AALBORG CSP
- Changing Energy



PRE-FEASIBILITY STUDY

Final report

AARHUS CENTRE TUZLA – UNIVERSITY OF TUZLA

Report on the dimensioning of the various components (PTES, heat pump, solar thermal system for REHEATEAST D.2.3.2 Transnational Supply Side Optimization Pilot 1

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1. Introduction

This study, which was commissioned by Aarhus Centre Tuzla, aims to investigate the future renewable district heating supply of the university campus in Tuzla, Bosnia Herzegovina. Various technologies were considered, such as Pit Thermal Energy Storage (PTES), a dual-source heat pump that can use both outdoor air and low-temperature PTES water, a solar thermal system and an electric boiler. These technologies and plants were analysed for the project in Tuzla regarding their suitability and dimensioned according to the scenario or district heating demand.

Aalborg CSP, in consultation with the Aarhus Centre and the University of Tuzla, has concluded that the initially designated system design with a solar thermal plant, PTES and heat pump is not suitable for the specific case of the University of Tuzla. Due to space limitations, restrictions respective to geography and geometry of the available land areas, lack of heat demand during summertime and increased heat storage demand, alternative and more suitable solution have been investigated.

It has been agreed to design a heat supply consisting of an air source heat pump and a steel tank heat storage for hourly, daily or weekly heat storage, while an electric boiler is integrated for redundancy, security of supply, operational flexibility and cost-efficient future integration of fluctuating renewable electricity. The proposed heat pump system is utilizing the environmentally friendly and real-life proven natural refrigerants propane and isobutane, allowing efficient heat production even during cold winter times when the heat demand is high. This solution promises enough available land areas, technical feasibility, as well as cost-efficient operation over the entire plant lifetime.

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1.1. Sector coupling for modern heat supply

District heating networks are being decarbonized by the integration of renewable energy sources, by creating synergies between the electricity sector and the heating sector through sector coupling and by using and storing waste heat or heat that would otherwise be lost. The goal of the district heating suppliers is now to supply their consumers with both cost-effective and green heat.

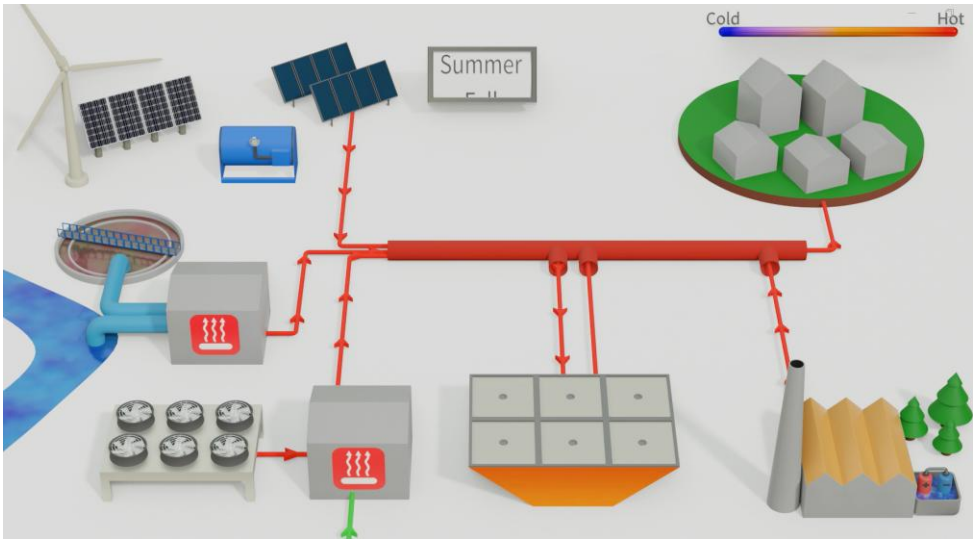


Figure 1: Concept of a sector-coupled energy system for renewable heat supply.

