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

Title	**Energy Retrofit of a Housing Estate**
Student	**Mundakattu, Atul**
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Lecturer	**Berger, Matthias**
External examiner	**Lieball, Kai**

Abstract German
Die Liegenschaft in Edlibach besteht aus 12 Einfamilienhäusern. Alle Häuser sind an einen zentralen Ölheizkessel angeschlossen. Ziel dieses Berichts ist es, eine energetische Sanierungsanalyse durchzuführen, indem verschiedene Heizenergiesysteme in Betracht gezogen werden, die energieeffizient, kosteneffektiv und die geringsten Umweltauswirkungen haben.

Zurzeit besteht die Heizungsanlage aus einem konventionellen Heizkessel, der bald sein Lebensende erreicht. Als erster Schritt wurde ein Brainstorming und eine Marktforschung durchgeführt, um die verschiedenen Energiesysteme zu analysieren. Von dort aus wurden diese Energiesysteme auf fünf Lösungen eingegrenzt, nämlich: Brennwertkessel, Photovoltaikanlagen mit und ohne Batterie, Solarthermieanlagen mit Eisspeicher oder Oberflächenwassertank und Anschluss an das Fernwärmenetz.

Die aktuelle Situation der Wohnsiedlung in Bezug auf die Gebäudehülle, den Energiebedarf und die anfallenden Kosten wurden untersucht. Die Auswahl der endgültigen Energiesysteme erfolgte nach sorgfältiger Prüfung der Energiepolitik und der Vorschriften für Gebäudeenergiesysteme. Anschließend wurden Energiesystemmodelle entwickelt, um die Systemleistungen und Energieflüsse innerhalb des Systems zu verstehen. Danach wurden die Gesamtbetriebskosten berechnet, um die Wirtschaftlichkeit des Systems zu prüfen. Eine der abschließenden Aufgaben war die Berechnung der Umweltemissionen des Systems während seiner Betriebsphase.

Die Ergebnisse zeigen, dass Systeme bestehend aus Photovoltaikmodulen, Wärmepumpe und einem Batteriespeicher aus allen drei betrachteten Perspektiven die attraktivste Lösung ist. Diese Ergebnisse zeigen auch, wie wichtig es ist, ein Energiesystem mit einer Kombination aus Photovoltaik-Modulen und solarthermischen Modulen zu betrachten. Diese Studie kann als Referenz für den Vergleich von Energiesystemen und für die Bewertung ihrer jeweiligen Leistungen verwendet werden.

Abstract English
This Bachelor thesis presents an energy retrofit analysis by considering various heating energy systems with an energy efficient, cost effective and with the least environmental impact. This is performed with a housing estate in Edlibach, which consists of 12 single family houses. All the houses are connected to a central oil-fired boiler.

At present, the heating system consists of a conventional boiler which is soon reaching its end life. As a first step, brainstorming and market research were executed to analyse the different energy systems. From there, these energy systems were narrowed down to five solutions which are: a condensing boiler, photovoltaic systems with and without battery, solar thermal systems with ice storage or a surface water tank and connection to the district heating grid.

The current situation of the housing estate regarding its building envelope, energy demand and cost encountered were studied. The choices of the final energy systems were made after carefully reviewing the energy policies and building energy system regulations. Afterwards, energy system models were developed to understand the system performances and energy flows within the system. Subsequently, the total cost of ownership was calculated to see when the system pays off. One of the final tasks was to calculate the system's environmental emissions during its operational phase.

The results show that systems consisting of photovoltaic modules, heat pump and a battery storage is the most attractive solution from all the three considered perspectives. These results also indicate the importance of considering energy system with a combination of photovoltaic modules and solar thermal modules. This study can be used as a reference for energy system comparisons and for evaluating their respective performances.

Place, date Horw, January 2021

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Abbreviations and acronyms

BE	Break-even
BS	Battery storage
CHF	Swiss Franc
DHW	Domestic hot water
HSLU	Hochschule Luzern
HP	Heat Pump
IEA	Internal Energy Agency
LCOE	Levelized cost of energy
Mio	Million
OC	Own consumption
PV	Photovoltaic
Rp.	Rappen
SWT	Surface water tank
ST	Solar thermal
SCR	Solar coverage ratio
SCR_{sys}	Solar coverage ratio system
SH	Space heating
SS	Self-sufficiency
STES	Seasonal thermal energy storage
TCO	Total cost of ownership

1. Introduction

Switzerland has the lowest carbon intensities among the IEA countries due to the carbon free electricity generation dominated by hydropower and nuclear generation. Following the decision made by the Swiss community in the year 2017 to phase out nuclear energy generation, the Swiss energy sector is now undergoing a large transition. In order to accommodate this decision, the Swiss Federal Council has developed the 2050 energy strategy, where all the nuclear energy sources would be replaced by a low carbon economy, in which higher energy efficient and renewable energy sources will be implemented. The main challenges that arise during this transition would be the low carbon generation and the maintenance of high standards of supply security. The average energy consumption per capita needs to be reduced by 43% and average electricity consumption per capita needs to be lowered by 13% in 2035 when compared to the levels in 2000 (Swiss Federal Office of Energy, 2018).

Keeping this in mind, while analysing the primary energy sector, approximately 50% of Switzerland’s primary energy consumption is attributed to buildings: 30% for heating, air conditioning and hot water, 14% for electricity and around 6% for construction and for maintenance. Almost 90% of the 1.5 million residential buildings have a central heating system. Only less than 5% of the buildings are connected to the district heating system. Even though the use of heating oil is declining, almost two out of three buildings are still heated using fossil fuels (Swiss Federal Office of Energy, n.d.).

Lucerne University of Applied Science and Arts (HSLU) obtained the commission by Bruno Imhof, managing director of InnovationsTransfer Zentralschweiz, ITZ to perform a study on the possible energy system retrofit options for a housing estate consisting of twelve single family houses. There are many potential solutions while switching the energy system of a housing estate. Considering the energy strategy 2050 developed by the Swiss Federal Council, an energy system consisting of non-renewable energy resource would be of the least significance while analysing the potential options.

The main sources for domestic hot water production in Switzerland are electricity and heating oil. In recent years, they are being replaced by heat pumps, gas and solar installations. In order to meet the targets of the Energy Strategy 2050, there is a necessity to switch from fossil fuel-based heating systems to a renewable heating system. Therefore, the main focus of this report is on analysing the potential solutions for energy retrofit of a central heating system of a housing estate whose current situation is explained in the following section.

1.1 Current situation

The housing estate in Krezrain 3, in Edlibach (Canton of Zug) consists of twelve single family houses built in 1999. The housing estate is connected to a centralised heating system consisting of an oil-fired boiler. All the houses have a floor heating system and also a buffer storage tank in the technical room.

1.2 Problem description

The oil-fired boiler that meets the space heating and domestic hot water demand is about 20 years old and has to be replaced. This leads to an energy system renewal before the existing heating system breaks down. In order to implement a new energy system, a techno-economic and environmental impact assessment have to be performed in order to analyse the possible new heating solutions.

1.3 Project aim and objectives

The aim of this project is to analyse the potential solutions for retrofitting the heating system which is energy efficient, cost effective and which should have the least possible environmental impact for a given housing estate consisting of twelve single family houses.

The following are the main objectives of this thesis:

1. Determining the possible technologies that could fulfil the heating demands of the housing estate.

2. Once the possible technologies are identified, examining the performances of each system would be the next step. Also, an evaluation on the system dimensioning needs to be performed.

3. Comparison of the energy systems in order to narrow it down to fewer systems for further analysis.

4. Construction of energy system models for the chosen technologies and run their energy simulations.

5. Afterwards, cost calculations such as total cost of ownership (TCO) and levelized cost of energy (LCOE) of the different energy systems need to be calculated.

6. Hereafter, a SWOT analysis and environmental impact assessment needs to be performed in order to evaluate the different solutions.

The thesis is structured as followed:
Chapter 2 provides the reader with an overview of the current situation and provides background information of the possible technologies considered with a description of their advantages with regard to a conventional oil-fired boiler. It also provides background information to the different methodologies which have been employed in this project to assess the energy systems. Chapter 3 consists of three different sections addressing the Planning Phase, Situation analysis and Technological options. Chapter 4 presents the results obtained for cost calculations, energy simulations performed using Polysun, and environmental emissions. In chapter 5, the results are discussed, and the thesis is being assessed. Chapter 6 winds up this thesis with a conclusion on this project.

2. Background

2.1 Current situation

The housing estate examined in this thesis is situated in Edlibach, a village within the municipality of Menzigen, in the canton of Zug. The estate consists of two single-family houses and ten semi-detached single-family houses. An overview of the estate can be seen in Appendix 1. The heating and domestic hot water production is met using a centralised oil-fired boiler. Since the boiler is soon reaching its end life, there is a necessity to replace the oil furnace.

The storage tank of the oil furnace has a capacity of 20’000 L and is located at the entrance underneath the garage. The oil tank is placed in a room of 53.8 m³ in size and there are twelve decentralised buffer storage tanks of 500L each in the technical room of each house. The tanks are provided with a flange heater which is mostly unused and are present for meeting the demands at times of peak loads. The connection to the water mains for water supply is implemented at the garage, one floor above the oil storage tank.

The heating bill for the years 2013 to 2019 of the housing estate was provided by the industrial partner. The energy bill of the year 2019 was not considered due to the unusual weather behaviour and a relatively shorter winter season which led to the reduced space heating requirements for that particular year. The highest resolution of data acquired was on a monthly basis. The energy and water usage of the twelve different households were present on the bill. All this information can be found in the appendices from Appendix 7 to Appendix 10. The total energy consumption for heating was 164.6 MWh for the year 2018. The reduced heat energy consumption for the house B6 (Family Weiss) is due to the wood oven facility which in addition to the oil furnace also supports the heat generation process. Electricity is being provided by the local utility company, WWZ AG and there also exists a possibility for district heating connection to their district heating grid. Some other documents such as the building occupancy, floor and roof plans were provided by the industrial partner which are needed for modelling the energy systems.

2.2 Possible technologies

In this section, iterative qualification methods such as brainstorming and market research was conducted to perform a literature-based research on the possible technologies. General brainstorming helped to gather a wide range of possible technologies. At a later stage, market research was conducted to understand what the components are and what principles are behind the functioning of the system. The technologies being looked at are the following:

1. Solar thermal system
2. Solar thermal/PV + Heat Pump + Ice Storage
3. ST + Sensible storage
4. New condensing boiler
5. PV + Battery storage
6. Ground sourced heat pumps
7. Air sourced heat pumps
8. PV + heat pump + COWA storage
9. District heating connection

The political, geographical and technical aspects of the housing estate in Edlibach constitute the framework of the brainstorming process. An example would be that the ground sourced heat pump would not be a technological solution apt for the housing estate due to the slopy terrain and governmental regulations which prevents the implementation of this technology. The table 1 summarises the system advantages from the secondary research performed to understand the different technologies to a deeper extent:

Table 1: Energy system technologies along with their advantages

Possible technologies	**Advantages**
Solar thermal system + STES	• Reduced energy/oil bills • Eco-friendly • Reduced carbon footprint
Solar thermal system + Sensible storage	• Reduced energy bills • Eco-friendly • Reduced carbon footprint • Possibility to store the excess of heat energy being produced. • Improved output control • Able to reduce the mismatch between supply and demand
ST + HP + Ice Storage	• Enables free cooling with heating • Reduced energy bills • Eco-friendly • Reduced carbon footprint • Possibility to store the excess of heat energy being produced • Improved output control • Able to reduce the mismatch between supply and demand • Ice acts as a storage and stores solar heat. It also serves as a source for heat pump during heating period • Seasonal performance factor of 3.5 to 6 • Can store eight times the energy content as sensible storage
New Condensing boiler	• Increased efficiency up to 95% compared to the traditional boilers with 65% to 80% energetic efficiency • More environmentally friendly • Relatively smaller size and does not require hot water tank • Safer due to fully sealed system
PV + BS	• Flexible output • Enables peak shaving with energy storage • Electricity feed-in possibilities • Reduced electricity consumption from the grid • Compatible with existing electrical installations
Ground sourced HP	• More durability • Lower environmental impact • Enables heating as well as cooling • Energy efficient with higher COP than air-sourced heat pump

Connection to the district heating grid	• Simplest option • Only needs a connection to the grid • Requires less space for connection
PV + HP + COWA storage	• Large storage capacity: 50-70 kWh/m³ • Simple insertion of COWA capsules into the tank • Stability of COWA capsules > 10'000 cycles • Non-toxic, non-flammable and recyclable • Environmentally friendly

From brainstorming and market research, the advantages of each of the systems were identified. This step enabled to narrow down the energy system technologies to five systems which will be analysed in detail and will be used for the modelling of energy systems and for performing the energy balances. An energy system with seasonal thermal energy storage (STES) is not feasible due to the special limitations of the housing estate. As previously mentioned, the ground sourced heat pump is also excluded due to the slopy terrain and governmental regulations. The PV system with a HP and Cowa storage is also not considered due to the inability to implement this energy system model using the simulation software, Polysun. The technologies chosen for a further analysis are the following:

1. Condensing boiler (reference case)
2. Solar thermal system with sensible storage (SWT) and a supplementary heat source
3. ST system with a HP and Ice storage
4. Connection to the district heating grid
5. PV with HP and battery storage

A condensing boiler is chosen as a benchmark case since the existing heating system consists of a conventional oil-fired boiler. It has an increased efficiency and thereby will lead to reduced heating bills and is also more environmentally friendly.

The second system being considered is the solar thermal system along with a short-term sensible energy storage. Unfortunately, a seasonal thermal energy storage (STES) cannot be considered due to the spatial limitations.

The third system considered is ST + HP + Ice storage system. Ice storage is used due to the increased energy storage capacity of ice over other sensible storage technologies. It also enables the possibility of cooling while considering the heating system.

The fourth solution considered is the connection to the district heating grid. This is the simplest solution and only needs an extended connection to the local heating grid. To ensure the feasibility of grid connection, the district heating grid needs to be contacted. It is also interesting to look at the energy efficiency and cost data of this solution.

The final solution chosen for further analysis is PV with a HP and Battery Storage system. This is another simple technology which has an interesting cost and energy wise performance structure. The wide-ranging availability of subsidies and feed-in tariffs makes it attractive as an alternative to the existing heating system.

2.3 Polysun- An energy modelling tool

Houses play a crucial role in the life of humans by providing shelter, comfort and also help in meeting the energy demand of different users at different points of time. To provide thermal comfort during our stay at a house and for supplying domestic hot water, we need an energy system that meets these requirements. This leads to the good planning of an energy system using an energy modelling tool. A scientific paper which reviews different tools and modelling approaches has been analysed to understand the features and capabilities of Polysun, an energy simulation tool (Allegrini et al., 2015). The figure in Appendix 21 summarises the areas of expertise of 20 different energy modelling tools.

Polysun like the other simulation tools is also an efficient software for simulation-based planning, design as well as for the optimization of complex energy systems for buildings or districts (Allegrini et al., 2015). It was developed by Velasolaris, a company based in Winterthur. Polysun, though not originally designed for network simulations, provides energy modelling that can simulate energy flows and pumping power requirements starting from a single or multi-family houses to a district heating networks with decentralised pumps. It is also provided with background data on system boundaries and also incorporates system profiles such as building standards, weather profiles and also a database with different component specifications which can be chosen based on the user's preference.

Figure 1 is used to demonstrate the steps that are involved in creating and running the energy simulations.

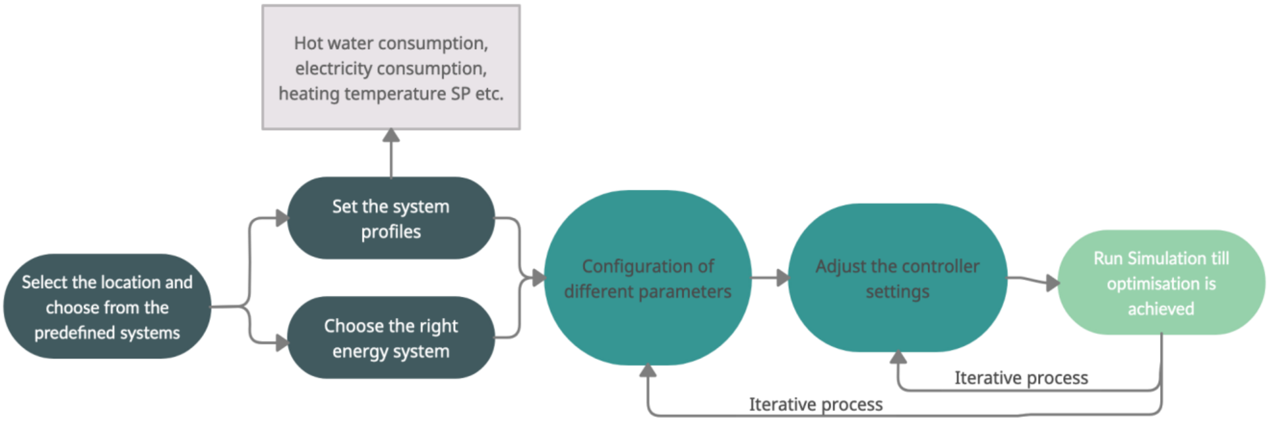

Figure 1: Processes involved in energy system modelling using Polysun

At first when opening a new project on Polysun, the user is asked to choose the location from the database or using the map function. From there, the user is directed to set the system boundary conditions by choosing the respective technologies and by assigning the profiles such as hot water demand, electricity consumption, building parameters etc. As a consecutive step, the parameters of the energy system components have to be configured and the corresponding controllers have to be adjusted properly. These processes as depicted in fig.1 are iterated till the maximum possible optimization is achieved. Polysun also enables the user to run a system comparison between different energy models which enables them to compare the systems with each other. A detailed report can then be exported from Polysun with an overview of the simulation results. Since HSLU holds a license for Polysun and due to the wide-ranging functionalities of it, the energy system modelling, and simulations were run using Polysun.

2.4 Evaluation of system performances

The energy simulations are performed using different system configurations. This leads to a need of evaluating the different systems. For assessing the systems consisting of ST modules, the solar coverage ratio (SCR) is used. SCR is defined as the ratio between the solar energy going into the system to the total energy including solar thermal energy consumed by the heating system. This evaluation is associated with systems such as surface water tank (SWT) and ice storage systems consisting of solar thermal modules. In order to assess the total energy consumption of the system, a factor called solar coverage ratio system is also implemented. This factor is defined as the ratio of solar energy input into the system to the total energy input into the system by also considering the electricity consumption of the households. In the case of ice storage, the denominator of the equation consists of solar thermal input, energy input into heat pump, pumping energy as well as the household electricity consumption. Whereas, for the system comprising of surface water tank, the denominator of the equation would include solar thermal energy input, pellet input, energy input of the circulation pumps and also the household electricity consumption.

For evaluating the different PV configurations, factors such as own consumption and self-sufficiency are defined. Own consumption (OC) is defined as the ratio of PV energy self-consumed over the total PV yield. Self-sufficiency is defined as the ratio of PV energy consumed to the sum of all energy forms going into the system. It also refers to the degree of autarky. Here the denominator would include factors such as electricity used up by circulation pumps, heat source and also the household electricity consumption. Provided below are the formulas which are used for evaluating the system performances:

$$SCR = \frac{Q_{sol}}{Q_{sol} + E_{cs}} \tag{1}$$

$$SCR_{system} = \frac{Q_{sol}}{Q_{sol} + E_{cs} + E_{hcs}} \tag{2}$$

$$OC = \frac{E_{ocs}}{Q_{inv}} \tag{3}$$

$$SS = \frac{E_{ocs}}{E_{cs} + E_{hcs}} \tag{4}$$

where Q_{sol} = solar heat input into the system, E_{cs} = energy consumption of additional heat source (pellet or heat pump), E_{ocs}= electricity own consumption, E_{hcs} = household electricity consumption, Q_{inv}= PV input into the system, OC = Own consumption, SS = self-sufficiency

Here the factors SS and SCR_{sys} are not entirely comparable due to the difference in energy forms of the considered systems. The aim of these factors is to see the levels to which autarky is achieved. For e.g., 40% SS would mean that 40% of the total energy used by the PV system is generated within the system and the remaining 60% of electricity is delivered by the electric grid. The same principle applies for SCR_{sys} ratio where it means that 40% of the total energy consumed is generated by the solar thermal system. Here higher levels of SS or SCR_{sys} can be achieved by means of a storage system such as battery storage in the case of PV systems and by means of ice storage tanks or surface water tanks for systems involving ST modules.

2.5 Calculation of costs

For the purpose of cost calculation, the total cost of ownership is implemented. Total cost of ownership (TCO) represents the purchase price of an asset along with the associated costs of operation. In this project, since a comparison of different energy systems is performed, it makes more sense to analyse the long-term price of the system rather than going for just the purchasing price. An energy system with a lower TCO is the better value in a long run.

The lifetime considered for the TCO calculation is 50 years. In the energy system solution description, the lifetimes of all the system components are shown. Most of the cost information are received from the Competence Centre for Thermal Energy Storage. The cost data for the energy system consisting of condensing boiler and some other system components were gathered from various leading industries and from price catalogues which were available on their respective websites. The total cost of ownership consists of two parts CAPEX and OPEX. CAPEX represents the capital expenditure of the system such as investment costs of the system components, installation costs and commissioning costs with the subsidies being subtracted from the final CAPEX value. OPEX represents the operating expenditure of the system during its entire lifetime. This includes the residual value, maintenance costs, replacement costs and energy costs. The residual value is the remaining cost of the system after its considered lifetime during the decommissioning phase. The maintenance costs would be costs encountered for maintaining the different system components and replacement cost signifies the costs of replacing a system component during the considered time horizon as soon as the component reaches its end life. The energy costs are the costs encountered by the system such as fuel and electricity costs. The residual value, maintenance costs, replacement costs, energy and fuel costs are converted to the present value using a discount factor. The reference system considered in this project is a condensing boiler and all the energy system TCOs are compared to this reference system. The relative TCO is defined by means of the following formula:

$$TCO_{sol}/TCO_{ref} = \frac{TCO\ (solution)}{TCO\ (reference)} \tag{5}$$

where solution refers to different solutions other than the benchmark case being described in this project.

The formula used for the calculation of the total cost of ownership is the following:

$$TCO[CHF] = CAPEX + OPEX - RV \tag{6}$$

where CAPEX= capital expenditure, OPEX = operating expenditures during the 50 years and RV= sum of all the residual values at the time of decommissioning (after 50 years)

Keeping these formulas in mind, an excel template was created and all these calculations have been performed for attaining the TCO results which will be presented in chapter 4.

2.6 Break-even analysis

Break-even analysis is a financial tool used for finding out whether a new service or product is profitable or not. Break-even point is the point where a company or organisation is neither making any money nor losing any money. Here for the purpose of evaluating the calculated TCOs, there is a need to see if the investment pays off within the considered period of energy system operation. For this purpose, there is a need to set a time horizon along which the total cost of ownership of the considered technologies are evaluated. A reference energy system also needs to be defined for comparing other system solutions to this reference case. During the analysis, if the relative TCO is lower than 1, this would mean that the system pays of within the considered time horizon and would also yield an additional revenue or savings. For a better understanding, an example is provided below.

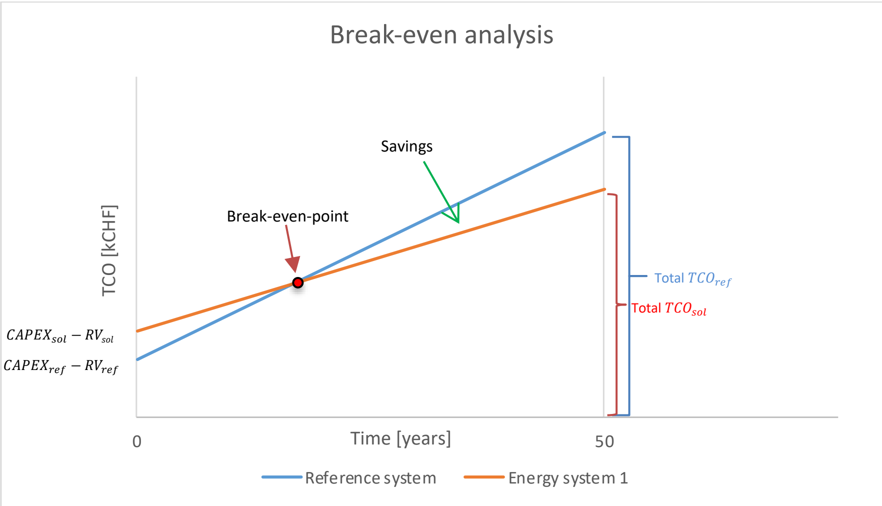

Figure 2: Break even analysis

Fig.2 depicts two energy systems where the reference case is fossil-fuel based energy and the other solution is renewable energy system. It can be observed that the initial investment costs (a.k.a. CAPEX) is higher for the renewable energy system when compared to the reference case. But during the operational phase, it can be noted that the renewable energy system has a less steeper curve and has secured smaller TCO value compared to the fossil fuel-based system. After the indicated break-even point, the renewable energy system starts to generate savings till the end of the considered time horizon. The formula used for calculating the time for energy system to break even is the following:

$$t = \frac{(RV_{ref} - RV_{sol}) - (CAPEX_{ref} - CAPEX_{sol})}{(OPEX_{ref} - OPEX_{sol})} * n \tag{7}$$

Where RV_{ref}= residual value of reference system, RV_{sol}=residual value of solution, $CAPEX_{ref}$ = capital expenditure of reference, $CAPEX_{sol}$= capital expenditure of solution, $OPEX_{ref}$=operating expenditure of reference, $OPEX_{sol}$= operating expenditure of solution, n= considered time horizon

3. Methodology

The methodology chapter is organized into 3 sections: Planning phase, situation analysis and system solutions. Planning phase focuses on the energy problems faced by the community and looks into the energy policies and regulations. It also presents a study on the stakeholders associated with this project. Situation analysis emphasizes on energy and cost related aspects of the housing estate. The third and final section presents the chosen energy system solutions with their technical descriptions.

3.1 Planning phase

The planning phase consists of several steps.

3.1.1 Energy problems, objectives and project barriers and drivers

What are the energy problems in the community?

There are different possibilities for choosing a new energy system. In the community, there exists a district heating grid which currently supplies hot water for DHW and space heating for 60 real estates. The district heating grid consists of two wood fired boilers and an oil furnace of power ratings 2400kW, 1600kW and 3200kW respectively. Annually, an amount of 6900MWh heat is being dispatched from this heating grid (Holzwärmeverbund Menzingen, 2020). The possibility and feasibility for a connection to this heating network needs to be analysed. Further specifications of this district heating grid can be found out on the website of WWZ under the region Menzingen at https://www.wwz.ch/de/privatpersonen/energie/waerme-kaelte/projekte.Electricity is also provided by WWZ and they need to be contacted to know further about the electricity feed-ins if a PV system is considered as a viable option.

Is there a need for integrated planning?

Integrated planning will ensure the participation of all the necessary stakeholders in the decision-making process. Thereby a well analysed environmentally and economically beneficial system can be chosen for this project.

What are the long-term objectives for energy supply?

The long-term objectives considered for energy supply are the following:
- Meeting the energy demand for space heating and domestic hot water even during the peak load times
- Consistent energy supply
- Minimal losses in the considered systems
- Financial benefits such as reduced energy and maintenance costs
- Maintain the necessary thermal comfort
- Reduce the CO_2 emission

3.1.2 Building regulations and funding programs in Switzerland

In Switzerland, each of the 26 cantons have their own building regulations. The 2014 MuKEn (Mustervorschriften der Kantone im Energiebereich) sets standards for nearly zero energy buildings in reference with the EU recommendations. According to this standard, space heating and water heating in the new residential buildings should only consume a maximum of 3.5 litres of oil equivalent per square metre (m^2) per year, or 35 kilowatt hours (kWh) per m^2 per year. These values are 10-15% improved compared to the 2008 MuKEn values. Since the code sets a goal for energy use per floor area, it enables designers and builders to decide on how to reach that target. The 2014 MuKEn kept the target value for full refurbishment of existing buildings at 7.5 litres of oil equivalent per m^2 per year, but introduced a requirement where a minimum share of 10% of renewable energy sources is required while replacing the energy system. The installation of new electric space heating systems was already banned in the 2008 MuKEn, and the 2014 version now adds the condition of replacing all remaining direct electric heating systems within 15 years of time (*Energy Policies of IEA Countries: Switzerland 2018 Review*, 2018).

Other measures which were a part of MuKEn 2014 include:

- Banning of electric water heaters after the year 2020
- Non-renewable energy generation cannot exceed the maximum of 90% when replacing the existing heating system. 100 kWh/m² and year applies as standard energy solution for heating and hot water.
- All public buildings need to install a heating system which is totally free of fossil fuels by 2050.
- A minimum share of electricity needs to be self-produced within the new buildings.
- The following are the standard solutions with heat pumps and hot water which comply with the requirements of the MuKEn (Art. 1.31, (EnDK 2014)):
    - HP with ground source, water or ambient air, electrically driven heat pump for heating and hot water throughout the year.
    - Natural gas-powered heat pump
    - Hot water heat pump with PV system, heat pump boilers and PV systems with at least 5 W/m² energy reference area

Funding Programs

One of the important funding programs for the building sector in Switzerland is the building program ("Das Gebaüdeprogramm"). This was developed by the conference of the cantonal energy directors (EnDK) together with the Federal Office of Energy (BFE) and the Federal Office for the Environment (BAFU). The main objective of this program is the reduction of CO_2 emission by the Swiss residential buildings.

In Switzerland, there is no direct funding for heat pumps, but when it comes to the remediation cases, they get a financial support. There are also cantonal subsidies for a system change in the heating system (e.g., for switching to heat pump). Another example would be BKW (Bernische Kraftwerke) where they support the replacement of a DHW heat pump with 600 Swiss francs.

The "EnergieSchweiz" program also has an important role in funding. For example, when it comes to increasing the share of renewable energies, indirect subsidies from the Federal Office for Energy SFOE and the Association of Heat Pumps Switzerland FWS play the most important roles. They also support all the suppliers and manufacturers in research, education and training and also in marketing and quality assurance (Banach & Fahrni, 2014).

Das Gebäudeprogram (Building refurbishment programme)

This programme is a result of the joined effort of the federal government and cantons to promote the energy efficiency of the buildings. The subsidies which were disbursed from 2010 to 2016 have resulted in cumulative savings of 115 TWh of energy (Das Gebäudeprogramm 2016, 2015). The program was managed on the federal level until 2016 and has been passed on to the cantons to increase its effectiveness and for a smoother functioning.

The fund from the federal government is now made available for the different cantons to either allocate the funding for the building envelop or for a renewable heating system. Within this framework of the "Gebäudeprogamm", the Confederation gives the cantons financial grants to:

- support energy-related renovations of the building envelope of existing heated buildings, i.e., better insulated roofs, walls, floors, ceilings and windows.
- promote the use of renewable energies, complete renovations of the heating system, the use of optimized building technology, and the use of waste heat (Das Gebäudeprogramm 2016, 2015).

Energiefranken

The Swiss Federal Confederation, cantons, cities and municipalities, as well as campaigns from regional energy suppliers and private institutions are supporting the promotion of renewable energies and increasing energy efficiency. Today, many funding programs are offered at various levels in Switzerland. The website "Energiefranken" https://www.energiefranken.ch/de/ provides a list of the different types of funding programs in Switzerland. The website lists all the energy promotion programs after entering the postcode of the building location. The search includes funding programs for the cantons, cities and municipalities as well as campaigns from regional energy supply companies.

3.1.3 Policies and regulations for building energy systems in Canton of Zug

The planning, construction and operation of buildings which are heated or cooled shall be based on the heat and building technology standards of the Swiss Association of Engineers and Architects (SIA) applicable to the building with the date of issue designated by the Construction Directorate, namely SIA standard 380/1 "Thermal energy in building construction", 380/4 "Electrical energy in building construction" and 382/1 "Ventilation and air-conditioning systems - general principles and requirements"(Kanton Zug - Erlass-Sammlung, n.d.).

The following applies in the Canton of Zug in addition:

1. For new or extended buildings, non-renewable energy shall not exceed 80 % of the permissible heat demand for heating and hot water.
2. The installation of a new system with direct electrical heating of domestic hot water is only permitted in residential buildings if the heat generator for space heating also heats or preheats the domestic hot water during the heating period or if predominantly renewable energy or waste heat that cannot be used in any other way is used to heat the domestic hot water.
3. Boilers powered by fossil fuels and operated with a safety temperature of less than 110 °C must be able to utilize the condensation heat. This requirement shall also apply to the replacement of a heat generation system, provided that it can be technically fulfilled, and the cost is proportionate.
4. The new installation of stationary electrical resistance heating systems for buildings is limited to emergency heating systems in exceptional cases.

Waste heat, in particular that from refrigeration as well as from commercial and industrial processes, shall be used as far as technically and operationally possible and economically viable, taking into account an imputed energy price surcharge of at least 5 Rp./kWh (crude oil, natural gas, electricity) (Kanton Zug - Erlass-Sammlung, n.d.).

