq}/kWh_{th}$ | 1.13E-07 |
| Terrestrial acidifications | kg $SO_{2eq}/kWh_{th}$ | 6.52E-04 |
| Freshwater eutrophication | kg $P_{eq}/kWh_{th}$ | 5.02E-05 |
| Marine eutrophication | kg $N_{eq}/kWh_{th}$ | 3.07E-05 |
| Human toxicity | kg 1,4-$DB_{eq}/kWh_{th}$ | 5.20E-02 |
| Photochemical oxidant formation | kg $NMVOC/kWh_{th}$ | 3.67E-04 |
| Particulate matter formation | kg $PM10_{eq}/kWh_{th}$ | 2.34E-04 |
| Terrestrial ecotoxicity | kg 1,4-$DB_{eq}/kWh_{th}$ | 3.17E-05 |
| Freshwater ecotoxicity | kg 1,4-$DB_{eq}/kWh_{th}$ | 6.10E-03 |
| Marine ecotoxicity | kg 1,4-$DB_{eq}/kWh_{th}$ | 5.40E-03 |
| Ionising radiation | kBq $U235_{eq}/kWh_{th}$ | 2.20E-02 |
| Agricultural land occupation | $m^2a/kWh_{th}$ | 1.08E-02 |
| Urban land occupation | $m^2a/kWh_{th}$ | 1.32E-03 |
| Natural land transformation | $m^2/kWh_{th}$ | 2.50E-05 |
| Water depletion | $m^3/kWh_{th}$ | 2.46E-03 |
| Metal depletion | kg $Fe_{eq}/ kWh_{th}$ | 1.17E-02 |
| Fossil depletion | kg $oil_{eq}/ kWh_{th}$ | 4.58E-02 |

*Figure 13: Results of the impact categories of GSHP*
*Source: (Aquino et al. 2017)*

According to this LCA, GWP of a ground-sourced heat pump amounts to 3,889.14 kg CO2(e) total over the given operational life of 20 years (Figure 12). This value can already assume the desired functional unit of "20yrs". The GWP is primarily accredited (73.7%) to the heating phase of the GSHP. This aligns with the hypothesized result of high emissions during the operational phase. However, the representative study also concludes by asserting that a supply of 100% renewable energy would result in an average of a 60% decrease of the measured indicators. 60% of the total CO2(e) would yield a GWP of about 2,330 CO2(e)/20yrs. In order to maintain consistency throughout heating system scenarios, the latter value is used a means for comparison of the environmental sustainability.

**Solar thermal LCA**

The information of the LCA for solar thermal system was extracted from the article "Domestic Solar thermal water heating: A sustainable option for the UK?" (Greening and Adisa Azapagic 2014). This study was chosen due to its analysis of evacuated tube collectors, or ETC, where most existing studies focus on the environmental impact of flat plate collectors. In addition, this study considers the location of the U.K. for the ETC installation site, which is assumed to have similar irradiation values to that of the Gasthaus Göscheneralp excluding the winter months where the sun path is behind the southern horizon of the mountains.

### 8.2.1.3 Goal and scope definition

The aim of the representative study is to compare the life cycle environmental impact of evacuated tube collectors to that of flat plate collectors. However, only the results of the ETC will be used in this report. The scope of the study is cradle-to-grave, which includes the environmental impact of manufacturing, operation, installation, and decommissioning of solar thermal systems. The capacity of the system considered is 10kW system with a lifespan of 25 years. This differs from the LCA of the ground-source heat pump by 5 years. The conversion to the desired FU is discussed in the results section of this LCA.

An excerpt (Figure 14) from the study shows the system boundaries for solar thermal system.

System boundaries for solar thermal systems.

| System boundaries | Solar thermal systems |
|---|---|
| Included within system boundaries | • Extraction and processing of fuels and raw materials<br>• System manufacture: collector, framework, pipework, pump, expansion vessel, hot water cylinder and assembly<br>• Installation: transport of engineer to site<br>• Operation: electricity for circulating the heat-transfer fluid through the system<br>• Maintenance (replacement of propylene glycol)<br>• Decommissioning: metals and glass recycling, inert material landfill disposal, wastewater treatment of propylene glycol; incineration of methanol<br>• All transport |
| Excluded from system boundaries | • Energy input into installation |

Figure 14: ETC LCA system boundaries
*Source: (Greening and Adisa Azapagic 2014)*

Multiple impact categories are assessed in the representative study. Figure 15 below summarises the contribution analysis for the evacuated tube system. The main concern in this study is the global warming potential measured in kg CO2 (e)/kWh.

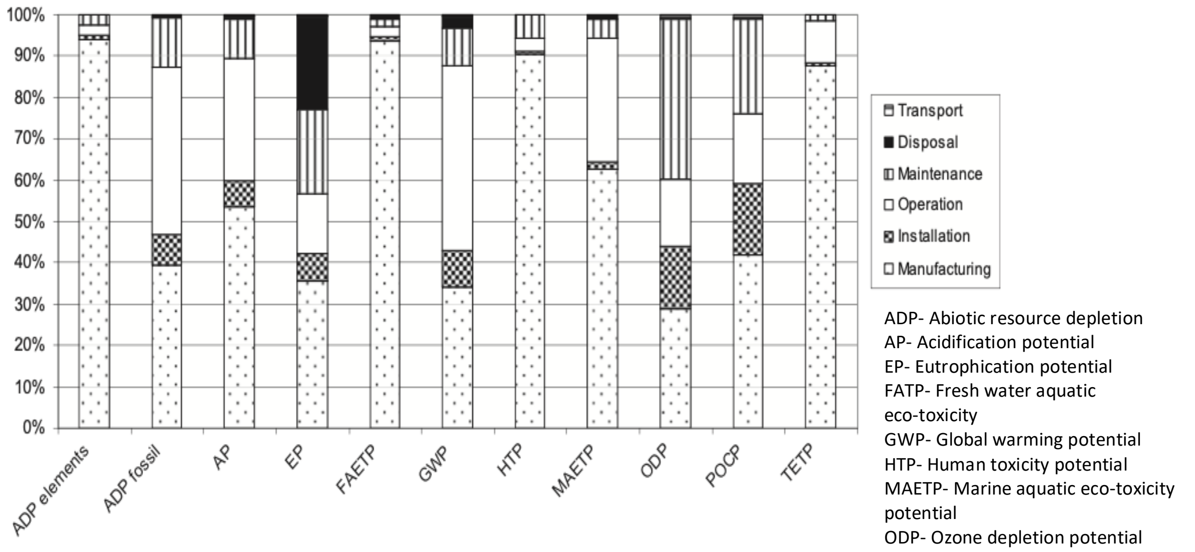



*Figure 15: Contribution analysis of processes for ETC*
*Source: Greening and Adisa Azapagic 2014*

### 8.2.1.4 Results

The global warming potential for the solar thermal system is 0.0386kg CO2 eq./kWh. The main contributors to the GWP are manufacturing and operation. The operation phase contributes to the GWP by 45- 50%. This is due to the energy being needed for pumping the water up to the storage tank attached to the solar thermal collector. Since the energy mix in the Göschenen comprises of 93% Hydropower and the remaining 7% a mix of other renewable energy resources, the operation phase can be neglected while calculating the GWP (Elektrizitätswerk Göschenen 2019). Therefore, the given GWP can be multiplied by 0.45 to better represent the operating characteristics of the Gasthaus Göscheneralp. This results in a GWP of 0.0174 kg CO2(e)/kWh. In order to arrive at the desired FU, the GWP must be multiplied by the amount of energy used over 20 years of operation, which is (0.0174 kg CO2(e)/kWh) x (4,400 kWh/a) x (20 a). This yields a final GWP of 1531.2 kg CO2(e)/20yrs.

**Building insulation LCA**

Rock wool, also known as mineral wool, was selected as the primary insulating material for the proposed heating solution of improving the thermal resistance of the building envelope. The environmental impact of this measure was evaluated based on the existing study, “Life Cycle Assessment of Rock Wool Insulation”, done by a consulting company (Flury and Frischknecht 2012). However, it is noteworthy that this LCA does not consider improved glazing, which would also be a measure taken to improve the thermal resistance of the Gasthaus Göscheneralp. Although glazing accounts for a large percentage of the overall building insulation costs (see section: 6.3.1.2 Building insulation costs), glazing only constitutes 10% of the surface area of the building envelope. Therefore, this suggests that the material amount of glass would be significantly less than that of the mineral wool making an environmental impact assessment of the glazing nonessential.

### 8.2.1.5 Goal and scope definition

The representative LCA was created to update old supply chain models of rock wool. It was commissioned by Flumroc AG, a rock wool producing company in Switzerland. Flumroc AG was also strategically selected because it is same company that the rock wool insulation pricing was based off in section “6.3.1.2 Building insulation costs” of this report. This LCA considers the manufacturing, packaging, and disposal stages of rock wool. An overview of the system boundaries can be seen in Figure 16.

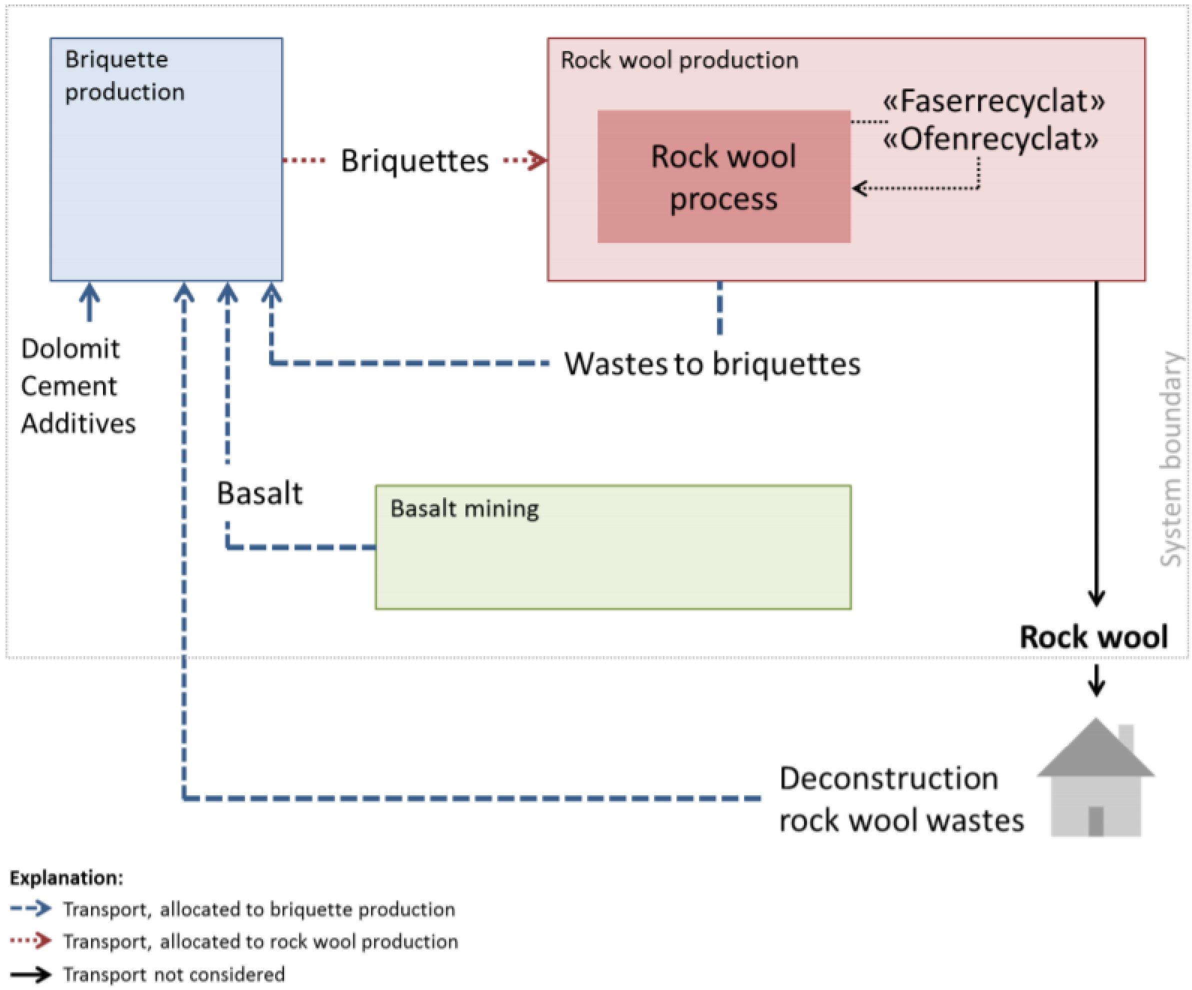



*Figure 16: Rock wool system boundaries*
*Scheme of the material flows between basalt mining, the briquette production, and the rock wool production. The reproduction is incomplete.*
*Source: (Flury and Frischknecht 2012)*

The operational phase was then assumed to be 20 years such that a base for comparison could be made with the other LCAs of the ETC and GSHP. With the afore mentioned stages considered, this LCA was acknowledged to be a valid representation of the environmental stress rock wool would elicit throughout its life cycle. To better understand the insulating material used in this study, the rockwool material properties can be viewed in Table 14.

*Table 14: Rock wool material properties*
*Source: (Flumroc AG 2020)*

| **Rock Wool Properties** | **Values** |
|---|---|
| **Heat conductivity [ W/mK]** | 0.033 |
| **Density [kg/m3]** | 60 |
| **Thickness [m]** | 0.1 |

#### 8.2.1.6 Results

The results of the LCA show that the majority of the GWP of rock wool stems from the production of the material, namely that of mining the minerals used in the insulation. Secondly, the end of life, or EOL, phase can be accredited for the additional contribution to its GWP from its expected disposal in a landfill as rock wool can only partially be recycled. The result in the study is a GWP of 1.01 CO2/kg.

The FU of the study must be converted from kg of rock wool to the desired FU of “20yrs”. This can be done by multiplying the GWP by the density of rock wool and the volume estimated to be installed (see Equation 16).

*Equation 16: Rock wool FU conversion*

$$\frac{CO2}{kg} \times \frac{kg}{m^3} \times m^3$$

The density of rock wool is taken as 60 kg/m3 from Table 14. Then, the volume is calculated with the surface area times the thickness of the insulation. The rock wool would cover the building envelope minus the windows, which is about 333 $m^2$ of surface area (see Table 1). Then a thickness of 0.1 cm is assumed as it is a realistic thickness of a typical rock wool layer which could be applied directly to the Gasthaus Göscheneralp as a refurbishment, not a new building of greater insulation thickness. Overall, when applying this factor, the rock wool has a GWP of 2,020 kg CO2(e)/20yrs.

**Main findings**

After comparing the results of the representative LCAs for the purposed heating system solutions, it can be concluded that the GSHP has the highest GWP at a total 2,330 kg CO2(e)/20yrs and is therefore the least sustainable in terms of environmental impact. In second position, the rock wool has an GWP of 2,020 CO2(e)/20yrs, which is only slightly less than the GSHP. Finally, in first position, the ETC solution is the most environmentally sustainable at 1530 kg CO2(e)/20yrs which is slightly lower than that of the GSHP.