Moving to low-cost decarbonized heat generation is complex and requires an understanding of multiple technologies. In Tuzla's case, these technologies are:

- Thermal Energy Storage (TES): PTES or steel Tank Thermal Energy Storage (TTES)
  - Daily/weekly/seasonal storage
- Power-to-Heat
  - Electric heat pumps
    - Water-to-water heat pumps for cooling the heat storage.
    - Air-to-water heat pumps to generate heat and, if necessary, store it when electricity prices are low.
  - Electric boilers
- Solar thermal energy

In addition, electricity-generating components such as photovoltaics (PV) and wind turbines can also be included in the overall system. The complexity in a renewable heat and electricity system arises when low costs and security of supply are paramount, as this requires the integration of different technologies.

When integrating different technologies, it is important to understand the use cases and requirements, as this will affect the interconnectivity between the physical components. For the district heating supplier, it is advantageous to think of the entire system as a single unit with external interfaces, which can supply a certain amount of heat per year at the required temperature, similar to a conventional boiler. It is therefore necessary to know all the technologies involved and understand how they can best harmonize with each other.

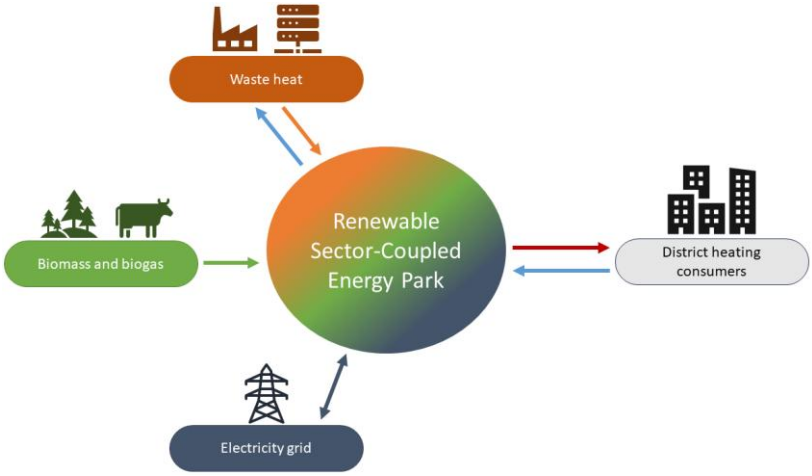


Figure 2: Diagram of the sector-coupled renewable energy park.

This report describes a sector-coupled renewable heat supply for the university campus of Tuzla, which can deliver future-proof, secure, price-stable, cost-effective renewable district heating on demand.

2. Overview of considered system technologies

In the energy system of the future, a variety of green technologies are interconnected to couple the electricity and heat sectors, ensuring auxiliary services and stability for the power grid while generating heat at low cost. The fluctuating renewable heat and electricity production and the associated fluctuating electricity price are bridged with a multifunctional heat storage system, such as the PTES.

2.1. Pit Thermal Energy Storage (PTES)

A Pit Thermal Energy Storage or PTES is a large thermal energy storage system that can be used as a seasonal or multifunctional heat storage system to supply demand-based heat as a base load and for peak periods. It can store heat at up to 95°C and can be cooled down to 10°C. The PTES can be connected to multiple heat sources that provide different temperatures, and it can serve as a heat source for an electric heat pump.

The PTES lid solution of Aalborg CSP is certified by Lloyd's Register. This floating cover has automatic and reliable rainwater drainage, is self-ventilating and permeable to diffusion, which allows for lower heat loss and prevents the formation of moisture accumulation within the insulation layers. The service life is more than 25 years, and the operation of the PTES-systems in Denmark show no signs of diminished performance even after years.

The PTES is an insulated reservoir or pit that is filled with water as a heat storage medium. When charging the PTES with heat, cold water is taken out from the bottom of the storage, while warm water is pushed in at the top of the storage through a diffusor. On the other hand, a discharge of the storage takes place by an inflow of cold water though the bottom diffusor of the storage and an outflow of the hot water in the top, which has been stored previously. Therefore, the water level in the PTES is stable. A sketch can be seen in Figure 3.