3.1.4 Stakeholders and stakes

For any organisational project, the important players must be identified at the beginning phase of the project. By implementing this strategy, an early alignment of goals and plans of the stakeholders can be ensured. In the context of energy system retrofit for a housing estate, the following stakeholders have been identified as the key stakeholders for performing stakeholder analysis. The listed stakeholders are provided below with a short description to understand the relevance of each one of them in this project.

1. House Owners
   One of the key stakeholders who would have the final right to decide which technology to go for is the house owner. They also contribute to the heating energy demand and the chosen energy system needs to comply with the needs and demands of the residential user.

2. Local Utility, WWZ
   The local utility company in the village of Menzingen is WWZ. They are responsible for providing electricity and also offers the possibility of connection to the district heating grid.

3. Technology providers
   The company which provides the chosen energy system technologies.

4. Municipality
   Municipality also plays a lead role in deciding which technology to go for. The subsidies and incentives mainly depend on the municipality where the real estate is located.

5. Government
   The ultimate decision makers when it comes to energy strategies and for the technology selections.

6. Service providers
   Service providers are responsible for providing maintenance and service provisions in case the energy system breaks down. They also are responsible for performing the regular inspections to make sure that the system is functioning faultlessly.

7. Investors/Banks
   Many projects concerning an energy system retrofit require a high investment cost. Hence a credit from an investor/ bank is essential to realise this project.

Stakeholder Analysis

After determining the stakeholders, a stakeholder analysis is performed to understand the nature of stakeholders' interest, their goals and motivation, potential concerns and their levels of influence. As a first step, the stakeholders are grouped into supporters and opponents.

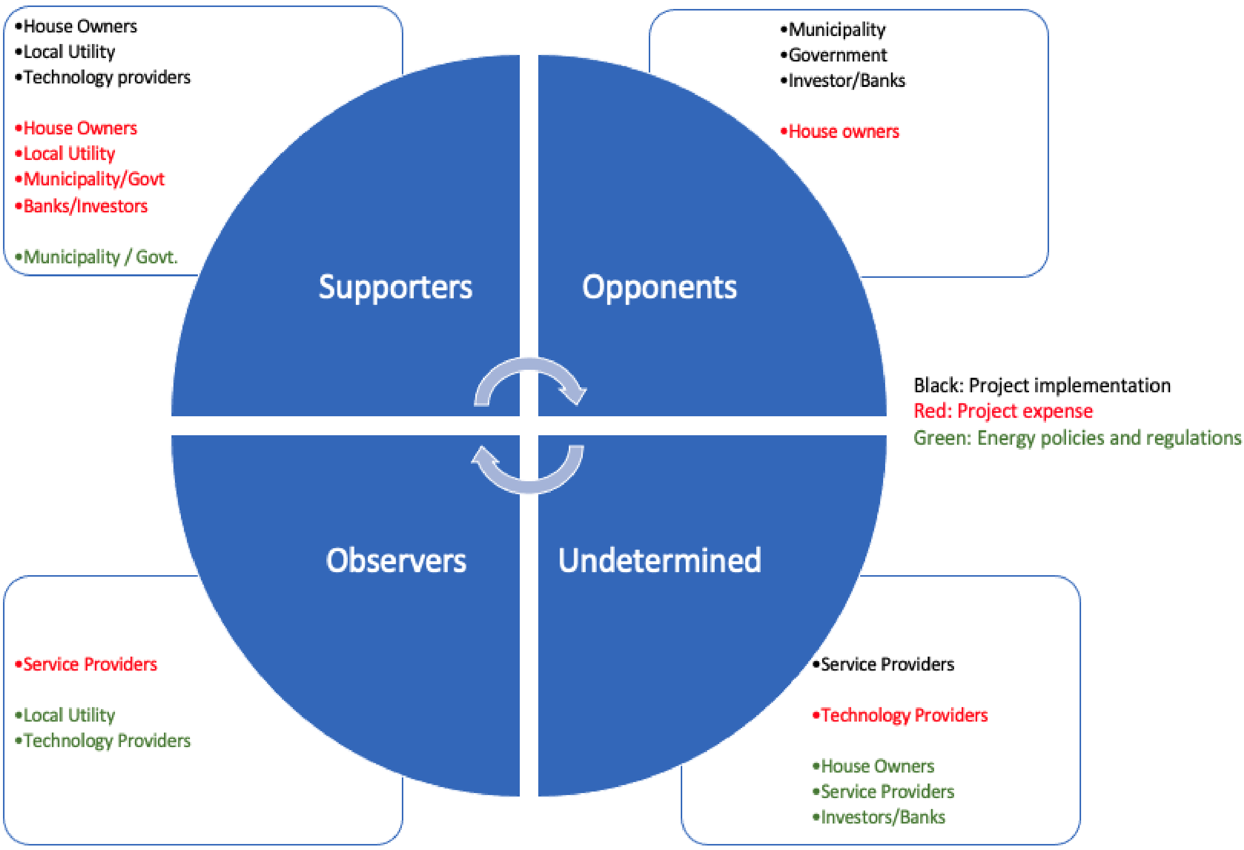

Figure 3: Classification of stakeholders based on their roles

As a next step, an interest/influence grid according to their level of interest and influence is created. The figure 4 shows the interest/influence matrix.

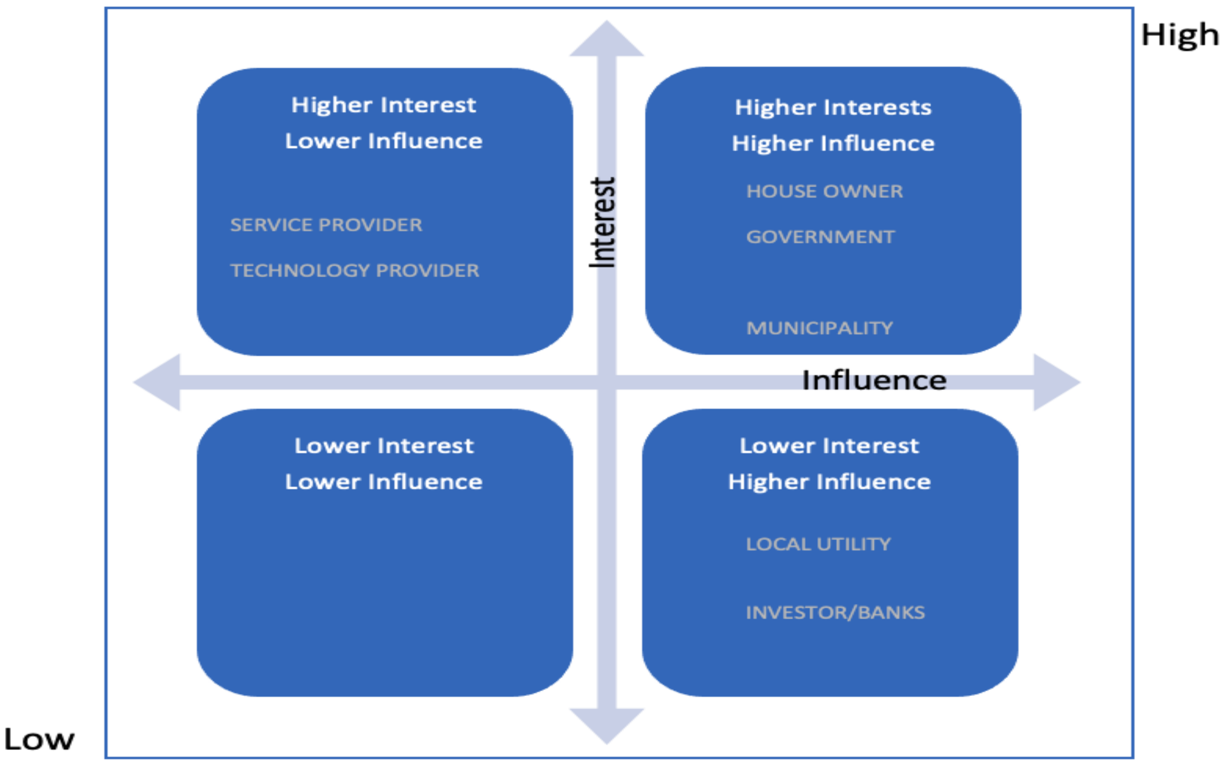

Figure 4: Interest/Influence matrix

1. High influence, high interest: These are the most important stakeholders who are prioritized by keeping them happy with the project's progress.
2. High influence, low interest: These are the stakeholders who are not very interested in the project but have a decision-making power.
3. Low influence, high interest: Stakeholders who are interested in the project but have less voice when it comes to the decision-making process.
4. Low influence, low interest: These are the stakeholders with the least influence and interest.

From the stakeholder analysis, the following conclusions can be derived. Most important stakeholders in terms of authority and interest are the house owners, municipality and the government. Since the heating system in the housing estate in Edlibach will soon reach its end life, the house owners are forced to replace the energy system. The municipality mainly determines which the possible technologies are for energy retrofit and also determines the subsidies and incentives for them. The government also plays an important role with respect to energy policies and technology selections.

The banks and local utilites have a relatively higher influence and lower interest. Banks can provide financial aids. A connection to the grid is only allowed if the intended project gets sanctioned by the local utility. Service providers and technology providers have a relatively higher interest and lower influence since they can't really participate in the decision-making process.

3.1.5 System definition

This section provides a better understanding of what the energy system consists of and also investigates different system diagram to understand relationship of the stakeholders to the system and its environment. This section includes delimitation of the energy system, environment-oriented approach and structure-oriented approach.

Delimitation of the energy system

System delimitation is the process of subdividing the system into an intervention system and its environment as shown in fig.5. The intervention system is the area within the energy system where there is a possibility to perform modifications and the parts of the surrounding systems relevant to the interventions assessed is called the environment. The figure below shows the system delimitation for the existing heating system which consists an oil-fired boiler.

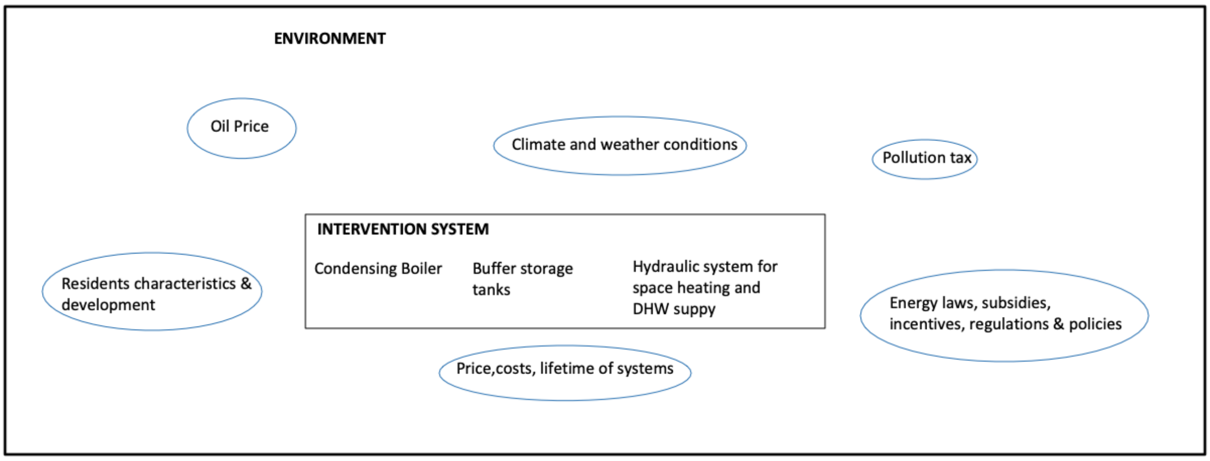

Figure 5: Intervention system and environment

Environment-oriented approach

An environment-oriented approach focusses on the interrelationships between the intervention system and its environment. This approach is usually used in the beginning phase of a project to identify the stakeholders, their stakes and also helps to have a better understanding of the challenges of an existing energy system. Fig.6 depicts the environment-oriented approach.

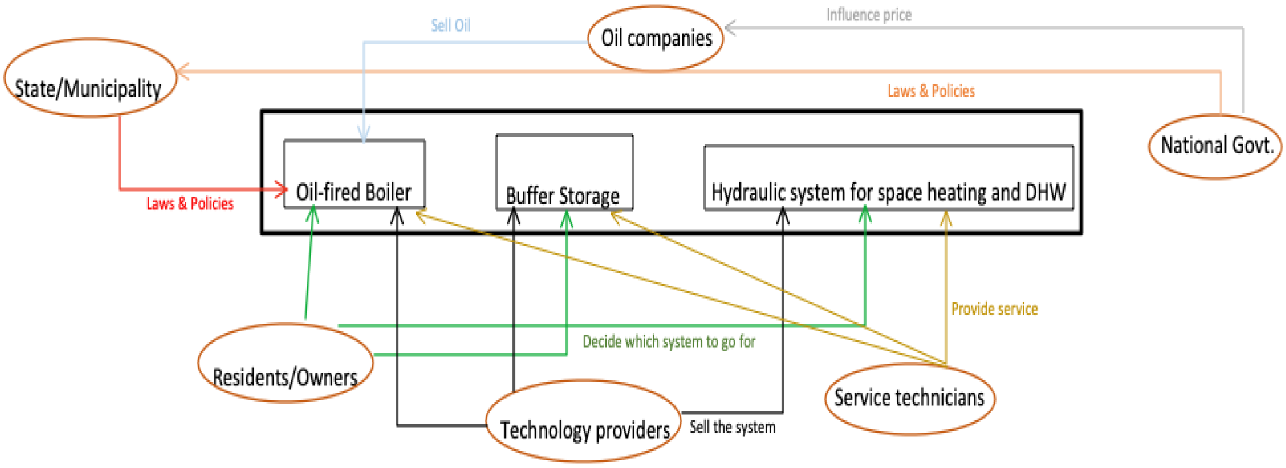

Figure 6: Energy system (intervention system) and its environment

Structure oriented approach

A structure-oriented system description is used here to describe the existing heating system and also describes the possible solutions. This approach will help in the planning of all the possible systems which could well replace the existing oil-fired boiler. It also represents the energy flows and relations between the different system components of an energy system.

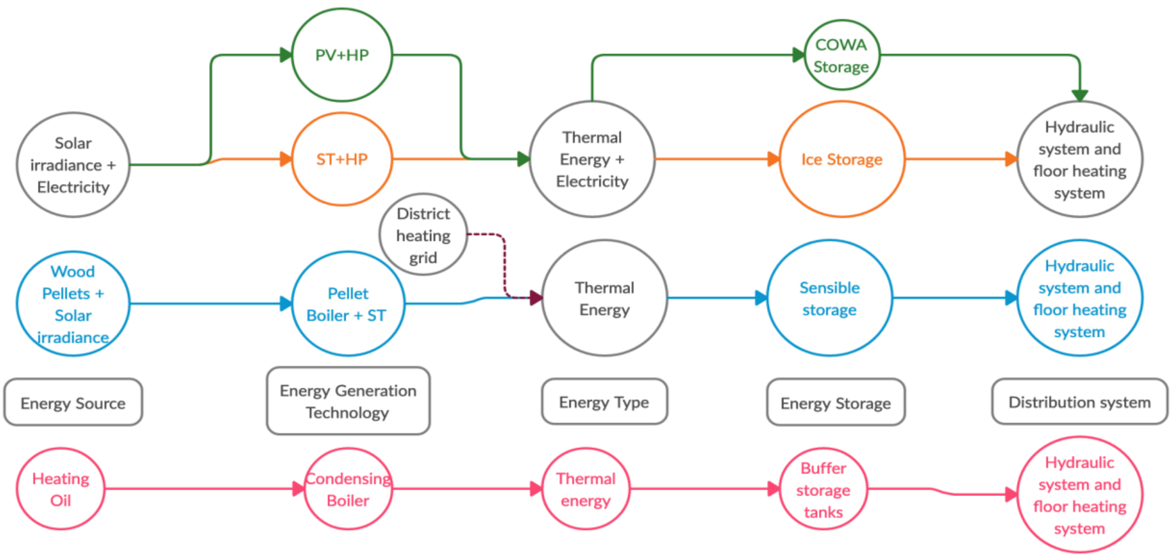

Figure 7: Base case and possible system solutions

3.1.6 Analytical goals of the energy system

This section specifically focusses on the system definition and also looks at the system boundaries, subsystems, inputs and outputs based on the analytical goals chosen. The energy system considered is heating energy system of a housing estate. The schematic representations from fig.8 to fig.10 show system boundaries which are set based on the analytical goals and depicts what goes in and out of the system. The three analytical goals chosen for this project are the following:

1) Energy balance/ Energetic efficiency

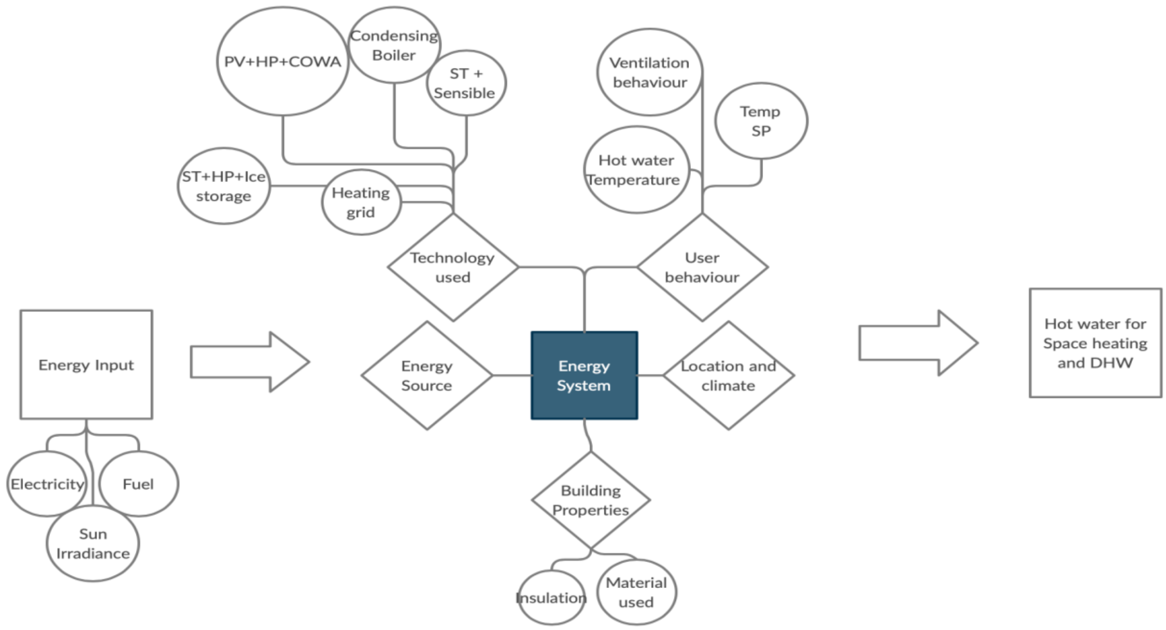

Figure 8: System boundary for energy performance analysis

2) Cost analysis

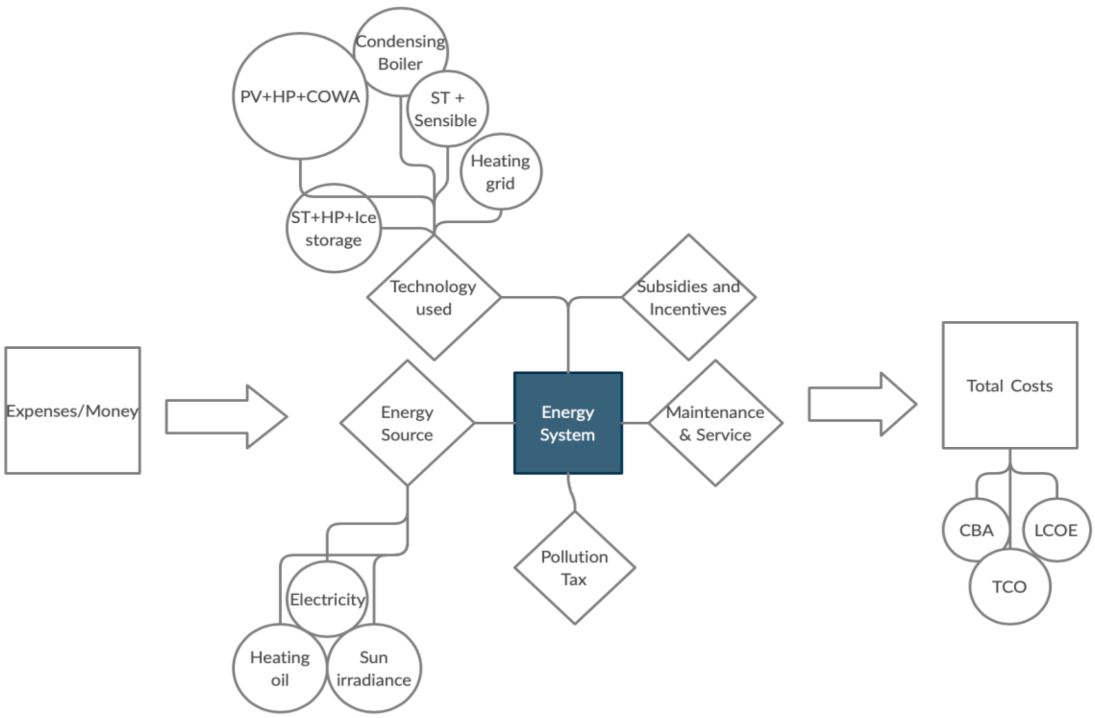

Figure 9: System boundary for costs analysis

3) Analysis of CO_2 emission of the different technologies

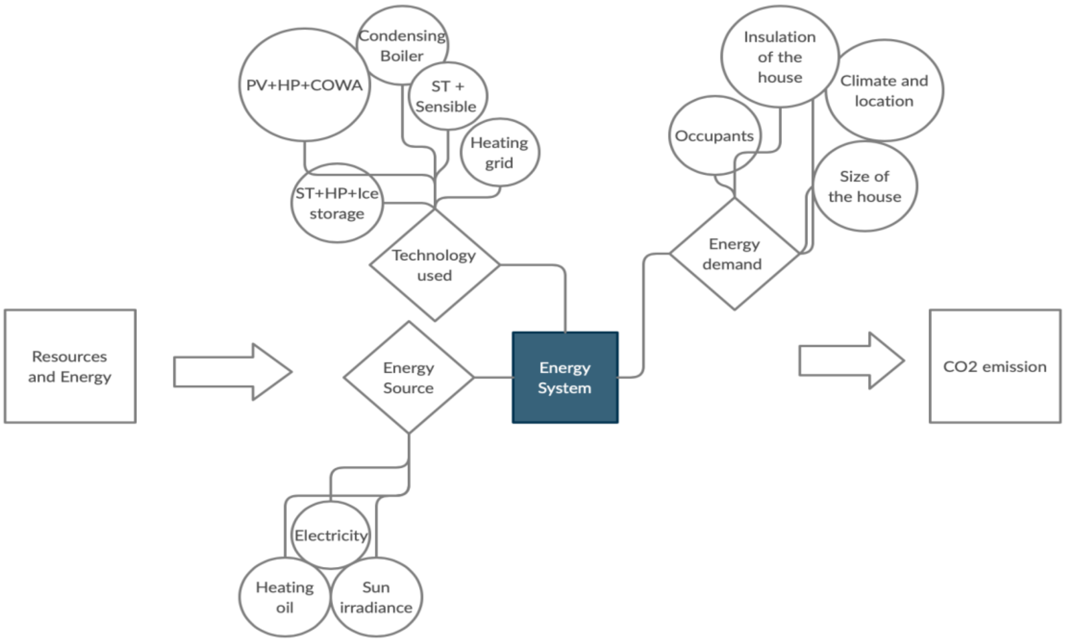

Figure 10: System boundary for CO_2 emission analysis

3.1.7 Availability of data sources, tools and competence

Due to the wide-ranging functionality of Polysun and the availability of a user's license for this simulation software, Polysun was chosen as the tool for creating energy system models and for comparing the energy wise performances of the systems throughout this project.

The documents provided by the industrial partner are the following:

- General overview of the area with house no.
- Building occupancy info
- Heating energy consumption bills from 2013 to 2019
- Floor plan
- Roof plan
- Electricity bills

3.2 Situation analysis

3.2.1 Current Energy System with Energy System Modelling Description

In this section, the existing infrastructure of the housing estate along with its current heating system is analysed. In fig. 11, the energy system schematics of the housing estate is shown. The heating energy system consists of an oil-fired boiler, which is provided with 12 decentralised buffer storage tanks and a floor heating system. To simplify energy modelling, the 12 decentralised 500L buffer storage tanks have been combined together to one large storage tank of capacity 6000L. The technical specification of the energy system and the buildings are provided in the table 2 and table 4 below. The maximum domestic hot water temperature is 50°C but the water in the storage tank is heated up to 60°C to prevent legionella and other bacterial growth. The building heated area was calculated from the floor plan shown in the appendices (Appendix 3 and Appendix 4) and this value is 183.4 m². The total energy reference area of the housing estate is 2201 m². At the bottom of the fig.11, electricity consumption of the household and the connection to the electricity grid are depicted.

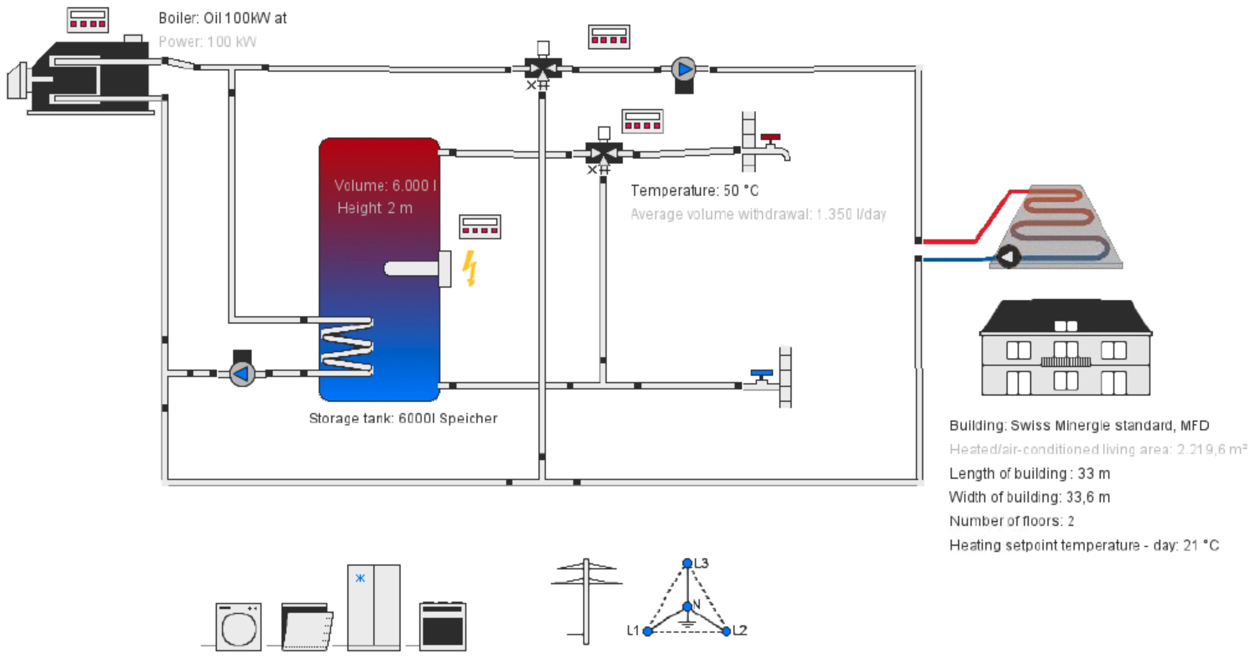

Figure 11: Current heating energy system schematics

After contacting Velasolaris (company which developed Polysun), the energy model for the simulations can be developed using one single multifamily house where all the 12 single family houses are combined together into one single building provided that the buildings were similar in size and energy demands. Since the heated area and number of occupants were more or less the same, the housing estate was modelled as one single building. The building was constructed in 1999 and had an energy consumption per area of 75 kWh/m², which was slightly higher than the Minergie standard with less than 50 kWh/m² *(Building Inventory and Refurbishment Scenario Database Development for Switzerland, n.d.).* The heating setpoint was set to 21°C during daytime and 19°C at night times. The purpose of this simulation was to perform an energy balance as well as to find the technical specifications of the different components constituting the energy system.

The goal of the simulation at the beginning was to adjust the different parameters of building standards, floor heating system and the boiler types to match the values of the current energy consumption. The controllers used for regulating the water temperature and flow rates also have to be adjusted in order to ensure a smooth functioning of the model by meeting the energy demand of the housing estate.

Several rounds of simulations were run until the correct system dimensions were found out. The heating energy bills were also provided by the industrial partner. The bills for domestic hotwater and space heating were calculated together. Hence, it was not possible to know the exact energy consumption for space heating and domestic hot water separately. The building standards were also unknown. Electricity bills of the household from Bruno Imhof, the representative of the real estate was also provided whereas the electricity bills of the other households were not available.

Due to these reasons, a literature-based research was performed to get an estimate of hot water consumption of an average person in Swiss household which was found out to be 40 to 50 L per person. The electricity consumption of an average single-family house in Switzerland consisting of four persons was 4500kWh (Domestic hot water heat pumps, 2016). The average electricity consumption of Bruno Imhof's household for the years 2017 and 2018 was 4075.5kWh. Since this value was slightly lower than the average swiss household electricity consumption, it was chosen as the reference value for the remaining households. Thereby, the total electricity consumption of the real estate was calculated to be 48’906kWh. The results which have been extracted from Polysun are listed below in tables 2,3 and 4. These values have been cross checked with the original energy bills to make sure that both the values are the same. The heating energy bill of 2018 was taken into consideration while modelling the base case energy system.

3.2.2 Energy demand in current system / base case

The energy demand in the current system along with the component overview of the energy system is being presented in this section. The results obtained from Polysun are the following (table 2,3 & 4):

Table 2: System Overview

Total fuel and/or electricity consumption	269’378 kWh
Total electricity consumption	48’956 kWh
Total oil consumption	220’422 kWh
Total energy consumption	166’848 kWh
Total efficiency	76 %

Table 3: Meteorological data overview

Average outdoor temperature	10°C
Global irradiation	1’171 kWh/m²

Table 4: Component overview

Boiler	
Boiler Power rating	100 kW
Energy from/to the system	168’331 kWh
Electric Consumers	
Electricity consumption	48’956 kWh
Electricity consumption of the profiles	48’906 kWh
Electricity consumption of the thermal components	49.8 kWh
Building	
Heated area	2’200 m²
Heating temperature setpoint	20.5 °C
Space heating demand	141’840 kWh
Solar gains through the window	49’394 kWh
Total energy losses	237’689 kWh
Heating/Cooling Element	
Floor heating element area	139 m²
Floor heating inlet temperature	35°C
Nominal return temperature	28°C
Net energy to heating/cooling modules	141’721 kWh
Hot water demand	
Daily water consumption	1350 L
Temperature setting	50°C
Energy demand	22’898 kWh
Storage tank	
Volume	6000 L
Heat loss	1128 kWh
Connection losses	233 kWh

Monthly Energy Demand:

The graph shown in Appendix 7 depicts the monthly heating energy demand for the year 2018. The highest energy demand can be observed in January with an energy consumption of 22’400 kWh followed by the months December, February and March. The increased energy consumption during winter is as a result of lower surrounding temperature which would lead to the increased space heating demand to ensure a comfortable range of room temperature. The domestic hot water consumption stays more or less the same over the course of the year. The summer months have the lowest heating energy consumption with the minimum energy consumption noted in August with 5900 kWh. This is due to the fact that there is almost no demand for space heating in the summer months. The values for monthly energy consumption for 2018 can be found in the Appendix 7.