The GWP of all solutions are relatively similar and do not vary greatly given a FU of 20 years. However, if a FU of kWh of thermal energy output is introduced the results shift in favour of the GSHP. The FU of kWh is applied for the GSHP and ETC using the kWh produced over the lifetime of 20 years. Then, for the building insulation, the kWh saved over the lifetime of 20 years is used. These figures are determined from the design and dimensioning sections 6.1.1.2, 6.2.1.2, and 6.3.1.1. These results, displayed in Table 15, show that the GSHP is favourable when considering g CO2(e)/kWh. This can be accredited to the GSHP supplying the entire yearly heat demand (57,000 kWh/a) of the building, making the total energy produced over the expected lifetime of 20 years to be much greater. This significantly lowers the specific GWP relative to thermal energy output. Also, because the ETC supplies only 10,000 kWh/a, it is now the least favourable alternative in terms of environmental sustainability.

*Table 15: Cumulative results of the representative LCAs*

| Environmental Criteria of GWP | GSHP | ETC | Rock Wool |
|---|---|---|---|
| **kg CO2(e)/20yrs** | 2,330 | 1,530 | 2,020 |
| **Total kWh/20yrs** | 1,140,000 | 200,000 | *358,000 |
| **g CO2(e)/kWh** | 2.04 | 7.65 | 5.64 |

**saved thermal energy*

Although the changing of the FU produces differing results, this report will proceed with the first established FU of total GWP over the expected 20 years of lifetime. This is considered the most tangible unit in that the GWP will result in a total amount of kg CO2(e) given that any one of the heating system alternatives is implemented, regardless of the heating output. The remaining energy demand deficit of the ETC and rock wool alternatives is assumed to be sourced by the green of the local utility. This causes no additional GWP given a lack of total kWh/20yrs. The initial results of kg CO2(e)/20yrs with be applied in the following chapter of the multi-criteria decision analysis.

## 8.3 Multi-criteria decision analysis

At this stage, the financial and environmental pillars of sustainability have been evaluated for the purposed heating solutions: a ground-source heat pump, an evacuated tube collector system, and improved building insulation. To provide a holistic evaluation of the purposed solutions, the social sustainability pillar must also be considered. Additionally, a scientifically defendable decision must be made to rank the heating solutions based on all three pillars of sustainability. Completion of the evaluation can be done by means of a multi-criteria decision analysis. The structure of the analysis is based on the criteria and stakeholders discussed in the "Selection of criteria" section of chapter 7. A value tree provides a schematic to visualize the relationship between the hierarchy of criteria and the alternatives of the decision (Figure 17).

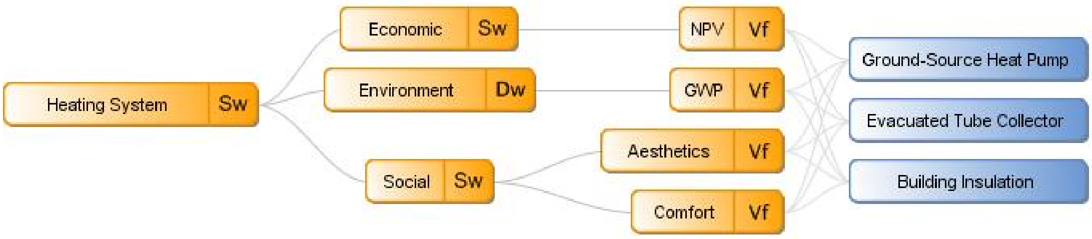



*Figure 17: MCDA value tree*
*Source: (Dee & Soft 2017)*

The overall decision of the heating system is shown on the left of Figure 16, with the pillars of sustainability being the first level criteria. Then, the second level criteria consist of NPV, GWP, Aesthetics and Comfort. Finally, these criteria each play into the sustainability score of the heating solution options.

**Assessment**

To perform the assessment of the MCDA, the evaluation criteria must be weighted given the interests of the relevant stakeholders. Ultimately, the weighting should describe the importance of factors that aid the success of the business of the Gasthaus Göscheneralp. The weighting process is subjective and demands justification, which is provided below.

Weighting factors were defined based on the criteria's influence on the success of the business functions of the Gasthaus Göscheneralp. It is assumed that financial gain is the primary driver in this decision. Therefore, the first level economic criteria is given 50% of the weight, leaving the remaining 50% to be split evenly between environmental and social criteria. The environmental sustainability has many stakeholders at play, which garners importance, but the social sustainability has a large effect on a crucial stakeholder- the customer. Given the perspective of the Gasthaus owner/manager, it can be assumed the environmental and social criteria are of similar importance.

On the second level criteria, only social sustainability considers two criteria. The second level criteria of NPV (economic viability) and GWP (environmental protection) assume the weight of the first level criteria. The second level criteria of societal equity are weighted further with aesthetics being 30%, and comfort being 70%. This is due to the comfort having a more lasting impression on the quality of the stay at the Gasthaus Göscheneralp. If guests are physically uncomfortable, they are less likely to return and less likely to recommend a visit to a friend.

Next, indicator values of aesthetics were assigned based on the visual impression on the customer. The solar thermal system received a relatively lower score of "3" because it is mounted on the front facade thereby detracting from the building’s rustic charm. The improved building insulation calls for replacing old windows, doors, and, adding a new layer of outer panelling to the façade to install the rock wool insulation. This gives potential to improve the aesthetics of the building thereby receiving a score of "7". Then, a ground-source heat pump does not affect the appearance of the building at all when installed in the basement, so a neutral score of "5" was given.

Indicator values for comfort were assigned based on the purposed heating solutions ability to provide comfort the customer across all senses. For instance, the GSHP provides the required thermal comfort, but its compressor is loud during operation and could bother customers who are dinning one floor above. For that reason, a comfort score of "6" was given. The ETCs operate without noise, but the power output may not meet the domestic hot water demand on peak days (see section 6.2.1.3). In extreme cases, this could result in guests needing to shower with cold water. This lowers the comfort score to a "3". On the other hand, improved building insulation reduces outside noise, mitigates fungus growth on interior walls, and provides over all improved thermal comfort (Jakob 2006). Additionally, upon installation, air leakage cold be sealed thus preventing discomfort from drafts within living spaces. The comfort score for improved building insulation is given a "10".

Lastly, indicator values for the criteria of GWP and NPV (relative to the base case) align with the baseline scenario values defined in sections 8.1 and 8.2 of this report. The tabulated indicator values can be seen below in Table 15.

*Table 16: MCDA indicator values and weighting*

| | | | | GSHP | ETC | Insulation |
|---|---|---|---|---|---|---|
| **ENVIRONMENT** | | | | | | |
| GWP [kg $CO_{2(e)}$/kWh] (higher is worse) | | | | 2330 | 1530 | 2020 |
| **ECONOMY** | | | | | | |
| better) | | | | 1180 | 7440 | -19582 |
| **SOCIETY (soft factors, scale 1-10)** | | | | | | |
| Asthetics, visual amenity (higher is better) | | | | 5.0 | 3.0 | 7.0 |
| Comfort (higher is better) | | | | 6.0 | 3.0 | 10.0 |
| ***Normalized indicator values and weighting*** | | | | | | |
| | **Weighting Factors Level 1** | **Weighting Factors Level 2** | **Weight on indicator level** | **GSHP** | **ETC** | **Insulation** |
| **ENVIRONMENT** | 25 | | | | | |
| $CO_2$-equivalents | | 100 | 25% | 0.00 | 100.00 | 38.75 |
| **Sustainability score of environment** | | | | 0.00 | 25.00 | 9.69 |
| **ECONOMY** | 50 | | | | | |
| NPV | | 100 | 50% | 76.83 | 100.00 | 0.00 |
| **Sustainability score of economy** | | | | 38.42 | 50.00 | 0.00 |
| **SOCIETY** | 25 | | | | | |
| Asthetics, visual amenity | | 30 | 8% | 50.00 | 0.00 | 100.00 |
| Comfort/Noise | | 70 | 18% | 42.86 | 0.00 | 100.00 |
| **Sustainability score of society** | | | | 11.25 | 0.00 | 25.00 |

### Initial results and sensitivity analysis

The analysis was performed using the software Decerns (Dee & Soft 2017). The initial results reveal that the evacuated tube collectors have the highest sustainability score, with the ground-sourced heat pump in second, leaving the improved building insulation in last place. This is to be expected as the ETC has a much greater economic sustainability score (seen in the CBA of section 8.1), and the economic sustainability has the highest weighting factor of 50%. The other alternatives follow suit in that the GSHP and the building insulation are ranked second and third in both economic sustainability as well as overall sustainability given the heavy weighting of financial benefits. An excerpt from the Decerns analysis shows the results below in Figure 17.

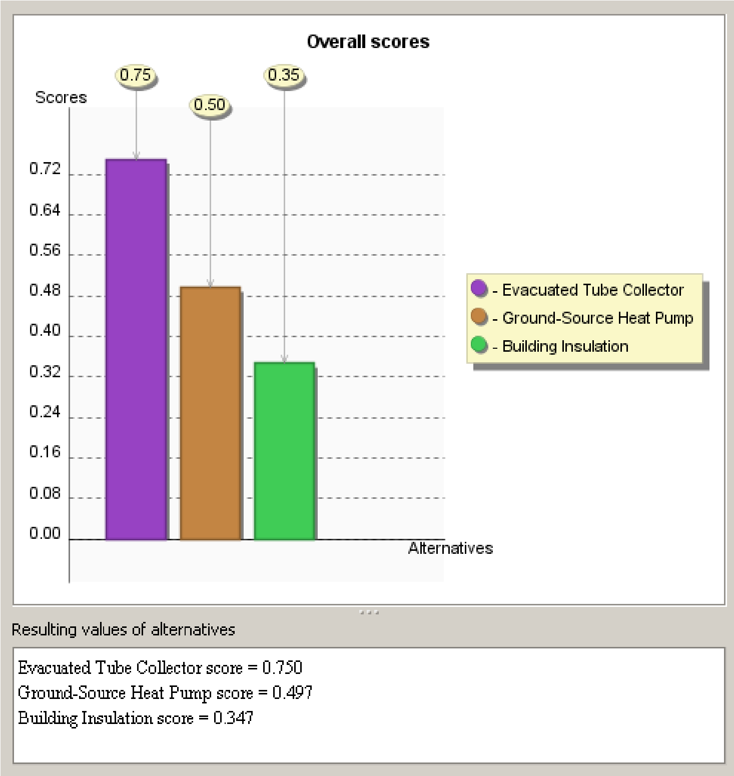



*Figure 18: MCDA overall sustainability scores*
*Source: (Dee & Soft 2017)*

Subsequently a sensitivity analysis was made to understand the robustness of the results. A result is robust if it does not drastically change when the weighting values are manipulated. This shows how definitive the sustainability ranking of the heating alternatives is. The indicator values could be systematically adjusted to analyse their robustness. This could be useful when the assumptions made in the financial and environmental evaluations are in question. However, it was chosen that the weighting values of the first level criteria (Economic, Sustainable, and Social sustainability) were manipulated because this has a clear impact on the results when only adjusting one variable at a time. This allows for clear causality to be seen in the results of the sustainability analysis. The weighting is also subject to vary the most when shifting the importance to other stakeholders. Additionally, manipulating the weighting can be visualized when using the functions of the Decerns software.

The weighting of the first level environmental criterion was adjusted and the relationship between other factors held constant. Figure 18 below depicts the results graphically.

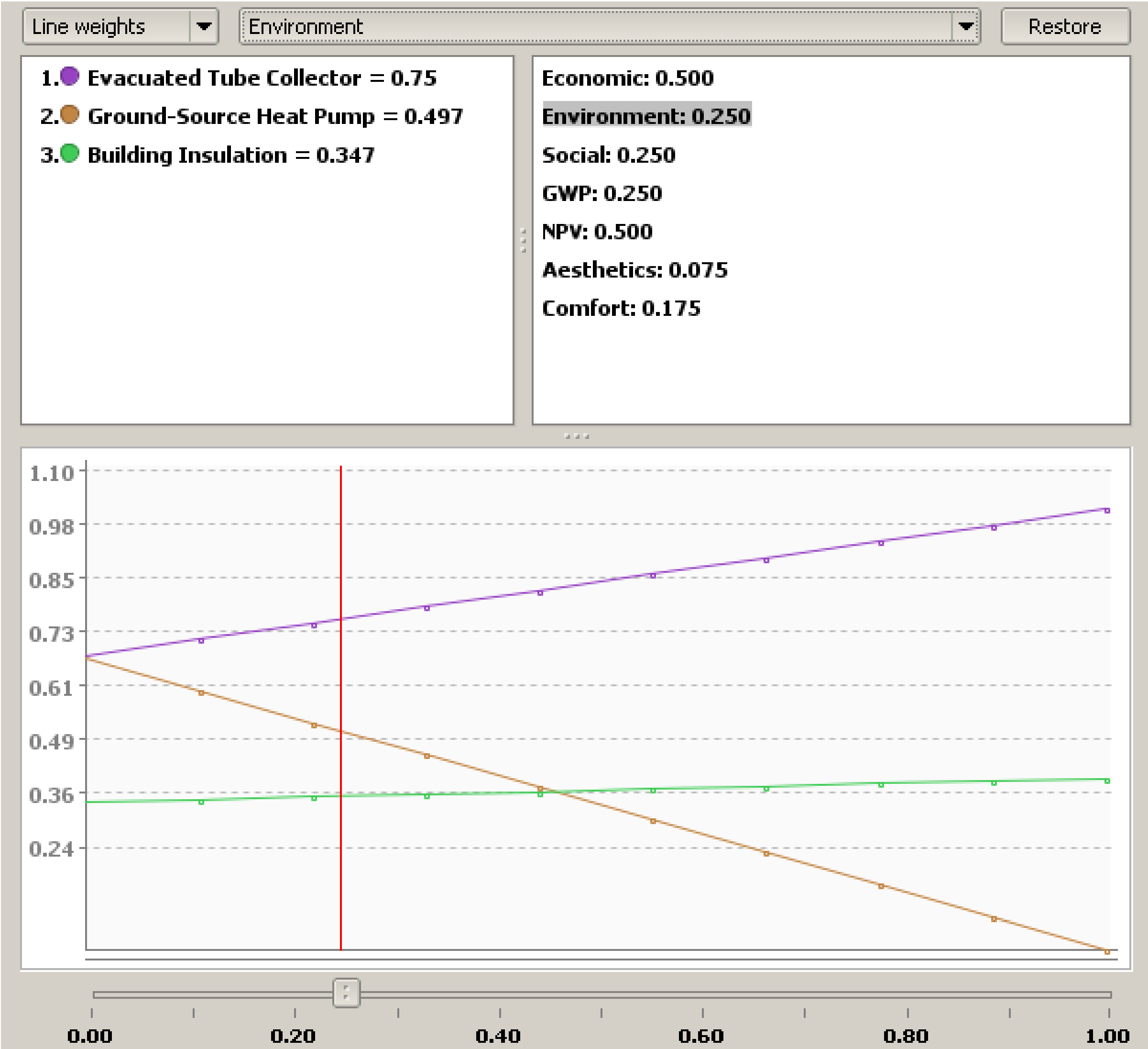



*Figure 19: Environmental sensitivity*
*Source: (Dee & Soft 2017)*

The vertical red line represents the baseline sustainability score (y-axis) with the initial weighting of 25% for environmental sustainability (x-axis). One can see that if the environmental weighting increases or decreases along the x-axis, the ETC has the highest sustainability score throughout the entire domain. This is important when considering the stakeholders of the municipality, utility and customers who are winter sport enthusiasts. These groups would benefit the most from the heating system having a low global warming potential, as mentioned in the "Selection of criteria" section. If urgency was given to combating climate change, then the ETC is a clear and robust solution in terms of environmental protection.