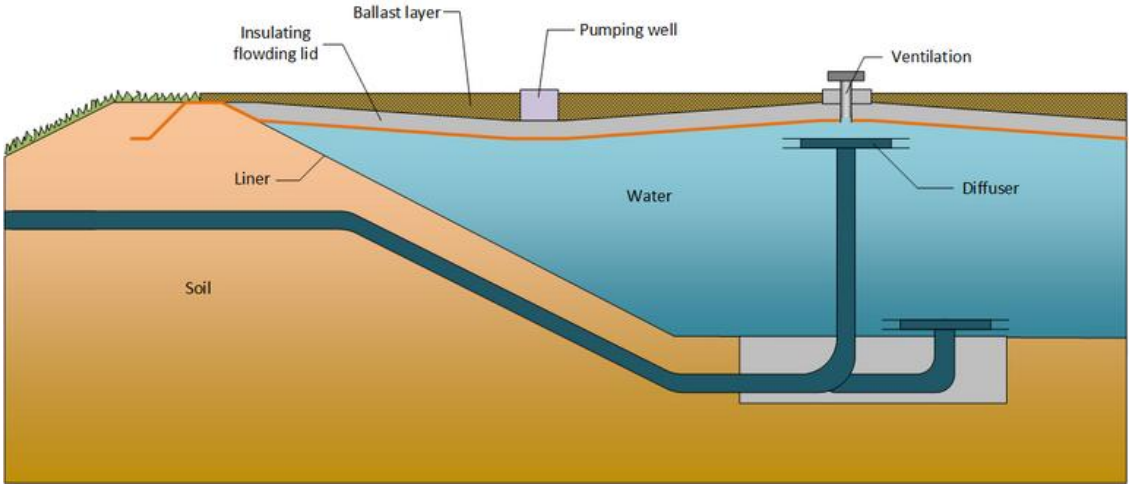


Figure 3: Sketch of a cross-section of the PTES and the certified insulating cover of Aalborg CSP.

The PTES is built by digging a pyramid-shaped pit where the ground is flat. After excavation, the pit is lined with a polymer lining that forms a watertight barrier to the surrounding soil. The pit is then filled with water, and the insulating cover is pulled over the water reservoir of the PTES. This process can be seen in the images in Figure 4 until Figure 9.



Figure 4: Lining of the pit and installation of three steel diffusers (inlet and outlet).

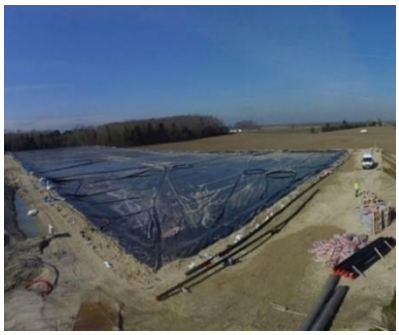


Figure 5: Temporary liner (sacrificial layer) of the pit during water filling.



Figure 6: Replacement of the temporary liner with permanent floating liner.



Figure 7: The filled pit is covered with a permanent floating liner.



Figure 8: Construction of Aalborg CSP's certified insulating cover.



Figure 9: Finished lid with gravel surface.

The cover supplied by Aalborg CSP is certified by Lloyd's Register, which covers a list of claims. Some of these certified properties are:

- Low heat loss for the entire PTES, depending on the storage size. This has also been shown in existing plants, e.g. in Dronninglund, Denmark, where heat losses are less than 10%
- Lifespan of at least 25 years with minimal maintenance costs.

The cover consists of:

- A high temperature resistant floating liner supplied in coordination with the company that provides the lining for the bottom and sides of the earth basin. This ensures a long service life.
- Multiple layers of insulation designed to withstand the hot temperatures and provide a good insulation value.
- A vapour-permeable membrane that ensures that water vapour can effectively diffuse out of the cover, increasing the life of the insulation material and reducing heat loss.
- A ballast layer with divided sections for automatic rainwater handling and reduced heat loss.

2.2. Tank Thermal Energy Storage (TTES)

For smaller storage capacities and volumes, for higher storage temperatures or for cases with limited space availability, tank thermal energy storages (TTES) are the preferred solution compared to a PTES. These storages are typically cheaper on the smaller scales compared to PTES systems. However, the limited storage volumes compared to the PTES limit their suitability for seasonal heat storage operation.