Heating energy consumption over the last 7 years

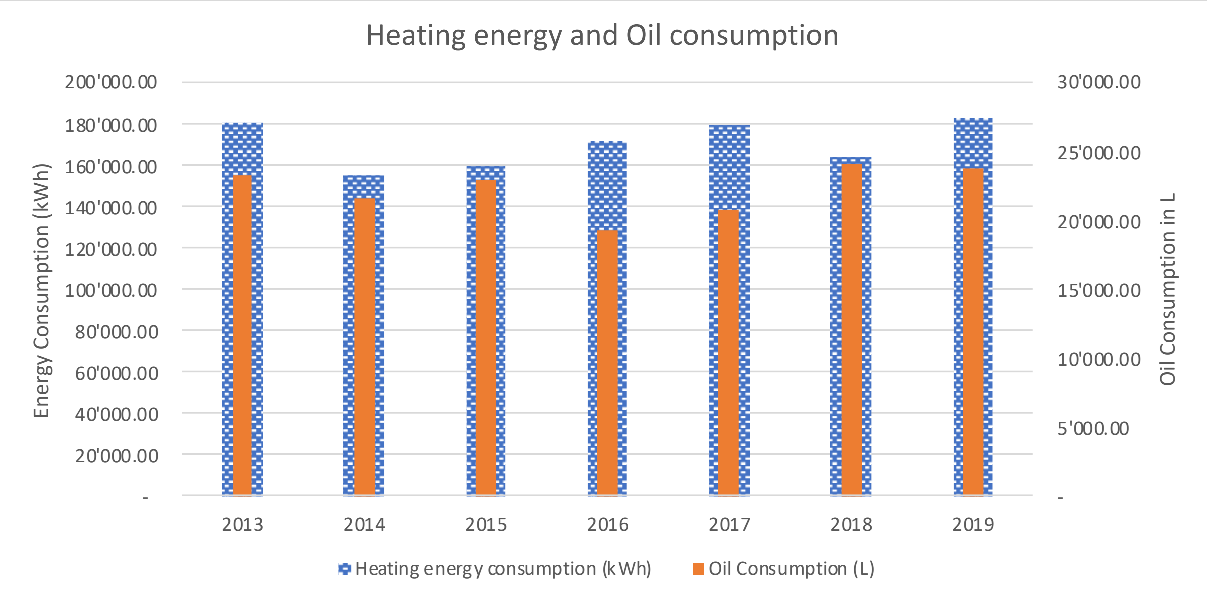

Figure 12: Heating energy and oil consumption over the last 7 years

The graph in fig.12 shows how the energy demand varied over the last seven years. The values taken for plotting this graph can be seen in Appendix 9. The x and y axis represent the year and the energy or oil consumption respectively. The y-axis on the left signifies the energy consumption in kWh and the secondary y-axis on the right depicts the oil consumption in liters for the considered years. The highest energy demand was observed for the year 2019 with a heating demand of 183 MWh and with 23’800 L of heating oil consumption. The largest heating oil consumption was seen for the year 2018 with a consumption of 24’100 L for an energy demand 164’600 kWh. The values of the year 2018 was taken as a reference case while modelling the energy system using Polysun. This approach was used because only the 2018 energy consumption data was provided at the beginning of this project. Another interesting aspect is the varying oil consumption leading to different energetic efficiencies of the system. The main reason for this behaviour is the varying heating value of the fuel, the different operating temperature of the oil furnace and also due to some technical problems that arose during its operation. After discussing this issue with the Mr. Imhof, representative of the housing estate, it was also brought to the notice that the heating oil consumption might also be inaccurately measured.

From secondary research, the energy density of heating oil was found to be 10’000 kWh/m³ (Nussbaumer & Schumacher, n.d.). This was used to convert heating oil in L to kWh in order to determine the overall efficiency of the system. The fact that the building A5 was mostly unoccupied from 2017 until now (2020) also needs to be taken into consideration while calculating the total energy demand of the housing estate. The energy consumption of the building A5 can be seen in Appendix 8. Another important aspect is that the Building B6 is provided with an individual wood heating oven which leads to a significant reduction in the heat energy consumption from the central heating system. While calculating the total energy demand of the housing estate, the entire heating demand of this building needs to be taken into account irrespective of the fact that energy is also being generated from the wood oven.

3.2.3 Weather data from the last decade

The housing estate is located in a village called Edlibach, within the municipality of Menzingen in the canton of Zug. The average weather data of canton of Zug was studied to get an understanding of how the weather pattern progressed over the last decade. In the fig.13, on the x-axis, the time period is represented and, on the y-axis, the minimum, maximum and average temperature in °C is shown. From the graph, it can be seen that the winters till 2017 were relatively colder where the temperature dropped to about -10°C. But a trend of relatively shorter and less cold winters can be observed from the year 2018. This phenomenon is most likely due to global warming and thereby the increased temperature of the earth's surface. The temperatures during the summer months are also gradually increasing. Henceforth it projects a relatively shorter and not that cold winter season and warmer summer months. This would lead to an increased cooling demand and a reduced overall space heating demand.

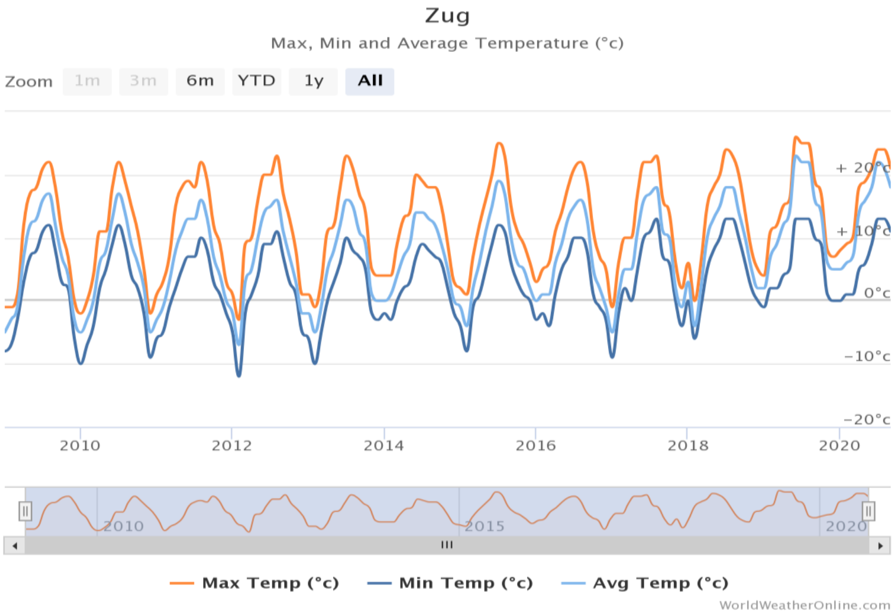

Figure 13: Weather data of the past decade for the canton of Zug
Source: www.worldweatheronline.com

3.2.4 Current costs

Now that the annual heating energy demand for space heating and DHW demand are stated, the financial aspects of the base case heating system needs to be found out. For this reason, the industrial partner was approached to collect the heating and maintenance as well as electricity bills for the housing estate. The electricity bills of only one building was provided which can be seen in Appendix 6. For easiness of calculation, a secondary research was performed to get an estimate of the electricity consumption of an average swiss single family house. This was found out to be 4500 kWh per household in Switzerland (Schweizerische Gesamtenergiestatistik 2019, 2019). This number is based on a Swiss household consisting of four persons. The average electricity consumption of Mr. Imhof's household (representative of the housing estate) was found out to be 4075.5 kWh. Since most of the households consisted of two people, this electricity consumption was then taken as the reference value for all the remaining households.

The electricity price consists of energy price, grid charges, value-added-tax and other sorts of levy charges. The average of the electricity bill for the years 2017 to 2018 and 2018 to 2019 were calculated.

This cost was then multiplied by 12 (houses) to get an estimate of the total electricity cost of the real estate.

A heating and additional expenditure bill was also obtained from the industrial partner for the year 2018. In the first part of the bill, it takes into account the quantity of oil used in that particular year, electricity consumption of the burner and the pumps, chimney sweeping charges, service of the burner, tank revision and heat metering costs for the hot water costs. The second part of the bill consists of water/wastewater consumption costs. The last section of the bill is operating costs, which are maintenance costs, basic water charges, insurance cost, shared electricity, janitor fees, bank interests and administration costs. This section of the bill is of the least significance as it will remain as fixed cost and cannot be eliminated by performing the energy retrofit. Hence this part is avoided when analysing the current costs of the housing estate.

The current costs for the housing estate are taken from 2018 energy bills. The detailed heating and additional expenditure bill of the real estate can be found in the Appendix 10.

Table 5: Current costs of housing estate

Current cost. factor	**Amount**	**Cost**
Heating oil	26’111 L	23’295.85 Fr.
Current for Burner + Pump		300 Fr.
Chimney sweeping		560 Fr.
Burner Service		631 Fr.
Tank revision		100 Fr.
Heat metering		500 Fr.
Tax		752.70 Fr.
Total heating cost		26’139.55 Fr.
Water/Wastewater costs	1’271’000 L	3305.10 Fr.
Total electricity costs for 12 houses	48’000 kWh	10’663.68 Fr.
Total Cost		**40’108.33 Fr.**

3.3 Technological options/ system solutions

This section provides a technological description of the technologies considered. Energy system modelling of the chosen technologies from section 2.2 was performed. This way, the energy balancing was achieved to get an energy system model which would fulfil the demands of the housing estate. The building specifications were carefully reviewed in order to choose the right building standards. The building energy consumption was found to be 75 kWh/m² which is slightly higher than the Minergie standard. All 12 buildings were merged into one multifamily house. When this step was performed, a mismatch in the energy demand of the building was noticed. The total energy consumption of a single-family house was roughly 14’000 kWh and for the combined building approach consisting of twelve buildings, the simulation yields 226’000 kWh as energy consumption. The correct result should be 168’000 kWh of heating energy consumption for the real estate. Henceforth, the building standard was tweaked until we had the desired energy demand.

Provided in table 6 are information about the meteorological data, building component and energy related information which would remain the same for all the different technological options considered.

Table 6: Meteorological, building component and energy related data

Meteorological data overview		
Average outdoor temperature	10°C	
Global irradiation	1’171 kWh/m²	
Electricity consumption of the profiles	kWh	48.906

Building Standard		
Heated/air-conditioned living area	m²	2.219,6
Heating setpoint temperature	°C	21
Heating energy demand excluding DHW	kWh	141.632
Specific heating energy demand excluding DHW [Qdem]	kWh/m²	63,8
Solar gain through windows	kWh	49.398
Total energy losses	kWh	237.445
Heating/Cooling element		
Power per heating/cooling element under standard conditions	W	10.000
Nominal inlet temperature	°C	35
Nominal return temperature	°C	28
Net energy from/to heating/cooling modules	kWh	141.515
Hot water demand	**Daily peaks**	
Volume withdrawal/daily consumption	l/d	1.350
Temperature setting	°C	50
Energy demand	kWh	22.898

The lifetimes of all the main components of the respective technologies are summarized in table 7. This information is crucial for calculating the levelized cost of energy (LCOE) or TCO of the considered solutions. Since there is a mismatch in the energy generated by PV and ST systems, it was decided to proceed with the total cost of ownership calculation over a lifetime of 50 years.

Table 7: Lifetimes of energy system components

System	Name	Lifetime
Components	Valve	15
	Pumps	15
	Pipe	20
	Condensing Boiler	15
	DHW Storage	15
	Electric Heating Element DHW	15
	Boiler accessories	15
	Control system	15
	Pellet Boiler (backup)	15
	Heat Pump	15
	Buffer Storage	15
	Heat pump accessories	15
	PV	30
	Battery	20
	ST modules	25
	Surface water tank	50
	Ice storage	50

3.3.1 Condensing boiler

System description

The first technological solution considered is a condensing boiler with water storage tank of 6000L in capacity as shown in fig.14. The floor heating system is directly connected to the boiler and the DHW is supplied from the tank. The tank is heated upto 60° C and provides domestic water at a maximum temperature of 50° C. The inlet temperatue for floor heating system is 35°C and the return temperature is 28°C. The condensing boiler of 70kW of power rating from Hoval AG is used as the heat source. The fuel used is still heating oil, but the boiler efficiency is increased from an average of 70% for the existing boiler to 98%. The high energetic efficiency is as a result of preheating the water using the flue gas to reduce the temperature range to which cold water has to be heated. The auxillary heating controller, mixing valve controller and heating/cooling controllers have to be finely adjusted such that the energy demand of the building will be met throughout the year.

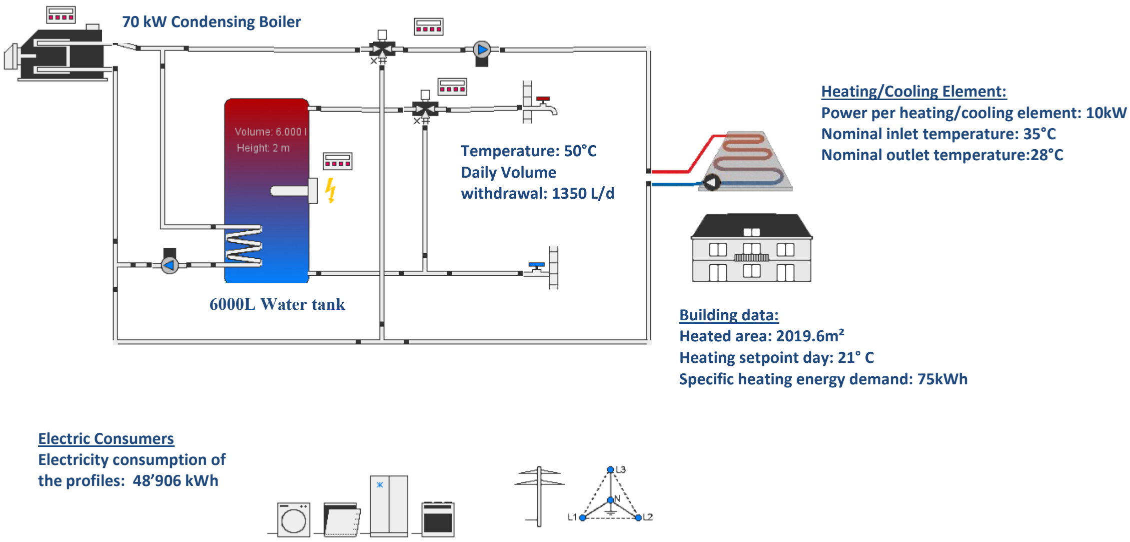

Figure 14: Condensing boiler energy system

Comparison of condensing boiler to the conventional boiler

The system efficiency has increased from 70% to 98%. Thereby around 4882 L of heating oil was saved by using this technology. The system retrofit can be easily performed by swapping the old conventional boiler by a new condensing boiler. As a next step, the energy balancing, cost calculations as well as the environmental impacts of this technology need to be assessed.

3.3.2 ST + HP + Ice storage system

Figure 15 depicts an ice storage system with ST modules and a HP. This technology consists of solar thermal systems which are oriented towards south with an inclination of 60° for the maximum solar yields. For all the different configurations of this technology, a glazed flat plate collector by Winkler Solarsysteme Spenglerei GmbH "VarioSol A-antireflex" is used. The collector size chosen for the simulations vary from 110 ST modules to 300 ST modules with 1 ST module occupying 4.07 m² of area. A total roof area of 1260 m² is available and thereby 300 modules which occupies 1221m² is chosen as the maximum number of modules covering the entire roof area. This is then connected to an ice storage tank. Different configurations of ST modules with different ice storage capacities have been implemented for providing a wide range of comparisons on a techno-economic and environmental basis. Ice storage systems with lower number of ST modules were not possible since they were not capable of meeting the building energy demand. This would also help in finding the best combinations of the different components. The table 8 below summaries the different system configurations used for this particular technology.

Table 8: Ice storage system configurations

HP	No. of Solar Thermal modules	Ice storage tank capacity [m³]
110kW	150, 160, 200, 250, 300	31.89
	130, 150, 200, 250, 300	53.8
	110, 150, 200, 250, 300	70.02

The ice storage tank acts as a heating source where the excess of thermal energy produced by ST system can be stored in the tank by melting ice and then heating it up to a temperature of 80°C. The ice storage tank is provided with two heat exchangers for the purpose of regeneration and energy extraction process through which the brine solution is circulated. The ice storage also acts as a source to the 110-kW heat pump which supplies hot water to the buffer tank and domestic hot water tank. The building is provided with a floor heating system whose inlet temperature is 35°C and return temperature is 28°C. The controllers are tweaked in such a way that the building energy demand was met.

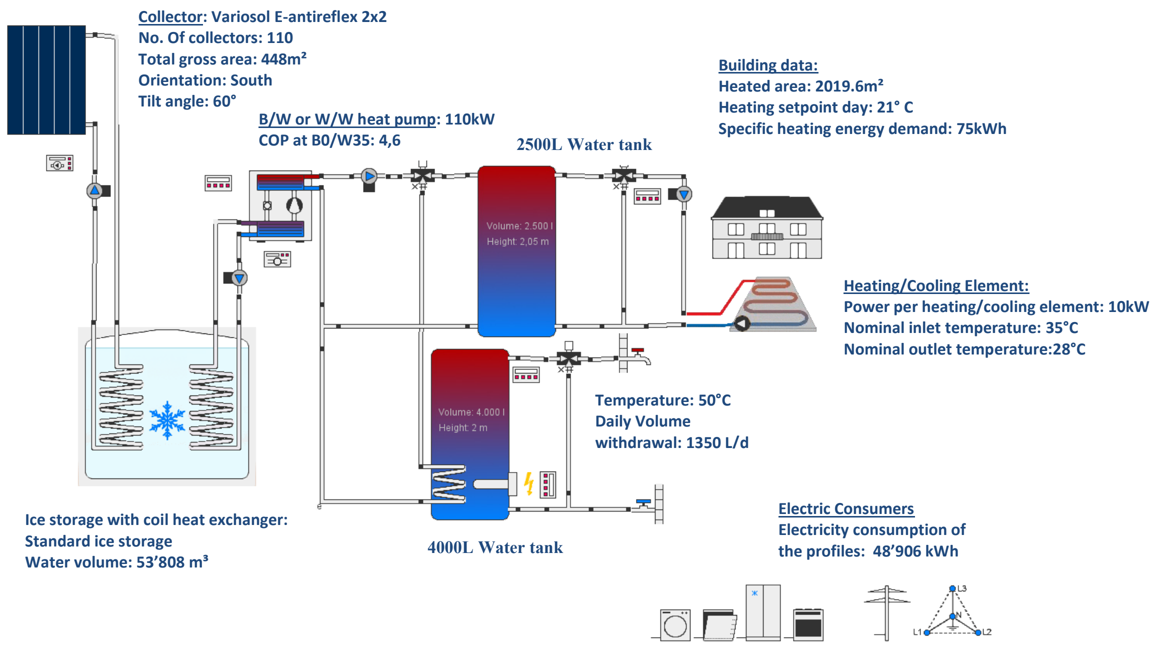

Figure 15: ST + HP + Ice storage energy system

Comparison of ST + HP + Ice storage to the conventional boiler

By the implementation of this system, it can be noted that the system completely avoids the usage of heating oil. The ST modules generate renewable heat energy and supplies it to the ice storage system. The ice storage would be placed in the room where the oil tank is currently located at the housing estate. The room can accommodate an ice storage tank with a maximum volume of 53.89 m³. The only external energy consumption of the system is the electricity consumed by the heat pump. Other than that, the system behaves as a stand-alone system and does not require any other form of energy input. This leads to a significantly reduced environmental impact. In the result section, the energy balances, cost calculations and environmental impacts of this system are presented.

3.3.3 Pellet Boiler + ST + Jenni Storage (Surface water tank)

This technology consists of a pellet boiler, solar thermal system and a large Jenni storage tank to store the thermal energy produced by the solar thermal systems and a pellet boiler. Solar thermal collectors along with the 70kW pellet boiler are used as a heat source. The solar thermal modules used for this technology are the same ones as in the case of an ice storage system. A combined tank is used to reduce the thermal energy losses of the tank into the technical room. The maximum temperature attained by the tank is restricted to 80°C. The fig.16 shows the schematics of the energy system with the system component specifications. A Jenni storage tank of four different capacities along with different ST module configurations have been used to perform a comparison on a techno-economic basis in order to find the optimal solution. The different configurations of this technology are provided in table 9.

Table 9: ST + Pellet boiler + SWT system configurations

Pellet boiler	No. of solar thermal modules	Surface water tank size [m³]
70 kW	10, 50, 100, 150, 200, 250, 300	10
	10, 50, 60, 100, 150, 200, 250, 300	40
	10, 50, 100, 120, 150, 200, 250, 300	50
	10, 50, 80, 100, 150, 200, 250, 300	120

The remaining system profiles such as domestic hot water, space heating demands, electricity consumption profiles and floor heater operating temperatures are kept the same way as described in section 3.3.1 in table 6.

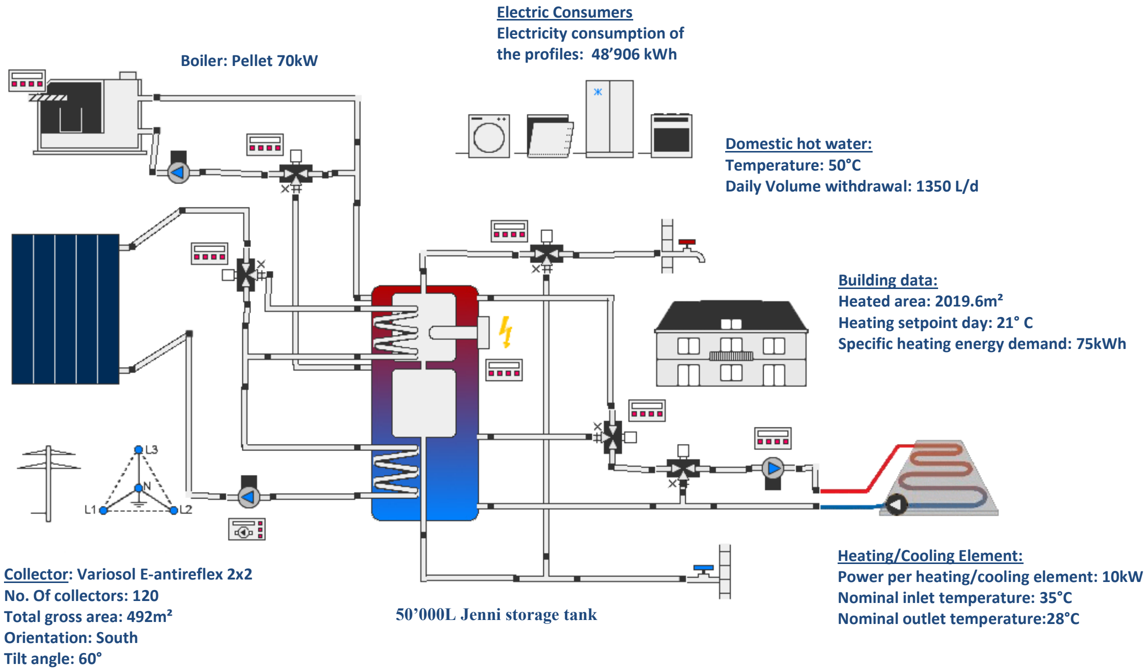

Figure 16: ST + Pellet boiler + SWT Energy system

Comparison of surface water tank to the conventional boiler

The only additional fuel requirement of this system is the pellet consumption during peak load times. Other than that, the main heat source of this technology is the solar thermal system. There is no need for heating oil and electricity as an energy source for the functioning of the system. Hence this solution is considered as CO_2 neutral solution. The reduced energy consumption is also due to the sensible energy storage by means of a Jenni storage tank which enables thermal energy storage during times when there is excess of solar thermal energy available.

3.3.4 PV System with a battery storage system and a Heat Pump

An energy system with and without a battery storage along with a heat pump is the second last technology being considered as a potential solution. An air-water heat pump of 130kW power rating is chosen as the suitable heat pump. Monocrystalline PV panels from Waris S.r.l. ("WRS290-MO60F") is used for all the energy systems consisting of PV panels. One PV module has a power rating of 0.29 kWp and occupies an area of 1.63 m². The different configurations of this technology are shown in table 10. A maximum of 700 PV modules is considered in both the cases which has a peak power of 203 kWp and occupies an area of 1141m². A lithium nickel manganese cobalt oxide (NMC) battery with a Sunny Tripower Storage inverter was used in all the systems.

Table 10: PV + battery + HP system configurations

	No. of PV modules [0.29 kWp/module]	Battery [kWh]
PV + battery + HP System	50, 100, 200, 300, 400, 500, 600, 700	-
	100, 200, 300, 400, 500, 600, 700	30, 50, 100, 200

A 4000L buffer storage tank and a 2000L domestic hot water tank with a flange heater are also present in this technological solution to provide thermal energy storage on an hourly basis. The energy systems with and without a battery storage are considered for providing a comparison of the associated cost of an additional battery storage system and also to analyse the potential differences in the own consumption and self-sufficiency rates. The fig.17 shows the schematics of this energy system with its respective system component descriptions.

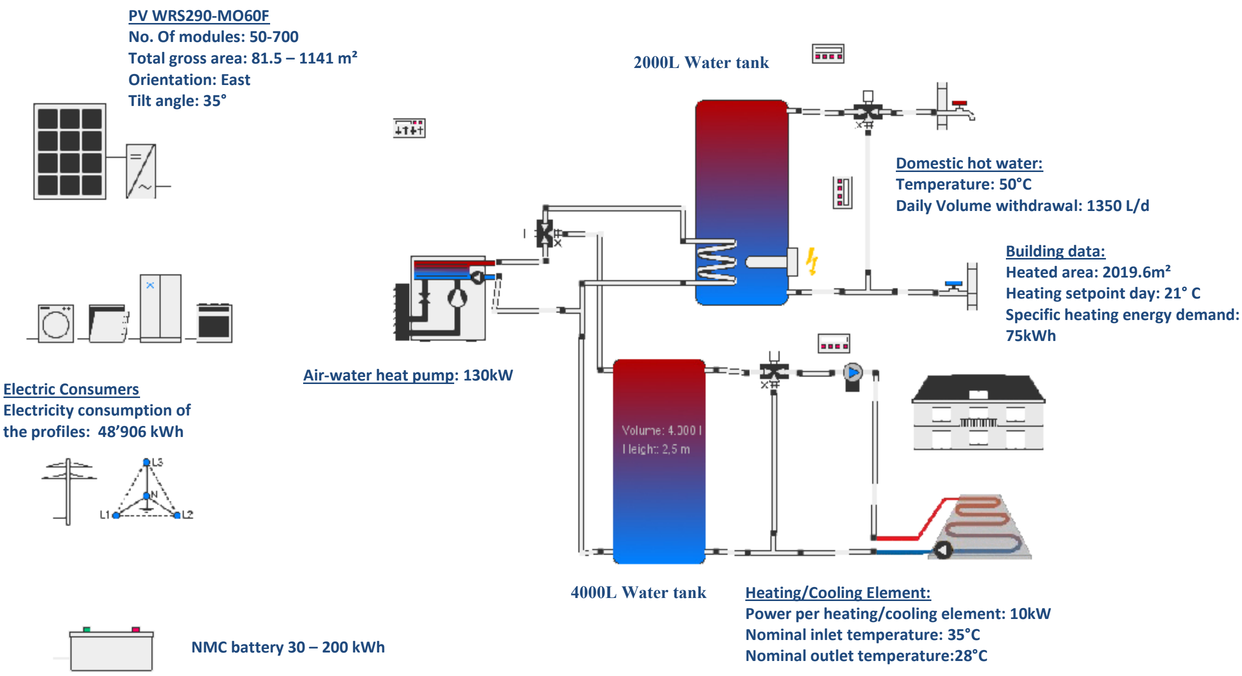

Figure 17: PV with battery and a HP system

Comparison of PV system to the conventional boiler

The only energy consumption of this system is electricity consumption by the heat pump and the circulation pumps. It is also interesting to note that the heat pump which is being used as a heat source has a COP between 3 to 4. This means that for 1kWh of electricity going into the system, an output of 4kWh of thermal energy is received. There is no need for heating oil for the functioning of this system. Hence this solution is considered as a renewable energy solution. The extent to which this system emits CO_2 during its operational phase can only be measured in terms of the energy mix of the electricity acquired from the local utility company, WWZ.

3.3.5 Connection to district heating grid

The final solution which was considered during the evaluation of potential solutions was the connection to a district heating grid. The heat for the Menzingen district heating network is generated by two woodchip boilers in the heating grid. The wood comes from the surrounding forests and is therefore a regional and renewable source of energy. The additional oil furnace serves as a redundancy (secondary heat source) and to cover the peak loads. The heated water reaches the properties in

Menzingen via a more than five-kilometre-long pipeline system that is constantly under expansion (Holzwärmeverbund Menzingen, 2020).

The heating plant, built in 2010, is state-of-the-art in terms of environmental technology. A waste heat recovery system ensures that the residual heat is used. Thanks to the latest filter technology, the emissions are significantly below the legal requirements. The table 11 lists the technical description of the heating grid (Holzwärmeverbund Menzingen, 2020).

Table 11: District heating grid details

District heating grid specifications	
Wood chip boiler 1	2’400 kW
Wood chip boiler 1	1’600 kW
Oil furnace (peak load)	3’200 kW
Heat recovery flue gas (wood)	800 kW
Heat recovery exhaust gas (oil)	400 kW
Energy delivered	6’900 MWh/year
Primary energy carrier	95% Wood / 5% Heating oil
CO_2 savings	1’900 tons/year
Heating oil saving	700’000 L/year
Heat distribution network	5’200 m
Supplied properties	60
Remote monitoring	24 hr service

The advantages of establishing a connection to the district heating grid are the following:

- 24 h hot water supply for meeting the space heating and domestic hot water demands
- Attractive cost structure
- Sustainable and CO_2neutral energy source
- Connections to the houses require significantly less space
- No need of purchasing and storing fuel
- Avoided maintenance tasks such as boiler maintenance, chimney sweeping, tank revision, service and repair etc.

Connection of the housing estate to the district heating grid

For finding the possibility for a district heating connection, the authorities of the heating grid Menzingen were contacted. By taking up contact with the authority, it was informed that the connection of Edlibach village to the heating grid of Menzingen was not considered as a feasible option due to the relatively longer distance from the heating network and the associated high investment costs. The energy demand of the housing estate analysed in this project is 166 MWh.

In order to get more clarity regarding this issue, an expert in the field of district heating was contacted. He informed that the linear density for the heat supply is roughly 2000 MWh/km. This would mean that the system network should not exceed a distance of 85m from the grid. It should be taken into notice that the approximate distance from the housing estate to the heating grid was calculated to be 1.7 km. This in turn signifies an energy demand of 2800 to 3400 MWh which is beyond the supply potential of the grid. The expert also informed that the installation cost of this network (provided that no other information was given) can be approximated to 1.5 Mio CHF/km of network expansion. Due to the high costs involved for such a low energy supply, this solution was considered as infeasible and was therefore not analysed in the further stages of this project.

4. Results

This chapter comprises of all the results of the analytic goals described in the planning phase section. After the energy system solutions were finalised, numerous of energy simulations were executed to receive the energy balancing results. Thereafter, costs of these energy systems and the time taken for the systems to break even were calculated. Here the result chapter is divided into four sections:

1) TCO results
2) Break-even results
3) Energy balancing results
4) CO_2 emission results

The energy simulations for different energy systems with varying configurations were run to see which configurations would be the most suitable in terms of energy performances as well as on a cost basis. For comparing the system performances, factors such as self-sufficiency and solar coverage ratio were defined. These factors along with the relative TCO are plotted against CAPEX of the different energy systems considered. The time horizon of each technology was set to 50 years. The relative TCO was calculated for this given period of time. All the energy systems considered have been assigned with a subsidy which were available on municipality, cantonal and national levels. The condensing boiler is chosen as a benchmark solution and the remaining systems are compared to this solution. A relative TCO of 1 would signify that the total cost of ownership of that particular technology at the end of 50 years is same as that of a condensing boiler. A relative TCO lower than 1 means that the investment pays off within the considered time horizon. In the case of a relative TCO which is larger than 1, it would mean that the system is more expensive than the reference case and will take longer than 50 years to breakeven or will never breakeven.

The different subsidies which were considered for the energy systems are described in table 12. These values were deducted from the CAPEX. Subsidies exist to make the system more attractive from a financial perspective for the investors. Usually, non-renewable energy systems have lower investment costs but instead have higher operating expenditures when compared to renewable energy sources. The subsidies would thereby make a renewable energy system more affordable.

Table 12: Subsidies available for the considered energy systems

Energy system	Subsidy	Source
ST + HP + Ice Storage	HP- 6000 Fr. ST- 24’000 Fr.	Menzingen municipality Menzingen municipality
ST + Pellet Boiler + SWT	For 10 ST modules- 40’400 Fr. For >50 ST modules- 56’200 Fr.	Myclimate, Energy 360° AG, Menzingen municipality
PV, PV + Battery storage	50 PV modules- 11’930 Fr. 100 PV modules- 16’860 Fr. 200 PV modules- 27’740 Fr. 300 PV modules- 34’300 Fr. 400 PV modules- 43’000 Fr. 500 PV modules- 51’700 Fr. 600 PV modules- 60’400 Fr. 700 PV modules- 69’100 Fr.	Pronovo, Menzingen municipality

Before starting with the TCO results, the economic parameters should also be defined. The electricity price for the year 2020 was considered. The high and low tariffs were combined for easiness of the calculations. The same principle was adopted for the feed-in tariff calculation. The current heating oil prices dropped by 15 Rp. /L and this phenomenon is mainly attributed to the current economic recession and more fuel oil production with respect to the demand. This has led to more financial benefits for the condensing boiler system when comparing it to the renewable energy system solutions.

Different scenarios were considered in the cost calculation. But for the purpose of documentation, only the scenario 1 with the current prices except for the heating oil case were considered. The heating oil price of the year 2018 was used to avoid the disparities within the result section. Inflation of 0% is assumed for the purpose of calculating the TCO. The table shown below contains the main economic parameters used for the TCO calculation.

Table 13: Scenario 1 parameter description for TCO calculation

Parameters	Value [Unit]
Time horizon	50 years
Heating oil Price	0.89 CHF/L
Pellet price	0.072 CHF/kWh
Electricity price	0.22 CHF/kWh
Feed-in Tariff	0.073 CHF/kWh
Interest rate (discount rate)	0%
VAT	excluded

It was also noticed that while comparing the TCOs of solar thermal systems, only the heating energy system costs were considered for the purpose of calculation and the electricity costs were neglected. When it comes to the TCO calculation for PV systems, there was a need to include the electricity consumption of not only the heating energy system, but also the electricity consumption of the household profiles and circulation pumps. This method was used since there was electricity which is self-consumed and also electricity which was fed back to the grid. The benchmark case also included the electricity costs in the TCO calculation of the PV system.