Next, social equity was adjusted while changing the other two criteria proportionally. Figure 19 below shows the results.

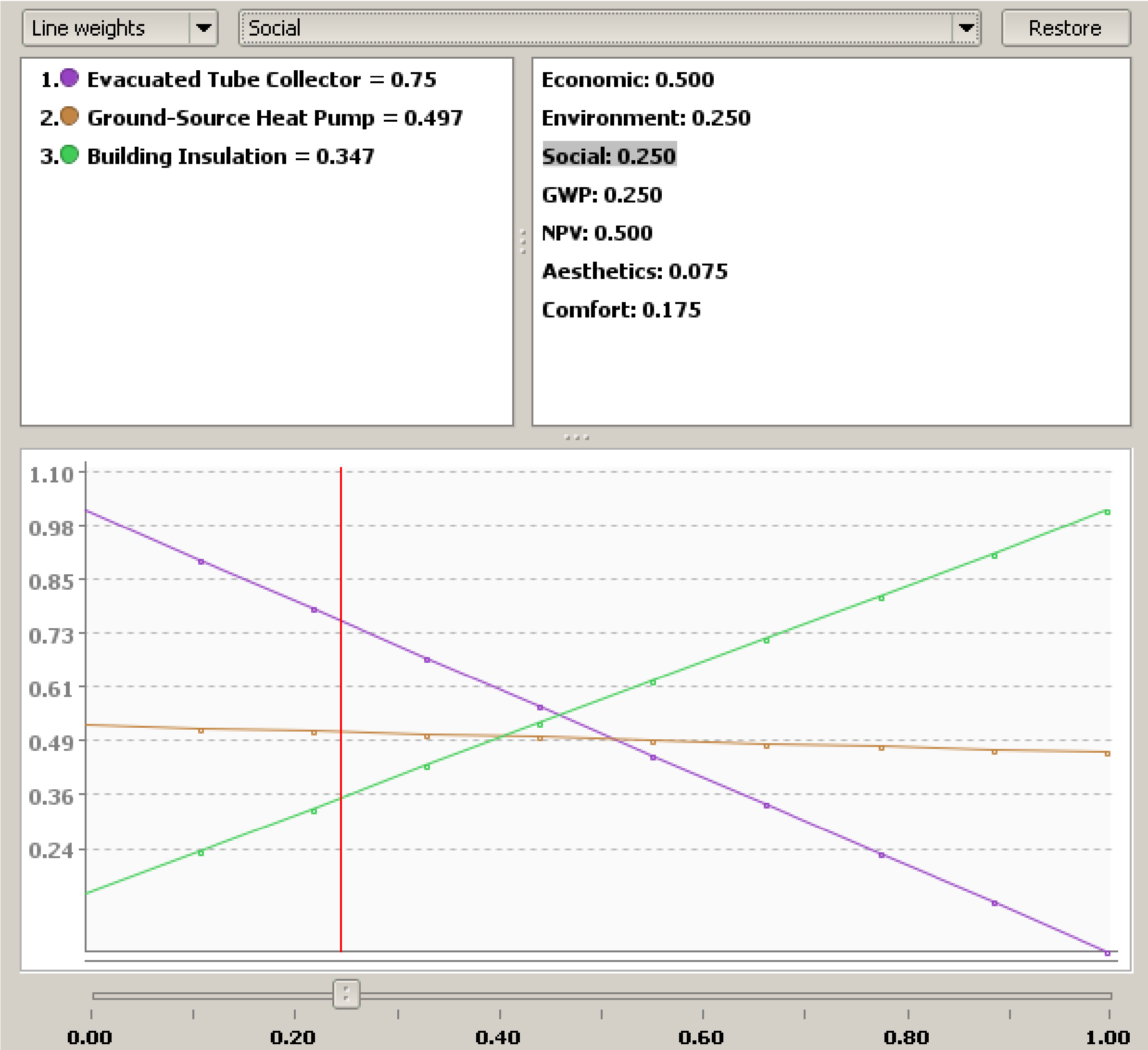



*Figure 20: Social sensitivity*

Again, the social sustainability was set to a weighting of 25% indicated by the red line. When the weighting is changed to about 47%, the building insulation becomes the highest ranked alternative in terms of social equity. If the owner/manager choses to prioritize the aesthetics and comfort over the price, then building insulation becomes the clear choice. This could be the case if customers complain about the current lack of comfort in the building, or if replacing the panelling and windows is already a high priority due to the building parts being at the end of its lifetime. Installing rock wool would then be easily installed and comfort within the living spaces would be improved. An increase of 22% to shift the advantage to the building insulation option is considerable, yet not beyond reason when defining the weighting of the criteria. Therefore, the social robustness is questionable for the initial results of the sustainability ranking.

Finally, the sensitivity analysis was performed with respect to economic sustainability. The results are shown below in figure 20.

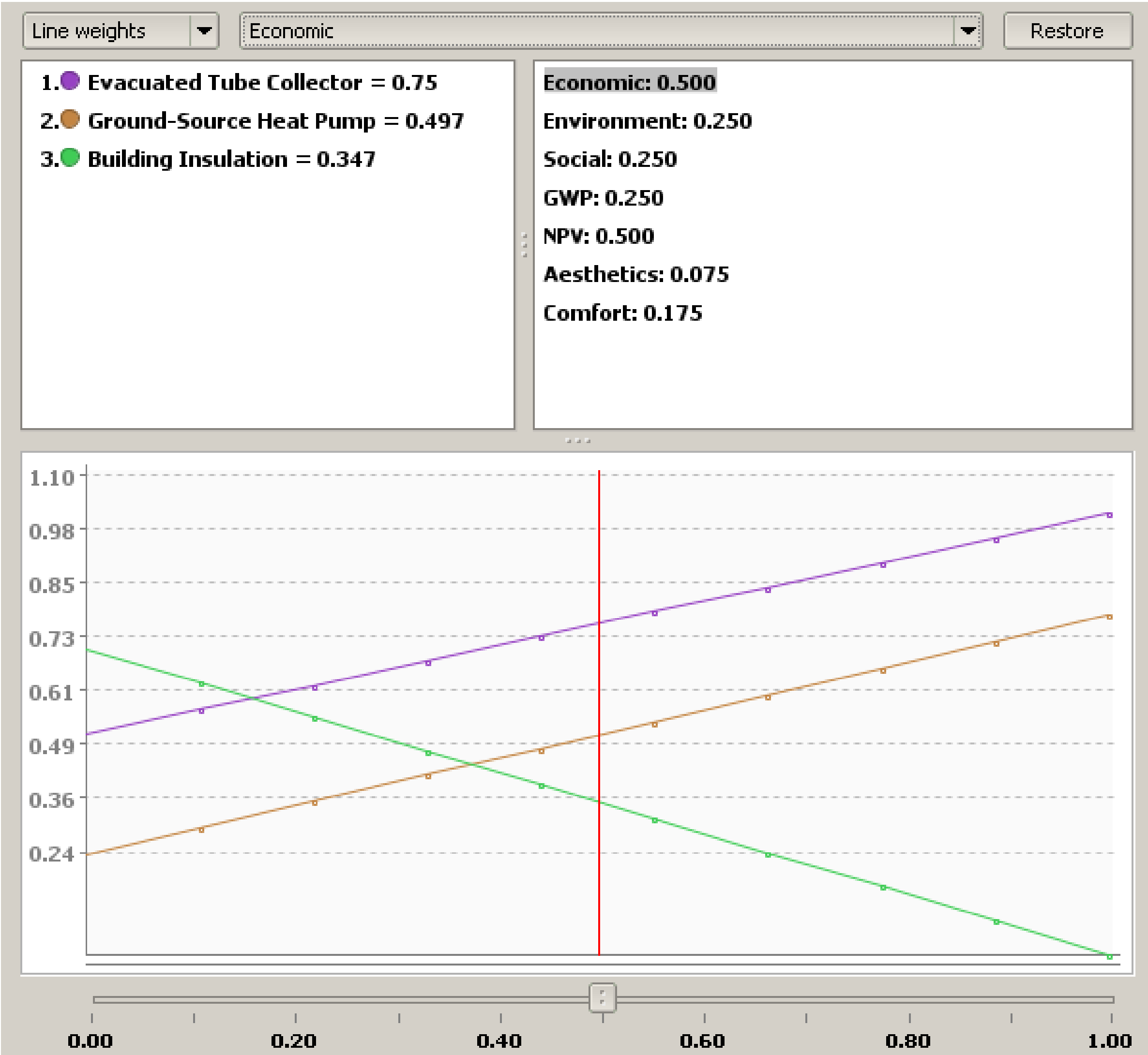



*Figure 21: Economic sensitivity*

Here, the environmental importance is already set quite high at 50%. If one reduces the percentage of economic weight to about 18%, then the evacuated tube collector drops to second position, and building insulation becomes the favourable investment choice. For environmental protection, the building insulation is ranked 2nd and is in close contention with being 1st. In social equity, it is clearly ranked 1st with a considerable lead. Therefore, the economic feasibility score requires a shift of about 32% percent to change the overall sustainability ranking. This, like the social sustainability, indicates a moderate yet questionable robustness. Also, the parallel relationship between the GSHP and ETC is also notable. This parallel quality stems from the relationship of indicator values between the two alternatives. When considering the social and environmental indicator values between the ETC and GSHP, the ETC scores higher in both categories. As economic sustainability decreases, social and environmental sustainability increase proportionally. This results in a parallel and constant relation between the two sustainability curves of the ETC and GSHP.

# 9 Recommendation

The aim of this project is to analyse various heating system alternatives for the Gasthaus Göscheneralp. The analysis is to encompass both the technical and financial feasibilities of the purposed heating solutions. After a holistic evaluation considering economic, social, and environmental sustainability, it is recommended to install an evacuated tube collector system on the south façade of the Gasthaus Göscheneralp. This would supplement the current electric heating elements within the storage tanks, and it would allow the wood stove to be uninstalled, as the solar collector would cover demand peaks of space heating.

The solar system offers a climate-neutral solution that lowers heating costs after an estimated 5 years given the results of the CBA. The MCDA supports this recommendation in that it takes a manipulation of 22% percent in social sustainability to change the ranking such that the building insulation solution becomes more feasible. The main advantage is the low investment cost of installation of the ETC compared to that of the ground-source heat pump and building insulation. The capital expense of the ETC is estimated to be 28% of the cost of the GSHP, and 30% of the building insulation renovation (see Table 11). In terms of environmental protection, the ETC is only marginal better than the other two alternatives. All alternatives have the same order of magnitude of GWP and the values have maximum of 35% difference. Then for social equity, the ETC is at a distance of from being ranked 1st behind the building insulation, yet the ETC still has the benefit of displaying an environmental awareness that might provoke a positive image for their customer base. Overall, the implementation of the evacuated tube collector is a robust solution that is rated highest in economic and environmental sustainability, and it is rated second in social sustainability.

Further measures to improve comfort in the living spaces can be made by improving the thermal resistance of the building envelope. Stepwise instalment of insulation material can be made thus allowing a more manageable payment option as costs can be distributed over a longer time-period. Additionally, if installation is done in-house, then only the cost of insulation materials must be considered and labour costs of an installation company could be saved. This could make the investment of improving the building installation more economical and it would shift the feasibility in its favour. This shift can be seen from the economic sensitivity analysis in the results of the MCDA. Installation of improved insulation materials is especially advised if the Gasthaus owner/manager deems the existing building parts to be outdated and at the end of their lifetime, therefore already needing refurbishment.

The ground-source heat pump is not recommended over the other heating alternatives because the sensitivity analysis provided no result in which the ground-sourced heat pump is advantageous. The large capital expense of drilling the boreholes, installation costs, and the purchase of the heat pump itself are unavoidable. The financial edge cannot be given to the GSHP despite the reduction of operating costs to one-fourth of the base case due to a fourfold increase of efficiency. Additionally, its noise during operation and its high environmental impact from the upstream supply chain of materials result in lower sustainability scores in both social and environmental criteria.

# 10 Outlook

The future conditions of the Gasthaus Göscheneralp are subject to change. Variations in the climate can cause the surrounding glaciers to melt and destabilize the snow reliability, which affects the interests of their customer base. However, lower temperatures could improve road access and offer an opportunity to cater to summer-related tourists earlier in the year. Governmental policies may change and increase energy tariffs or further subsidize mobility, which would threaten the economic prosperity of the Gasthaus, or enable more people to easily reach the Göscheneralp valley. Tourism patterns may change given political instability, natural disasters, or even pandemic events. It is imperative to make decisions based on known evidence. Then when new information comes to light, continually revaluate the situation and the previous decisions made. In this report, a critical reflection attempts to address the most prominent uncertainties, and to reflect on questionable assumptions made in this analysis.

## 10.1 Critical reflection

Although the recommendation is made to implement the evacuated tube collector system, this result is subject change given an uncertainty of the price of the solar system offered by suppliers and installers. This could also vary greatly given a change in subsidies from canton Uri, as the subsidies are projected to cut the capital expenses by over 50%. If the cost of the solar system is varies significantly higher than the estimated cost of 13,200 CHF, then the investment decision must be revaluated.

Another uncertainty is the support from additional subsidies. Other organizations exist to foster sustainable tourism in Swiss alpine regions, namely Berghilfe (Berghilfe 2019). With support from additional subsidies, the building insulation and even the ground-sourced heat pump could become feasible options.

A large risk exists in the changing of energy prices. At the current rates, flanged and immersion heaters are economically viable primary heating technologies. However, energy prices may rise due to less reliability in hydro power, the diminishing of foreign energy imports, high taxation from the government, or any other number of reasons. If prices rise, the current heating technology of flanged and immersion heaters would cause large operational expenses. Then, a heat pump would be a clear solution given that the heat pump uses one-fourth the electric energy than the electric-resistant heaters. Additionally, photovoltaic panels that supply electric energy may also be a feasible option, and an analysis of this alternative should be made. Regardless of the proper response, fluctuations of energy prices should be monitored closely.