Figure 10: 1.000 m³ TES in Ørum, Denmark, engineered and delivered by Aalborg CSP. This TES is connected to the solar thermal plant in the background. The heat pump inside the technical building can flexibly choose either air as a heat source via the air coolers on the left of the TES, or the storage water from the TES and thereby increasing storage capacity and efficiency of the solar thermal plant.

Steel-made TTES are standard components of most district heating systems. They are welded on site on a pre-prepared foundation. Then the storage tanks are waterfilled, tested and finally insulated. The insulation of the storage tank will consist of 2 layers of mineral wool slab each with a thickness of 150 mm.

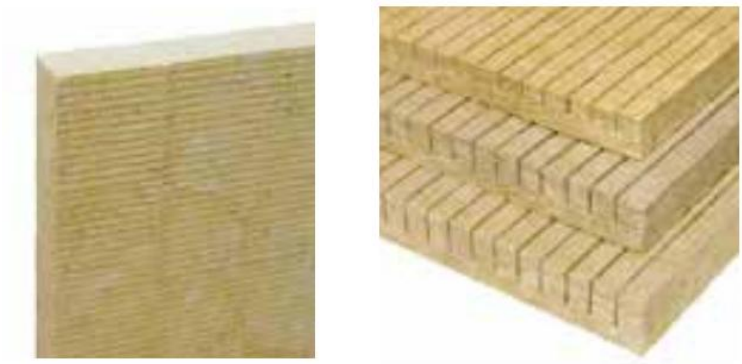


Figure 11: Insulation material Paroc Pro Slab 35



Figure 12: Spreading oil and sand mixture over concrete foundation for a 1,250 m^3 TTES in Havdrup, Denmark.

2.3. Electric heat pump

The heat inside the TES is not always at the right temperature to be used directly for district heating. A heat pump can use the TES as a heat source to make unusable low-temperature heat usable. In addition, when the electricity price is low, heat can be extracted from the ambient air with the same heat pump and be stored in the TES.

A heat pump has two sides, a cooling side and a heating side. It generates heat on the heating side using electricity and low-temperature heat on the cooling side. This principle is depicted in Figure 13. A common performance indicator of the heat pump is therefore the COP (Coefficient of Performance), which describes how much heat is generated by the heat pump in relation to the electricity required for the work.

Aalborg CSP has delivered several heat pumps in recent years, including a heat pump system for a Danish district heating supplier in Ørum, where a dual-source heat pump is switching flexibly between air and water as heat sources, by cooling out the TES connected to a solar thermal plant (see Figure 10). By doing so, the storage capacity of the TES is increased due to the larger temperature difference within, and the efficiency of the solar thermal plant is increased. Click on this link for further information.

In general, there are synthetic and natural refrigerants that generate usable heat in heat pumps through evaporation and condensation. Aalborg CSP uses only natural refrigerants due to the negative environmental impact of synthetic refrigerants and political efforts to limit their use.