4.1 TCO results

ST + Pellet boiler + SWT system TCO results:

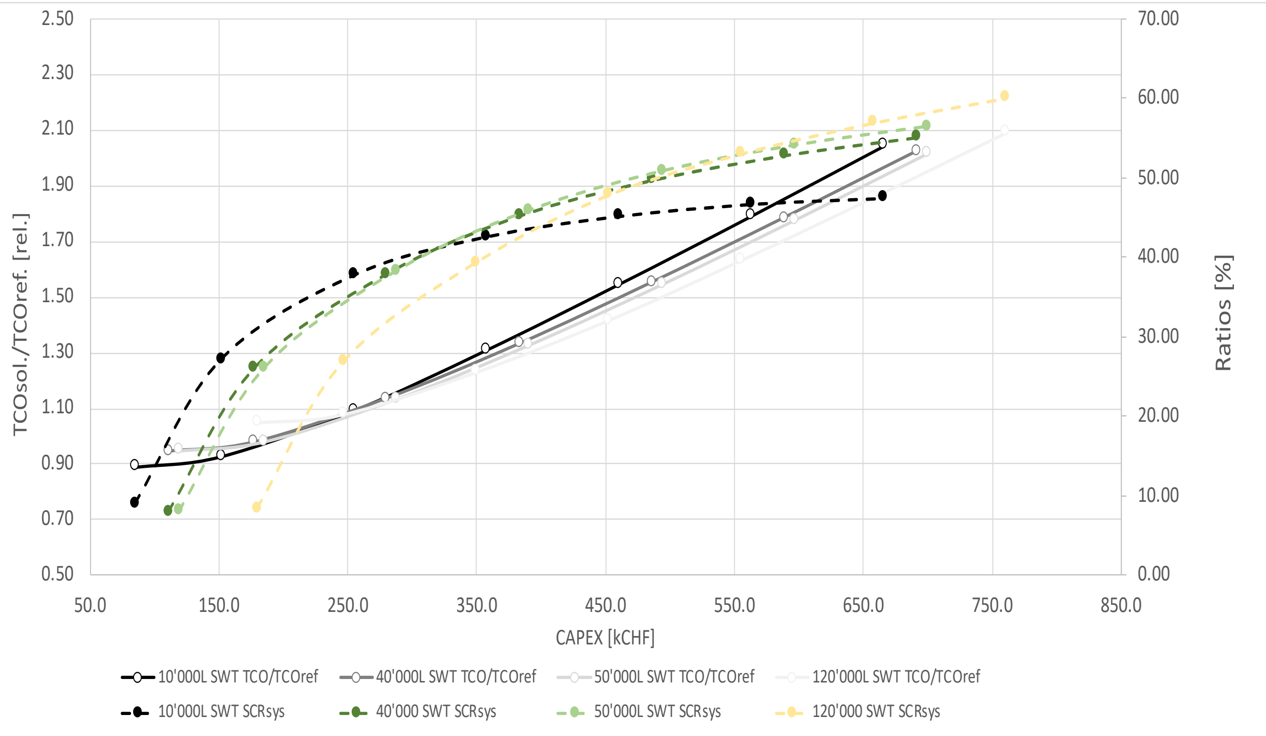

Figure 18: SWT relative TCO and autarky results

Fig.18 presents the results obtained for the energy system consisting of varying ST modules, pellet boiler and a surface water tanks of four different capacities. On the x-axis, the CAPEX in thousands of

CHF is represented whereas on the y-axis, the relative TCO and the SCRsys ratios. On the left, the plotted curves begin with 10 ST modules and reaches 300 ST module configuration which occupies the entire roof area. The solid lines represent the relative TCO and dashed lines represent the solar coverage ratio of the system (autarky level). The lowest relative TCO is for the 10'000L SWT system ranging from 0.89 to 2.04.

Till 100 ST modules, there is only a need to have a 10'000L SWT since there is no increase in levels of autarky with respect to increase in SWT capacity. An autarky of 37.75% is achieved with 10'000L SWT and 300 ST module configuration. The maximum achievable solar coverage ratio is 60% for the system consisting of a 120'000L SWT and 300 ST modules. From a financial perspective, this system never pays off. This system configuration is also not feasible due to the site specifications since the maximum allowable SWT capacity is limited to 54'000 L. This was only considered as a result for seeing the level of energy autarky increase that can be achieved by raising the SWT capacity from 40'000L to 120'000L with a maximum ST configuration (300 ST modules). Only 5% increase in autarky level is achieved by increasing the SWT capacities from $40m^3$ to $120m^3$.

ST + Heat Pump + Ice storage results

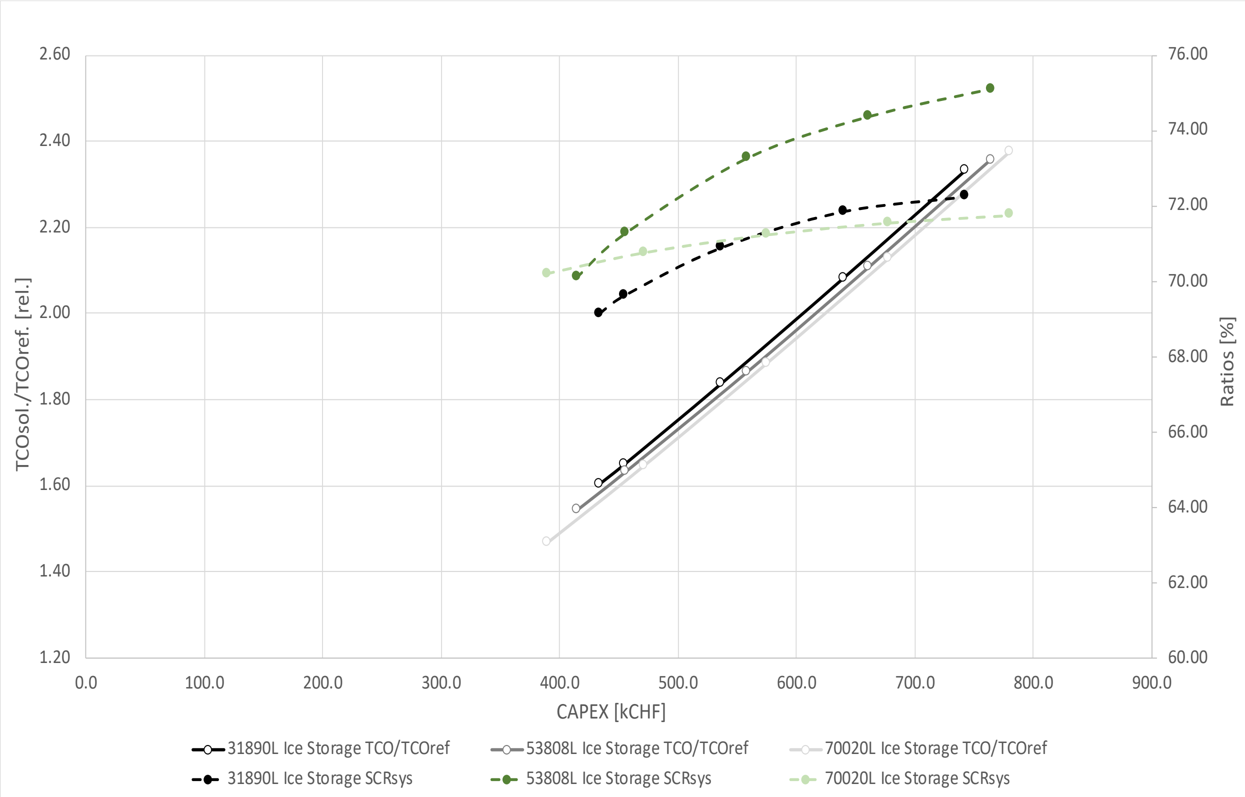

Figure 19: ST + HP + Ice storage system relative TCO and autarky results

Fig. 19 presents the results of energy system consisting of ST modules, heat pump and an ice storage tank. From a financial point of view, the relative TCOs vary from 1.47 to 2.37 for the depicted ice storage systems. Hence, none of the systems will break even as the relative TCOs are greater than 1. Here the full exergy benefits of the ice storage system is not exploited since cooling demand is not considered in this project. But still, it is interesting to compare the solar coverage ratio (autarky level) of the different systems. The table below shows the ST module configurations for the three different ice storage systems used.

Table 14: Ice storage system configurations

Ice Storage tank capacity [L]	ST modules increasing from left to right
31’890	150, 160, 200, 250, 300
53’808	130, 150, 200, 250, 300
70’020	110. 150, 200, 250, 300

For the smallest tank capacity of 31’890L, the autarky levels only vary from 69% to 72% as the number of ST modules are increased from 150 to 300. When the tank capacity is increased to 53’808L, the SCRsys ratios (autarky level) lie between 70% to 75% for the considered ST module configurations. Finally, for the largest tank which is larger in size than the available room space, the autarky levels lie between 70% to 72%. Therefore, all the results show that there is only a need to go for the lowest ST module configuration and also for the smallest ice storage tank system.

PV system & PV system with battery storage results

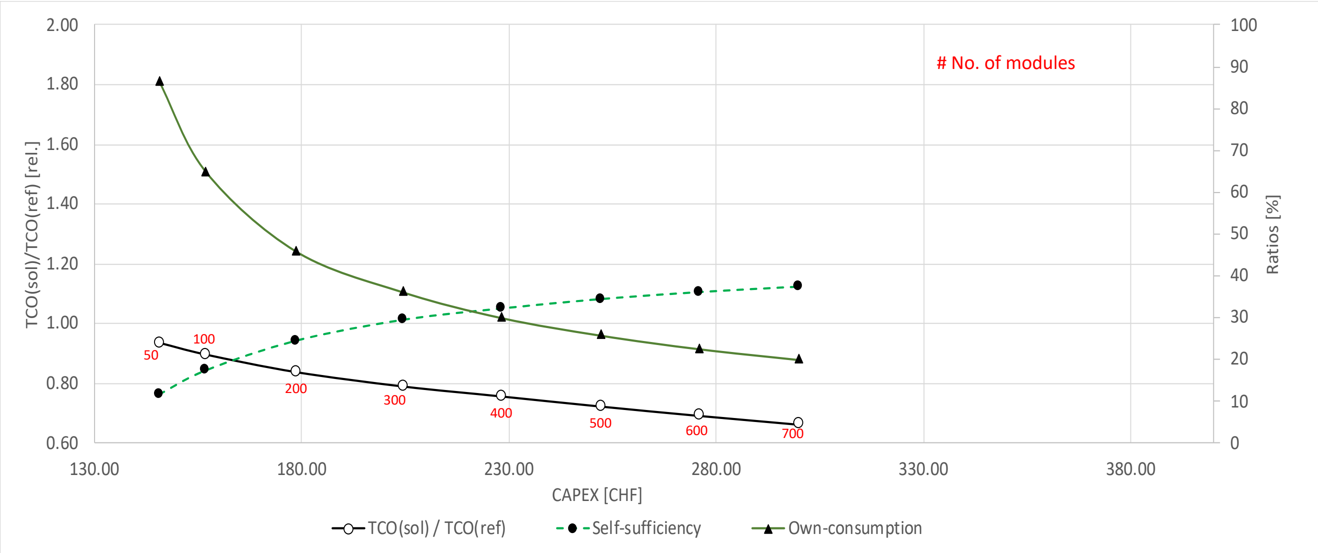

Figure 20: PV system relative TCO and energy performance ratio results

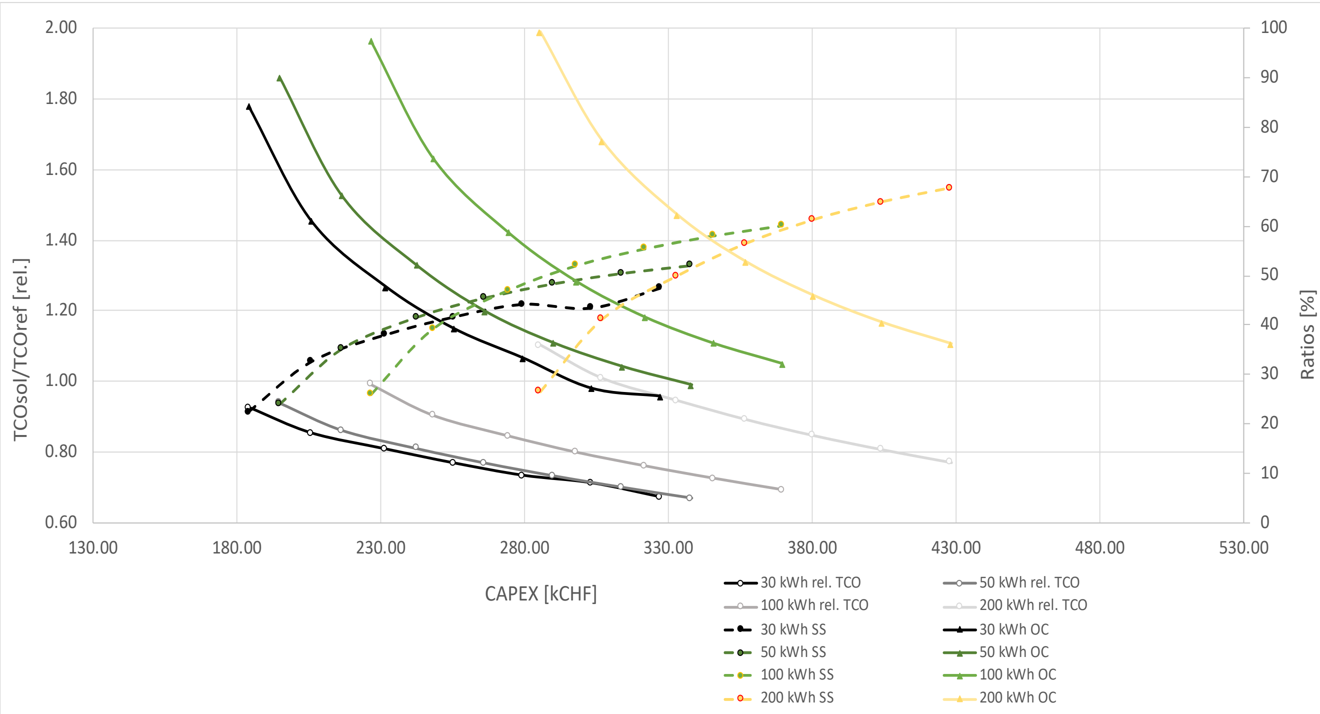

Figure 21: PV with battery system relative TCO and energy performance ratio results

Both the figures above depict the relative TCOs and energy performance ratios such as own consumption and self-sufficiency attained over the CAPEX for PV system and PV with battery storage systems. Fig.20 represents the energy system with PV and a heat pump. The plotted values depict PV systems consisting of 50 to 700 modules. The exact configurations of the system used is shown in table 10 from section 3.3.4. Relative TCOs vary from 0.66 to 0.93. This means that all the systems are less expensive than the benchmark case which is a condensing boiler. This would mean that the energy system pays off within the considered 50 years and would also contribute to some savings with respect to the reference case. Own consumption varies from 86% to 20% as the PV panels are increased from 50 to 700 modules. Self-sufficiency is increased from 12% to 37% as the number of PV modules are increased from the lowest to the highest possible configuration. Here, for the purpose of increasing own consumption and for improving the values of self-sufficiency, the energy system consisting of PV is also provided with a battery storage to analyse the improved benefits.

Fig.21 summarises the results obtained for energy system consisting of PV, heat pump and a battery storage system of varying storage capacities. This case was considered due to the importance of achieving higher values for self-sufficiency and thereby reducing the dependence of electricity consumption from the grid. The PV systems considered here ranges from 100 to 700 PV modules as we go from left to right within the plotted lines. From 100 PV module configuration onwards, the relative TCO is lower than 1 till a battery capacity of 100kWh is reached. For a 200kWh battery, the system breaks even in less than 50 years (relative TCO <1) from a configuration of more than 300PV modules. From a financial perspective, it would make the most sense to go for the smallest battery capacity (30 kWh or 50 kWh) since they have the smallest relative TCOs. Own consumption increases from 26% to 36% as we increase the battery capacity from 30kWh to 200kWh for 700 PV modules. The own consumption decreases as the no. of PV modules are increased. The self-sufficiency varies from 48% to 68% for the highest roof occupancy with 700 modules as the battery capacity is increased from 30 kWh to 200 kWh. Since the peak power of the PV system with the highest module configuration (with 700 PV modules) was $200\mathrm{kW_{peak}}$, the maximum battery capacity was restricted to 200kWh.

4.2 Break-even results

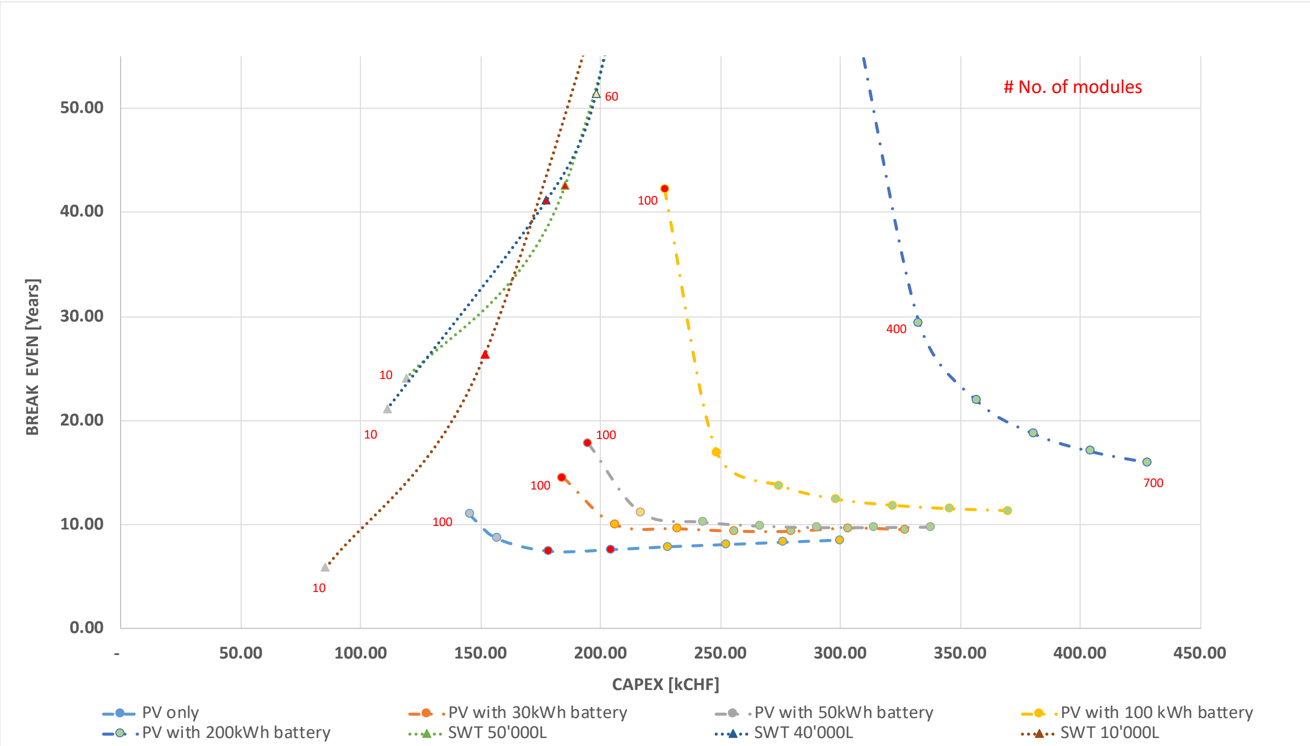

Figure 22: Break-even results of energy systems

This section incorporates all the energy systems which pays off during the considered time horizon which is 50 years. These results would give the investor a better overview of which investments would break even in less than 50 years and can be considered for the further stages of this project. Fig.22 depicts CAPEX values on the x-axis and break-even time in years on the y-axis.

From cost results, it can be noticed that the ice storage system never breaks even and therefore is not depicted in this graph. For PV systems without storage, all the systems break even within 12 years after the commissioning of the system. When PV systems are provided with a battery storage, it is more profitable as the number of modules is increased to the maximum possible configuration (700 PV modules) which also increases the own-consumption and self-sufficiency ratios.

For the SWT results, it is clear that the systems with lower ST module configuration only break even during the considered time horizon (50 years). The maximum possible configuration which breaks even in 50 years is limited to 60 ST modules with a 40’000L SWT.

4.3 Energy balancing results

This section of the results is where the energy flows of the technological solutions are analysed. It includes all the energies going into the system and energy forms coming out of the system. The purpose of this section is to explain how much energy is being consumed and how the energy losses would occur within the considered energy systems.

Condensing boiler energy balancing results:

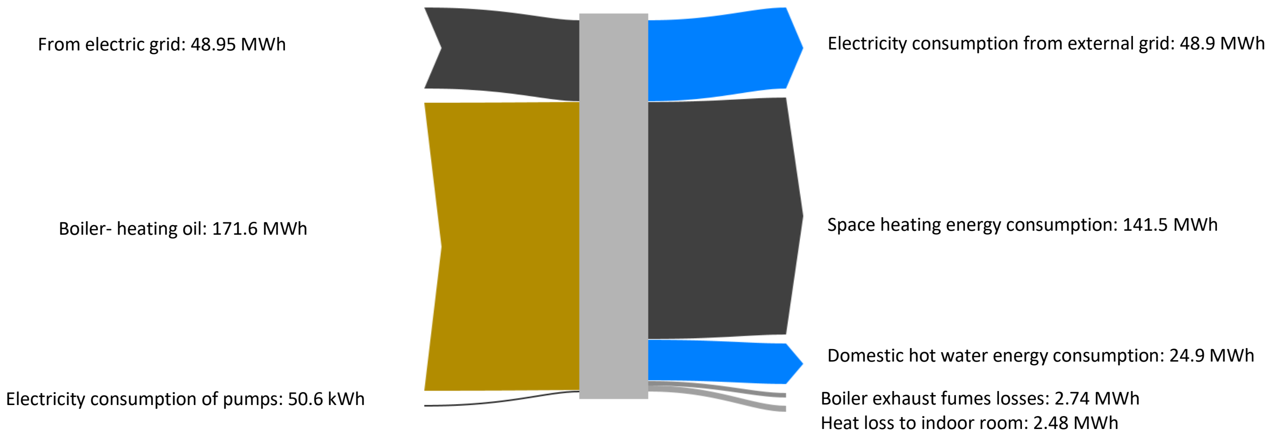

Figure 23: Condensing boiler energy flow diagram

It can be seen that the highest energy consumption of the housing estate can be attributed to fuel consumption by the condensing boiler which takes care of space heating and domestic hot water demands. Heat losses to the indoor room and the exhaust fumes losses are negligible compared to the DHW and space heating demands.

Surface water tank energy balancing results:

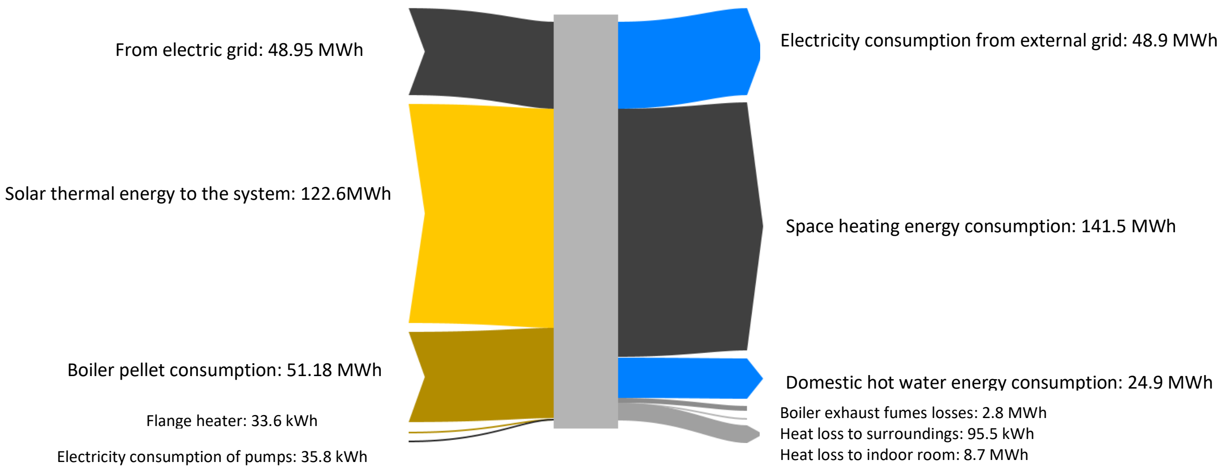

Figure 24: SWT energy flow diagram

Here the 70-kW pellet boiler together with 300 Solar thermal modules acts as the heat sources which meets the space heating and DHW demand. The excess of solar thermal energy can be stored by means of the 40'000L surface water tank and can be used later. The major heat source is the solar thermal system, with pellet boiler as a supplementary heat source which is only used during peak demands. The electricity consumption is mainly attributed to the household profiles, flange heater and pumps. As mentioned, the heat losses and exhaust fumes losses are negligible compared to the space heating and DHW energy supply.

Ice storage system energy balancing results:

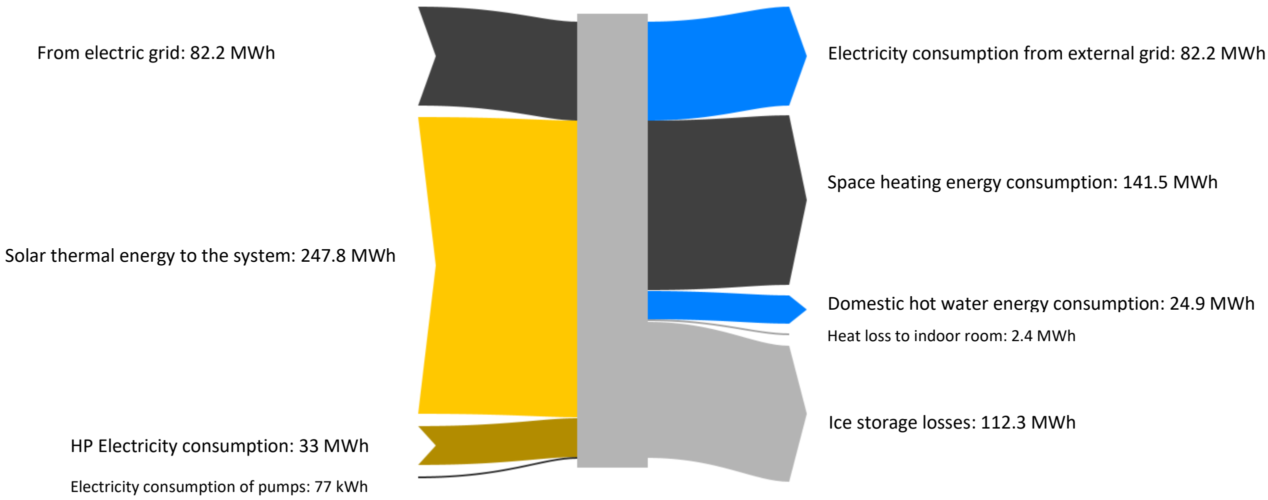

Figure 25: Ice storage system energy flow diagram

This system consists of 300 ST modules, a 110kW heat pump and 53'808 L Ice storage tank. The main heat source of this system is the heat pump and the ice storage tank acts as a source which is charged by means of the ST energy. This is the reason why the electricity consumption has increased to 82.2 MWh compared to the previously discussed systems. Another important finding is the high energy loss via the ice storage tank which is close to 112 MWh. In reality, the ice storage tank is placed in the room where the fuel tank is currently located. This could lead to different levels of ice storage losses. This phenomenon can be reduced by choosing a better insulation for the tank walls with a lower thermal transmittance value (U value).

PV with 700 modules energy balancing results:

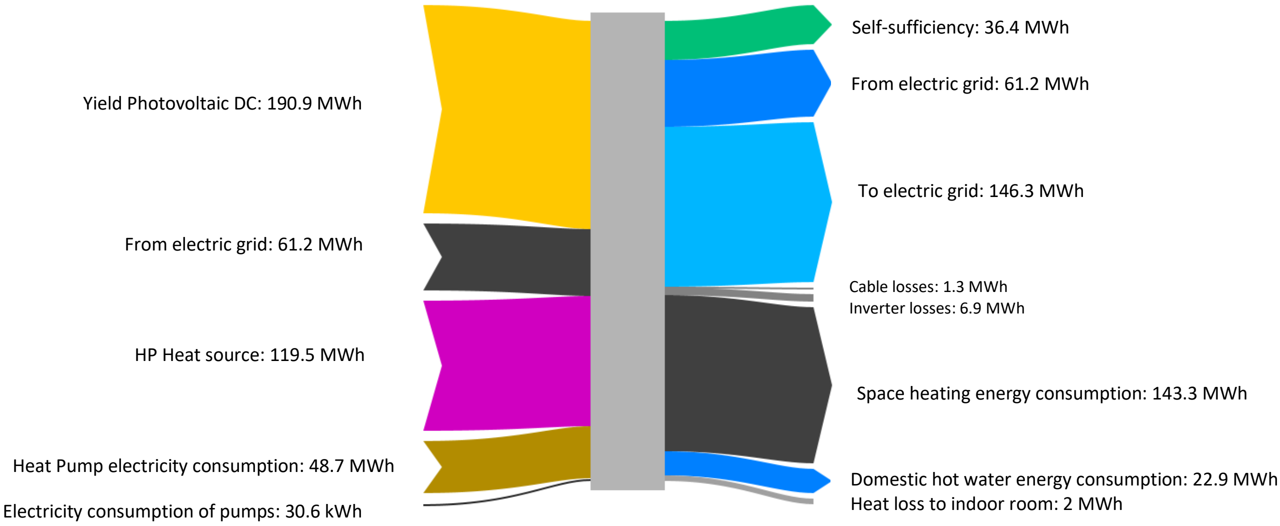

Figure 26: PV system energy flow diagram

This system consists of 700 PV modules and a 130-kW heat pump. Here the heat pump is the only heat source, and this very well explains the increased electricity consumption of the housing estate. It can also be seen that a large proportion of the electricity generated from PV is fed into the grid (146.3 MWh) whereas self-consumed PV energy is restricted to 36.4 MWh. The remaining energy consumptions of the system is similar to the previous cases.

PV with 700 modules and a 30kWh battery system energy balancing results:

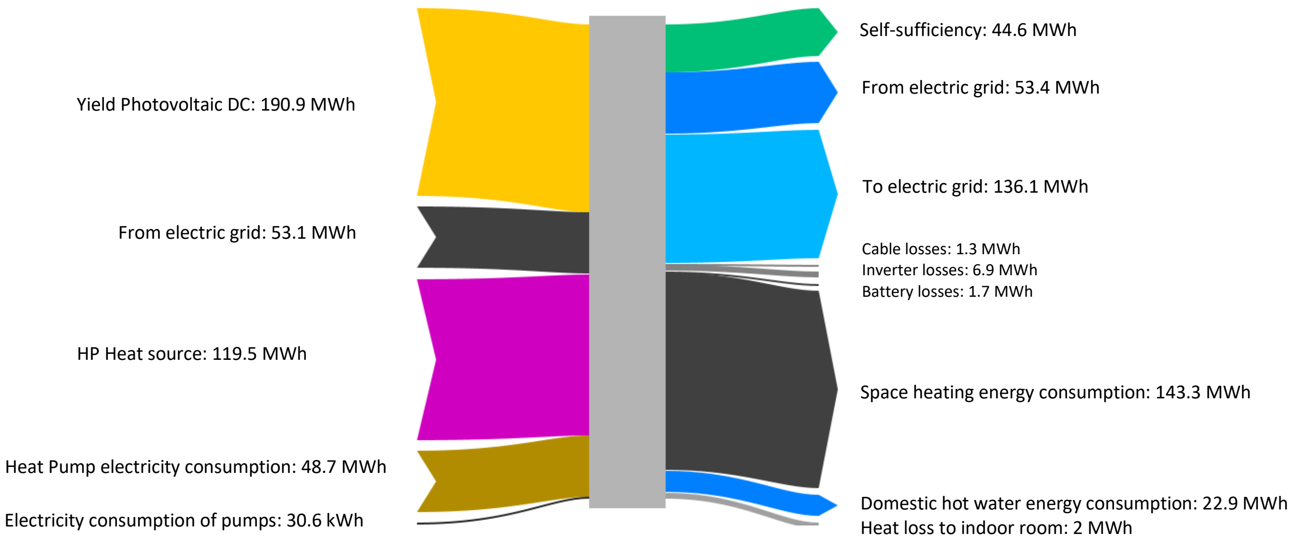

Figure 27: PV system with battery storage energy flow diagram

Fig.27 depicts a system with 700 PV modules, with a 30kWh battery system and a 130kW heat pump system. Energy flows are similar to the PV system except for the electricity consumption. Here 8MWh less electricity is being consumed from the grid which indicates an increased rate of self-sufficiency. In the losses section, there are battery losses in addition to the cable and inverter losses. Apart from these differences, the system behaves similar to a PV system without a battery storage.