Throughout this analysis, many assumptions were made. To ground the results in more concrete data, further steps could be made. Firstly, the indicator values of the second-tier social criteria were assumed. A short survey given to customers of the Gasthaus Göscheneralp could be an effective to quantify the importance of comfort and aesthetics. For example, questions could be asked such as:

on a scale of one to ten, how much do you value constant warm water when showering?
on a scale of one to ten, how highly would you rate the thermal comfort of your stay?
on a scale of one to ten, to what degree would solar panels on the facade lessen the aesthetics of the building?

With the answers from this survey, a discrete number could be defined to rate the social criteria of the Gasthaus. In addition to the assumption made for the social indicator values, many assumptions were made during the heat demand calculation. For example, the domestic hot water demand profiles were synthesized based on verbal confirmation from the Gasthaus owner/manager, and the value of air exchange rate which affects the space heat demand was taken from an industry norm. However, to reduce the uncertainties of these results, smart meters could be installed at the heat production technologies. Then, the data of heating profiles could be stored, and sources of high heat demand could be addressed and improved. This measure would be quick implement, but it requires understanding of the demand profiles and, further action must be taken to improve the inefficiencies.

Despite the uncertainties mentioned above, this report aims to aid in the decision of implementing a heating system that can improve the business of the Gasthaus Göscheneralp while still supporting the climate goals of Switzerland. This report could also be used as a template for further applications of heating system analyses, which study other accommodation and food and beverage services in alpine regions.

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# Appendix

## Building Site Photos

*Figure 22: Storage tanks*


*Figure 23: Space heating storage data plate*

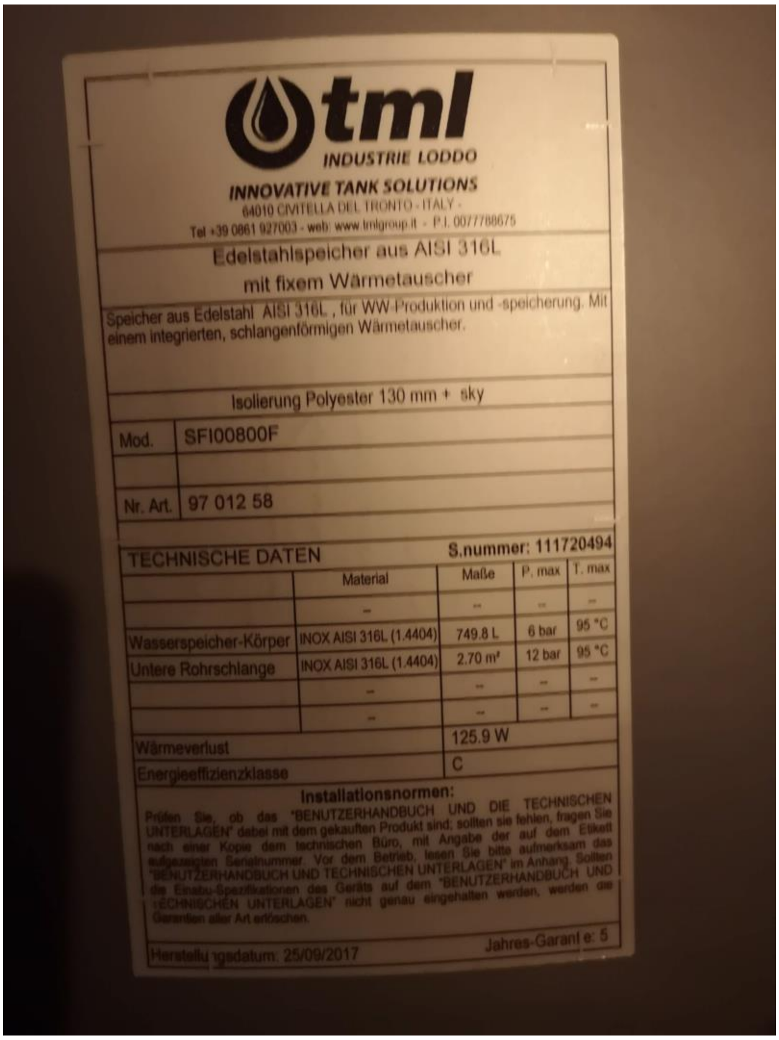


*Figure 24: Boiler storage data plate*

*Figure 25: Flanged heater (boiler)*


*Figure 26: Immersion heater (space heater)*

*Figure 27: Wood stove*

*Figure 28: Radiator- kitchen*

*Figure 29: Radiator- living space*

*Figure 30: Radiator- dining hall*

*Figure 31: Radiator- sleeping quarters*

*Figure 32: Expansion tank (top floor)*

## Floor Plans

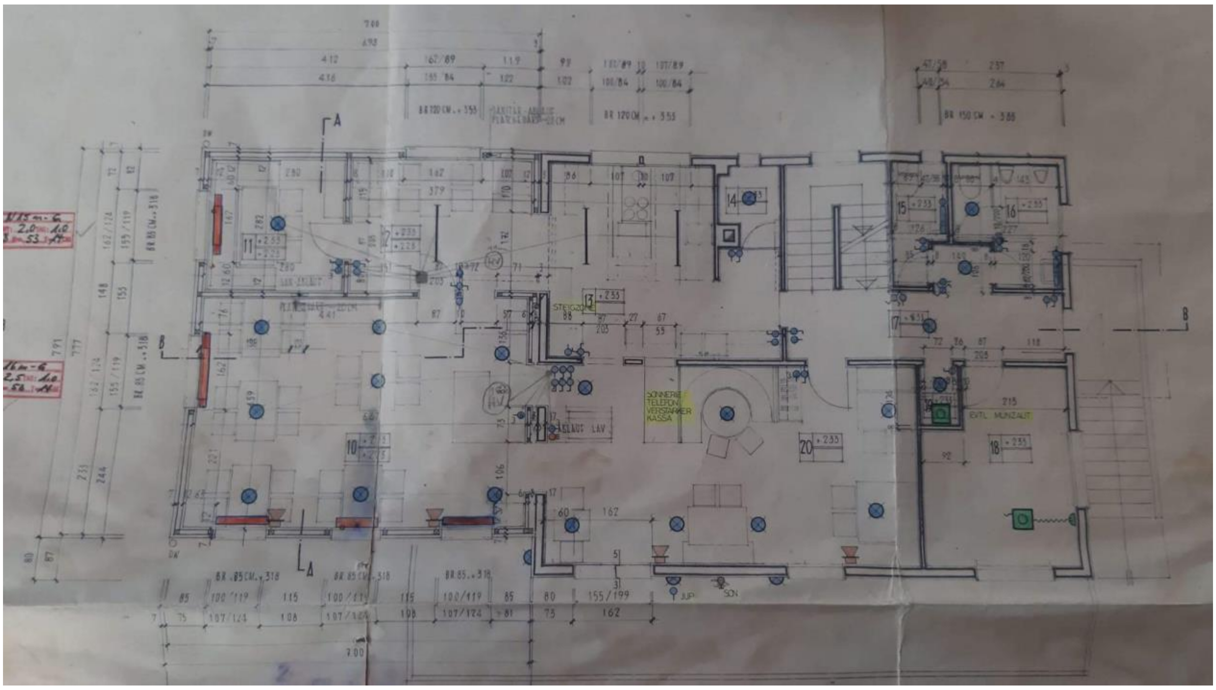


*Figure 33: Building plan- ground and first floors*

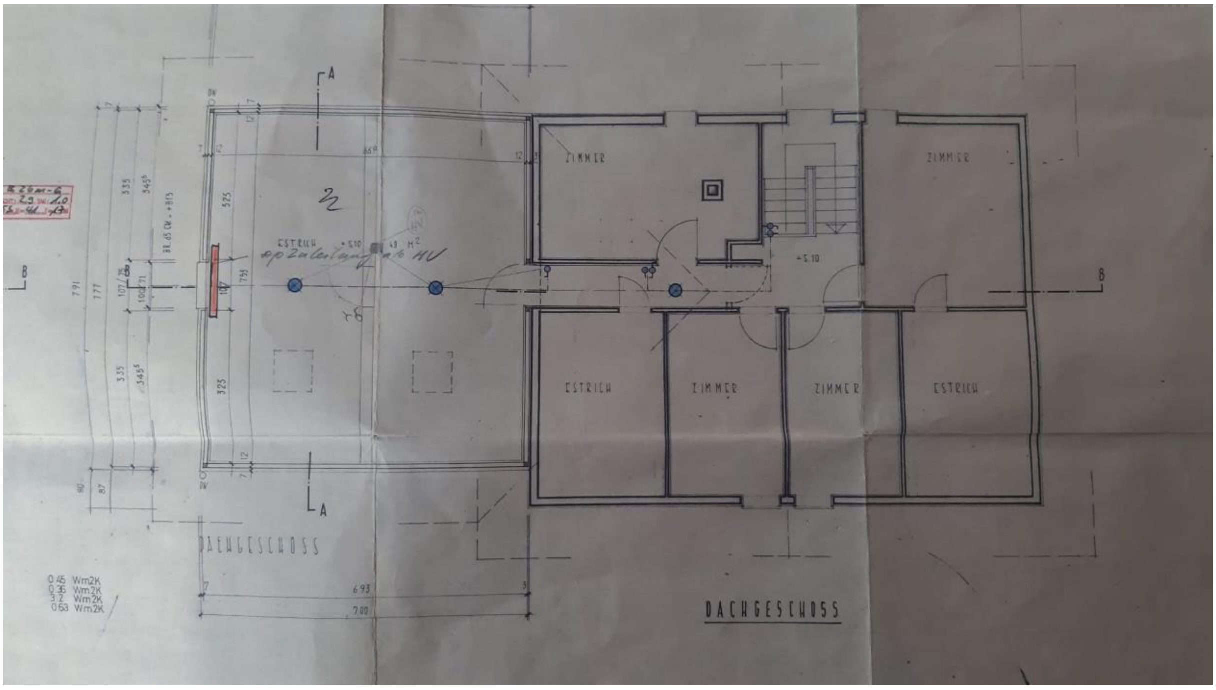



*Figure 34: Top floor*

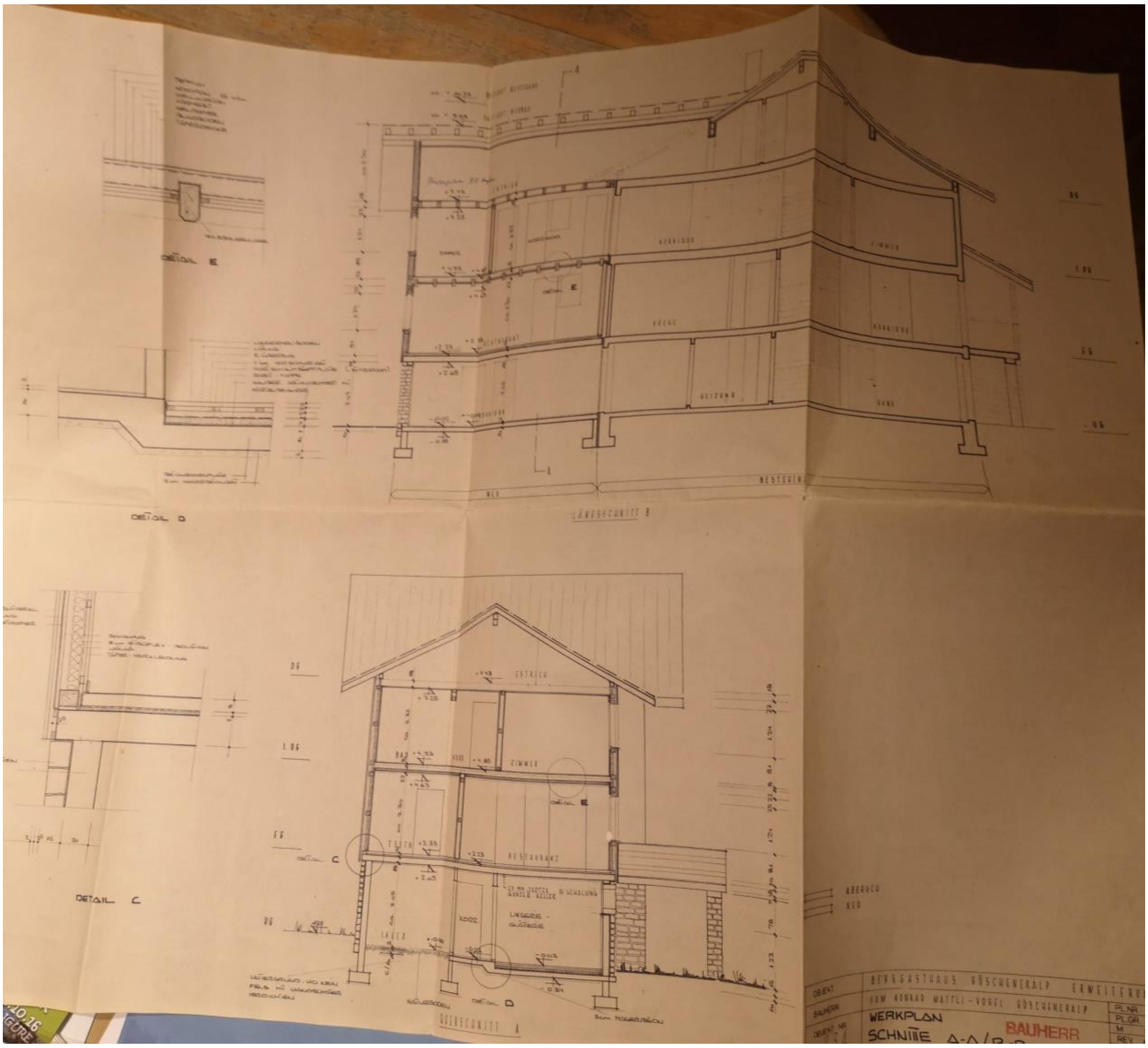
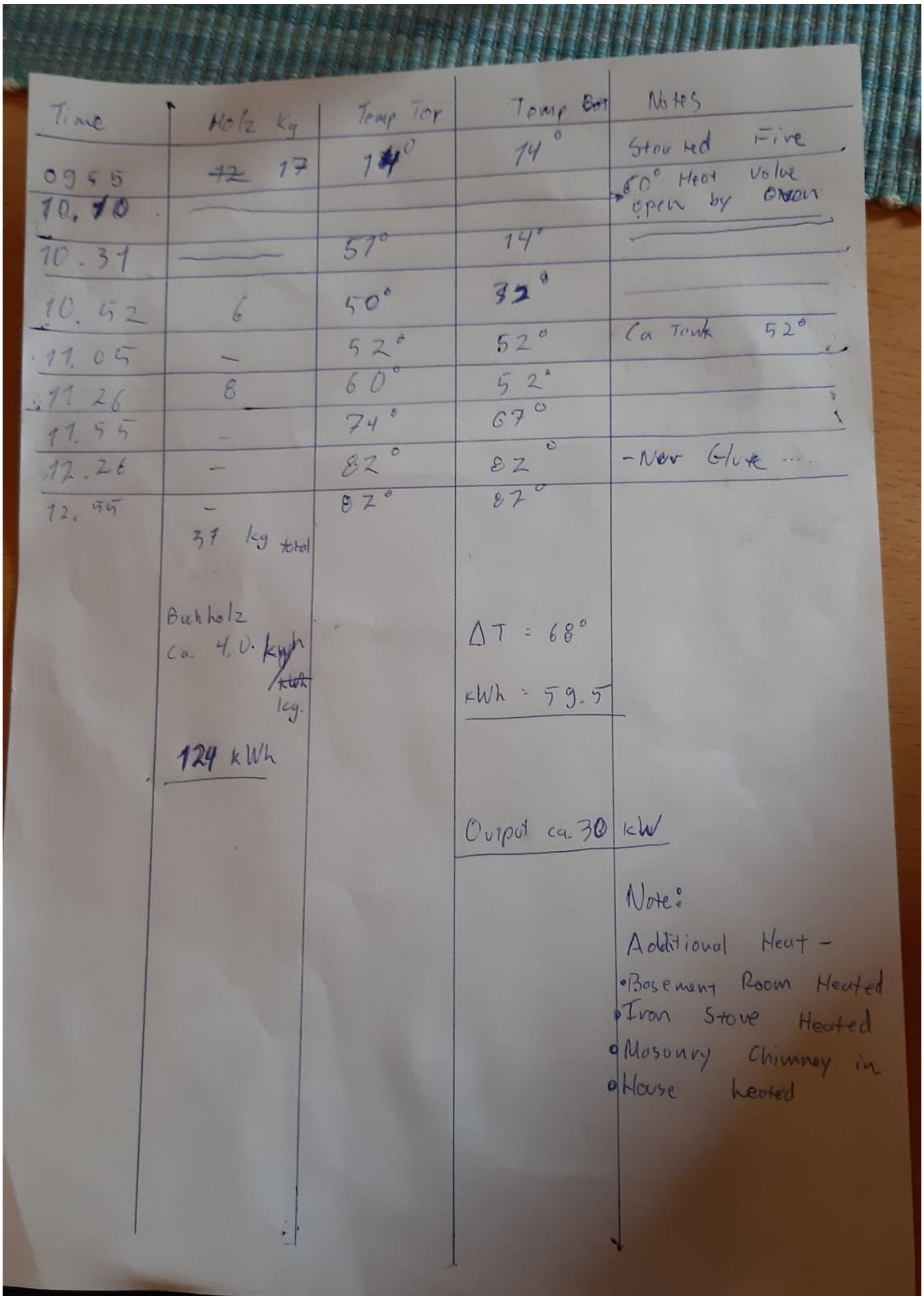