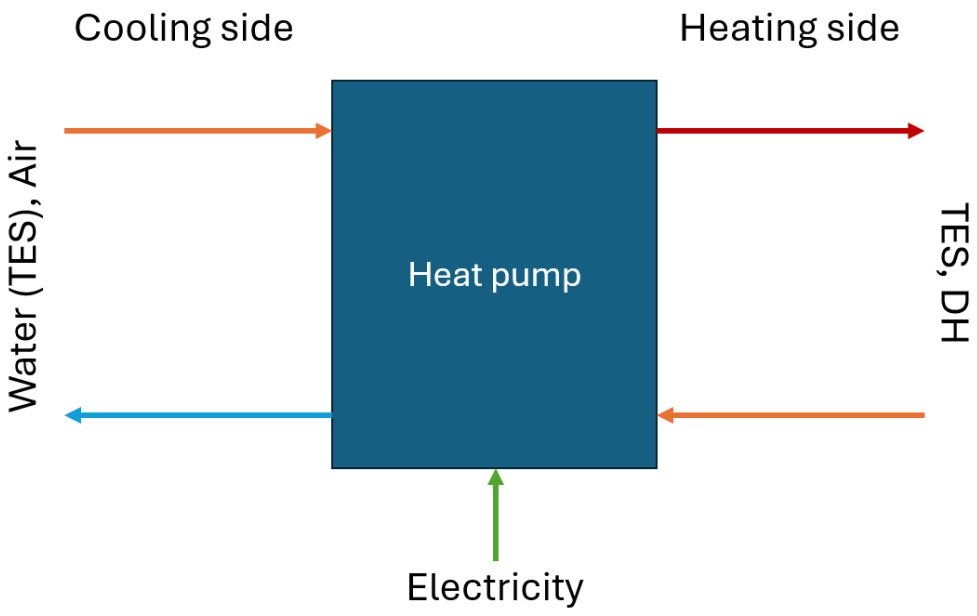


Figure 13: Simplified operating principle of the heat pump. The colours represent the temperature at which blue is coldest, orange is medium, and red is hot.

There are three natural refrigerants that are used in large heat pumps. These are carbon dioxide, ammonia and hydrocarbon gases such as propane, isobutane or pentane. All refrigerants have advantages and disadvantages:

- Carbon dioxide (R-744) operates at a pressure of up to 120 bar and is best suited for low temperatures and smaller plants. These plants are typically inexpensive to procure, but inefficient and therefore expensive to operate.
- Ammonia (R-717) works with a pressure of up to 60 bar and is flexible in the temperature range. The systems are expensive but have a high coefficient of performance.
- Hydrocarbon gases (e.g. propane R-290 or isobutane R-600a etc.) operate at a lower pressure of 10-20 bar, and each hydrocarbon gas has its own specific temperature range. Therefore, a heat pump can be designed to include several stages, each with a different gas, to meet the specific requirements.

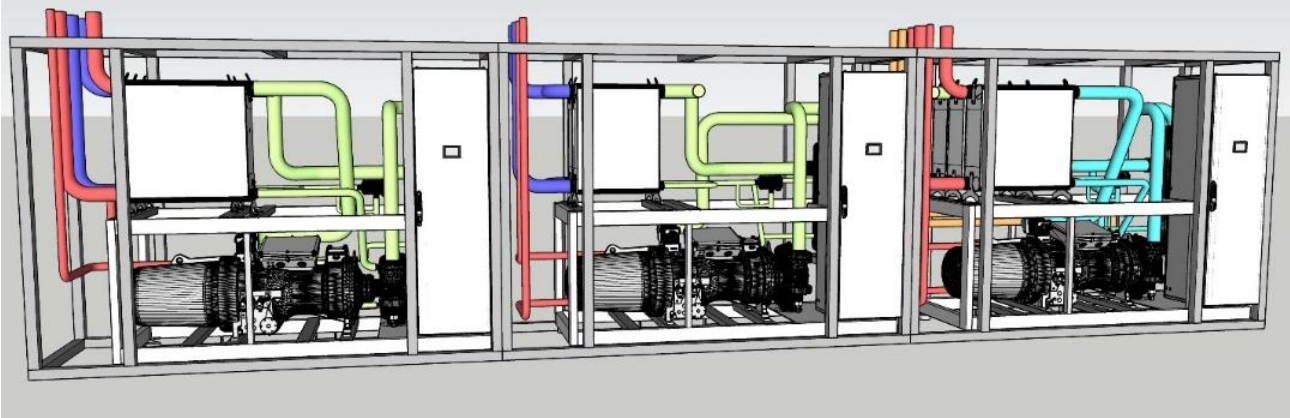


Figure 14: Exemplary 3D-model of a multi-stage heat pump with isobutane.

2.4. Electric boiler

Electric boilers come in different variants depending on the available voltage (low or high voltage) and can supply either steam or hot water. The most suitable design in Tuzla is a high-voltage electrode boiler for hot water preparation.

The operating principle of the boiler is simple: electricity is passed through the water to be heated between the electrode and the counter electrode. Heat is generated by the electrical resistance of the water. The load of the boiler is controlled by covering the electrode with an insulated plate to obstruct the current. To ensure a uniform temperature throughout the boiler, a circulation pump and a nozzle (called jet tube) are used to direct water to the electrode. This water jet also increases the lifetime of the electrodes, as local hot spots are prevented by the water jet. The boiler and components can be seen in the following figures.