4.4 Carbon dioxide emission results

The Earth's climate has been evolving globally and regionally where some of the causes can be attributed to human activities. Nowadays, there are increased concerns about greenhouse gas emission. This section provides a comparative study of the greenhouse gas emission in particular CO_2 emissions of all the heating energy systems considered. At present, on a residential scale, there is a need for paying pollution tax on the pollution caused by the energy system. This levy is usually included within the heating oil prices. As of 2018, there is a need to pay CHF 96 per tonne of CO_2 emitted (FOEN, n.d.). The CO_2 levy is mainly imposed on fossil heating and process fuels. No levy is imposed on heat sources such as wood and biomass since these energy resources are considered as CO_2 neutral. This is because the amount of CO_2 released during the wood combustion is equal to the CO_2 intake during its formation process (FOEN, n.d.).

The combustion of one litre of heating oil would result in 2.65 kg of CO_2. This would mean a levy of approximately CHF 0.25 per litre of heating oil used. Two thirds of the CO_2 levy collected is redistributed annually to the public and economy independent of their emissions. One third of it is allocated to building programs and renewable energy subsidy programs (FOEN, n.d.).

But, in the future due to the environmental and sustainability goals developed by the Swiss government for meeting the 2050 Energy Strategy, there are chances for phasing out non-renewable energy resources by increasing taxations on the pollutions caused. This could make the fossil fuel-based heating system less attractive from a financial point of view.

For easiness in comparing the CO_2 emissions of the heating energy systems considered, the following strategy has been adopted. The existing solution, which is a conventional boiler is taken as the reference case and the remaining technologies are compared to this on a scale from 0 to 100% in terms of their CO_2 emissions. Therefore, the energy system with the highest pollution which is the conventional boiler is assigned 100% and the other technologies depict their pollution reduction with respect to the conventional boiler. Only the pollutions during the operational phase over the course of 50 years is considered in this evaluation. Fig.28 displays the results obtained during the comparative study.

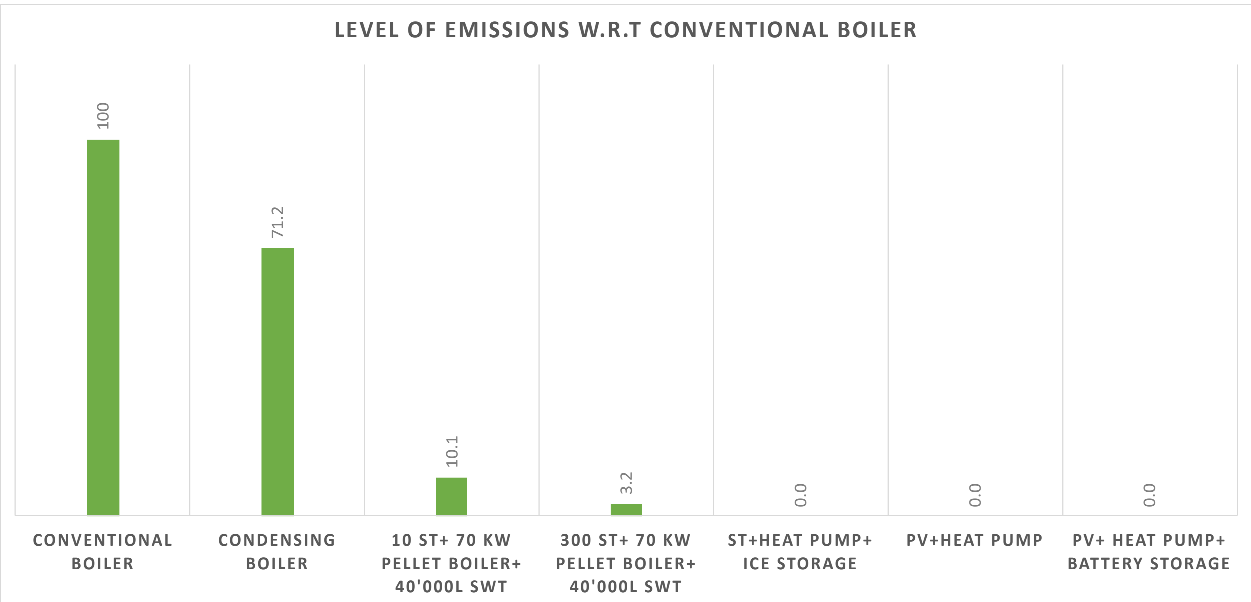

Figure 28: Carbon dioxide emission results of different energy systems

From the results obtained by performing an environmental assessment in terms of CO_2 emissions, the following are the main observations. The conventional boiler secured a score of 100% making it the least attractive option in terms of CO_2 emissions. This is followed by the condensing boiler solution where the emissions are decreased by 18.8%.

For energy systems consisting of a pellet boiler, the ‘carbon neutral’ emissions factor for wood pellets of 0.04 kg CO_2 e/kWh is used (Johnston, n.d.). The highest and the lowest ST module configurations (10 & 300 ST modules) for the 40’000 L SWT system with a pellet boiler is considered in this assessment. The SWT system with 10 ST modules decreased its CO_2 emission by 90% and the SWT system with 300 ST modules decreased its emissions further by 97% with respect to the conventional boiler. For technologies with a heat pump as its heat source, the emissions are set to 0 since the energy mix of the electricity consumed from the grid comprises of 20% solar and 80% hydropower electricity, which makes it 100% renewable. Therefore, from an environmental point of view, the systems consisting of ST system, heat pump and ice storage and also the systems consisting of PV modules and heat pump (with and without a battery) are the most attractive cases. For more information, refer to the table in Appendix 14 which provides the numerical results of the conducted study.

5. Discussion

In this thesis, I have investigated the potential benefits of different energy systems on a technological, economic and environmental basis. The main findings of this study are the following:

On a technological basis, the energy balances of the different energy systems have been found out. PV systems with a maximum configuration (700 PV modules) achieves a self-sufficiency ratio (energy autarky) of only 37%. By adding an additional 200 kWh battery, energy autarky can be increased to roughly 68% for the maximum PV module configuration. Another important aspect which was noticed was that own consumption (PV electricity self-consumed over the grid feed-in) could only be increased to 36% as a battery with 200kWh is added to the PV system. When analysing the energy balancing results of a SWT system, for achieving solar coverage ratio of system (SCR_{sys}) which is greater than 35%, a minimum of 100 ST modules are required. Another important observation is that autarky level greater than 50% can also be obtained with a minimum of 200 ST modules and with a minimum surface water tank capacity of 40’000L. For ice storage systems, it was discovered that irrespective of the considered tank size and ST module configuration, the SCR_{sys}ratio was always close to 70%. This in turn would suggest that it is more reliable to have a system with the lowest tank size and ST module setup. This also suggests that systems with lower ST module configurations ranging from 50 to 100 modules could also be considered in the further stages of this analysis.

From an economic perspective, it is more attractive to proceed with PV or PV with a battery system. The system becomes more profitable and pays off faster as we increase the number of PV modules to the maximum allowable configuration. It was also found out that the SWT solution only pays off when the system had the least ST module configurations (10 & 50 ST modules) till a SWT capacity of 50’000L. For ice storage, the results have proven that system never breaks even.

As a next measure, the technical and economic evaluations were combined into one single graph and only the systems which break even in less than 50 years are considered in this approach. The systems were then divided into three categories based on their degrees of autarky. The chosen levels are >20%, >30% and >40%. These were set as the threshold values for the final discussion. The housing estate was built in 1999 and this led to the choice of these threshold autarky levels. An autarky greater than 50% would only be possible in reality for Minergie standard buildings which is not the case here for this housing estate. The fig. 29 represents the technical and economic evaluation results.

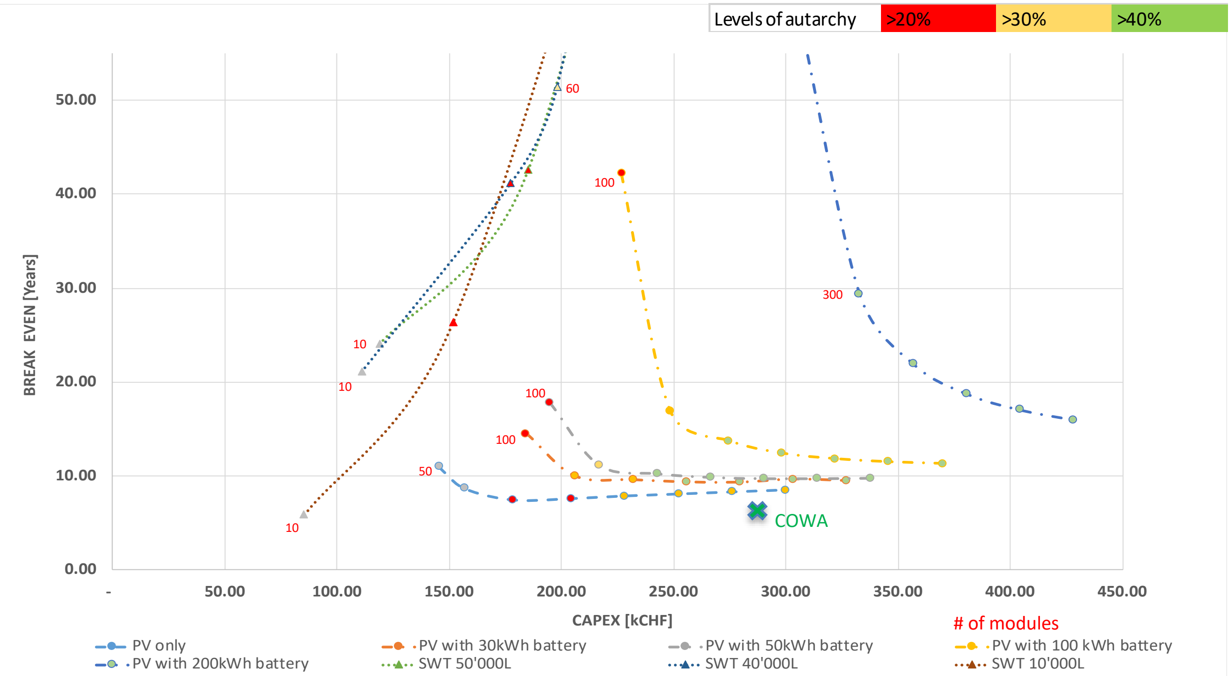

Figure 29: Break even and autarky results combined

From a financial and energy performance point of view, an energy system which is depicted by the green marker, found on the bottom of the fig.29 is considered to be the best choice of energy system. Here the system which satisfies these criteria the most are the PV systems with the highest module configuration and with a battery capacity of 50 kWh and 100 kWh respectively.

Due to the inability to integrate Cowa storage system into the simulation software, it was decided to proceed without considering COWA storage as one of the final solutions. But from an energy performance point of view, the PV systems with a heat pump along with the Cowa storage tanks can achieve roughly 40% more own consumption when compared to a PV system with a heat pump. This would result in higher levels of energy autarky than PV systems (greater than 40%) (Compact thermal energy storage, n.d.). The Cowa storage system also needs to have a TCO smaller than 1.5 million CHF to break-even within the considered 50 years. By performing a quick calculation, it was found out that the CAPEX for a system consisting of 400PV panels with a HP and 12 decentralised Cowa storage tanks (combi tanks) of 1000L each would be roughly 290'000 CHF and the associated operating expenditure will be lower than the PV system's OPEX values. Therefore, from an economic perspective, the system can be placed below or at the same levels of a PV system. The green cross in fig.29 represents where the Cowa storage system with 400 PV panels and a 130kW heat pump can be placed.

When looking at the CO_2 emissions of the energy systems, it was understood that the condensing boiler reduced its emission by 30%. The SWT system further reduced its emission up to 97% and the remaining systems which have a heat pump as their heat source have no emissions due to the 100% renewable energy mix of the electricity consumed from the external grid.

5.1 Risk analysis

All the obtained results were analysed to see if they were also plausible from a technology point of view. Whenever some mistakes occurred during the energy modelling process, it was identified when the system performances were graphically plotted and interpreted. Also, in order to analyse the risks assigned with the parameter values for TCO calculations, different scenarios with the extreme values for fuel, energy prices and discount rates have been set and their relative TCOs have been calculated for the respective cases. The following trends have been noticed. For systems consisting of PV panels, the system pays off faster as we increase the feed-in tariff. This would be an ideal assumption for the near future to promote PV technology. It can also be beneficial for all the renewable energy systems if the fuel oil price shoots up. Whenever a discount rate was considered, the system performed worse than the system with a discount rate of 0%. For solar thermal systems, the risk analysis shows a similar pattern. As heating oil prices increase, the system would pay off even faster which can be seen as a realistic scenario in the near future. An increased discount rate negatively affects the break-even time. It was also noted that, if the pellet prices were provided with an additional allowance thereby reducing the pellet prices, the SWT systems with higher ST module configurations suddenly start paying off within the considered 50 years. This could also be considered as a likely scenario for meeting the pollution reduction targets set by the nation.

5.2 SWOT analysis

For interpreting all the results obtained, a SWOT analysis is performed. This analysis identifies the strengths, weaknesses, opportunities and threats pertaining to the considered energy systems on the basis of three aspects: system performances, economic performances and in terms of emissions. This section deals with the potential strengths of the system and highlights their weaknesses. Moreover, it identifies useful areas of further research (opportunities) and depicts the threats that might restrict the systems from further consideration.

SWOT analysis for condensing boiler

	Strengths	Weaknesses
Technology	• Easier to implement since the basic foundation from conventional boiler setup already exists • Efficiency > 95%	• Energy autarky is not achieved • Dependent on heating oil
Financial perspective	• One of the cheapest technologies. • Less investment costs	• Required to pay pollution tax which is usually included in heating oil price. • Higher operating expenditure • No subsidies available
Emissions	• Emissions reduced by roughly 30% compared to conventional boiler	• Highest in terms of emission among the compared technologies
	Opportunities	**Threats**
Technology	• Potential for further improvements in efficiency	• Chances for abolishment of this technology as measure to meet the 2050 energy strategy and for meeting the pollution goals • Changing user attitude to opt for renewable energy system
Financial perspective		• Rising fuel prices, increase in taxes and levies • Subsidies and incentives of renewable energy systems making it more attractive
Emissions	• Chances of advancements in emission control technologies	• Presence of renewable energy systems with zero emissions

Swot analysis for PV system (with and without a battery)

	Strengths	Weaknesses
Technology	• Improving efficiency of PV systems (At the moment roughly at 30% (Solar Cell Efficiency - Energy Education, n.d.) • COP of heat pump is roughly between 3-4 • Availability of large roof area • Achieves high values of energy autarky and self-consumption can further be increased using a battery storage	• Efficiency still limited to 30% on a commercial scale • Diminishes the aesthetics of the property when PV placed on the roof
Financial perspective	• Energy system breaks-even the fastest • Availability of subsidies and incentives • Lower operating expenditure	• Higher initial investment costs
Emissions	• Emissions during operation is 0% due to the 100% renewable electricity from external grid	• The manufacturing and decommissioning stages are not considered in this evaluation which have considerable environmental impacts
	Opportunities	**Threats**
Technology	• Potential for further efficiency improvements	• Lower efficiency of PV modules

Financial perspective	• More allocation subsidies and incentive programs • Further decrease in PV manufacturing costs	• Falling fuel prices would increase the relative TCOs of PV systems
Emissions	• Possibility of performing an LCA study from cradle to grave for knowing the correct values of emissions and global warming potential	

SWOT analysis for SWT system

	Strengths	Weaknesses
Technology	• Higher efficiency of the ST modules which is around 90% (Solar PV or Solar Thermal System, 2014) • SWT enables hot water storage on a daily and weekly basis based on SWT tank size chosen • Achieves energy autarky up to 56% with maximum ST module configurations and SWT of 50’000L • Pellet boiler is considered as a carbon-neutral solution	• Diminishes the aesthetics of the property when ST modules are placed on the roof • Limited to smaller no. of ST modules thereby decreasing the levels of energy autarky when considering the system which pays off
Financial perspective	• Energy system breaks-even with ST module configurations of up to 60 modules and with a max. SWT capacity limited to 50’000L • Availability of subsidies and incentives • Lower operating expenditure	• Higher initial investment costs • As no. of ST modules increases, this system becomes more expensive
Emissions	• Emissions during operation is reduced between 90 to 97% based on system configurations	• The manufacturing and decommissioning stages are not considered in this evaluation which have considerable environmental impacts
	Opportunities	**Threats**
Technology	• Potential for further efficiency improvements • Could be combined with PV systems to analyse the autarky increase • Hybrid cells are also interesting to be looked at	• Tank size is limited which prevents the scope of considering seasonal thermal energy storage
Financial perspective	• More allocation of funds to subsidies and incentive programs • Further decrease in ST system costs	• Falling fuel prices would increase the relative TCOs of ST systems
Emissions	• Possibility of performing an LCA study from cradle to grave for knowing the correct values of emissions and global warming potential	

SWOT analysis for ice storage system

	Strengths	Weaknesses
Technology	• High efficiency of ST systems which is around 90% (Solar PV or Solar Thermal System, 2014) • Enables free cooling • Seasonal performance factor of 3.5 to 6 • Can store up to 8 times the energy content as in SWT case • Highest energy autarky levels of up to 75% during system performance evaluation	• Diminishes the aesthetics of the property when ST modules are placed on the roof • Free cooling is not considered in this project (exergy wise not considered to its full potential)
Financial perspective		• Higher investment costs • Energy system never breaks even
Emissions	• Emissions during operation is 0% due to the 100% renewable electricity from external grid	• The manufacturing and decommissioning stages are not considered in this evaluation which have considerable environmental impacts
	Opportunities	**Threats**
Technology	• Potential for further efficiency improvements • Could be combined with PV systems to analyse the autarky increase • Hybrid cells are also interesting to be looked at	• Tank size is limited which prevents the scope of considering seasonal thermal energy storage
Financial perspective	• More allocation of funds to subsidies and incentive programs • Could possibly help the systems to break even • Possibilities for further ST system costs reduction	• Falling fuel prices would increase the relative TCOs of this technology
Emissions	• Possibility of performing an LCA study from cradle to grave for knowing the correct values of emissions and global warming potential	

5.3 Limitations of this project

The system boundaries set in this project limited the scope of this thesis. Since the energy demand of the building was already known, it was easier to create the energy system models and to find the system properties. The thermal insulation of the building could also be studied in depth in order to assess the factors such as heat and infiltration losses. While considering the electricity consumption profile, only the electricity bills of Mr. Imhof, representative of the housing estate was contemplated and taken as a reference for calculating the total electricity consumption of the housing estate. The potential for building refurbishment was also out of scope in this thesis. Another important limitation was the modelling of the housing estate as one single multi-family house which can lead to differences in heat losses and infiltration values. This was compensated by changing the building properties and energy consumption values.

For the systems involving ice storage, the free cooling scenario was not considered, and this limits the benefits of this energy system potential from an exergy point of view. The heating set point considered was the same (21°C) for all the 12 buildings. The domestic hot water temperature was set to 50°C for ease of calculation. In reality, both these values vary according to the user's preferences.

During the TCO calculations, a different calculation approach can be implemented, and this could also produce different cost results. The low and high feed-in tariffs were combined for easier interpretation and calculation purpose. All these decisions can have a significant impact on the attained results.

5.4 Future developments

The current developments of Swiss residential buildings and heating energy system are going in line with the environmental and energy goals set by the nation. The electric grid needs to be readjusted to accept the transition from non-renewable to renewable energy generation. Trends such as increased use of electric vehicles will also lead to the need of charging stations on a residential scale. In order to attain a grid stability, there needs to be a match between supply and demand of energy. On a residential scale, this can be achieved by implementing storage devices like battery systems to decrease feed-ins and increase the rates of self-consumption. Whereas for the heating sector, the new energy regulations slowly increase the importance of thermal energy storage on a daily, weekly and seasonal basis. At the moment, from preliminary research it was concluded that no subsidies were available for thermal and electrical energy storage for the analysed housing estate in Edlibach. It is possible for this behaviour to change in the near future. New subsidies might emerge which would promote thermal and electrical energy storage.

5.5 Recommendations

From an energy and economic standpoint, I would suggest an energy system consisting of 700 PV panels and a battery storage system of 50kWh or 100kWh. The heat source for this technology would be an air-sourced heat pump of 130kW power rating. The domestic hot water storage consists of a 2000L tank and the space heating buffer storage has a capacity of 4000L. During the study, it was observed that a combination of solar thermal systems along with the PV systems can be considered as a potential solution. The system with 300PV panels and 100kWh battery already attains a self-sufficiency of 47%. The remaining roof area can be occupied by ST modules to further increase the degrees of autarky. Here the storage tank size can also further be increased to make it capable of storing the excess of heat produced with the PV electricity on a daily basis. The smallest SWT capacity of 10 m³ performed better which points to considering SWT sizes between 10m³ and 40m³ for achieving sort of a linearisation. Thereby the optimal tank size can be found out. Similarly, ST module configurations can be varied between 10 and 50 for finding the optimal module configuration. It would also be interesting to look at hybrid modules to see the different cost structure and energetic performances of these energy systems. The Cowa storage system is an interesting technological solution which could be analysed as well.

The feasibility of building refurbishments is another interesting area which needs to be explored. By increasing the thermal insulation of the building, it could lead to a reduction in the energy consumption of the considered energy reference area which is currently at 75kWh/m². There exist several building refurbishment programs to promote the improvement of building envelope standards. In the further stages of this project, it would also be more appropriate to include cost data from energy system quotes obtained for the housing estate in Edlibach for achieving higher levels of accuracy in the cost results.

For systems consisting of PV and battery storage, electric vehicle charging stations can also be included as an additional load in the electricity profiles. This would make it possible to charge the electric cars with the surplus of solar energy produced from the photovoltaic systems. Polysun also offers the possibility to include e-vehicles in the energy system modelling process.

6. Conclusion

This study has successfully explored five different energy systems on the technological, economic and environmental levels. An energy system which fulfils all the mentioned criteria were identified in the final stage of this thesis which is a PV system with a battery storage. Therefore, the aim of this project which was to analyse the potential solutions for retrofitting the heating system with an energy efficient, cost effective and with the least environmental impact was fulfilled and all the objectives were met.

The only unexpected outcome that occurred was the infeasibility of the technological solution where a connection to the district heating grid was planned. This was one of the most interesting solution which turned out to be infeasible during the technology evaluation phase. Another limitation which would have a significant impact on the results was the avoidance of COWA storage system in the preliminary stages of this project. This was done due to the inability to include COWA system into the energy simulation software, Polysun.

As a suggestion for future research, it is interesting to analyse the potential for building envelope refurbishment. This is an attractive area which was not considered within the scope of this thesis. As a matter of fact, there are plenty of incentive programs which enables us to consider this as a possibility along with the energy system retrofit. The addition of e-vehicle charging stations and the combination of PV and ST modules with different capacities of surface water tank and batteries are also interesting areas that could be investigated. Cowa storage systems could be considered in this analysis. Also, an energy system which comprises of hybrid modules (PVT) could also be included in the further stages of this assessment.

This thesis can be considered as a reference for energy retrofit analysis of moderately insulated buildings in Switzerland. The energy system modelling tool, Polysun is an efficient energy simulation software for energy system modelling and for attaining the energy balancing results. The research conducted for the incentive programs in Switzerland is quite extensive and would also help in other projects with a similar scope. Finally, the analytic goals would help to investigate the considered energy systems from three different perspectives. Instead of concluding the project by a SWOT analysis, a different approach such as cost-benefit analysis (CBA) or a multi-criteria decision-making analysis (MCDA Analysis) could also be implemented for assessing the solution concepts.

The results were carefully reviewed and was also discussed with the coach to ensure its credibility. The coach also confirmed that the results were comparable to the SCCER WP5 paper published by the Swiss Competence Centre for Energy Research.

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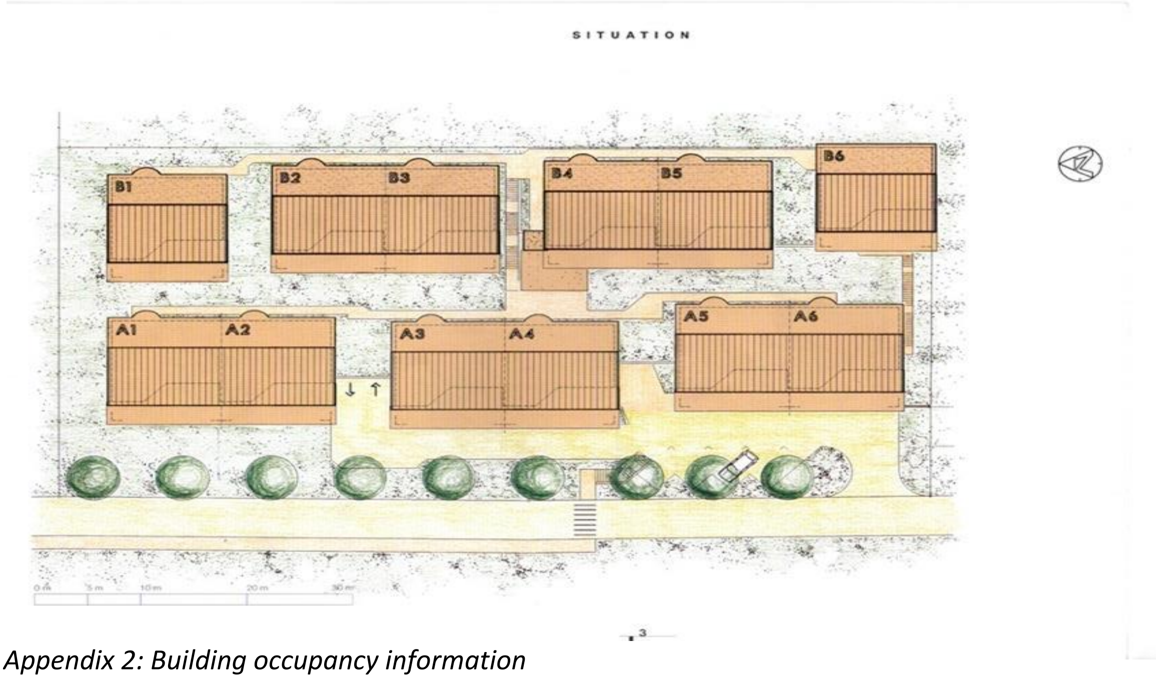
8. Appendices

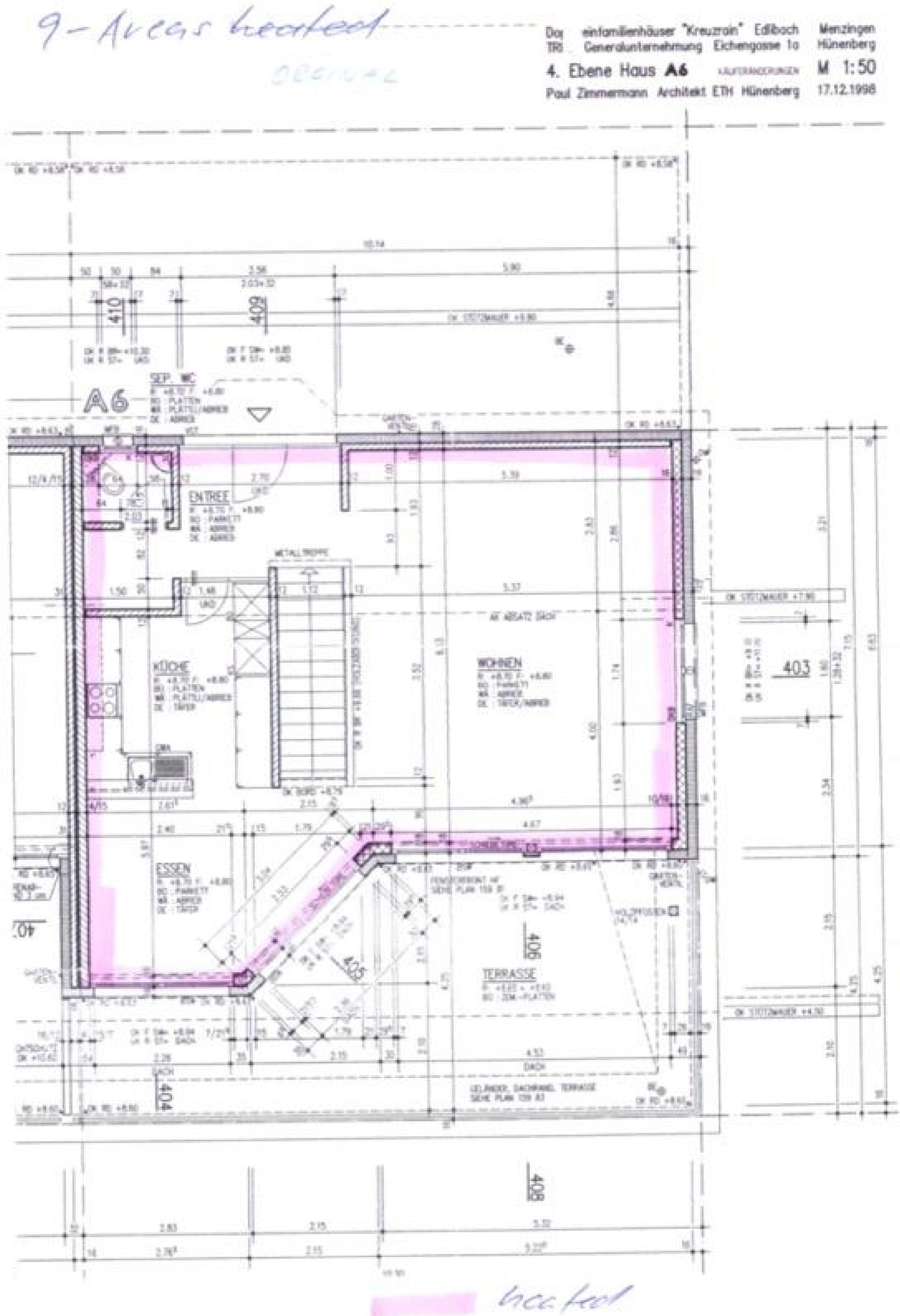
Appendix 1 General overview of area with building number



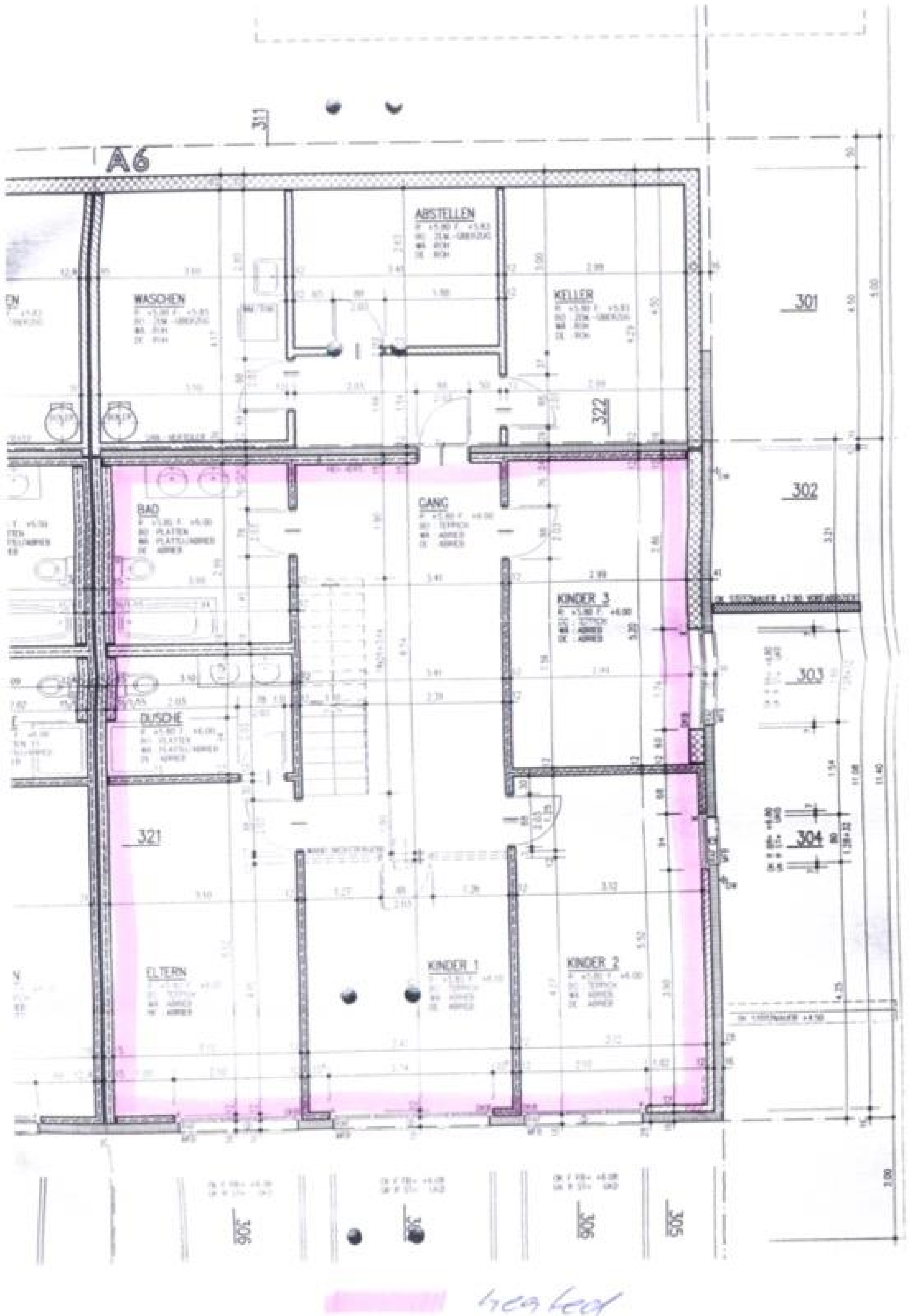
Appendix 2: Building occupancy information