*Figure 35: Cross section*

## Wood stove experiment



| Time | Holz Kg | Temp Top | Temp Bot | Notes |
|---|---|---|---|---|
| | | 14° | 14° | Stove red Fire |
| 0955 | ~~12~~ 17 | 14° | | 60° Heat Value open by oven |
| 10.10 | | | | |
| 10.31 | — | 57° | 14° | |
| 10.52 | 6 | 50° | 32° | |
| 11.05 | — | 52° | 52° | Ca Tank 52° |
| 11.26 | 8 | 60° | 52° | |
| 11.55 | — | 74° | 67° | |
| 12.26 | — | 82° | 82° | - New Glut ... |
| 12.55 | — | 82° | 82° | |

31 kg total

Buchholz ca. 4,0 kWh / kg.

124 kWh

ΔT = 68°

kWh = 59.5

Output ca. 30 kW

Note:
Additional Heat -
• Basement Room Heated
• Iron Stove Heated
• Masonry Chimney in House heated

*Figure 36: Data and results*
*Source: Gasthaus technician*

## Hydraulic blueprints

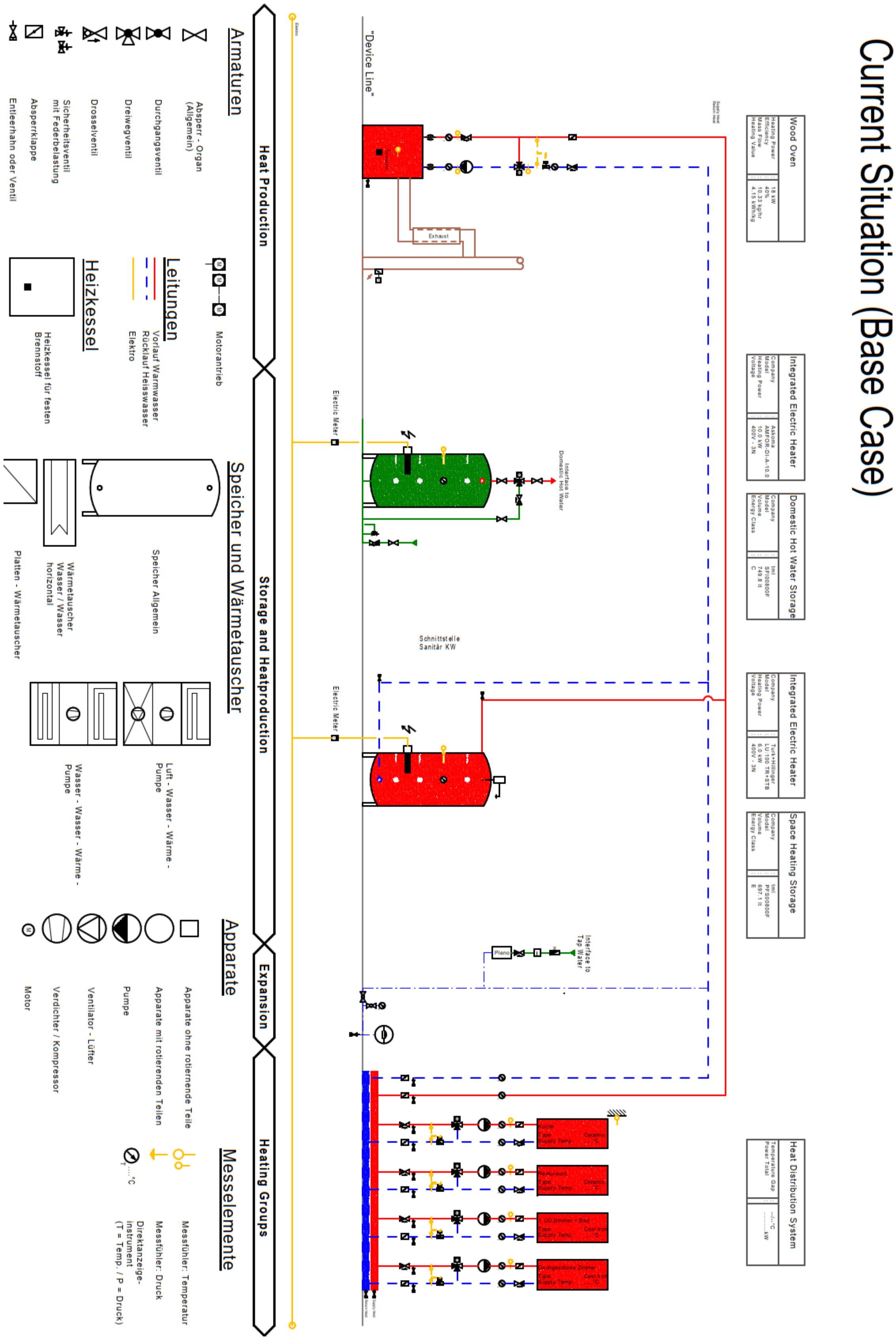



*Figure 37: Current situation schematic*
Source: own illustration

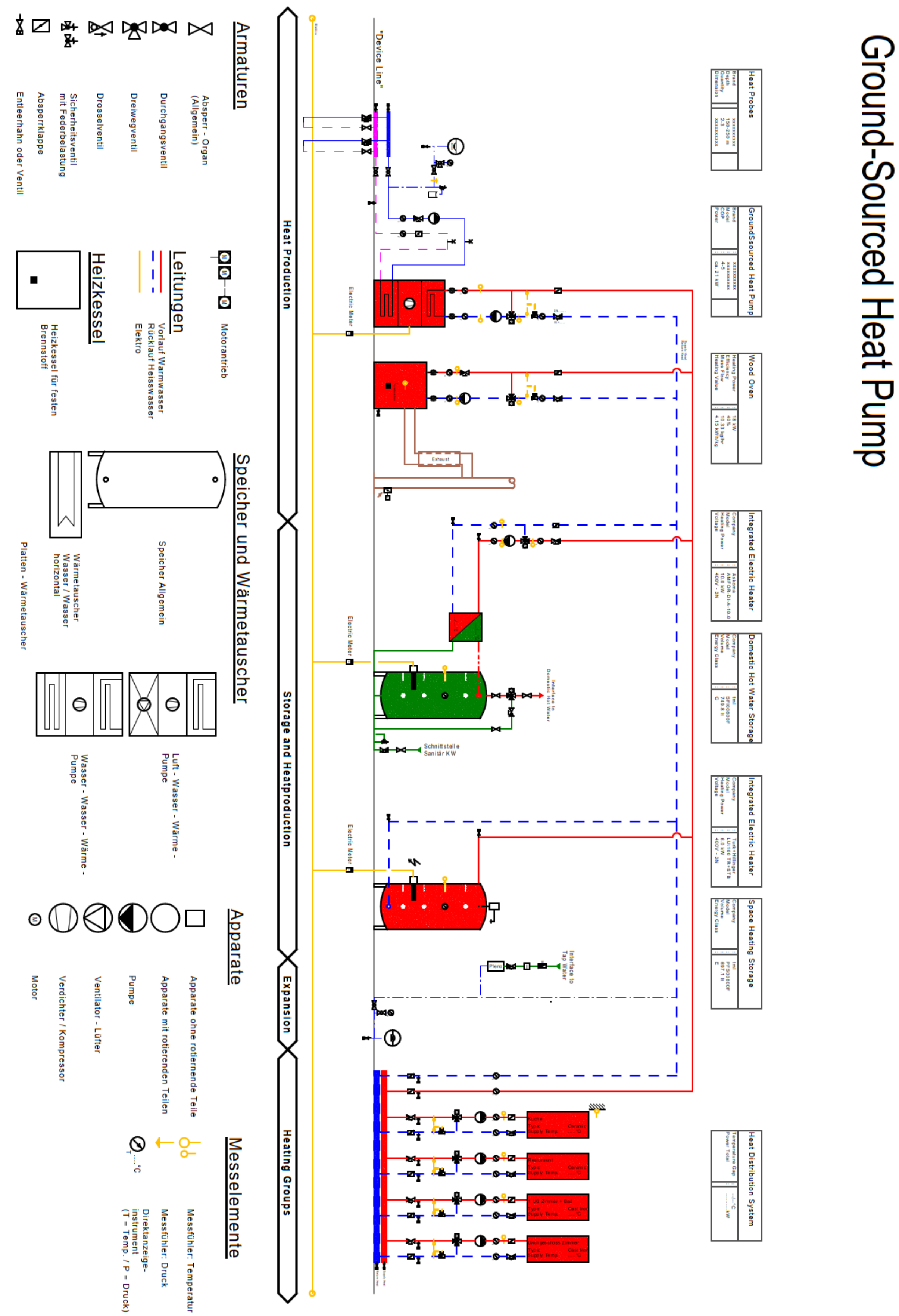



*Figure 38: Ground sourced heat pump schematic*

Source: Own illustration

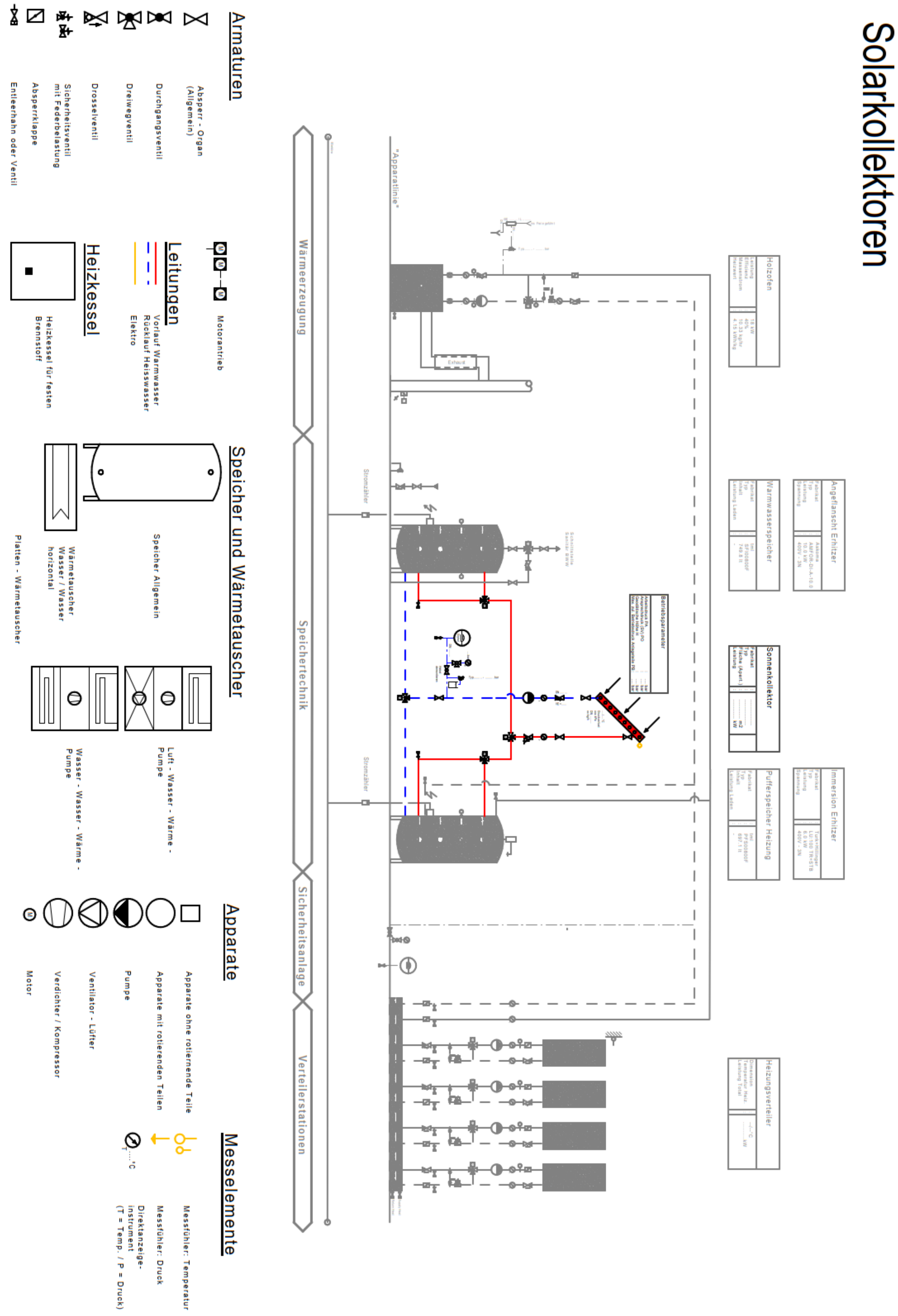



*Figure 39: Solar collector schematic*

Source: own illustration

**Product comparison**

| Action | Make | Model | Components | Heating Power | Heater | Installation (estimate) | Other (drilling, components, etc…) | Total | Pros and Cons |
|---|---|---|---|---|---|---|---|---|---|
| **Geothermal Heat Pump** | AIT | SWC 172 H3 | pumps, piping, valves | 17.2 at A-7/W35 | 27000 | 4000 | 13000 | 44000 | With boiler and pufferspeicher |
| | CTA Optiheat | OH 1-18 all-in-one | pumps, piping, valves | 16.2 at A-7/W35 | 22000 | 7000 | 28000 | 57000 | No boiler or pufferspeicher |
| | Hoval | UltraSource T cf (17) | pumps, piping, valves | 21 at A-7/W35 | 19000 | 5000 | 24000 | 48000 | No boiler or pufferspeicher |
| **Vacuum Tube Solar Collectors** | SolTop | Vakuum Röhrenkollektor T6-DF | pumps, piping, valves, installation, instructions, warrenty | 12kW at max | 23000 | 2000 | 8000 | 33000 | With storage |
| | Amk-Solac | DRC 10, Vakuumröh-Kollektor-Modul | valves, seals, controllers, sensors, pumps, heating coil | 12kW | 14400 | 3000 | 2600 | 20000 | Without storage |
| **Building Envelope Rennovation** | (representative study) | Rock Wool | Rock wool and glass | 5.8kW (saved) | 52000 | - | - | 52000 | - |