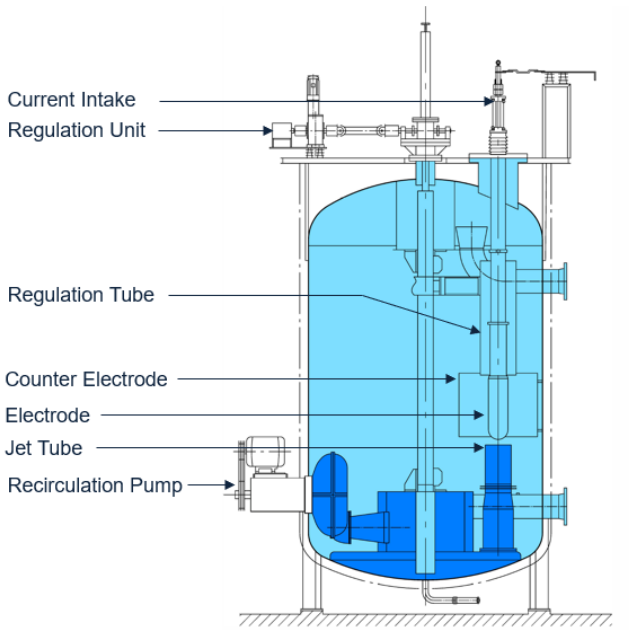


Figure 15: Overview of electrode boilers with main components highlighted.



Figure 16: 3D model of an electrode boiler.

The high-voltage electrode boiler can be directly connected to 6-24 kV power lines and has high efficiency. The performance values of the boiler are summarized in Table 1.

Table 1: Performance values of the electrode boiler.

Parameter	Value
Efficiency	>99%
Warm start from standby mode	< 5 min
Cold start to 100% load	< 30 min
Response Time (Min to Max)	~1 min
Control range	10 – 100%

As the university campus of Tuzla is likely to be equipped with several PV installations on roofs in the future, the integration of an electric boiler could be advisable. These PV installations might lead to an overproduction of electricity, which can then be utilized to power the electric boiler. If in the future electricity prices are becoming more volatile due to the large-scale integration of PV systems in Bosnia Herzegovina and neighbouring countries, electric boilers could pose to be a revenue creating investment, by utilizing hours with negative electricity prices or offering grid stabilisation services. Additionally, electric boilers pose very low investment costs and low maintenance costs.

2.5. Solar thermal plant

Ground-mounted solar thermal systems generate a large amount of low-cost heat during the summer months, which can be stored for the fall and winter. In Denmark, many district heating networks are equipped with this technology. Some district heating networks also operate a PTES to make the heat usable for the winter and thus increase the solar share of the heat supply.

Figure 17 and Figure 18 show solar thermal flat plate collectors and an overview of a solar thermal system in Denmark. Figure 19 shows a process flow diagram (PFD) of a typical solar thermal plant. These systems usually consist of a solar field with the solar collectors, in which the heat transfer fluid (usually a water-glycol mixture) is heated, a storage tank for storing excess heat on very sunny days, heat exchangers for hydraulic decoupling of the solar system from the heating network, as well as pipelines, pumps and control technology. Each solar thermal plant must be adapted to the project-specific requirements and may therefore deviate from this standard design, as there is no "one-size-fits-all" solution.



Figure 17: Solar thermal flat plate collectors.



Figure 18: Solar thermal system seen from above.