2 - Building Occupancy - Kreuzrain 3 (confidental)						
House No.	Residents No.	Age 1)	Occupancy	Job	Remarks	Access to heating/hat water
A1	2	67	full time	retired		standard
		63	full time	engineer		
A2	2	51	full time	lawyer		standard
		51	full time	lawyer		
A3	2	50	full time	engineer		standard
		45	full time	office clerk		
A4	2	70	full time	retired		standard
		67	full time	retired		
A5	2	66	part time	retired	until 31.12.2020 expat status thereafter - full time	standard
		63	part time	office clerk	until 30.6.2020 expat status threafter - full time	
A6	2	63	full time	managemen		standard
		58	full time	office clerk		
B1	5	55	full time	houseman		standard
		55	full time	management		
		19	full time	apprentice		
		16	full time	apprentice		
		15	full time	schoolar		
B2	2	61	full time	engineer		standard
		63	full time	retired		
B3	2	73	full time	retired		standard
		68	full time	retired		
B4	2	61	full time	police (office)		standard
		59	full time	office clerk		
B5	2	72	full time	retired		standard
		65	full time	retired		
B6	2	82	full time	retired		individual wood heating oven
		78	full time	retired		and access to area supply
1)	Close estimate					

Appendix 3: Floor plan- Ground floor



Appendix 4: Floor plan- 1st Floor



Appendix 5: Electricity consumption

VERBRAUCH

Produkt
WasserSonnenStrom 80:20 – mit Solarförderung

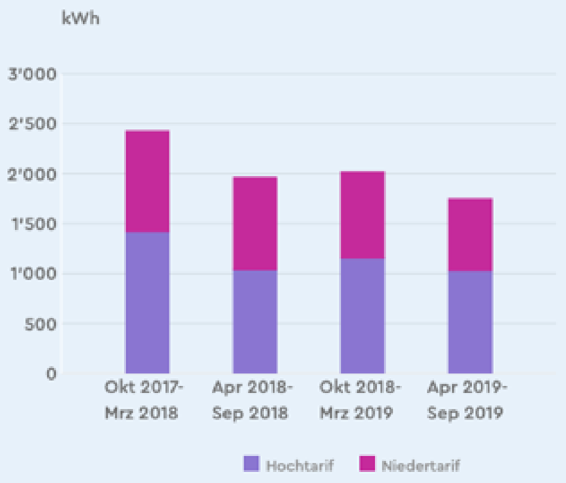
KOSTEN MENGE

Verbrauchsjahre anzeigen

2 Jahre

ZUSAMMENFASSEN ZU EINEM JAHR

Mengenvergleich



Anlagenummer: 7027832

kWh	Okt 2017- Mrz 2018	Apr 2018- Sep 2018	Okt 2018- Mrz 2019	Apr 2019- Sep 2019
Hochtarif	1'422	1'039	1'155	1'030
Niedertarif	1'004	921	863	717
Total	**2'426**	**1'960**	**2'018**	**1'747**

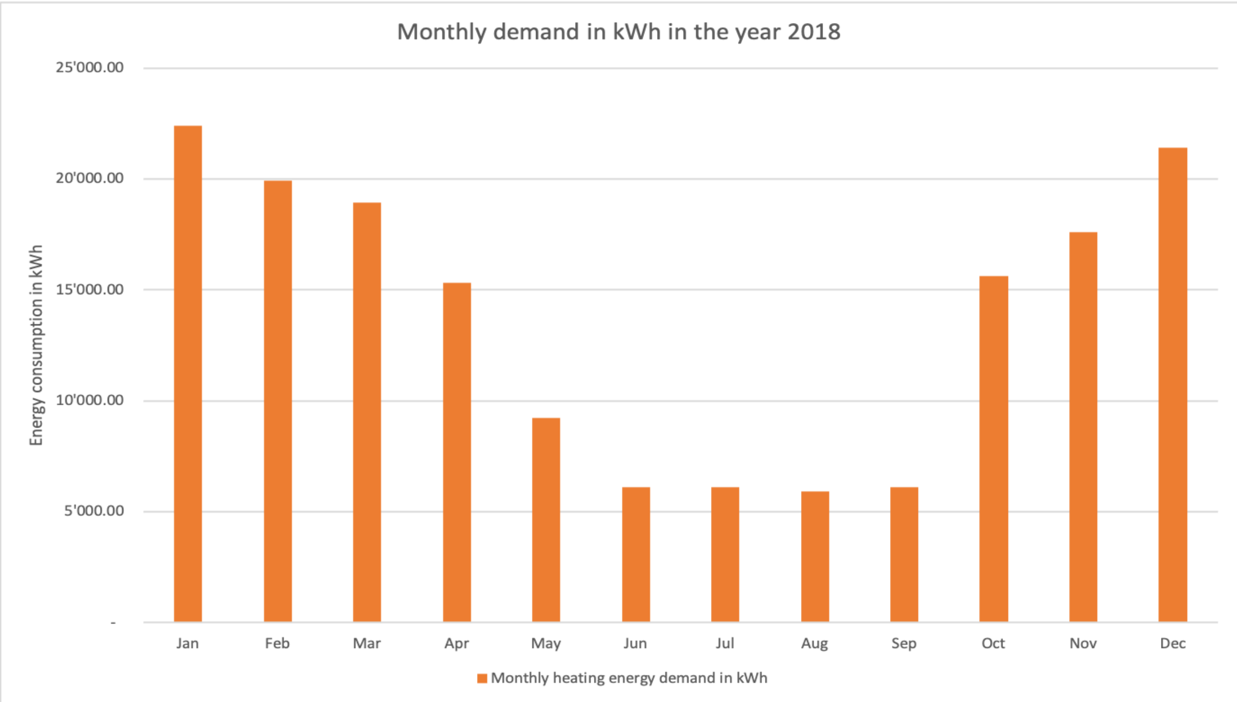
Appendix 6: Electricity bills

CHF	Okt 2017 - Mrz 2018	Apr 2018 - Sep 2018	Okt 2018 - Mrz 2019	Apr 2019 - Sep 2019
Energie	203.68	159.61	168.93	148.78
Netz	205.97	166.40	173.63	154.19
Abgaben	73.08	66.62	68.84	59.83
Mehrwertsteuer	37.87	30.23	31.68	27.94
Total	520.60	422.86	443.08	390.74

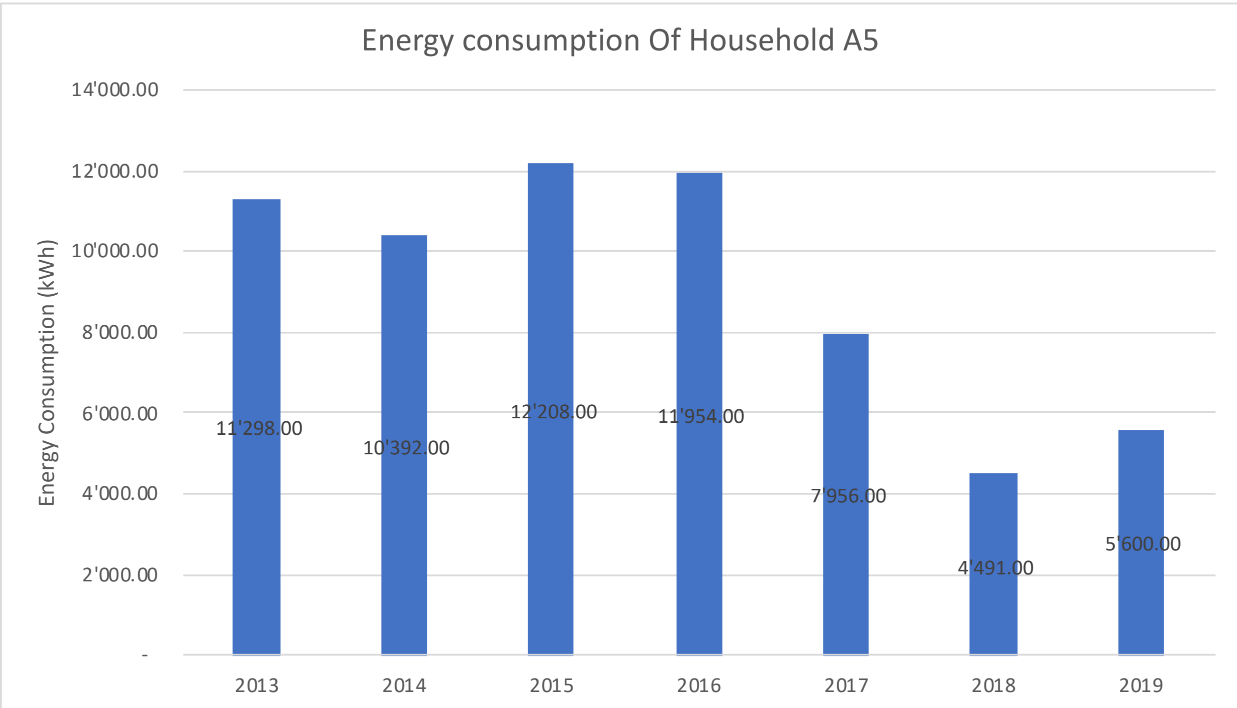
Appendix 7: Monthly heating energy demand for 2018

Months	Monthly heating demand in %	Monthly heating energy demand in kWh
Jan	13.60%	22'391.04
Feb	12.10%	19'921.44
Mar	11.50%	18'933.60
Apr	9.30%	15'311.52
May	5.60%	9'219.84
Jun	3.70%	6'091.68
Jul	3.70%	6'091.68
Aug	3.60%	5'927.04
Sep	3.70%	6'091.68
Oct	9.50%	15'640.80
Nov	10.70%	17'616.48
Dec	13.00%	21'403.20

Total yearly heating demand (kWh)	164'640.00



Appendix 8: Energy consumption of household A5 over last 7 years



Appendix 9: Oil and heating energy consumption over last 7 years

Year	Heating energy consumption (kWh)	Oil Consumption (L)
2013	181297	23312
2014	155528	21597
2015	159319	22943
2016	172245	19374
2017	179304	20828
2018	164640	24102
2019	183350	23824

Appendix 10: Heating and additional expenditure bill for the year 2018

Cham, 31. Januar 2019

Abrechnung: 53501
MEG Kreuzrain 3
6313 Edlibach

Abrechnungsperiode:
01.01.2018 - 31.12.2018

Heizkostenabrechnung

		Menge	Beträge in CHF
4010	Heizöl-Vorrat Anfang Periode	14'300.00	12'091.00
4000	Schätzle AG:Heizöl	8'001.00	7'032.90
4000	Schätzle AG:Heizöl	5'503.00	6'025.80
4000	Schätzle AG:Heizöl	10'007.00	9'216.45
4020	Heizöl-Vorrat Ende Periode	-11'700.00	-11'070.30
Total Heizöl-Verbrauch		26'111.00	23'295.85
4002	Strom Brenner+Pumpen		300.00
4003	Kaminfeger		560.00
4004	Brennerservice		631.00
4005	RST Tankrevision		100.00
4008	RST Wärmezähler		500.00
Zwischentotal			**25'386.85**
Verwaltungshonorar 3% von 23'295.85			698.90
zuzüglich 7.7% MWSt auf 698.90			53.80
Total Heizkosten			**26'139.55**

Verteilung
100% nach Heizeinheiten (he 1) 164.6400

Monatsgewichtung								
	Jan	13.60	Apr	9.30	Jul	3.70	Okt	9.50
	Feb	12.10	Mai	5.60	Aug	3.60	Nov	10.70
	Mar	11.50	Jun	3.70	Sep	3.70	Dez	13.00

Cham, 31. Januar 2019

Abrechnung: 53502
MEG Kreuzrain 3
6313 Edlibach

Abrechnungsperiode:
01.01.2018 - 31.12.2018

Betriebskostenabrechnung

		Menge	Beträge in CHF
4610	Wasser-/Abwasserkosten		3'305.10
Total Wasser-/Abwasserkosten			**3'305.10**
Verteilung			
100% nach Kaltwasserzähler (kw 1)			1'271.0000
4200	Versicherungen		1'234.95
4300	Hauswart-Entschädigung		8'736.35
4400	Unterhalt Liegenschaft		2'014.00
4410	Service Abonnemente		4'167.65
4480	Einlage Erneuerungsfonds		6'000.00
4600	Strom allgemein		1'713.60
4615	Grundgebühr Wasser/Abwasser		1'784.65
4700	Bankzinsen/Spesen		113.40
4760	Verwaltungshonorar		5'675.80
Total Betriebs-/Unterhaltskosten			**31'440.40**
Verteilung			
100% nach Wohneinheiten (we 1)			12.0000
Gesamttotal			**34'745.50**

Hammer Retex AG Kostenverteilung 31.01.2019 09:19

Kostenverteilung

01.01.2018 - 31.12.2018

Liegenschaft: 5350, Kreuzrain 3, 6313 Edlibach

	Eigentümer	Name	Objekt-Nr.	Tage	Heiz-/Warmwasserkosten (100%)			Wasser-/Abwasserkosten (100%)			Betriebs-/Unterhaltskosten (100%)		
					Tage	he 1	Betrag	Tage	kw 1	Betrag	Tage	we 1	Betrag
A1	100101	Schönbächler Beat + Schönbächle	1001	360	360	7.6630	1'216.65	360	53.0000	137.80	360	1.0000	2'620.05
A2	100202	Staffelbach D. + Ziegler C.	1002	360	360	21.3820	3'394.80	360	87.0000	226.25	360	1.0000	2'620.05
A3	100303	IMAG Staub AG	1003	360	360	14.5390	2'308.35	360	88.0000	228.85	360	1.0000	2'620.05
A4	100401	Pezzatti B. + G.	1004	360	360	16.9140	2'685.40	360	160.0000	416.05	360	1.0000	2'620.05
A5	100502	Magnin Jean-Louis	1005	360	360	4.4910	713.05	360	7.0000	18.20	360	1.0000	2'620.05
A6	100601	Imhof Bruno	1006	360	360	14.2090	2'255.95	360	122.0000	317.25	360	1.0000	2'620.05
B1	200101	Wurr Daniel + Suter Dagmar	2001	360	360	21.9040	3'477.65	360	250.0000	650.10	360	1.0000	2'620.05
B2	200201	Brun Peter + Alice	2002	360	360	14.5280	2'306.60	360	104.0000	270.45	360	1.0000	2'620.05
B3	200302	Bollag Patricia	2003	360	360	16.1520	2'564.40	360	88.0000	228.85	360	1.0000	2'620.05
B4	200401	Hofmann P. + G.	2004	360	360	7.5970	1'206.15	360	101.0000	262.65	360	1.0000	2'620.05
B5	200501	Birrer Armin	2005	360	360	17.6560	2'803.20	360	117.0000	304.25	360	1.0000	2'620.05
B6	200601	Weiss Karl	2006	360	360	7.6050	1'207.45	360	94.0000	244.45	360	1.0000	2'620.05
	Total			✓		164.6400	26'139.65		1'271.0000	3'305.15		12.0000	31'440.60

Seite 1a

Hammer Retex AG — Kostenverteilung — 31.01.2019 09:19

Eigentümer	Name	Objekt-Nr	Tage	Total	Akonto	Nachbelastung Gutschrift(-)
100101	Schönbächler Beat + Schönbächle	1001	360	3'974.50	4'336.00	-361.50
100202	Staffelbach D. + Ziegler C.	1002	360	6'241.10	5'204.00	1'037.10
100303	IMAG Staub AG	1003	360	5'157.25	4'852.00	305.25
100401	Pezzatti B. + G.	1004	360	5'721.50	6'036.00	-314.50
100502	Magnin Jean-Louis	1005	360	3'351.30	4'148.00	-796.70
100601	Imhof Bruno	1006	360	5'193.25	5'444.00	-250.75
200101	Wurr Daniel + Suter Dagmar	2001	360	6'747.80	6'504.00	243.80
200201	Brun Peter + Alice	2002	360	5'197.10	5'240.00	-42.90
200302	Bollag Patricia	2003	360	5'413.30	5'768.00	-354.70
200401	Hofmann P. + G.	2004	360	4'088.85	4'524.00	-435.15
200501	Birrer Armin	2005	360	5'727.50	5'900.00	-172.50
200601	Weiss Karl	2006	360	4'071.95	4'336.00	-264.05
Total				60'885.40	62'292.00	-1'406.60

Seite 1b

Appendix 11: Condensing boiler results

System overview

Total fuel and/or electricity consumption	220’566 kWh
Total electricity consumption	48’957 kWh
Total oil consumption	171’609 kWh
Total energy consumption	166’651 kWh
Total efficiency	97 %

Component overview

Boiler	**Condensing boiler 70kW**	
Power	kW	67
Total efficiency	%	97,9
Energy from/to the system	kWh	167.984
Fuel and electricity consumption	kWh	171.609
Fuel consumption of the back-up boiler	l	17.162
Exhaust fumes losses	kWh	2.746
Electric consumers	**Standard**	
Electricity consumption	kWh	48.957
Electricity consumption of the thermal components	kWh	50,6
Pump Heat source	**Eco, small**	
Circuit pressure drop	bar	0,393
Flow rate	l/h	940
Fuel and electricity consumption	kWh	5
Pump Heating loop	**Eco, medium**	
Circuit pressure drop	bar	1,59
Flow rate	l/h	10.213
Fuel and electricity consumption	kWh	45,6
Storage tank Potable water tank	**6000l Speicher**	
Volume	l	6.000
Height	m	2
Material		Steel
Insulation		Rigid PU foam
Thickness of insulation	mm	100
Heat loss [Qhl]	kWh	1.080
Connection losses	kWh	201

Appendix 12: HP + ST + Ice Storage results

Simulation results

System overview:

Total fuel and/or electricity consumption of the system	94.506 kWh
Total electricity consumption	94.798 kWh
Total energy consumption	166.232 kWh
Seasonal performance factor	3,6
Primary energy factor	0,49

Solar thermal energy overview:

Collector area	447,7 m2
Solar fraction total	53,3 %
Solar fraction hot water	59,4 %
Solar fraction building	48,2 %
Total annual field yield	192.384,6 kWh
Max. energy savings	51.860,6 kWh
Max. reduction in CO2 emissions	27.818 kg

Overview heat pump:

Seasonal performance factor (without pump energy)	3,7
Total electricity consumption when heating	45.507 kWh
Total energy savings	123.309 kWh
Total reduction in CO2 emissions	66.143 kg

Component overview:

Collector	**VarioSol E-antireflex 2x2**	
Number of collectors		110
Number of arrays		20
Total gross area	m2	447,7
Total aperture area	m2	400,4
Tilt angle (hor.=0°, vert.=90°)	°	60
Orientation (E=+90°, S=0°, W=-90°)	°	0
Collector field yield	kWh	192.385
Irradiation onto collector area [Esol]	kWh	509.187
Collector efficiency [Qsol / Esol]	%	37,8
Electric consumers	**Standard**	
Electricity consumption [Ecs]	kWh	94.798
Electricity consumption of the thermal components [Ethcs]	kWh	45.892
Ice storage with coil heat exchanger	**Standard ice storage**	
Ice storage shape		Cuboid
Water volume [VH2O]	m3	53,8
Ice storage length	m	6,3
Ice storage width	m	3,65
Water level without ice	m	2,34
Ice fraction (Maximum)	%	100

Appendix 13: ST + Pellet Boiler + Jenni Storage results

System overview:

Total fuel and/or electricity consumption of the system	130.201 kWh
Total electricity consumption	48.950 kWh
Total pellet consumption	81.251 kWh
Total energy consumption	162.963 kWh
System performance	2
Primary energy factor	0,6
Comfort demand	Energy demand covered

Overview solar thermal energy:

Collector area	492 m2
Solar fraction total	55,5%
Solar fraction hot water	77,3 %
Solar fraction building	53,7 %
Total annual field yield	94.296,4 kWh
Max. fuel savings	19.956,9 kg: [Pellets]
Max. energy savings	99.784,6 kWh
Max. reduction in CO2 emissions	5.029 kg

Component overview:

Boiler	**Pellet 80kW**	
Power	kW	79
Total efficiency	%	93
Energy from/to the system	kWh	75.537
Fuel and electricity consumption	kWh	81.251
Fuel consumption of the back-up boiler	kg	16.250
Energy savings solar thermal	kWh	99.785
CO2 savings solar thermal	kg	5.029
Fuel savings solar thermal	kg	19.957
Exhaust fumes losses [Qex]	kWh	4.469
Collector	**VarioSol A-antireflex 2x2**	
Data Source		TÜV
Number of collectors		120
Number of arrays		20
Total gross area	m2	492
Total aperture area	m2	440,4
Tilt angle (hor.=0°, vert.=90°)	°	60
Orientation (E=+90°, S=0°, W=-90°)	°	0
Collector field yield [Qsol]	kWh	94.296

Irradiation onto collector area [Esol]	kWh	560.055
Collector efficiency [Qsol / Esol]	%	16,8
Electric consumers	**Standard**	
Electricity consumption of the profiles [Epcs]	kWh	48.906
Electricity consumption of the thermal components [Ethcs]	kWh	43,9
Storage tank Combined tank	**Jenni storage**	
Volume	l	50.000
Height	m	8
Material		S235JRG
Insulation		Fibreglass and mineral wool matting
Thickness of insulation	mm	300
Heat loss [Qhl]	kWh	4.334

Appendix 14: Environmental analysis results in terms of CO_2 emissions of the chosen energy systems

Technology	CO2 emssion [tons]	Oil consumption[L] /pellet [kWh]	Total oil [L]/pellet [kWh] consumption	CO2 emssion [kg/L] / [kg/kWh]	Level of emission w.r.t Conventional boiler
Conventional boiler	3'193.52	24'102.00	1'205'100.00	2.65	100
Condensing boiler	2'273.97	17'162.00	858'100.00	2.65	71.2
10 ST+ 70 kW Pellet boiler+ 40'000L SWT	322.37	161'187.00	8'059'350.00	0.04	10.1
300 ST+ 70 kW Pellet boiler+ 40'000L SWT	102.37	51'183.00	2'559'150.00	0.04	3.2
ST+Heat Pump+ Ice storage	-	-	-	-	0.0
PV+Heat pump	-	-	-	-	0.0
PV+ Heat Pump+ Battery storage	-	-	-	-	0.0

Appendix 15: Overview of SS and OC results of PV systems

		Self-sufficiency [%] & Own consumption [%]															
PV Panels #		50		100		200		300		400		500		600		700	
PV only		12	86	17	65	24	46	29	36	32	30	34	26	36	23	37	20
BES [kWh]	30			22	84	33	61	38	48	42	39	44	33	43	27	48	26
	50			24	90	35	66	42	52	46	43	48	36	51	32	52	28
	100			26	97	39	74	47	59	52	49	56	42	58	36	60	32
	200			26	99	41	77	50	62	56	53	61	46	65	40	68	36

SS

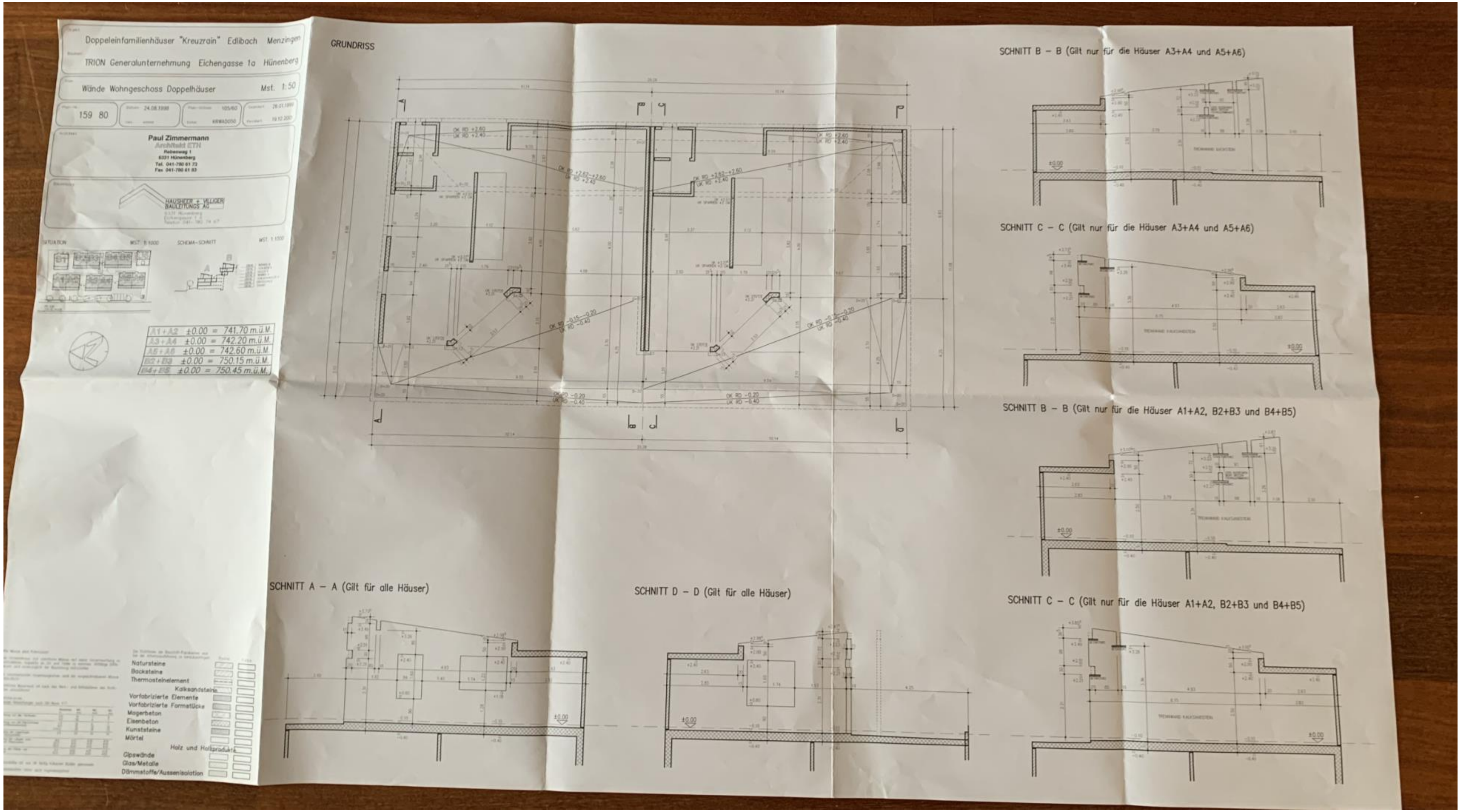
OC

Appendix 16: Overview of SCR and SCRsys results of systems containing ST modules

Solar coverage ratio [%] and solar coverage ratio_system [%]															
ST modules #		10		50		100		150		200		250		300	
SWT [L]	10000	11.53	9.02	34.69	27.17	48.4	37.75	54.62	42.58	57.96	45.16	59.95	46.69	60.94	47.43
	40000	10.1	7.93	33.21	26.02	48.41	37.87	57.81	45.17	63.59	49.65	67.63	52.78	70.55	55.05
	50000	10.23	8.04	33.32	26.11	48.93	38.27	58.68	45.86	64.98	50.75	69.16	53.99	72.19	56.34
	120000	10.69	8.41	34.22	26.83	50.24	39.32	61.14	47.8	67.8	52.98	72.81	56.88	76.85	59.99
Ice [L]	31890							83.72	69.14	85.26	70.89	86.1	71.85	86.59	72.24
	53808							85.14	71.26	86.8	73.25	87.68	74.35	88.25	75.08
	70020							84.98	70.75	85.68	71.23	86.14	71.55	86.45	71.75

SCR
SCRsys

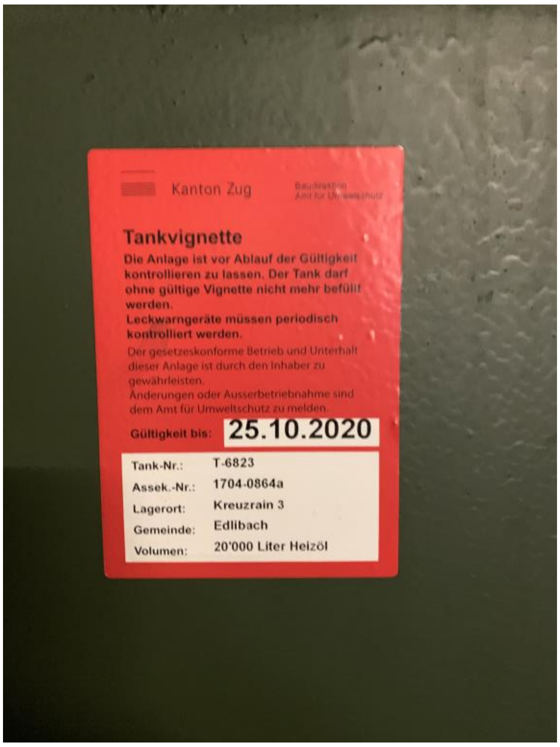
Appendix 17: Architectural details plan



Appendix 18: Photos of pipelines and buffer storage tanks from technical room

Appendix 19: Temperature readings from floor heater and boiler pipelines

Appendix 20: Oil tank specifications (Tank vignette photo)



Appendix 21: Comparison of different energy modelling tools

	External air flow	SW radiation	LW radiation	Building thermal	User behaviour	Building system	Thermal network	Electrical network	Gas network	District plant	Thermal storage	Wind power	Photovoltaics	Ground source	Spatial	Transportation	Embodied energy	
CitySim	X[1]	D[2]	D	S	D	S	S	X	X	X	S[3]	S[4]	S	S[4]	D	X	X	City energy simulation for groups of buildings / city quarters.
EnergyPlus	S	D	S[4]	D	D	D	S	X	X	S	S	S	S	D	S[5]	X	X	Detailed building simulation, limited interactions.
ESP-r	S	D	S	D	D	D	S	D[6]	X	S	D[7]	S	S	S	S	X	X	Detailed building simulation, thermal and elec networks possible.
IDA ICE	S	D	S	D	D	D	D[8]	X	X	S	S	X	S	D	S	X	X	Detailed building simulation, thermal networks possible.
Polysun	X[9]	D	S	S[10]	D	D	D	S	X	S	D	X	D	D	X	X	X	Detailed solar thermal and hydraulic systems.
TRNSYS	L	D	D	D	D	D	D	S	X	D	D	D	D	D	X	X	X	Detailed simulation tool for systems and single buildings.
Envi-met	S	S	S	S	X	X	X	X	X	X	X	X	X	X	S	X	X	Microclimate model.
KULeuven IDEAS lib	S	D	D	D	D[11]	D	S	D	X	S	S	X	D[12]	D[13]	X	X	X	District-level Modelica library.
LBNL District lib	S	D	D	D	S	D	S	D	X	S	S	S	D	D[14]	X	X	X	District (and building) Modelica libraries.
energyPRO	X	X	X	L	X	D	D	D	X	D	D	D	D	S	S[15]	X	X	Techno-economic simulation of energy systems.
RETScreen	X	X	X	S	X	S	S	X	X	S	S	S	S	S	X	X	X	Energy, life cycle cost, emissions, finance and risk analysis.
HOMER	X	X	X	L[16]	X	X	X	X[17]	X	S	X	D	D	X	X	X	X	Microgrid design optimisation.
Termis	X	X	X	L	X	X	D	X	X	S	S	X	X	X	L	X	X	Operate, simulate & optimise district heating networks.
Neplan	X	X	X	L	X	X	D	D	D	S	X	D	S	X	L[18]	X	X	Simulate & optimise electrical, water, gas and heating networks.
NetSim	X	X	X	L	X	X	D	X	X	D	X	X	X	X	L[19]	X	X	District heating, cooling and steam simulation environment.
EnerGis	X	X	X	S	X	S	S[20]	X	X	S	X	X	S	S	D	X	X	GIS-based urban energy and district heat network design tool.
SynCity	X	X	X	S	D	S[21]	S	S	S	S	D	S	S	S	D[22]	D	X	Integrated tool for holistic urban energy systems modelling [23].
EPIC-HUB	X	X	X	L	X	S	S	S	S	S	X	L	L	X	S	X	X	Middleware platform for multi-carrier infrastructure systems.
MEU	X	L	L	L[24]	S	S	S	S	X	S	X	X	S	X	D	X	X	Energy management tool for cities and multi-energy utilities.
UMI	X	L[25]	L	L	X	X	X	X	X	X	X	X	L	X	D[26]	D[27]	S	Rhino-based link to Radiance and EnergyPlus.
Radiance	X	D	D	X	X	X	X	X	X	X	X	X	D	X	D	X	X	Powerful ray-tracing program.
Solene	L	D[28]	D	S	S	X	X	X	X	X	X	X	X	X	D	X	X	Energy simulation for city quarters.
Fluent	D	D	D	X	X	X	X	X	X	X	X	X	X	X	X	X	X	CFD software.
OpenFOAM	D	X	D[29]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Extensible CFD software.