## Product Offers

**AMK-SOLAC Systems AG**
member of AMK group

Lagerstrasse 30
CH-9470 Buchs (SG)
Tel. +41 (0)81 750 16 90
Fax +41 (0)81 750 16 91
sales@amk-solac.com
www.amk-solac.com

Herr
Clint Christen

# Offerte Nr. 105'114

**Buchs, 22.05.2020** Seite 1

**Ihre Kunden-Nr.** : 2369
**Ihr Zeichen** :
**Versandart** : ab Lager Buchs **Unser Zeichen** : Kurt Amrein

**Bemerkung** : Objekt: Gwüest 5, 6487 Göschenen

| Pos | Art.-Nr. | Bezeichnung | Menge | Preis | Rabatt | Betrag CHF |
|---|---|---|---|---|---|---|
| 1 | 20.4020 | DRC 10, Vakuumröh.-Kollektor-Modul<br>2.04 m² Bruttofläche,<br>1.72 m², Aperturfläche:<br>2.73 m², Absorberfläche: | 7 Stk. | 1'470.00 | 20% | 8'232.00 |
| 2 | 20.4129 | S-Profil-Set mit 2 Stück, Länge 1050 mm<br>für DRC 10 | 7 Set | 71.00 | 25% | 372.75 |
| 3 | 10.4145 | Kollektorhaken-Set (4 Stk) kpl.<br>mit Hammerkopfschrauben<br>mit U-Scheiben & Muttern | 7 Set | 49.00 | 20% | 274.40 |
| 4 | 20.2031 | Tichelmann Hydraulik-Grundset, DRC 10<br>mit U-Bogen, Dichtungen, Fühler PT1000, | 1 Set | 89.00 | 20% | 71.20 |
| 5 | 20.2032 | Tichelmann Hydraulik-Erw.set, DRC 10<br>2 Kompensatoren ½", 67 mm,<br>inkl. Dichtungen 13x18.5x1.6 mm | 6 Set | 55.00 | | 330.00 |
| 6 | 20.2053 | Anschluss-Set ½" , BL 480 mm, DRC/OWR<br>2 x Wellrohre ½" mit CU-Übergang Ø 18 mm<br>inkl. Dichtungen 13x18x1.6 mm | 1 Set | 106.00 | 20% | 84.80 |
| 7 | 20.4071 | Dichtung aus Gylon ½", Set à 5 Stk.<br>hochtemperaturbeständig, 13x18.5x1.6, | 1 Pack | 8.00 | 20% | 6.40 |
| 8 | 50.5112 | Solarregler Level 7<br>Systemregler für Solar-u.Heizsysteme,<br>80 vordefinierte Grundsysteme<br>für 1- bis 4-Speichersysteme<br>1- bis 2-Kollektorfelder<br>Beleuchtetes System-Monitoring-Display<br>8 Relaisausgänge / 10 Sensoreingänge<br>2 Eingänge für Grundfos Direct Sensors<br>2 PWM-Ausgänge für drehzahlgeregelte Ansteuerung von HEPumpen<br>Betriebsstundenzähler<br>Datenaufzeichnung und Sicherung mit SD-Karte<br>Frostschutzfunktion<br>Kollektornotabschaltung<br>Vorranglogik/Paralell-/Pendelladung | 1 Stk. | 667.00 | 20% | 533.60 |

**Übertrag Seite 2** **9'905.15**

**AMK-SOLAC Systems AG**

member of AMK group

**Offerte Nr. 105'114 vom 22.05.2020** **Seite 2**

| Pos | Art.-Nr. | Bezeichnung | Menge | Preis | Rabatt | Betrag CHF |
|---|---|---|---|---|---|---|
| | | **Übertrag von Seite 1** | | | | **9'905.15** |
| | | Bypass Solarkreis<br>Schaltuhr/Uhrzeit<br>Mischerregelung für 1Heizkreis<br>Schaltleistung 1 (1) A, 100 ... 240V (Halbleiterrelais)<br>Schaltleistung 4 (2)A, 100 ... 240V (Standardrelais)<br>Gesamtabsicherung 4 A<br>Standby_Leistungsaufnahme: < 2W<br>Schutzart: IP 30<br>Abmessung 176x162x44 mm Wandmontage<br>Diverses Zubehör erhältlich | | | | |
| 9 | 50.5031 | Universalfühler PT1000B (grau)<br>für Kollektor, 260°C, 2m lang,<br>T max Kabel:<br>+220° (20000h); +260° (3000h); +300° (100h) | 4 Stk. | 55.00 | 20% | 176.00 |
| 10 | 50.6059 | Pumpengruppe OSS II HE, 1,5-6 l/min<br>HE-Pumpe Grundfos , 2-Strang Tacosetter<br>Setter-IL, Thermometer 0-160°C, Kugelhähnen<br>Anschluss Expansionsgefäss AG- 3/4" | 1 Stk. | 791.00 | 20% | 632.80 |
| 11 | 50.6028 | Motorventil 2-Weg, 230 V, DN20, (FR)<br>VVI46.20, mit Antrieb SFA21/18<br>kvs3.5, stromlos geschlossen | 4 Stk. | 161.00 | 20% | 515.20 |
| 12 | 50.5102 | Tyfocor LS, 20 Liter Kanister<br>LS-Wärmeträgerflüssigkeit (Fertigmisch.)<br>Kälteschutz -28°C | 6 Kanister | 126.00 | | 756.00 |
| 13 | 50.7534 | Wassererwärmer für Solar AS/2 750 lt<br>2 Glattrohrwärmetauscher 1.17m2 /1.93m2<br>und Revisionsflansch<br>Ø= 910/750mm H=2023mm Kippmass 1990mm<br>inkl. Isolation | 1 Stk. | 4'150.00 | 30% | 2'905.00 |

| | |
|---|---|
| **Warenwert CHF** | **14'890.15** |
| ./. 10.00 % Projektrabatt von 14'890.15 | 1'489.01 |
| **Subtotal CHF** exkl. MWSt. und Versand | **13'401.15** |
| + MWST-Betrag 7.70 % von 13'401.15 | 1'031.90 |
| **TOTAL CHF** inkl. MWSt. | **14'433.05** |

**Lieferbedingungen:** ab Werk per LKW
**Zahlungsbedingungen:** 0

Gültigkeit der Offerte 3 Monate ab Datum.

Unsere aktuellen allgemeinen Geschäftsbedingungen sowie die Bedingungen Transportschäden werden zur Kenntnis genommen und in ihrer Gesamtheit anerkannt.

Wir würden uns freuen, den Auftrag zu Ihrer vollen Zufriedenheit ausführen zu dürfen und danken Ihnen für das entgegengebrachte Vertrauen.

Mit freundlichen Grüssen
**AMK-Solac System AG**

*Figure 40: AMK Solac Systems AG offer*

Elgg, 18. Mai 2016 Aktualisiert: 22. Juni 2016

SOLTOP
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unser Objekt: Zürich, Hinterbergstr. 108, 110
Anlagetyp: STRATIVARI 1700/320, T6 DF 18 m2 VRK, AD
Kunden Nr.: K3081 Objekt. Nr. 150338 / 10000

MWSt-Nr.

zuständiger Verkäufer
Schweizer, Noel
079 316 62 45

Offerte erstellt
stefan.leuthold@soltop.ch

Auftragsabwicklung
Innendienst / Technik
052 397 77 77

Benz + Cie AG
z.Hd. Herr Giovanni Ratano
Universitätstr. 69
Postfach
8006 Zürich

## Offerte Nr. 16 - 102369

Solaranlage für Warmwasser, Heizungsunterstützung und Poolerwärmung

Sehr geehrter Herr Rubino

Herzlichen Dank für Ihr Interesse an unseren Produkten. Gerne stellen wir Ihnen folgende freibleibende Offerte zu. Bei Interesse würden wir die Offerte gerne mit Ihnen vor Ort besprechen. Rufen Sie uns bitte an, wir freuen uns darauf.

Die Kollektoranlage:
Vakuumröhrenkollektor T6-DF, SPF Nr C1248
Unseren Vakuumröhrenkollektor SOLTOP T6-DF empfehlen wir überall dort, wo Kollektoren flach liegend oder senkrecht an der Fassade montiert werden sollen. Der T6-DF ist alternativ zum Flachkollektor auch auf Schrägdächern einsetzbar.
Optimierter Vakuumröhrenkollektor mit nach der Sonne ausrichtbaren hochselektiven Kupferabsorbern. Einfaches, patentiertes Stecksystem für lückenlose Montage mehrerer Module nebeneinander. Die gesamte Kollektorhydraulik ist im vollisolierten Sammelrohrkasten integriert.
Hageltest SPF 35 mm bestanden.

Bauseits: Von der Kollektoranlage in die Zentrale:
Solarleitungen im Freien: Kupfer Glattrohr 22mm, anorganisch isoliert und verblecht.
Fühlerkabel.
Solarleitungen im Gebäude: Auch schwarz unverzinkt möglich.
Silberhaltiges Weichlot oder SOLARTAUGLICHES Pressystem.

Die Zentrale:
STRATIVARI zeichnet sich durch höchste Leistung und Vielseitigkeit aus:
- Die beiden Solartauscher bringen die Energie zusammen mit der SOLTOP QUICKBOX temperaturgerecht in den Speicher ein. Dadurch haben sie sofort heisses statt lauwarmes Wasser.
- Der grosszügige Brauchwassereinsatz mit Vorwärmwendel ist aus Edelstahl und garantiert einwandfreie Hygiene, hohen Solarertrag und maximalen Komfort.
- Die speziell für STRATIVARI entwickelte Rücklaufschichtlanze sowie die neue Bivalenz-Mischergruppe SOLTOP Eta sorgen dafür, dass die Energie optimal genutzt wird.
- SOLTOP übernimmt die Systemgarantie (250.-) für die optimale Kombination mit JEDEM Kessel.
SOLTOP Steamback-Systeme entleeren bei Bedarf automatisch die Kollektoren. Eine Überhitzung des Systems ist damit ausgeschlossen, der Solarertrag gleichzeitig optimal.

Schwimmbaderwärmung
Generell ist darauf zu achten, dass das Schwimmbad entweder eingegraben oder gegen aussen gut isoliert sein muss. Zudem ist es in der Nacht mit einer Folie abzudecken, um die

Offerte Nr. 16 - 102369

Elgg, 18. Mai 2016

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Aktualisiert: 22. Juni 2016

Verluste zu minimieren.

Interessante Angaben zu unseren Produkten finden Sie in unseren Prospekten oder www.soltop.ch.

Bauseits:
- Beantragen von Subventionen - Bitte beachten: Subventionen müssen in der Regel VOR Baubeginn bewilligt sein. Unter anderem subventionieren: Bund (nur für Photovoltaik), ev. Kanton, ev. Gemeinde, ev. Energieversorger (Gaswerk, EW, ...) etc. -
Baugesuch falls erforderlich.
- Beachten Sie auch den allfälligen Steuerspareffekt.

| Pos. | Unsere Art. Nr. | Bezeichnung | Menge | Einhei | Preis | Total CHF |
|---|---|---|---|---|---|---|
| 1 | B Obj. Daten | Wichtige Angaben | | | | 0.00 |

Objektdaten
- Anzahl Personen: 560L/h
- Dach (Typ, Neigung, Eindeckung): FD
- Anlagehöhe Speicher bis Kollektor:
- Einbringmasse: Bitte prüfen
- Zusatzheizung: Gas 50 KW

Weitere wichtige objektspezifische Angaben:
-

Materiallieferung Solaranlage

Kollektoranordnung: Siehe Dachplan, Low-Flow 20l / h / m²

| Pos. | Unsere Art. Nr. | Bezeichnung | Menge | Einhei | Preis | Total CHF |
|---|---|---|---|---|---|---|
| 4 | B 51.000.020 | Fühler für Kollektor PT 1000, ohne Dose | 1.0 | Stk | 34.00 | 34.00 |

Kollektorfühler PT 1000 FKP 6, mit Silikonkabel 2,3 m, temperaturbeständig bis 240°C Empfehlung: Fühlerkabel mechanisch schützen und getrennt von elektrischen Leitungen verlegen.

| Pos. | Unsere Art. Nr. | Bezeichnung | Menge | Einhei | Preis | Total CHF |
|---|---|---|---|---|---|---|
| 5 | B 13.000.003 | Vakuum-Röhrenkollektor T6-DF - 20° | 18.0 | Modul | 1'280.00 | 23'040.00 |

Unseren Vakuumröhrenkollektor SOLTOP T6-DF empfehlen wir überall dort, wo Kollektoren flach liegend oder senkrecht an der Fassade montiert werden sollen. Der T6-DF ist alternativ zum Flachkollektor auch auf Schrägdächern einsetzbar. Optimierter Vakuumröhrenkollektor mit nach der Sonne ausrichtbaren hochselektiven Absorbern. Direkt durchströmt, hydraulische Anbindung der einzelnen Röhren am Sammelrohr durch Verschraubung. Borsilicatglas 2.8 mm mit gleichbleibend hoher Lichtdurchlässigkeit und hoher Hagelresistenz. Hageltest 35 mm am SPF bestanden. Patentierte Glas-Metall-Verbindung im Thermokompressionsverfahren für langzeitstabiles Hochvakuum (10-8 bar). Barium-Getter. Einfaches, patentiertes Stecksystem für lückenlose Montage mehrerer Module nebeneinander. Seriell oder parallel verschaltbar, für Lowflow- und Highflow- Anlagen. Die gesamte Kollektorhydraulik ist im vollisolierten Sammelrohrkasten integriert. Absorberausrichtung - 20° (vom Röhrenende aus gesehen 20° im Gegenuhrzeigersinn nach links). Unter anderer Bestellnummer auch verfügbar: + 20° oder 0°. Mit Zusatzaufwand ausrichtbar von -20° bis +20°. Befestigungsschrauben für C-Schienenmontage am Kollektor vorhanden. 6 Röhren, Glasrohrdurchmesser = 100 mm Aperturfläche = 1.1 m2, Absorberfläche = 1.0 m2 L = 2100 mm, B = 721 mm, H = 126 mm Gewicht = 35 kg Inhalt = 1.4 Liter max Betriebsdruck = 6 bar. SPF Prüf-Nr. = C 1248: ETA 0.0 = 75%, 0.05 = 66%, 0.1 = 54%. Solar Keymark Prüf-Nr. 011-7S1453R nach EN 12975 Umweltzeichen Blauer Engel, Hagelschutzzertifikat SPF 35 mm Nr C1213IMP.