(Source: A review of modelling approaches and tools for the simulation of district-scale energy systems,2015)

Appendix 22: ST system energy performance, relative TCO and break-even results

Time Horizon	50	years

	Szenario 0	Szenario 1	Szenario 2	Szenario 3	Szenario 4
Heating oil price	0.89	0.89	0.89	0.85	0.8
Electricity Price [CHF/kWh]	0.22	0.22	0.22	0.20	0.25
Feed-in Tariff [CHF/kWh]	0.0732	0.1	0.10	0	0
Interest Rate [%]	0	2	0	2	2

TCO 0-System				
Szenario 0	Szenario 1	Szenario 2	Szenario 3	Szenario 4
CHF 979'826.51	CHF 643'126.04	CHF 979'826.51	CHF 621'554.36	CHF 594'589.77

Technology Subsidies	SWT =10	SWT >=50
	40400	56200
	Ice storage	
	30000	

für Jenni System	Szenario 0	Szenario 1	Szenario 2	Szenario 3	Szenario 4
Pellet Price [CHF/kWh]	0.072	0.072	0.07	0.08	0.1
Electricity Price [CHF/kWh]	0.22	0.22	0.22	0.2	0.25
Feed-in Tariff [CHF/kWh]	0.0732	0.1	0.10	0	0
Interest Rate [%]	0	2	0.00	2	2
Stromverbrauch [kWh]	48906	48906	48906	48906	48906

System	ST-Modul	Storage Volum	SCR Syst [%]	SCR [%]	ST Material + Installation [CHF]	System Components + Installation [CHF]	CAPEX [CHF]	Grid Feed [kWh]	Pellet demand [kWh]	Energy Deficit [kWh]	Energy Demand covered	CAPEX in kvalues	Standardized TCO Szenario 0 TCO/TCO_ref	Szenario 1 TCO/TCO_ref	Szenario 2 TCO/TCO_ref	Szenario 3 TCO/TCO_ref	Szenario 4 TCO/TCO_ref	Break-Even-Point Szenario 0 BEP [year]	Szenario 1	Szenario 2
0-System	0	0	0.00	0	CHF 0.00	CHF 70'926.34	CHF 70'926.34	0	17162											
ST_SWT	10	50000	8.04	10.23	CHF 23'717.40	CHF 135'445.54	CHF 118'762.94	0	161'156	231	yes	118.8	0.95	0.98	0.89	1.08	1.30	24.00	39.07	15.24
	50	50000	26.11	33.32	CHF 105'981.40	CHF 135'445.54	CHF 185'226.94	0	118'171	94	yes	185.2	0.98	1.05	0.94	1.13	1.31	42.59	69.11	32.28
	100	50000	38.27	48.93	CHF 208'811.40	CHF 135'445.54	CHF 288'056.94	0	89'817	104	yes	288.1	1.13	1.25	1.10	1.33	1.49	135.23	213.57	96.12
	120	50000	41.54	53.12	CHF 249'943.40	CHF 135'445.54	CHF 329'188.94	0	82'298	112	yes	329.2	1.21	1.35	1.18	1.43	1.58	291.37	440.83	173.89
	150	50000	45.86	58.68	CHF 311'641.40	CHF 135'445.54	CHF 390'886.94	0	72'320	117	yes	390.9	1.33	1.50	1.30	1.58	1.73			1358.93
	200	50000	50.75	64.98	CHF 414'471.40	CHF 135'445.54	CHF 493'716.94	0	61'124	106	yes	493.7	1.55	1.77	1.52	1.85	2.00			
	250	50000	53.99	69.16	CHF 517'301.40	CHF 135'445.54	CHF 596'546.94	0	53'724	103	yes	596.5	1.78	2.05	1.76	2.14	2.29			
	300	50000	56.34	72.19	CHF 620'131.40	CHF 135'445.54	CHF 699'376.94	0	48'373	109	yes	699.4	2.01	2.33	2.00	2.43	2.60			
	10	120000	8.41	10.69	CHF 23'717.40	CHF 196'643.74	CHF 179'961.14	0	160'870	114	yes	180.0	1.05	1.11	0.99	1.22	1.44	93.85	156.79	47.23
	50	120000	26.83	34.22	CHF 105'981.40	CHF 196'643.74	CHF 246'425.14	0	116'916	67	yes	246.4	1.08	1.18	1.04	1.27	1.45	92.64	150.98	64.09
	80	120000	34.94	44.62	CHF 167'679.40	CHF 196'643.74	CHF 308'123.14	0	97'894	65	yes	308.1	1.16	1.30	1.13	1.38	1.55	169.21	271.67	112.41
	100	120000	39.32	50.24	CHF 208'811.40	CHF 196'643.74	CHF 349'255.14	0	87'665	66	yes	349.3	1.23	1.38	1.20	1.47	1.63	313.24	490.53	182.68
	150	120000	47.80	61.14	CHF 311'641.40	CHF 196'643.74	CHF 452'085.14	0	68'106	69	yes	452.1	1.42	1.62	1.39	1.71	1.85			
	200	120000	52.98	67.80	CHF 414'471.40	CHF 196'643.74	CHF 554'915.14	0	56'342	59	yes	554.9	1.63	1.89	1.61	1.97	2.12			
	250	120000	56.88	72.81	CHF 517'301.40	CHF 196'643.74	CHF 657'745.14	0	47'537	47	yes	657.7	1.86	2.16	1.84	2.26	2.41			
	300	120000	59.99	76.85	CHF 620'131.40	CHF 196'643.74	CHF 760'575.14	0	40'313	51	yes	760.6	2.09	2.44	2.07	2.54	2.70			
	10	40000	7.93	10.10	CHF 23'717.40	CHF 127'582.54	CHF 110'899.94	0	161'187	333	yes	110.9	0.94	0.97	0.89	1.07	1.29	21.11	34.40	13.15
	50	40000	26.02	33.21	CHF 105'981.40	CHF 127'582.54	CHF 177'363.94	0	118'262	149	yes	177.4	0.98	1.04	0.94	1.13	1.30	41.21	66.97	30.92
	60	40000	29.05	37.09	CHF 126'547.40	CHF 127'582.54	CHF 197'929.94	0	111'187	138	yes	197.9	1.00	1.08	0.96	1.16	1.33	51.37	83.20	38.71
	100	40000	37.87	48.41	CHF 208'811.40	CHF 127'582.54	CHF 280'193.94	0	90'684	143	yes	280.2	1.13	1.25	1.10	1.33	1.49	144.91	228.46	99.45
	150	40000	45.17	57.81	CHF 311'641.40	CHF 127'582.54	CHF 383'023.94	0	73'796	141	yes	383.0	1.33	1.50	1.30	1.58	1.73			8227.72
	200	40000	49.65	63.59	CHF 414'471.40	CHF 127'582.54	CHF 485'853.94	0	63'489	135	yes	485.9	1.55	1.77	1.53	1.85	2.01			
	250	40000	52.78	67.63	CHF 517'301.40	CHF 127'582.54	CHF 588'683.94	0	56'340	140	yes	588.7	1.78	2.05	1.76	2.14	2.30			
	300	40000	55.05	70.55	CHF 620'131.40	CHF 127'582.54	CHF 691'513.94	0	51'183	136	yes	691.5	2.02	2.34	2.00	2.44	2.60			
	10	10000	9.02	11.53	CHF 23'717.40	CHF 101'851.54	CHF 85'168.94	0	157'342	1'777	yes	85.2	0.89	0.90	0.83	1.00	1.21	5.85	9.42	4.02
	50	10000	27.17	34.69	CHF 105'981.40	CHF 101'851.54	CHF 151'632.94	0	115'866	786	yes	151.6	0.93	0.98	0.89	1.06	1.23	26.31	42.83	20.62
	100	10000	37.75	48.40	CHF 208'811.40	CHF 101'851.54	CHF 254'462.94	0	90'251	1'029	yes	254.5	1.09	1.20	1.06	1.27	1.43	103.61	164.11	75.53
	150	10000	42.58	54.62	CHF 311'641.40	CHF 101'851.54	CHF 357'292.94	0	79'037	1'024	yes	357.3	1.31	1.46	1.28	1.54	1.70			
	200	10000	45.16	57.96	CHF 414'471.40	CHF 101'851.54	CHF 460'122.94	0	73'049	1'040	yes	460.1	1.55	1.75	1.52	1.84	2.00			
	250	10000	46.69	59.95	CHF 517'301.40	CHF 101'851.54	CHF 562'952.94	0	69'465	1'035	yes	563.0	1.79	2.04	1.77	2.14	2.31			
	300	10000	47.43	60.94	CHF 620'131.40	CHF 101'851.54	CHF 665'782.94	0	67'731	881	yes	665.8	2.04	2.34	2.02	2.45	2.63			

System	ST-Modul	Storage Volum	SCR Syst [%]	SCR [%]	ST Material + Installation [CHF]	System Components + Installation [CHF]	CAPEX [CHF]	Grid Feed [kWh]	Grid Supply [kWh]	Energy Deficit [kWh]	Energy Demand covered	CAPEX in kvalues	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	BEP [year]		
ST_Ice Storage	130	53.808	70.09	84.17	CHF 270'509.40	CHF 173'535.08	CHF 414'044.48	0	38'812	4	yes	414.0	1.54	1.72	1.542	1.74	1.93			
	150	53.808	71.26	85.14	CHF 311'641.40	CHF 173'535.08	CHF 455'176.48	0	37'556	4	yes	455.2	1.63	1.83	1.632	1.86	2.04			
	200	53.808	73.25	86.80	CHF 414'471.40	CHF 173'535.08	CHF 558'006.48	0	35'174	4	yes	558.0	1.86	2.11	1.863	2.15	2.34			
	250	53.808	74.35	87.68	CHF 517'301.40	CHF 173'535.08	CHF 660'836.48	0	33'849	5	yes	660.8	2.11	2.41	2.106	2.46	2.66			
	300	53.808	75.08	88.25	CHF 620'131.40	CHF 173'535.08	CHF 763'666.48	0	33'004	5	yes	763.7	2.35	2.70	2.355	2.76	2.98			
	150	31.89	69.14	83.72	CHF 311'641.40	CHF 151'660.04	CHF 433'301.44	0	37'995	4	yes	433.3	1.60	1.79	1.603	1.82	2.00			
	160	31.89	69.61	84.14	CHF 332'207.40	CHF 151'660.04	CHF 453'867.44	0	37'373	5	yes	453.9	1.65	1.85	1.648	1.87	2.06			
	200	31.89	70.89	85.26	CHF 414'471.40	CHF 151'660.04	CHF 536'131.44	0	35'754	5	yes	536.1	1.84	2.08	1.836	2.11	2.30			
	250	31.89	71.85	86.10	CHF 517'301.40	CHF 151'660.04	CHF 638'961.44	0	34'488	5	yes	639.0	2.08	2.37	2.080	2.42	2.62			
	300	31.89	72.24	86.59	CHF 620'131.40	CHF 151'660.04	CHF 741'791.44	0	33'739	4	yes	741.8	2.33	2.67	2.330	2.72	2.94			
	110	70.02	70.19	84.17	CHF 229'377.40	CHF 189'715.30	CHF 389'092.70	0	39'069	5	yes	389.1	1.47	1.64	1.466	1.65	1.83			
	150	70.02	70.75	84.98	CHF 311'641.40	CHF 189'715.30	CHF 471'356.70	0	36'709	5	yes	471.4	1.65	1.86	1.646	1.88	2.07			
	200	70.02	71.23	85.68	CHF 414'471.40	CHF 189'715.30	CHF 574'186.70	0	34'716	5	yes	574.2	1.88	2.14	1.882	2.18	2.37			
	250	70.02	71.55	86.14	CHF 517'301.40	CHF 189'715.30	CHF 677'016.70	0	33'408	4	yes	677.0	2.13	2.43	2.126	2.48	2.69			
	300	70.02	71.75	86.45	CHF 620'131.40	CHF 189'715.30	CHF 779'846.70	0	32'558	4	yes	779.8	2.37	2.73	2.374	2.79	3.01			

Appendix 23: PV system energy performance, relative TCO and break-even results

	Szenario 0	Szenario 1	Szenario 2	Szenario 3	Szenario 4
Electricity Price [CHF/kWh]	0.22	0.22	0.222	0.2	0.18
Feed-in Tariff [CHF/kWh]	0.073	0.073	0.073	0.06	0.12
Interest Rate [%]	0	0	2	2	2
Heating oil price	0.89	0.73	0.89	0.85	0.8

TCO 0-System

Szenario 0	Szenario 1	Szenario 2	Szenario 3	Szenario 4
CHF 1'518'353.51	CHF 1'381'057.51	CHF 984'652.05	CHF 929'235.46	871502.7518

SUBSIDIES

PV / PV+Battery	Subsidies
50	11930
100	16860
200	27740
300	34300
400	43000
500	51700
600	60400
700	69100

								Oil Consumption	Total Electricity consumption
0-System	0	0	0	0	CHF 0.00	CHF 70'926.34	CHF 70'926.34	17'162.00	48'957.00

System	PV-Modul	Storage Volume	Self-sufficiency [%]	Own-consumption ratio [%]	PV Material + Installation [CHF]	System Components + Installation [CHF]	CAPEX [CHF]	Grid Feed [kWh]	lectricity consumption	Energy Deficit [kWh]	Self Consumption	CAPEX [kCHF]	Standardized TCO Szenario 0 TCO/TCO_ref	Szenario 1 TCO/TCO_ref	Szenario 2 TCO/TCO_ref	Szenario 3 TCO/TCO_ref	Szenario 4 TCO/TCO_ref	Break-Even-Point Szenario 0 BEP [year]	Szenario 1	Szenario 2
PV_only	50	0	12	86	CHF 37'943.50	CHF 119'533.00	CHF 145'546.50	1'768.00	97'644.00	40.20	11'283.00	145.55	0.93	1.03	0.97	0.96	0.96	10.98	-	33.64
	100	0	17	65	CHF 54'208.00	CHF 119'533.00	CHF 156'881.00	9'191.00	97'644.00	40.20	16'910.00	156.88	0.90	0.98	0.94	0.94	0.92	8.68	30.58	25.57
	200	0	24	46	CHF 86'737.00	CHF 119'533.00	CHF 178'530.00	28'401.00	97'644.00	40.20	23'800.00	178.53	0.84	0.92	0.89	0.90	0.84	7.44	14.19	21.60
	300	0	29	36	CHF 119'266.00	CHF 119'533.00	CHF 204'499.00	50'731.00	97'644.00	40.20	28'695.00	204.50	0.79	0.87	0.85	0.87	0.77	7.60	11.98	20.98
	400	0	32	30	CHF 151'795.00	CHF 119'533.00	CHF 228'328.00	73'076.00	97'644.00	40.20	31'336.00	228.33	0.76	0.83	0.83	0.86	0.71	7.89	11.49	21.34
	500	0	34	26	CHF 184'324.00	CHF 119'533.00	CHF 252'157.00	96'981.00	97'644.00	40.20	33'523.00	252.16	0.72	0.80	0.81	0.85	0.65	8.09	11.15	21.58
	600	0	36	23	CHF 216'853.00	CHF 119'533.00	CHF 275'986.00	121'462.00	97'644.00	40.20	35'143.00	275.99	0.69	0.76	0.79	0.84	0.59	8.31	11.02	21.92
	700	0	37	20	CHF 249'382.00	CHF 119'533.00	CHF 299'815.00	146'300.00	97'644.00	40.20	36'406.00	299.82	0.66	0.73	0.77	0.83	0.53	8.52	10.98	22.28
Design Solution PV only																				
System	PV-Modul	Storage Volume	Self-sufficiency [%]	Own-consumption ratio [%]	PV Material + Installation [CHF]	System Components + Installation [CHF]	CAPEX [CHF]	Grid Feed [kWh]	lectricity consumption	Energy Deficit [kWh]	Self consumption	CAPEX [kCHF]	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	BEP [year]		
PV_Battery	100	30	22	84	CHF 54'208.00	CHF 146'839.40	CHF 184'187.40	4'102.00	97'959.00	40.20	21'099.00	184.19	0.93	1.02	0.98	0.98	0.98	14.50	114.87	39.41
	200	30	33	61	CHF 86'737.00	CHF 146'839.40	CHF 205'836.40	20'297.00	97'916.00	40.20	31'904.00	205.84	0.85	0.94	0.91	0.93	0.90	9.98	19.81	27.72
	300	30	38	48	CHF 119'266.00	CHF 146'839.40	CHF 231'805.40	40'934.00	98'150.00	40.20	37'368.00	231.81	0.81	0.89	0.88	0.90	0.83	9.60	15.50	25.85
	400	30	42	39	CHF 151'795.00	CHF 146'839.40	CHF 255'634.40	63'485.00	98'124.00	40.20	40'918.00	255.63	0.77	0.84	0.85	0.89	0.77	9.36	13.70	24.90
	500	30	44	33	CHF 184'324.00	CHF 146'839.40	CHF 279'463.40	87'089.00	98'106.00	40.20	43'415.00	279.46	0.73	0.81	0.83	0.87	0.70	9.34	12.88	24.58
	600	30	43	27	CHF 216'853.00	CHF 146'839.40	CHF 303'292.40	114'161.00	97'644.00	40.20	42'444.00	303.29	0.71	0.78	0.82	0.87	0.64	9.67	12.94	25.20
	700	30	48	26	CHF 249'382.00	CHF 146'839.40	CHF 327'121.40	136'101.00	98'084.00	40.20	46'605.00	327.12	0.67	0.74	0.79	0.85	0.58	9.50	12.23	24.63
Design Solution Battery																				
System	PV-Modul	Storage Volume	Self-sufficiency [%]	Own-consumption ratio [%]	PV Material + Installation [CHF]	System Components + Installation [CHF]	CAPEX [CHF]	Grid Feed [kWh]	lectricity consumption	Energy Deficit [kWh]	Self Consumption	CAPEX [kCHF]	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	BEP [year]		
PV_Battery	100	50	24	90	CHF 54'208.00	CHF 157'633.00	CHF 194'981.00	2'581.00	97'902.00	40.20	23'520.00	194.98	0.94	1.03	0.99	1.00	1.00	17.76	541.04	46.62
	200	50	35	66	CHF 86'737.00	CHF 157'633.00	CHF 216'630.00	17'696.00	97'859.00	40.20	34'506.00	216.63	0.86	0.95	0.93	0.94	0.92	11.15	22.72	30.47
	300	50	42	52	CHF 119'266.00	CHF 157'633.00	CHF 242'599.00	37'557.00	97'838.00	40.20	40'746.00	242.60	0.81	0.89	0.89	0.91	0.85	10.24	16.49	27.33
	400	50	46	43	CHF 151'795.00	CHF 157'633.00	CHF 266'428.00	59'799.00	97'825.00	40.20	44'604.00	266.43	0.77	0.85	0.86	0.89	0.78	9.85	14.35	26.03
	500	50	48	36	CHF 184'324.00	CHF 157'633.00	CHF 290'257.00	83'104.00	97'816.00	40.20	47'400.00	290.26	0.73	0.81	0.83	0.88	0.72	9.72	13.35	25.47
	600	50	51	32	CHF 216'853.00	CHF 157'633.00	CHF 314'086.00	107'155.00	97'809.00	40.20	49'450.00	314.09	0.70	0.77	0.81	0.87	0.66	9.71	12.82	25.27
	700	50	52	28	CHF 249'382.00	CHF 157'633.00	CHF 337'915.00	131'726.00	97'804.00	40.20	50'979.00	337.92	0.67	0.74	0.79	0.86	0.60	9.76	12.52	25.25
System	PV-Modul	Storage Volume	Self-sufficiency [%]	Own-consumption ratio [%]	PV Material + Installation [CHF]	System Components + Installation [CHF]	CAPEX [CHF]	Grid Feed [kWh]	lectricity consumption	Energy Deficit [kWh]	Self consumption		TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	BEP [year]		
PV_Battery	100	100	26	97	CHF 54'208.00	CHF 189'433.00	CHF 226'781.00	670.00	97'882.00	40.20	25'431.00	226.78	0.99	1.09	1.06	1.07	1.08	42.19	-	91.33
	200	100	39	74	CHF 86'737.00	CHF 189'433.00	CHF 248'430.00	13'727.00	97'821.00	40.20	38'475.00	248.43	0.90	0.99	0.98	1.00	0.99	16.94	45.16	43.57
	300	100	47	59	CHF 119'266.00	CHF 189'433.00	CHF 274'399.00	32'279.00	97'796.00	40.20	46'023.00	274.40	0.85	0.93	0.93	0.96	0.92	13.74	23.96	35.44
	400	100	52	49	CHF 151'795.00	CHF 189'433.00	CHF 298'228.00	53'457.00	97'781.00	40.20	50'946.00	298.23	0.80	0.88	0.90	0.94	0.85	12.40	18.77	32.01
	500	100	56	42	CHF 184'324.00	CHF 189'433.00	CHF 322'057.00	76'235.00	97'773.00	40.20	54'269.00	322.06	0.76	0.84	0.87	0.92	0.79	11.80	16.59	30.37
	600	100	58	36	CHF 216'853.00	CHF 189'433.00	CHF 345'886.00	99'780.00	97'766.00	40.20	56'824.00	345.89	0.73	0.80	0.84	0.91	0.72	11.48	15.38	29.43
	700	100	60	32	CHF 249'382.00	CHF 189'433.00	CHF 369'715.00	123'892.00	97'761.00	40.20	58'813.00	369.72	0.69	0.76	0.82	0.90	0.66	11.30	14.64	28.87
System	PV-Modul	Storage Volume	Self-sufficiency [%]	Own-consumption ratio [%]	PV Material + Installation [CHF]	System Components + Installation [CHF]	CAPEX [CHF]	Grid Feed [kWh]	lectricity consumption	Energy Deficit [kWh]	Self Consumption		TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	TCO/TCO_ref	BEP [year]		
PV_Battery	100	200	26	99	CHF 54'208.00	CHF 247'933.00	CHF 285'281.00	167.00	97'882.00	40.20	25'934.00	285.28	1.10	1.21	1.19	1.20	1.23	-	-	-
	200	200	41	77	CHF 86'737.00	CHF 247'933.00	CHF 306'930.00	11'902.00	97'812.00	40.20	40'300.00	306.93	1.01	1.11	1.10	1.13	1.14	57.92	-	110.87
	300	200	50	62	CHF 119'266.00	CHF 247'933.00	CHF 332'899.00	29'513.00	97'785.00	40.20	48'790.00	332.90	0.95	1.04	1.05	1.09	1.07	29.27	97.50	66.78
	400	200	56	53	CHF 151'795.00	CHF 247'933.00	CHF 356'728.00	49'247.00	97'765.00	40.20	55'157.00	356.73	0.89	0.98	1.01	1.06	0.99	21.87	41.58	52.32
	500	200	61	46	CHF 184'324.00	CHF 247'933.00	CHF 380'557.00	70'593.00	97'751.00	40.20	59'911.00	380.56	0.85	0.93	0.98	1.04	0.92	18.67	29.63	45.49
	600	200	65	40	CHF 216'853.00	CHF 247'933.00	CHF 404'386.00	93'182.00	97'741.00	40.20	63'423.00	404.39	0.81	0.89	0.95	1.02	0.86	16.97	24.57	41.68
	700	200	68	36	CHF 249'382.00	CHF 247'933.00	CHF 428'215.00	116'548.00	97'733.00	40.20	66'158.00	428.22	0.77	0.85	0.92	1.00	0.80	15.92	21.77	39.26

Appendix 24: ST system TCO results

Szenario 0

Row	System	ST-Modul	Index	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	Opex [CHF]	E-Cost [CHF]
17				TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	Opex [CHF]	E-Cost [CHF]
18	0-System	0		CHF 979'826.51	CHF 36'505.05	CHF 35'463.17	CHF 146'233.05	0.07	CHF 763'709.00	CHF 15'274.18
19				1	2	8	14			
20			Index	Szenario 0						
21	System	ST-Modul		TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	Opex [CHF]	E-Cost [CHF]
22		10	1	CHF 928'817.81	CHF 37'265.18	CHF 103'427.90	CHF 163'730.55	0.13	CHF 580'161.60	CHF 11'603.23
23		50	2	CHF 960'641.25	CHF 40'555.74	CHF 144'559.90	CHF 245'994.55	0.19	CHF 425'415.60	CHF 8'508.31
24		100	3	CHF 1'111'528.65	CHF 44'668.94	CHF 195'974.90	CHF 348'824.55	0.26	CHF 323'341.20	CHF 6'466.82
25		120	4	CHF 1'185'644.97	CHF 46'314.22	CHF 216'540.90	CHF 389'956.55	0.28	CHF 296'272.80	CHF 5'925.46
26		150	5	CHF 1'301'501.25	CHF 48'782.14	CHF 247'389.90	CHF 451'654.55	0.30	CHF 260'352.00	CHF 5'207.04
27		200	6	CHF 1'514'157.45	CHF 52'895.34	CHF 298'804.90	CHF 554'484.55	0.33	CHF 220'046.40	CHF 4'400.93
28		250	7	CHF 1'740'479.25	CHF 57'008.54	CHF 350'219.90	CHF 657'314.55	0.34	CHF 193'406.40	CHF 3'868.13
29		300	8	CHF 1'974'177.45	CHF 61'121.74	CHF 401'634.90	CHF 760'144.55	0.35	CHF 174'142.80	CHF 3'482.86
30										
31		10	1	CHF 1'029'845.55	CHF 38'489.14	CHF 145'511.00	CHF 163'730.55	0.17	CHF 579'132.00	CHF 11'582.64
32		50	2	CHF 1'058'180.59	CHF 41'779.70	CHF 186'643.00	CHF 245'994.55	0.23	CHF 420'897.60	CHF 8'417.95
33		80	3	CHF 1'141'478.47	CHF 44'247.62	CHF 217'492.00	CHF 307'692.55	0.27	CHF 352'418.40	CHF 7'048.37
34		100	4	CHF 1'205'838.79	CHF 45'892.90	CHF 238'058.00	CHF 348'824.55	0.29	CHF 315'594.00	CHF 6'311.88
35		150	5	CHF 1'388'388.19	CHF 50'006.10	CHF 289'473.00	CHF 451'654.55	0.33	CHF 245'181.60	CHF 4'903.63
36		200	6	CHF 1'598'999.59	CHF 54'119.30	CHF 340'888.00	CHF 554'484.55	0.35	CHF 202'831.20	CHF 4'056.62
37		250	7	CHF 1'820'263.39	CHF 58'232.50	CHF 392'303.00	CHF 657'314.55	0.36	CHF 171'133.20	CHF 3'422.66
38	ST_SWT	300	8	CHF 2'047'218.79	CHF 62'345.70	CHF 443'718.00	CHF 760'144.55	0.37	CHF 145'126.80	CHF 2'902.54
39										
40		10	1	CHF 925'924.47	CHF 37'107.92	CHF 108'128.70	CHF 163'730.55	0.12	CHF 580'273.20	CHF 11'605.46
41		50	2	CHF 957'963.91	CHF 40'398.48	CHF 149'260.70	CHF 245'994.55	0.19	CHF 425'743.20	CHF 8'514.86
42		60	3	CHF 983'086.27	CHF 41'221.12	CHF 159'543.70	CHF 266'560.55	0.20	CHF 400'273.20	CHF 8'005.46
43		100	4	CHF 1'111'644.91	CHF 44'511.68	CHF 200'675.70	CHF 348'824.55	0.25	CHF 326'462.40	CHF 6'529.25
44		150	5	CHF 1'303'809.91	CHF 48'624.88	CHF 252'090.70	CHF 451'654.55	0.29	CHF 265'665.60	CHF 5'313.31
45		200	6	CHF 1'519'666.51	CHF 52'738.08	CHF 303'505.70	CHF 554'484.55	0.32	CHF 228'560.40	CHF 4'571.21
46		250	7	CHF 1'746'891.91	CHF 56'851.28	CHF 354'920.70	CHF 657'314.55	0.34	CHF 202'824.00	CHF 4'056.48
47		300	8	CHF 1'981'288.51	CHF 60'964.48	CHF 406'335.70	CHF 760'144.55	0.35	CHF 184'258.80	CHF 3'685.18
48										
49		10	1	CHF 872'916.09	CHF 36'593.30	CHF 94'178.70	CHF 163'730.55	0.10	CHF 566'431.20	CHF 11'328.62
50		50	2	CHF 910'171.93	CHF 39'883.86	CHF 135'310.70	CHF 245'994.55	0.17	CHF 417'117.60	CHF 8'342.35
51		100	3	CHF 1'070'919.73	CHF 43'997.06	CHF 186'725.70	CHF 348'824.55	0.24	CHF 324'903.60	CHF 6'498.07
52		150	4	CHF 1'283'511.13	CHF 48'110.26	CHF 238'140.70	CHF 451'654.55	0.28	CHF 284'533.20	CHF 5'690.66
53		200	5	CHF 1'514'916.13	CHF 52'223.46	CHF 289'555.70	CHF 554'484.55	0.30	CHF 262'976.40	CHF 5'259.53
54		250	6	CHF 1'754'975.53	CHF 56'336.66	CHF 340'970.70	CHF 657'314.55	0.32	CHF 250'074.00	CHF 5'001.48
55		300	7	CHF 2'001'694.93	CHF 60'449.86	CHF 392'385.70	CHF 760'144.55	0.33	CHF 243'831.60	CHF 4'876.63
56			8							
57										
58	System	ST-Modul		TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	Opex [CHF]	E-Cost [CHF]
59		130	1	CHF 1'511'274.85	CHF 93'569.32	CHF 222'022.24	CHF 541'845.45	0.27	CHF 426'932.00	CHF 8'538.64
60		150	2	CHF 1'598'643.57	CHF 95'214.60	CHF 242'588.24	CHF 582'977.45	0.28	CHF 413'116.00	CHF 8'262.32
61		200	3	CHF 1'825'403.37	CHF 99'327.80	CHF 294'003.24	CHF 685'807.45	0.31	CHF 386'914.00	CHF 7'738.28
62		250	4	CHF 2'063'790.17	CHF 103'441.00	CHF 345'418.24	CHF 788'637.45	0.32	CHF 372'339.00	CHF 7'446.78
63		300	5	CHF 2'307'456.97	CHF 107'554.20	CHF 396'833.24	CHF 891'467.45	0.33	CHF 363'044.00	CHF 7'260.88
64										
65		150	1	CHF 1'571'097.51	CHF 94'777.10	CHF 231'650.72	CHF 582'977.45	0.28	CHF 417'945.00	CHF 8'358.90
66	ST_Ice Storage	160	2	CHF 1'614'847.87	CHF 95'599.74	CHF 241'933.72	CHF 603'543.45	0.28	CHF 411'103.00	CHF 8'222.06
67		200	3	CHF 1'799'408.31	CHF 98'890.30	CHF 283'065.72	CHF 685'807.45	0.30	CHF 393'294.00	CHF 7'865.88
68		250	4	CHF 2'038'444.11	CHF 103'003.50	CHF 334'480.72	CHF 788'637.45	0.31	CHF 379'368.00	CHF 7'587.36
69		300	5	CHF 2'283'166.91	CHF 107'116.70	CHF 385'895.72	CHF 891'467.45	0.32	CHF 371'129.00	CHF 7'422.58
70										
71		110	1	CHF 1'436'863.86	CHF 92'247.64	CHF 209'546.35	CHF 500'713.45	0.27	CHF 429'759.00	CHF 8'595.18
72		150	2	CHF 1'613'273.30	CHF 95'538.20	CHF 250'678.35	CHF 582'977.45	0.29	CHF 403'799.00	CHF 8'075.98
73		200	3	CHF 1'844'312.10	CHF 99'651.40	CHF 302'093.35	CHF 685'807.45	0.31	CHF 381'876.00	CHF 7'637.52
74		250	4	CHF 2'082'885.90	CHF 103'764.60	CHF 353'508.35	CHF 788'637.45	0.33	CHF 367'488.00	CHF 7'349.76
75		300	5	CHF 2'326'497.70	CHF 107'877.80	CHF 404'923.35	CHF 891'467.45	0.34	CHF 358'138.00	CHF 7'162.76
76										