Kollektoranordnung: 6Reihen à 3 Kollektoren, parallel geschaltet, Low-Flow 20l / h / m²

| Pos. | Unsere Art. Nr. | Bezeichnung | Menge | Einhei | Preis | Total CHF |
|---|---|---|---|---|---|---|
| 7 | B 17.200.030 | Verbindungsset T6-DF parallel | 12.0 | Set | 48.00 | 576.00 |

Hochtemperatur-Verbindungsset zu SOLTOP Vakuumkollektoren T6-DF für parallele Verschaltung. Lieferung: 2 Stk Verbindungsnippel 22 mm mit O-Ring, 2 Stk Dichtplatten.

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Seite 3 / 7
Offerte Nr. 16 - 102369
Elgg, 18. Mai 2016 Aktualisiert: 22. Juni 2016

SOLTOP
SONNE WÄRME STROM

| Pos. | Unsere Art. Nr. | Bezeichnung | Menge | Einhei | Preis | Total CHF |
|---|---|---|---|---|---|---|
| 8 | B 17.200.031 | Verbindungsset T6-DF seriell<br>Hochtemperatur-Verbindungsset zu SOLTOP Vakuumkollektoren T6-DF für serielle Verschaltung. Lieferung: 1 Stk Verbindungsnippel 22 mm mit O-Ring, 1 Stk Verbindungsnippel 22 mm ungebohrt mit O-Ring, 2 Stk Dichtplatten. Einbauposition gemäss Schema beachten. | 3.0 | Set | 49.50 | 148.50 |
| 9 | B 17.200.032 | Anschlussset T6-DF einfach 18 mm<br>1 Hochtemperatur-Anschlusset einfach mit O-Ring-Dichtungen zu SOLTOP Vakuumkollektoren T6-DF. Lieferung: 1 Stk Anschlussnippel 18 mm, 1 Stk Endstopfen, 1 Stk Haltebrille, 1 Stk Abdeckplatte, 1 Stk Innensechskantschraube M 6 x 25 mm, 1 Stk Innensechskantschraube M 6 x 12 mm, 1 Stk Sicherungsscheibe | 6.0 | Set | 68.00 | 408.00 |
| 10 | B 42.000.205 | VS Muffe 22 - 22 inkl. Stützhülsen<br>Set bestehend aus 1Stk Muffe 22 - 22, 2 Stk Stützhülse 22 x 1 | 3.0 | Set | 23.80 | 71.40 |
| 11 | B 17.000.256 | VS Reduzierring 22 - 18 mm | 6.0 | Stk | 10.00 | 60.00 |
| 12 | B 17.200.035 | Winkelentlüfter SOLTOP T6<br>1Stk VSH T mit Hand-Entlüfter und O-Ringdichtungen zu SOLTOP Vakuumkollektoren T6-DF. Bestehend aus: 1Stk Winkelentlüfter VR T6 (17.200.048), 1Stk Handentlüfter R 1/2'' VR T6 (17.200.049), 1Stk O-Ring 18x3 VR T6 (17.200.050) | 4.0 | Set | 21.50 | 86.00 |
| 13 | B 42.000.237 | VS Winkel 22 - 22 inkl. Stützhülsen<br>Set bestehend aus 1Stk Winkel 22 - 22, 2 Stk Stützhülse 22 x 1 | 3.0 | Set | 28.80 | 86.40 |
| 14 | B 42.000.217 | VS T 22 - 22 - 22 inkl. Stützhülsen<br>Set bestehend aus 1Stk Tee 22 - 22 - 22, 3 Stk Stützhülsen 22 x 1 | 4.0 | Set | 38.20 | 152.80 |
| 15 | B 17.022.050 | Betonplatten Set zu Röhrenkollektor T6-DF<br>Vakuumplatte zementgrau inkl. Bohrung, Schrauben und C-Schiene. Bestehend aus: 1 Stk Gartenplatten V-zementgrau, 1 Stk Schlossschraube Inox A2 M8 x 60 mm Schaft 38 mm, 1 Stk Unterlagsscheibe, DI = 8.4 mm, DA = 24 mm, 1 Stk Mutter, M 8, 1 Stk Schutzvlies Tunprotect ACM 700, C-Schiene feuerverzinkt, 21 mm x 41 mm auf benötigte Länge geschnitten, Schienenverbinder 16 x 48 x 300 wenn nötig. Abmessungen Betonplatte: B = 500 mm, L = 500 mm, H = 40 mm, Gewicht = 25 kg. | 36.0 | Set | 41.00 | 1'476.00 |

**Zwischensumme** 26'139.10

Materiallieferung Solarleitung:

Bauseits:
- Verrohrung 18 mm, im Aussenbereich Kupfer, innen auch schwarz unverzinkt möglich, 50mm anorganisch isoliert und verblecht, Fühlerkabel
- Schutzrohre

| Pos. | Unsere Art. Nr. | Bezeichnung | Menge | Einhei | Preis | Total CHF |
|---|---|---|---|---|---|---|
| 18 | B 42.000.047 | Fühlerkabel Silikon 2 x 0.75 mm2 (bis 50m)<br>Steuerkabel 2 x 0.75 mm2 zur Verlängerung des Fühlerkabels bis maximal 50 m. Hinweis: Fühlerleitungen über 50 m müssen mit 2 x 1.5 mm2 verlängert werden. | 30.0 | m | 2.00 | 60.00 |
| 19 | B 41.020.015 | FLEXTUBE Inox DN 20 / 15 m<br>Solarleitung aus zwei Wellrohren, Vorlauf vom Kollektor ROT, Rücklauf zum Kollektor BLAU markiert. Silikon-Fühlerkabel 2 x 0.75 mm2. Komplett wärmegedämmt durch einen geschlossenporigen EPDM-Kautschuk-Schlauch, Schutzhülle aus UV-beständigem, sehr robustem schwarzem Wirkstrumpf. Wichtig: Nur für Einsatz im Schrägdach oder in der Steigzone, für horizontale Strecken nicht verwenden. Automatischer Entlüfter in der Solargruppe wird empfohlen. Nachentlüftung durch SOLTOP wird verrechnet. VKF Norm 5.3 (schwerbrennbar) Dimensionen Wellrohr: DN 20, AD = 24.9 mm, ID = 20.5 mm, Inhalt = 0.41 l/m Abmessungen fertig isolierte FLEXTUBE: B = 100 mm, H = 60 mm, L = 15 m | 1.0 | Ring | 1'150.00 | 1'150.00 |

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Seite 4 / 7
Offerte Nr. 16 - 102369
Elgg, 18. Mai 2016 Aktualisiert: 22. Juni 2016

SOLTOP
SONNE WÄRME STROM

| Pos. | Unsere Art. Nr. | Bezeichnung | Menge | Einhei | Preis | Total CHF |
|---|---|---|---|---|---|---|
| 20 | B 41.016.111 | Flextube Überg. DN 16 - 18 Klemmverschr. | 4.0 | Set | 19.30 | 77.20 |
| | | Set zum Verbinden der Flextube DN 16 an ein Systemrohr 18 mm z.B. Kupferrohr 18 mm. Bestehend aus: 1 Stk Flextube Übergang DN 16 Klemmv. 18 mm, 1 Stk Stützhülse 18 x 1. | | | | |
| 21 | B 41.000.100 | Flextube Rohrabschneider Inox 6 - 35 mm | 1.0 | Stk | 60.00 | 60.00 |
| | | Rohrabschneider für Flextube und Flexsingle Solarleitungen aus Edelstahl Wellrohr, inkl. Ersatzschneidrad. Für Leitungen von 6 - 35 mm. | | | | |
| | Zwischensumme | | | | | 1'347.20 |

Materiallieferung Zentrale:

| Pos. | Unsere Art. Nr. | Bezeichnung | Menge | Einhei | Preis | Total CHF |
|---|---|---|---|---|---|---|
| 24 | C 22.000.172 | STRATIVARI Kombisol Systemspeicher 1700 - 320 L | 1.0 | Stk | 7'605.00 | 7'605.00 |

Solar/Heizungs-Schichtspeicher mit integriertem Edelstahlboiler 320 Liter mit Vorwärmtauscher. Die Sonnenenergie wird über zwei Wärmetauscher oben und unten entsprechend dem Temperaturniveau eingeschichtet. Der variable Heizbereich ist je nach Wärmeerzeuger (Wärmepumpen, Gas-, Öl-, Pellets-, Holzkessel) optimiert und der Heizungsrücklauf erfolgt über eine Schichtlanze. Sämtliche Schicht-Anschlüsse passen für die Heizgruppe SOLTOP Eta 4W mit Bivalenzmischer. Alle Stutzen liegen im 90° Segment vorne. Wärmedämmung aus PU-Hartschaum 100 mm mit Polystyrol Mantel blau.

Gesamtinhalt 1710 Liter, Boiler 320 Liter (1.4571, 6/10 bar), Gewicht 440 Kg D brutto 1300 mm, H brutto 2130 mm, D netto 1100 mm, Kippmass 2200 mm,
Register Solar oben 1.2 m2, unten 3.6 m2
Betriebsdruck 3 bar, Prüfdruck 4.5 bar, Datenblatt vorhanden

| Pos. | Unsere Art. Nr. | Bezeichnung | Menge | Einhei | Preis | Total CHF |
|---|---|---|---|---|---|---|
| 25 | B 22.000.151 | Zubehörset STRATIVARI Kombisol 900 - 2000 | 1.0 | Set | 155.00 | 155.00 |
| | | 1 Stk Thermometer, 6 Stk Kabelverschraubungen, 1 Stk SV 3 bar, Schnellentlüfter, Stopfen EE etc. | | | | |
| 26 | D 27.000.010 | Heiz-Anschl-Set 5 fach - STRATIVARI Kombisol | 1.0 | Set | 190.00 | 190.00 |
| | | Zubehör für konvenzionellen Heizungsanschluss am Strativari Kombisol Speicher 900 - 2000 Liter für 5 Anschlussleitungen 1 . | | | | |

Einbringmass für Strativari 1700 beträgt min. 1100 mm. Raumhöhe 2130 mm.

| Pos. | Unsere Art. Nr. | Bezeichnung | Menge | Einhei | Preis | Total CHF |
|---|---|---|---|---|---|---|
| 28 | B 31.000.126 | QUICK-BOX für STRATIVARI Kombisol SR4 WMZ | 1.0 | Stk | 2'495.00 | 2'495.00 |

Komplette Solargruppe mit Hocheffizienzpumpe für Schichtladung, inklusive Regler und Volumenmessteil für die Wärmezählung. In formschönem, wärmegedämmtem Kanal, silbergrau pulverbeschichtet, vormontiert. Material: Abstellungen, Sicherheitsventil, Füllgarnitur, EMB Pumpe, Umstellventil, Rückschlagventil, Entlüftungsflasche, Rohre gedämmt, Durchflussanzeige. Integrierter Mikroprozessor-Regler SOLTOP mit grafischem Display, voreingestellt für optimalen Betrieb, Drehzahlregelung, Temperaturanzeigen für Kollektor, Speicher oben und unten, Betriebszustandsvisualisierung, Wärmemengenzählung mit Volumenmessteil, Fehlermeldung in Textformat, inkl. Elektroschema. Für SOLTOP STRATIVARI Kombisol 900 - 2000 Liter, Dimension: 3/4", Rohre CU 18 mm Hocheffizienzpumpe Wilo Yonos PARA ST 7.0 Durchflussanzeige 0.5 - 15 l/min Regler SOLTOP SR4, Lieferung: In Kartonschachtel mit Montageanleitung und Elektroschema für Elektriker. Montagezeit vor Ort: ca. 60 Minuten.