Szenario 1

Row	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	Opex [CHF]	E-Cost [CHF]
17	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	Opex [CHF]	E-Cost [CHF]
18	CHF 643'126.04	CHF 13'562.65	CHF 22'733.37	CHF 83'059.17	0.11	CHF 479'969.81	CHF 15'274.18
19		2	8	14			
20	Szenario 1						
21	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	Opex [CHF]	E-Cost [CHF]
22	CHF 629'814.95	CHF 13'845.05	CHF 66'301.58	CHF 93'980.09	0.19	CHF 364'615.39	CHF 11'603.23
23	CHF 674'312.64	CHF 15'067.59	CHF 92'668.90	CHF 144'122.54	0.27	CHF 267'361.84	CHF 8'508.31
24	CHF 807'100.77	CHF 16'595.76	CHF 125'628.06	CHF 206'800.60	0.36	CHF 203'210.93	CHF 6'466.82
25	CHF 868'864.65	CHF 17'207.02	CHF 138'811.72	CHF 231'871.82	0.38	CHF 186'199.19	CHF 5'925.46
26	CHF 964'452.85	CHF 18'123.93	CHF 158'587.21	CHF 269'478.66	0.41	CHF 163'623.97	CHF 5'207.04
27	CHF 1'136'060.95	CHF 19'652.09	CHF 191'546.36	CHF 332'156.72	0.43	CHF 138'293.03	CHF 4'400.93
28	CHF 1'316'257.50	CHF 21'180.26	CHF 224'505.51	CHF 394'834.78	0.45	CHF 121'550.53	CHF 3'868.13
29	CHF 1'501'089.90	CHF 22'708.43	CHF 257'464.66	CHF 457'512.84	0.47	CHF 109'443.89	CHF 3'482.86
30							
31	CHF 716'888.35	CHF 14'299.79	CHF 93'278.60	CHF 93'980.09	0.25	CHF 363'968.31	CHF 11'582.64
32	CHF 759'193.68	CHF 15'522.33	CHF 119'645.92	CHF 144'122.54	0.32	CHF 264'522.41	CHF 8'417.95
33	CHF 834'319.84	CHF 16'439.23	CHF 139'421.41	CHF 181'729.38	0.37	CHF 221'485.14	CHF 7'048.37
34	CHF 889'952.35	CHF 17'050.49	CHF 152'605.07	CHF 206'800.60	0.39	CHF 198'342.03	CHF 6'311.88
35	CHF 1'042'639.16	CHF 18'578.66	CHF 185'564.22	CHF 269'478.66	0.43	CHF 154'089.80	CHF 4'903.63
36	CHF 1'212'962.16	CHF 20'106.83	CHF 218'523.38	CHF 332'156.72	0.46	CHF 127'473.75	CHF 4'056.62
37	CHF 1'389'979.89	CHF 21'635.00	CHF 251'482.53	CHF 394'834.78	0.47	CHF 107'552.44	CHF 3'422.66
38	CHF 1'570'574.64	CHF 23'163.17	CHF 284'441.68	CHF 457'512.84	0.48	CHF 91'208.15	CHF 2'902.54
39							
40	CHF 625'093.92	CHF 13'786.63	CHF 69'314.99	CHF 93'980.09	0.18	CHF 364'685.53	CHF 11'605.46
41	CHF 669'727.36	CHF 15'009.16	CHF 95'682.31	CHF 144'122.54	0.26	CHF 267'567.73	CHF 8'514.86
42	CHF 693'107.98	CHF 15'314.80	CHF 102'274.14	CHF 156'658.15	0.29	CHF 251'560.55	CHF 8'005.46
43	CHF 804'271.19	CHF 16'537.33	CHF 128'641.46	CHF 206'800.60	0.35	CHF 205'172.52	CHF 6'529.25
44	CHF 963'001.14	CHF 18'065.50	CHF 161'600.62	CHF 269'478.66	0.40	CHF 166'963.42	CHF 5'313.31
45	CHF 1'136'620.60	CHF 19'593.67	CHF 194'559.77	CHF 332'156.72	0.43	CHF 143'643.84	CHF 4'571.21
46	CHF 1'317'385.03	CHF 21'121.84	CHF 227'518.92	CHF 394'834.78	0.45	CHF 127'469.23	CHF 4'056.48
47	CHF 1'502'656.36	CHF 22'650.00	CHF 260'478.07	CHF 457'512.84	0.46	CHF 115'801.52	CHF 3'685.18
48							
49	CHF 581'912.28	CHF 13'595.43	CHF 60'372.46	CHF 93'980.09	0.15	CHF 355'986.22	CHF 11'328.62
50	CHF 629'824.08	CHF 14'817.97	CHF 86'739.78	CHF 144'122.54	0.24	CHF 262'146.78	CHF 8'342.35
51	CHF 768'809.19	CHF 16'346.13	CHF 119'698.93	CHF 206'800.60	0.33	CHF 204'192.85	CHF 6'498.07
52	CHF 940'376.56	CHF 17'874.30	CHF 152'658.09	CHF 269'478.66	0.38	CHF 178'821.18	CHF 5'690.66
53	CHF 1'123'767.76	CHF 19'402.47	CHF 185'617.24	CHF 332'156.72	0.41	CHF 165'273.34	CHF 5'259.53
54	CHF 1'312'598.00	CHF 20'930.64	CHF 218'576.39	CHF 394'834.78	0.43	CHF 157'164.54	CHF 5'001.48
55	CHF 1'505'613.87	CHF 22'458.81	CHF 251'535.54	CHF 457'512.84	0.44	CHF 153'241.36	CHF 4'876.63
56							
57							
58	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	Opex [CHF]	E-Cost [CHF]
59	CHF 1'108'976.18	CHF 34'763.61	CHF 142'325.48	CHF 319'054.98	0.37	CHF 268'314.86	CHF 8'538.64
60	CHF 1'179'068.83	CHF 35'374.88	CHF 155'509.14	CHF 344'126.20	0.39	CHF 259'631.89	CHF 8'262.32
61	CHF 1'359'540.65	CHF 36'903.05	CHF 188'468.29	CHF 406'804.26	0.41	CHF 243'164.66	CHF 7'738.28
62	CHF 1'547'319.71	CHF 38'431.22	CHF 221'427.45	CHF 469'482.32	0.43	CHF 234'004.68	CHF 7'446.78
63	CHF 1'738'417.10	CHF 39'959.38	CHF 254'386.60	CHF 532'160.38	0.44	CHF 228'163.03	CHF 7'260.88
64							
65	CHF 1'153'379.82	CHF 35'212.33	CHF 148'497.74	CHF 344'126.20	0.38	CHF 262'666.78	CHF 8'358.90
66	CHF 1'188'467.62	CHF 35'517.97	CHF 155'089.57	CHF 356'661.81	0.38	CHF 258'366.77	CHF 8'222.06
67	CHF 1'334'826.40	CHF 36'740.50	CHF 181'456.89	CHF 406'804.26	0.40	CHF 247'174.31	CHF 7'865.88
68	CHF 1'523'013.34	CHF 38'268.67	CHF 214'416.04	CHF 469'482.32	0.42	CHF 238'422.21	CHF 7'587.36
69	CHF 1'714'774.40	CHF 39'796.84	CHF 247'375.19	CHF 532'160.38	0.43	CHF 233'244.23	CHF 7'422.58
70							
71	CHF 1'053'223.35	CHF 34'272.57	CHF 134'327.92	CHF 293'983.76	0.37	CHF 270'091.55	CHF 8'595.18
72	CHF 1'194'459.45	CHF 35'495.11	CHF 160'695.24	CHF 344'126.20	0.39	CHF 253'776.41	CHF 8'075.98
73	CHF 1'377'620.50	CHF 37'023.27	CHF 193'654.39	CHF 406'804.26	0.42	CHF 239'998.42	CHF 7'637.52
74	CHF 1'565'517.09	CHF 38'551.44	CHF 226'613.54	CHF 469'482.32	0.43	CHF 230'955.96	CHF 7'349.76
75	CHF 1'756'579.91	CHF 40'079.61	CHF 259'572.70	CHF 532'160.38	0.44	CHF 225'079.75	CHF 7'162.76
76							

Appendix 25: PV system TCO results

Row	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
14									
15									
16									
17			TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
18	0-System	0	CHF 1'518'353.51	CHF 36'505.05	CHF 35'463.17	CHF 146'233.05	0.05	CHF 1'302'236.00	CHF 26'044.72
19				2	8	14			
20			Szenario 0						
21	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
22	PV_only	50	CHF 1'419'148.00	CHF 83'214.27	CHF 94'983.47	CHF 318'314.50	0.10	CHF 943'517.80	CHF 18'870.36
23		100	CHF 1'359'924.65	CHF 89'177.92	CHF 103'115.72	CHF 334'579.00	0.12	CHF 854'526.85	CHF 17'090.54
24		200	CHF 1'272'533.35	CHF 101'105.22	CHF 119'380.22	CHF 367'108.00	0.14	CHF 708'620.35	CHF 14'172.41
25		300	CHF 1'200'019.05	CHF 113'032.52	CHF 135'644.72	CHF 399'637.00	0.17	CHF 573'270.85	CHF 11'465.42
26		400	CHF 1'150'104.00	CHF 124'959.82	CHF 151'909.22	CHF 432'166.00	0.20	CHF 462'660.60	CHF 9'253.21
27		500	CHF 1'099'488.95	CHF 136'887.12	CHF 168'173.72	CHF 464'695.00	0.23	CHF 351'350.35	CHF 7'027.01
28		600	CHF 1'053'008.50	CHF 148'814.42	CHF 184'438.22	CHF 497'224.00	0.26	CHF 244'174.70	CHF 4'883.49
29		700	CHF 1'009'152.00	CHF 160'741.72	CHF 200'702.72	CHF 529'753.00	0.30	CHF 139'623.00	CHF 2'792.46
30	Design Solution PV only								
31	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
32	PV_30kWh Battery	100	CHF 1'406'791.71	CHF 104'196.44	CHF 117'021.25	CHF 389'191.80	0.13	CHF 820'587.70	CHF 16'411.75
33		200	CHF 1'296'767.16	CHF 116'123.74	CHF 133'285.75	CHF 421'720.80	0.16	CHF 652'047.95	CHF 13'040.96
34		300	CHF 1'226'747.31	CHF 128'051.04	CHF 149'550.25	CHF 454'249.80	0.19	CHF 519'192.90	CHF 10'383.86
35		400	CHF 1'165'795.36	CHF 139'978.34	CHF 165'814.75	CHF 486'778.80	0.22	CHF 397'545.75	CHF 7'950.92
36		500	CHF 1'112'670.96	CHF 151'905.64	CHF 182'079.25	CHF 519'307.80	0.25	CHF 283'726.15	CHF 5'674.52
37		600	CHF 1'080'152.36	CHF 163'832.94	CHF 198'343.75	CHF 551'836.80	0.28	CHF 190'512.35	CHF 3'810.25
38		700	CHF 1'019'835.56	CHF 175'760.24	CHF 214'608.25	CHF 584'365.80	0.32	CHF 69'500.35	CHF 1'390.01
39	Design Solution Battery								
40	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
41	PV_50kWh Battery	100	CHF 1'426'824.15	CHF 110'132.92	CHF 122'415.72	CHF 410'779.00	0.14	CHF 808'781.35	CHF 16'175.63
42		200	CHF 1'308'850.60	CHF 122'060.22	CHF 138'680.22	CHF 443'308.00	0.17	CHF 632'292.60	CHF 12'645.85
43		300	CHF 1'230'322.15	CHF 133'987.52	CHF 154'944.72	CHF 475'837.00	0.20	CHF 490'928.95	CHF 9'818.58
44		400	CHF 1'167'253.05	CHF 145'914.82	CHF 171'209.22	CHF 508'366.00	0.23	CHF 367'164.65	CHF 7'343.29
45		500	CHF 1'112'030.00	CHF 157'842.12	CHF 187'473.72	CHF 540'895.00	0.26	CHF 251'246.40	CHF 5'024.93
46		600	CHF 1'062'312.05	CHF 169'769.42	CHF 203'738.22	CHF 573'424.00	0.30	CHF 140'833.25	CHF 2'816.67
47		700	CHF 1'016'449.10	CHF 181'696.72	CHF 220'002.72	CHF 605'953.00	0.33	CHF 34'275.10	CHF 685.50
48									
49	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
50	PV_100kWh Battery	100	CHF 1'506'368.30	CHF 127'622.92	CHF 138'315.72	CHF 474'379.00	0.15	CHF 794'515.50	CHF 15'890.31
51		200	CHF 1'373'070.45	CHF 139'550.22	CHF 154'580.22	CHF 506'908.00	0.18	CHF 602'702.45	CHF 12'054.05
52		300	CHF 1'284'887.85	CHF 151'477.52	CHF 170'844.72	CHF 539'437.00	0.21	CHF 451'684.65	CHF 9'033.69
53		400	CHF 1'213'965.35	CHF 163'404.82	CHF 187'109.22	CHF 571'966.00	0.25	CHF 320'066.95	CHF 6'401.34
54		500	CHF 1'154'879.85	CHF 175'332.12	CHF 203'373.72	CHF 604'495.00	0.28	CHF 200'286.25	CHF 4'005.73
55		600	CHF 1'101'453.80	CHF 187'259.42	CHF 219'638.22	CHF 637'024.00	0.31	CHF 86'165.00	CHF 1'723.30
56		700	CHF 1'052'206.20	CHF 199'186.72	CHF 235'902.72	CHF 669'553.00	0.35	-CHF 23'777.80	-CHF 475.56
57									
58	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
59	PV_200kWh Battery	100	CHF 1'675'246.25	CHF 159'797.92	CHF 167'565.72	CHF 591'379.00	0.17	CHF 790'818.45	CHF 15'816.37
60		200	CHF 1'532'132.70	CHF 171'725.22	CHF 183'830.22	CHF 623'908.00	0.20	CHF 589'189.70	CHF 11'783.79
61		300	CHF 1'437'000.75	CHF 183'652.52	CHF 200'094.72	CHF 656'437.00	0.23	CHF 431'222.55	CHF 8'624.45
62		400	CHF 1'355'409.85	CHF 195'579.82	CHF 216'359.22	CHF 688'966.00	0.26	CHF 288'936.45	CHF 5'778.73
63		500	CHF 1'285'744.15	CHF 207'507.12	CHF 232'623.72	CHF 721'495.00	0.30	CHF 158'575.55	CHF 3'171.51
64		600	CHF 1'225'247.50	CHF 219'434.42	CHF 248'888.22	CHF 754'024.00	0.33	CHF 37'383.70	CHF 747.67
65		700	CHF 1'170'483.80	CHF 231'361.72	CHF 265'152.72	CHF 786'553.00	0.37	-CHF 78'075.20	-CHF 1'561.50

Row	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
17			TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
18	0-System	0	CHF 1'381'057.51	CHF 36'505.05	CHF 35'463.17	CHF 146'233.05	0.05	CHF 1'164'940.00	CHF 23'298.80
19				2	8	14			
20			Szenario 1						
21	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
22	PV_only	50	CHF 1'419'148.00	CHF 83'214.27	CHF 94'983.47	CHF 318'314.50	0.10	CHF 943'517.80	CHF 18'870.36
23		100	CHF 1'359'924.65	CHF 89'177.92	CHF 103'115.72	CHF 334'579.00	0.12	CHF 854'526.85	CHF 17'090.54
24		200	CHF 1'272'533.35	CHF 101'105.22	CHF 119'380.22	CHF 367'108.00	0.14	CHF 708'620.35	CHF 14'172.41
25		300	CHF 1'200'019.05	CHF 113'032.52	CHF 135'644.72	CHF 399'637.00	0.17	CHF 573'270.85	CHF 11'465.42
26		400	CHF 1'150'104.00	CHF 124'959.82	CHF 151'909.22	CHF 432'166.00	0.20	CHF 462'660.60	CHF 9'253.21
27		500	CHF 1'099'488.95	CHF 136'887.12	CHF 168'173.72	CHF 464'695.00	0.23	CHF 351'350.35	CHF 7'027.01
28		600	CHF 1'053'008.50	CHF 148'814.42	CHF 184'438.22	CHF 497'224.00	0.26	CHF 244'174.70	CHF 4'883.49
29		700	CHF 1'009'152.00	CHF 160'741.72	CHF 200'702.72	CHF 529'753.00	0.30	CHF 139'623.00	CHF 2'792.46
31	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
32	PV_30kWh Battery	100	CHF 1'406'791.71	CHF 104'196.44	CHF 117'021.25	CHF 389'191.80	0.13	CHF 820'587.70	CHF 16'411.75
33		200	CHF 1'296'767.16	CHF 116'123.74	CHF 133'285.75	CHF 421'720.80	0.16	CHF 652'047.95	CHF 13'040.96
34		300	CHF 1'226'747.31	CHF 128'051.04	CHF 149'550.25	CHF 454'249.80	0.19	CHF 519'192.90	CHF 10'383.86
35		400	CHF 1'165'795.36	CHF 139'978.34	CHF 165'814.75	CHF 486'778.80	0.22	CHF 397'545.75	CHF 7'950.92
36		500	CHF 1'112'670.96	CHF 151'905.64	CHF 182'079.25	CHF 519'307.80	0.25	CHF 283'726.15	CHF 5'674.52
37		600	CHF 1'080'152.36	CHF 163'832.94	CHF 198'343.75	CHF 551'836.80	0.28	CHF 190'512.35	CHF 3'810.25
38		700	CHF 1'019'835.56	CHF 175'760.24	CHF 214'608.25	CHF 584'365.80	0.32	CHF 69'500.35	CHF 1'390.01
40	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
41	PV_50kWh Battery	100	CHF 1'426'824.15	CHF 110'132.92	CHF 122'415.72	CHF 410'779.00	0.14	CHF 808'781.35	CHF 16'175.63
42		200	CHF 1'308'850.60	CHF 122'060.22	CHF 138'680.22	CHF 443'308.00	0.17	CHF 632'292.60	CHF 12'645.85
43		300	CHF 1'230'322.15	CHF 133'987.52	CHF 154'944.72	CHF 475'837.00	0.20	CHF 490'928.95	CHF 9'818.58
44		400	CHF 1'167'253.05	CHF 145'914.82	CHF 171'209.22	CHF 508'366.00	0.23	CHF 367'164.65	CHF 7'343.29
45		500	CHF 1'112'030.00	CHF 157'842.12	CHF 187'473.72	CHF 540'895.00	0.26	CHF 251'246.40	CHF 5'024.93
46		600	CHF 1'062'312.05	CHF 169'769.42	CHF 203'738.22	CHF 573'424.00	0.30	CHF 140'833.25	CHF 2'816.67
47		700	CHF 1'016'449.10	CHF 181'696.72	CHF 220'002.72	CHF 605'953.00	0.33	CHF 34'275.10	CHF 685.50
49	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
50	PV_100kWh Battery	100	CHF 1'506'368.30	CHF 127'622.92	CHF 138'315.72	CHF 474'379.00	0.15	CHF 794'515.50	CHF 15'890.31
51		200	CHF 1'373'070.45	CHF 139'550.22	CHF 154'580.22	CHF 506'908.00	0.18	CHF 602'702.45	CHF 12'054.05
52		300	CHF 1'284'887.85	CHF 151'477.52	CHF 170'844.72	CHF 539'437.00	0.21	CHF 451'684.65	CHF 9'033.69
53		400	CHF 1'213'965.35	CHF 163'404.82	CHF 187'109.22	CHF 571'966.00	0.25	CHF 320'066.95	CHF 6'401.34
54		500	CHF 1'154'879.85	CHF 175'332.12	CHF 203'373.72	CHF 604'495.00	0.28	CHF 200'286.25	CHF 4'005.73
55		600	CHF 1'101'453.80	CHF 187'259.42	CHF 219'638.22	CHF 637'024.00	0.31	CHF 86'165.00	CHF 1'723.30
56		700	CHF 1'052'206.20	CHF 199'186.72	CHF 235'902.72	CHF 669'553.00	0.35	-CHF 23'777.80	-CHF 475.56
58	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
59	PV_200kWh Battery	100	CHF 1'675'246.25	CHF 159'797.92	CHF 167'565.72	CHF 591'379.00	0.17	CHF 790'818.45	CHF 15'816.37
60		200	CHF 1'532'132.70	CHF 171'725.22	CHF 183'830.22	CHF 623'908.00	0.20	CHF 589'189.70	CHF 11'783.79
61		300	CHF 1'437'000.75	CHF 183'652.52	CHF 200'094.72	CHF 656'437.00	0.23	CHF 431'222.55	CHF 8'624.45
62		400	CHF 1'355'409.85	CHF 195'579.82	CHF 216'359.22	CHF 688'966.00	0.26	CHF 288'936.45	CHF 5'778.73
63		500	CHF 1'285'744.15	CHF 207'507.12	CHF 232'623.72	CHF 721'495.00	0.30	CHF 158'575.55	CHF 3'171.51
64		600	CHF 1'225'247.50	CHF 219'434.42	CHF 248'888.22	CHF 754'024.00	0.33	CHF 37'383.70	CHF 747.67
65		700	CHF 1'170'483.80	CHF 231'361.72	CHF 265'152.72	CHF 786'553.00	0.37	-CHF 78'075.20	-CHF 1'561.50

Row	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
17			TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
18	0-System	0	CHF 984'652.05	CHF 13'562.65	CHF 22'733.37	CHF 83'059.17	0.07	CHF 821'495.83	CHF 26'142.63
19				2	8	14			
20			Szenario 2						
21	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
22	PV_only	50	CHF 954'189.22	CHF 30'916.42	CHF 60'888.35	CHF 180'268.61	0.15	CHF 598'402.18	CHF 19'043.08
23		100	CHF 921'218.35	CHF 33'132.08	CHF 66'101.46	CHF 189'247.77	0.17	CHF 542'120.21	CHF 17'252.01
24		200	CHF 874'689.38	CHF 37'563.41	CHF 76'527.68	CHF 207'206.08	0.20	CHF 449'989.02	CHF 14'320.10
25		300	CHF 839'240.57	CHF 41'994.73	CHF 86'953.90	CHF 225'164.40	0.24	CHF 364'618.00	CHF 11'603.32
26		400	CHF 817'341.34	CHF 46'426.06	CHF 97'380.12	CHF 243'122.71	0.28	CHF 294'936.56	CHF 9'385.83
27		500	CHF 795'030.71	CHF 50'857.38	CHF 107'806.35	CHF 261'081.02	0.32	CHF 224'843.72	CHF 7'155.25
28		600	CHF 775'354.20	CHF 55'288.71	CHF 118'232.57	CHF 279'039.34	0.36	CHF 157'385.00	CHF 5'008.50
29		700	CHF 757'349.21	CHF 59'720.03	CHF 128'658.79	CHF 296'997.65	0.40	CHF 91'597.80	CHF 2'914.94
31	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
32	PV_30kWh Battery	100	CHF 960'972.37	CHF 38'711.88	CHF 75'015.48	CHF 219'991.00	0.19	CHF 520'490.36	CHF 16'563.67
33		200	CHF 900'026.84	CHF 43'143.21	CHF 85'441.71	CHF 237'949.31	0.23	CHF 413'942.63	CHF 13'172.98
34		300	CHF 866'124.66	CHF 47'574.53	CHF 95'867.93	CHF 255'907.63	0.27	CHF 330'118.24	CHF 10'505.42
35		400	CHF 837'230.29	CHF 52'005.86	CHF 106'294.15	CHF 273'865.94	0.31	CHF 253'441.66	CHF 8'065.33
36		500	CHF 813'321.99	CHF 56'437.18	CHF 116'720.37	CHF 291'824.26	0.34	CHF 181'751.15	CHF 5'783.91
37		600	CHF 802'553.92	CHF 60'868.51	CHF 127'146.59	CHF 309'782.57	0.38	CHF 123'200.87	CHF 3'920.65
38		700	CHF 774'049.61	CHF 65'299.83	CHF 137'572.81	CHF 327'740.88	0.42	CHF 46'914.34	CHF 1'492.97
40	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
41	PV_50kWh Battery	100	CHF 977'651.45	CHF 40'917.45	CHF 78'473.57	CHF 232'143.10	0.20	CHF 512'971.23	CHF 16'324.39
42		200	CHF 911'642.25	CHF 45'348.78	CHF 88'899.79	CHF 250'101.42	0.24	CHF 401'359.83	CHF 12'772.56
43		300	CHF 872'327.87	CHF 49'780.10	CHF 99'326.01	CHF 268'059.73	0.28	CHF 312'123.23	CHF 9'932.76
44		400	CHF 842'084.38	CHF 54'211.42	CHF 109'752.23	CHF 286'018.04	0.32	CHF 234'097.54	CHF 7'449.74
45		500	CHF 816'838.92	CHF 58'642.75	CHF 120'178.45	CHF 303'976.36	0.36	CHF 161'069.86	CHF 5'125.76
46		600	CHF 795'100.26	CHF 63'074.07	CHF 130'604.67	CHF 321'934.67	0.40	CHF 91'549.00	CHF 2'913.38
47		700	CHF 775'817.24	CHF 67'505.40	CHF 141'030.89	CHF 339'892.98	0.44	CHF 24'483.77	CHF 779.15
49	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
50	PV_100kWh Battery	100	CHF 1'039'861.34	CHF 47'415.47	CHF 88'666.13	CHF 267'945.50	0.22	CHF 503'884.18	CHF 16'035.21
51		200	CHF 964'090.78	CHF 51'846.80	CHF 99'092.35	CHF 285'903.82	0.26	CHF 382'511.42	CHF 12'172.74
52		300	CHF 918'626.57	CHF 56'278.12	CHF 109'518.57	CHF 303'862.13	0.30	CHF 287'125.00	CHF 9'137.24
53		400	CHF 883'380.39	CHF 60'709.45	CHF 119'944.79	CHF 321'820.45	0.34	CHF 204'096.60	CHF 6'495.01
54		500	CHF 855'674.43	CHF 65'140.77	CHF 130'371.01	CHF 339'778.76	0.38	CHF 128'608.43	CHF 4'092.73
55		600	CHF 831'573.60	CHF 69'572.10	CHF 140'797.23	CHF 357'737.07	0.42	CHF 56'725.39	CHF 1'805.18
56		700	CHF 810'134.51	CHF 74'003.42	CHF 151'223.45	CHF 375'695.39	0.46	-CHF 12'495.91	-CHF 397.66
58	System	PV-Modul	TCO [CHF]	Residual Value [CHF]	Maintenance [CHF]	Replacement [CHF]	CAPEX/TCO	E-Cost tot [CHF]	E-Cost/a [CHF]
59	PV_200kWh Battery	100	CHF 1'168'665.70	CHF 59'369.38	CHF 107'416.59	CHF 333'808.42	0.24	CHF 501'529.08	CHF 15'960.27
60		200	CHF 1'086'642.60	CHF 63'800.71	CHF 117'842.81	CHF 351'766.73	0.28	CHF 373'903.77	CHF 11'898.82
61		300	CHF 1'036'751.59	CHF 68'232.03	CHF 128'269.03	CHF 369'725.04	0.32	CHF 274'090.55	CHF 8'722.44
62		400	CHF 994'709.55	CHF 72'663.36	CHF 138'695.25	CHF 387'683.36	0.36	CHF 184'266.30	CHF 5'863.95
63		500	CHF 960'263.92	CHF 77'094.68	CHF 149'121.47	CHF 405'641.67	0.40	CHF 102'038.45	CHF 3'247.19
64		600	CHF 931'659.08	CHF 81'526.01	CHF 159'547.69	CHF 423'599.99	0.43	CHF 25'651.40	CHF 816.31
65		700	CHF 906'706.20	CHF 85'957.33	CHF 169'973.91	CHF 441'558.30	0.47	-CHF 47'083.69	-CHF 1'498.35

Appendix 26: PV system costs

Input				
Input Field				
System	Name	Lifetime	CAPEX	
Komponenten	Valve	15	CHF 1'680.00	
	Pumps	15	CHF 6'312.00	
	Pipe	20	CHF 4'500.00	
	Heat Pump	15	CHF 65'830.00	130kW
	DHW Storage	15	CHF 10'961.00	2000L
	Electric Heatin Element DHW	15	CHF -	
	Buffer Storage	15	CHF 3'651.00	4000L
	Heat Pump accessories	15	CHF 2'023.00	
	Control System	15		
	Backup Heating	15		
	Installation	50	CHF 24'576.00	
	Maintenace System		1520.234439	
Subsidies				
Variabel Cost				
50	Photovoltaic elements (external)	30	CHF 37'943.50	
100	Photovoltaic elements (external)	30	CHF 54'208.00	
200	Photovoltaic elements (external)	30	CHF 86'737.00	
300	Photovoltaic elements (external)	30	CHF 119'266.00	
400	Photovoltaic elements (external)	30	CHF 151'795.00	
500	Photovoltaic elements (external)	30	CHF 184'324.00	
600	Photovoltaic elements (external)	30	CHF 216'853.00	
700	Photovoltaic elements (external)	30	CHF 249'382.00	
Variable Maintenance			Maintenance	
50	Photovoltaic elements (external)		1900	
100	Photovoltaic elements (external)		2062	
200	Photovoltaic elements (external)		2388	
300	Photovoltaic elements (external)		2713	
400	Photovoltaic elements (external)		3038	
500	Photovoltaic elements (external)		3363	
600	Photovoltaic elements (external)		3689	
700	Photovoltaic elements (external)		4014	

Appendix 27: PV + Battery system cost

Input				
Input Field				
System	Name	Lifetime	CAPEX	
Komponenten	Valve	15	CHF 1'680.00	
	Pumps	15	CHF 6'312.00	
	Pipe	20	CHF 4'500.00	
	Heat Pump	15	CHF 65'830.00	
	DHW Storage	15	CHF 10'961.00	
	Electric Heatin Element DHW	15	CHF -	
	Buffer Storage	15	CHF 3'651.00	
	Heat Pump accessories	15	CHF 2'023.00	
	Control System	15		
	Backup Heating	15		
	Installation	50	CHF 24'576.00	
Subsidies				
Variabel Cost PV				
100	Photovoltaic elements (external)	30	CHF 54'208.00	
200	Photovoltaic elements (external)	30	CHF 86'737.00	
300	Photovoltaic elements (external)	30	CHF 119'266.00	
400	Photovoltaic elements (external)	30	CHF 151'795.00	
500	Photovoltaic elements (external)	30	CHF 184'324.00	
600	Photovoltaic elements (external)	30	CHF 216'853.00	
700	Photovoltaic elements (external)	30	CHF 249'382.00	
Variabel Cost Battery				Maintenace tot
30	Battery	20	CHF 27'306.40	CHF 1'798.35
50	Battery	20	CHF 38'100.00	CHF 1'906.23
100	Battery	20	CHF 69'900.00	CHF 2'224.23
200	Battery	20	CHF 128'400.00	CHF 2'809.23
	Battery	20		
	Battery	20		
	Battery	20		

Appendix 28: Condensing boiler cost

Input				
Input Field				
System	Name	Lifetime	CAPEX	
Komponenten	Valve	15	1682	
	Pumps	15	9262	
	Pipe	20	5796	
	Condensing Boiler	15	3937	
	DHW Storage	15	24500	6000L
	Electric Heatin Element DHW	15	0	
	Boiler accessories	15	1538	
	Control system	15	3962	
Installation	Installation	50	20250	
Subsidies			0	
Maintenance			709	

Appendix 29: SWT system cost

System	Name	Lifetime	CAPEX
Komponenten	Valve	15	CHF 1'681.56
	Pumps	15	CHF 9'261.81
	Pipe	20	CHF 5'795.97
	Heat Pump	15	
	DHW Storage	15	
	Electric Heatin Element DHW	15	
	Buffer Storage	15	
	Heat Transfer Fluid (HTF)	15	
	Control System	15	CHF 1'063.70
	Backup Heating	15	CHF 30'800.00
	Installation	50	CHF 29'713.50
Subsidies			
Variabel Cost ST			
120	Soarthermie	25	CHF 249'943.40
80	Soarthermie	25	CHF 167'679.40
60	Soarthermie	25	CHF 126'547.40
10	Soarthermie	25	CHF 23'717.40
50	Soarthermie	25	CHF 105'981.40
100	Soarthermie	25	CHF 208'811.40
150	Soarthermie	25	CHF 311'641.40
200	Soarthermie	25	CHF 414'471.40
250	Soarthermie	25	CHF 517'301.40
300	Soarthermie	25	CHF 620'131.40
Variabel Cost Storage			
50000	Surface Water Tank	50	57'129.00
120000	Surface Water Tank	50	118'327.20
40000	Surface Water Tank	50	49'266.00
10000	Surface Water Tank	50	23'535.00

Appendix 30: Ice storage system cost

Input				
Input Field				
System	Name	Lifetime	CAPEX	
Komponenten	Valve	15	CHF 1'681.56	
	Pumps	15	CHF 9'261.81	
	Pipe	20	CHF 5'795.97	
	Heat Pump	15	CHF 56'570.00	100kW
	DHW Storage	15	CHF 11'876.00	2500L
	Electric Heatin Element DHW	15	CHF 0.00	
	Buffer Storage	15	CHF 4'189.00	4000L
	Control System	15	CHF 3'003.00	
	Back Up Heating	15	CHF 0.00	
	Installation	50	CHF 20'250.00	w/o Storage
Subsidies				
Variabel Cost ST				
130	Soarthermie	25	270509.4	
160	Soarthermie	25	332207.4	
110	Soarthermie	25	229377.4	
150	Soarthermie	25	311641.4	
200	Soarthermie	25	414471.4	
250	Soarthermie	25	517301.4	
300	Soarthermie	25	620131.4	
Variabel Cost Storage				
53.808	Ice Storage	50	60908	
31.89	Ice Storage	50	39033	
70.02	Ice Storage	50	77088	