Option SMS Meldemodul für Fernüberwachung (zwingend falls Option 5-Jahres Garantie gewünscht)

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Seite 5 / 7
Offerte Nr. 16 - 102369
Elgg, 18. Mai 2016 Aktualisiert: 22. Juni 2016

SOLTOP
SONNE WÄRME STROM

| Pos. | Unsere Art. Nr. | Bezeichnung | Menge | Einhei | Preis | Total CHF |
|---|---|---|---|---|---|---|
| 30 | B 51.000.068 | SMS Meldemodul zu SR4 bei Vollgarantie<br>inkl. SIM-Karte (Swisscom) nur mit Vollgarantie SOLTOP erhältlich. Zur Überwachung der Solaranlage via SMS. Bei aktiver Fehlermeldung wird an bis zu 5 verschiedene Empfänger ein SMS gesandt. Ebenfalls via SMS kann der Anlagenstatus abgefragt oder die Parameter des Überwachungsgerät angepasst werden. Das Meldemodul muss an einem Ort mit Handy Empfang des Swisscom-Netz montiert werden. Die Verbindung zum Solarregler erfolgt mit 2 adriger Bus Leitung (nicht enthalten). Gehäuse Kunststoff weiss, IP20 II, 130 x 76 x 27 mm, Wandmontage, Schnittstelle Pro-Bus (Prozeda), Versorgung 230 V 50 HZ, Aufnahmeleistung ca. 1 W | 1.0 | Stk | 200.00 | Option |
| 31 | B 33.100.071 | Thermomischer DN 32 mit Zirk, o Pumpe, lose<br>Um die Verbrauchstemperatur von 55° C des Warmwassers zu garantieren (dringend empfohlen). Regelbereich 45 - 65° C Material lose geliefert: 1 Stk Thermischer Mischer JRGUMAT DN 32 G 2“ komplett mit 3 Stk Raccord 1 1/4“ IG, 1 Stk MS Kappe 3/4'', 2 Stk Rückschlagventile (Kalt- und Warmwasser) 1 1/4'', 2 Stk Rückschlagklappen 3/4''. Hinweis: Bei Anlagen, die bisher mit Schwerkraft betrieben wurden, muss eine Pumpe eingebaut werden. (Widerstand des Thermomischers) Zirkulationspumpe bauseits. | 1.0 | Set | 954.00 | 954.00 |
| 32 | B 37.200.077 | Expansionsgefäss 200 Liter<br>Druckexpansionsgefäss für Heizungsanlagen. Mit frostschutztauglicher Membrane. Inhalt = 200 Liter VD = 1.5 bar Anschl. 1''AG D = 484 mm, H = 1300 mm. Für Standmontage. | 1.0 | Stk | 659.00 | 659.00 |
| 33 | B 47.000.022 | Frostschutz Protect P 100 % 10 L Kanister<br>Bewährter Frostschutz auf Propylenglykolbasis für Solaranlagen. Giftklassenfrei, humantoxikologisch unbedenklich. Farbe Hellblau. Ungemischt bzw zur bauseitigen Verdünnung gemäss angestrebter Frostgrenze. | 1.0 | Stk | 78.00 | 78.00 |
| 34 | B 47.000.023 | Frostschutz Protect P 100 % 20 L Kanister<br>Bewährter Frostschutz auf Propylenglykolbasis für Solaranlagen. Giftklassenfrei, humantoxikologisch unbedenklich. Farbe Hellblau. Ungemischt bzw zur bauseitigen Verdünnung gemäss angestrebter Frostgrenze. | 2.0 | Stk | 156.00 | 312.00 |
| 35 | B 37.000.115 | Auffanggefäss 60 Liter<br>Robustes PE-Kunststoff-Weithalsfass 60 l mit Deckel und Metallspannring. Temperaturbeständig, zur Aufnahme des Solarmediums aus dem Sicherheitsventil. DM = 400 mm H = 610 mm | 1.0 | Stk | 70.00 | 70.00 |
| 36 | B 37.000.070 | Luftwärmetauscher 1" 20 kW bis 60 m2<br>Aluminiumgehäuse mit Cu/Al Wärmetauscher und hochwertigem, temperaturbeständigen Ziehl Abegg Ventilator. Geeignet für die Überschussabführung bei grossen Solaranlagen. Die warme Abluft kann zur Holztrocknung, Wäschetrocknung, etc. verwendet werden. Luftmenge = 2100 m3, Glycoldurchsatz bis 1000 l, Heizleistung = 20 kW. Anschlüsse = 1" 230 V, 0.23 kW, 1410 U/Min. Rohranschluss Austritt 350 mm, Gewicht ca. 16 kg. | 1.0 | Stk | 2'257.00 | 2'257.00 |
| 37 | B 37.000.088 | 3-Weg Umstell-Kugelhahn 3/4" Belimo L<br>Hochwertiger Umstellkugelhahn mit vormontiertem Antrieb für Um-Schaltung (L-Bohrung). Schweizerfabrikat. Dimension 3/4 " kvs 21 L 78 mm PN 16 Antrieb 230V Bis 120°C, Glycoltauglich bis 50 V%. Antrieb seitlich oder oben montieren | 1.0 | Stk | 323.00 | 323.00 |
| | | Zwischensumme | | | | 15'098.00 |
| 39 | B 91.000.038 | Dienstleistung SOLTOP<br>Liefern des hydraulischen und elektrischen Schemas; entsprechend dem Lieferumfang SOLTOP. Anlagedokumentation inkl. Box für Wandmontage. | 1.0 | Pau | 280.00 | 280.00 |
| | | Zwischensumme | | | | 280.00 |

Inbetriebnahme STRATIVARI 900/1200+ durch SOLTOP.

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Seite 6 / 7
Offerte Nr. 16 - 102369
Elgg, 18. Mai 2016 Aktualisiert: 22. Juni 2016

SOLTOP
SONNE WÄRME STROM

| Pos. | Unsere Art. Nr. | Bezeichnung | Menge | Einhei | Preis | Total CHF |
|---|---|---|---|---|---|---|
| 42 | S 99.300.002 | IB STRATIVARI 900/1200+ | 1.0 | Pau. | 650.00 | 650.00 |

Kontrollieren der Anlage: Sicherheitskomponenten, Steambackgefäss. Spülen und Füllen des Solarkreises, Inbetriebnahme. Einstellen und Kontrollieren der Reglerfunktionen. Erstellen eines Inbetriebnahmeprotokolles zu handen des Installateurs. Anbringen der Betriebsdokumentation. Wichtig: Der Bauherr muss für Instruktionen vor Ort anwesend sein. Sollte nachträglich eine Instruktion verlangt werden, muss diese zusätzlich verrechnet werden. Folgende Bedingungen müssen bauseitig durch den Installateur vorgängig sichergestellt werden: - Eine Person der installierenden Firma sowie Bauherr anwesend - System elektrisch fertig angeschlossen, inkl. Fühler und Nachheizung - Speicher heizungsseitig angeschlossen, gefüllt und entlüftet - Heizungsexpansion an Speicher angeschlossen, Vordruck entsprechend der Anlage richtig eingestellt - Boiler sanitärseitig angeschlossen und gefüllt - Solarkreis fertig angeschlossen, abgedrückt, dicht - Genügend Glykol vor Ort Mehraufwand infolge nicht fertiggestellter Installation wird zusätzlich verrechnet.

Option Montagehilfe solar durch SOLTOP.

| | | | | | | |
|---|---|---|---|---|---|---|
| 44 | S 99.001.102 | Montageinstruktion Kollektorfeld - 1 Manntag | 1.0 | Pau | 1'150.00 | Option |

inkl. Vorbereitung und Reisezeit. Der SOLTOP Montageinstruktor leitet die Monteure des lokalen Installateurs zur korrekten Montage des Kollektorfeldes an, indem er bei der Montage unterstützend mitarbeitet. Folgende Bedingungen müssen bauseitig durch den Installateur vorgängig sichergestellt werden: - Termin muss. min. 2 Wochen im Voraus reserviert werden - min. 2 Personen der installierenden Firma anwesend - Ort Solaranlage genau definiert (Montageplan muss vor Ort sein) - Dach muss für Montage vorbereitet sein (entkiest / Ziegel abgedeckt) - Absturzsicherung oder Gerüst gemäss SUVA-Empfehlung - Hebevorrichtung für Warentransport auf das Dach

Option 5 Jahres-Vollgarantie:

| | | | | | | |
|---|---|---|---|---|---|---|
| 46 | S 99.400.011 | 5 Jahres-Vollgarantie Typ 2: Druckgefüllte Systeme | 1.0 | Pau. | 1'500.00 | Option |

SOLTOP erteilt 5 Jahre Vollgarantie auf das komplette Solarsystem bei Vetragsabschluss innert 6 Monaten ab IB. Inkl. Fernüberwachung durch SOLTOP und Kosten für SIM Karte, Störungsbehebung und alle Ersatzteile. Auch ohne Störmeldung mindestens eine Komplettwartung vor Ort inbegriffen. Bedingung: Swisscom Handyempfang. Mögliche Systeme: STRATIVARI 900/1200+, QUICKSOL 1200+ Die Abrechnung erfolgt als 5-Jahrespauschale bei Vertragsabschluss. Kosten pro Jahr Fr. 300.-

Zwischensumme 650.00

Materiallieferung Poolerwärmung:
bauseits

Zwischensumme 43'514.30

| | | |
|---|---|---|
| LSVA + Nebenk. 2.4% (auf Material) | | 809.10 |
| Gesamttotal exkl. MWSt. | | 44'323.40 |
| Mehrwertsteuer 8.0 % | | 3'545.87 |
| Gesamttotal inkl. MWSt. | CHF | 47'869.27 |

Bauseitige Leistungen:
Beantragen von Subventionen - Förderbeiträge müssen VOR Baubeginn bewilligt sein. Siehe auch www.energiefranken.ch
Baugesuch falls erforderlich
Absturzsicherung oder Gerüst
Durchbrüche

Seite 7 / 7
Offerte Nr. 16 - 102369
Elgg, 18. Mai 2016

SOLTOP
SONNE WÄRME STROM

Sanitäranschlüsse
Heizungsanschlüsse Elektroanschlüsse
Isolierarbeiten

Offertgültigkeit: Ein Monat
Aktualisiert: 22. Juni 2016

*Figure 41: Soltop offer*

## CBA full results

*Table 17: CBA excel excerpt*

| Year | DF | $CF_{Basecase}$ | $NPV_{Basecase}$ | $Earnings_{BaseCase}$ | $CF_{Insulation}$ | $NPV_{Insulation}$ | $Earnings_{Insulation}$ | $CF_{GSHP}$ | $NPV_{GSHP}$ | $Earnings_{GSHP}$ | $CF_{ETC}$ | $NPV_{ETC}$ | $Earnings_{ETC}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1.000 | -5,953 | -5,953 | -5,953 | -22,350 | -22,350 | -22,350 | -47,000 | -47,000 | -47,000 | -13,200 | -13,200 | -13,200 |
| 1 | 0.926 | -5,953 | -5,512 | -11,466 | -26,520 | -24,556 | -46,906 | -1,895 | -1,755 | -48,755 | -4,700 | -4,352 | -17,552 |
| 2 | 0.857 | -5,953 | -5,104 | -16,570 | -4,170 | -3,575 | -50,481 | -1,895 | -1,625 | -50,379 | -4,700 | -4,029 | -21,581 |
| 3 | 0.794 | -8,953 | -7,107 | -23,677 | -7,170 | -5,692 | -56,172 | -1,895 | -1,504 | -51,884 | -4,700 | -3,731 | -25,312 |
| 4 | 0.735 | -5,953 | -4,376 | -28,053 | -4,170 | -3,065 | -59,238 | -1,895 | -1,393 | -53,276 | -4,700 | -3,455 | -28,767 |
| 5 | 0.681 | -5,953 | -4,052 | -32,105 | -4,170 | -2,838 | -62,076 | -1,895 | -1,290 | -54,566 | -4,700 | -3,199 | -31,966 |
| 6 | 0.630 | -5,953 | -3,752 | -35,856 | -4,170 | -2,628 | -64,703 | -1,895 | -1,194 | -55,760 | -4,700 | -2,962 | -34,928 |
| 7 | 0.583 | -5,953 | -3,474 | -39,330 | -4,170 | -2,433 | -67,137 | -1,895 | -1,106 | -56,866 | -4,700 | -2,742 | -37,670 |
| 8 | 0.540 | -5,953 | -3,216 | -42,546 | -4,170 | -2,253 | -69,389 | -1,895 | -1,024 | -57,890 | -4,700 | -2,539 | -40,209 |
| 9 | 0.500 | -5,953 | -2,978 | -45,524 | -4,170 | -2,086 | -71,475 | -1,895 | -948 | -58,838 | -4,700 | -2,351 | -42,560 |
| 10 | 0.463 | -5,953 | -2,758 | -48,282 | -4,170 | -1,932 | -73,407 | -1,895 | -878 | -59,716 | -4,700 | -2,177 | -44,737 |
| 11 | 0.429 | -5,953 | -2,553 | -50,835 | -4,170 | -1,788 | -75,195 | -1,895 | -813 | -60,528 | -4,700 | -2,016 | -46,753 |
| 12 | 0.397 | -5,953 | -2,364 | -53,199 | -4,170 | -1,656 | -76,851 | -1,895 | -753 | -61,281 | -4,700 | -1,866 | -48,620 |
| 13 | 0.368 | -5,953 | -2,189 | -55,388 | -4,170 | -1,533 | -78,385 | -1,895 | -697 | -61,978 | -4,700 | -1,728 | -50,348 |
| 14 | 0.340 | -5,953 | -2,027 | -57,415 | -4,170 | -1,420 | -79,804 | -1,895 | -645 | -62,623 | -4,700 | -1,600 | -51,948 |
| 15 | 0.315 | -5,953 | -1,877 | -59,292 | -4,170 | -1,315 | -81,119 | -1,895 | -597 | -63,220 | -4,700 | -1,482 | -53,430 |
| 16 | 0.292 | -5,953 | -1,738 | -61,030 | -4,170 | -1,217 | -82,336 | -1,895 | -553 | -63,773 | -4,700 | -1,372 | -54,801 |
| 17 | 0.270 | -5,953 | -1,609 | -62,639 | -4,170 | -1,127 | -83,463 | -1,895 | -512 | -64,286 | -4,700 | -1,270 | -56,072 |
| 18 | 0.250 | -5,953 | -1,490 | -64,128 | -4,170 | -1,044 | -84,507 | -1,895 | -474 | -64,760 | -4,700 | -1,176 | -57,248 |
| 19 | 0.232 | -5,953 | -1,379 | -65,508 | -4,170 | -966 | -85,473 | -1,895 | -439 | -65,199 | -4,700 | -1,089 | -58,337 |
| 20 | 0.215 | -5,953 | -1,277 | -66,785 | -4,170 | -895 | -86,368 | -1,895 | -407 | -65,605 | -4,700 | -1,008 | -59,345 |
| 21 | 0.199 | -5,953 | -1,183 | -67,968 | -4,170 | -828 | -87,196 | -1,895 | -376 | -65,982 | -4,700 | -934 | -60,279 |
| 22 | 0.184 | -5,953 | -1,095 | -69,063 | -4,170 | -767 | -87,963 | -1,895 | -349 | -66,330 | -4,700 | -865 | -61,143 |
| 23 | 0.170 | -5,953 | -1,014 | -70,077 | -4,170 | -710 | -88,673 | -1,895 | -323 | -66,653 | -4,700 | -800 | -61,944 |
| 24 | 0.158 | -5,953 | -939 | -71,016 | -4,170 | -658 | -89,331 | -1,895 | -299 | -66,952 | -4,700 | -741 | -62,685 |
| 25 | 0.146 | -5,953 | -869 | -71,885 | -4,170 | -609 | -89,940 | -1,895 | -277 | -67,229 | -4,700 | -686 | -63,371 |

| | Values | Unit | Base Case |
|---|---|---|---|
| Basecase | Energy consumption | KWh/a | 53400 |
| | Energy price | CHF/kWh | 0.1 |
| | Discount rate | % | 8% |
| | Construction cost | CHF | 0 |
| | New stove cost | CHF | 3000 |
| | Annual fixed cost | CHF | 620 |
| Insulation | Energy consumption | KWh/a | 35500 |
| | Energy price | CHF/kWh | 0.1 |
| | Discount rate | % | 8 |
| | Construction cost 1/2 | CHF | 22350 |
| | New stove cost (year 5) | CHF | 3000 |
| | Annual fixed cost | CHF | 620 |
| | Construction cost 2/2 | CHF | 22350 |
| GSHP | Energy consumption | KWh/a | 14250 |
| | Energy price | CHF/kWh | 0.1 |
| | Discount rate | % | 8 |
| | Installation cost | CHF | 47000 |
| | Maintenance cost | CHF/a | 470 |
| ETC | Energy consumption | KWh/a | 47000 |
| | Energy price | CHF/kWh | 0.1 |
| | Discount rate | % | 8 |
| | Installation cost | CHF | 13200 |