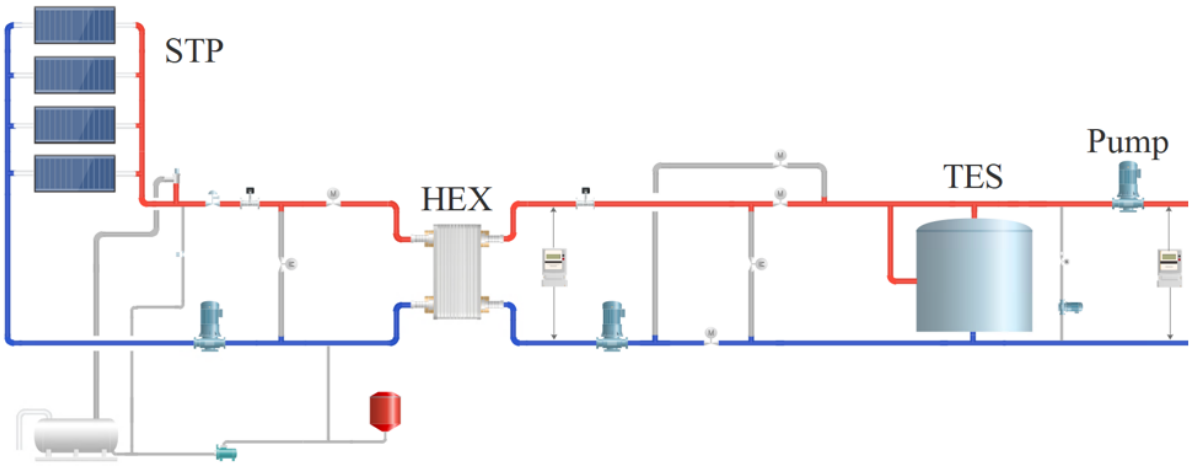


Figure 19: Process flow diagram (PFD) of a typical solar thermal plant, consisting of the solar field (STP), heat exchanger (HEX), thermal energy storage (TES), and other components.

2.6. Photovoltaic modules

Photovoltaic (PV) modules can be installed on the cover of the PTES using Aalborg CSP's patented mounting solution. The modules make it possible to operate the electric heat pump and the electric boiler partly with self-produced electricity or to generate additional income when the unused generated electricity is sold to the power grid. Thus, the lid area of the PTES is used in the best possible way.

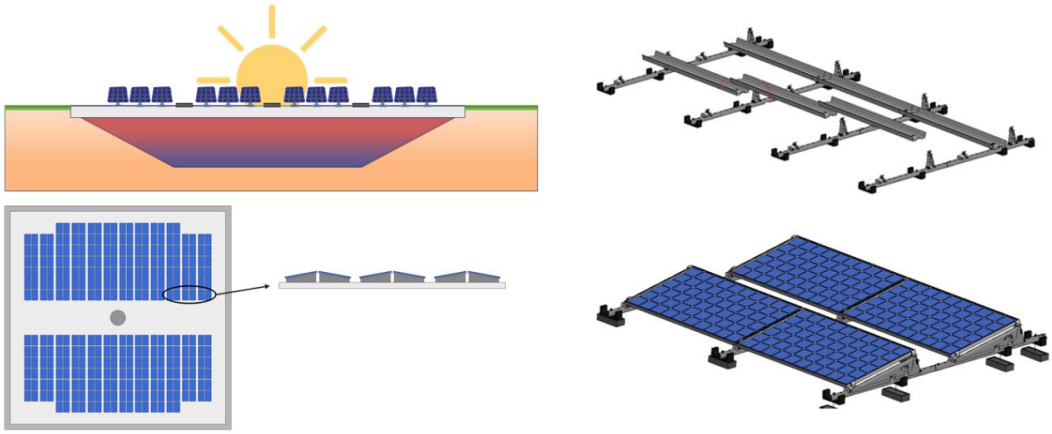


Figure 20: Figure of the patented PV installation on the PTES floating cover.

3. Initial scope of the pre-feasibility study

The initial scope of the pre-feasibility study aimed to design a heating system consisting of a solar thermal plant, a PTES for seasonal storage and an electrical heat pump, resulting in a sector-coupled renewable energy system.

The sector-coupled renewable energy system consists of different technologies, each with its own advantages and capable of delivering heat under different operating conditions or operating patterns, as shown in Table 2 . In the table, variability is indicated as either high or low: high means that the heat source changes its output quickly, and low means that the heat source is slow to adjust its heat production. The special characteristics of the solar thermal plant are that its heat output is not easy to control due to fluctuating solar radiation and the system cannot be switched off.

Table 2: Overview of the operating samples.

System component	Operational mode
PTES	Seasonally, daily and at peak times. High variability.
Heat pump	Seasonal and daily, with low variability.
Electric Boiler	Peak load supply. High variability.
Solar thermal energy	Seasonal and with high variability. Cannot be switched off.

The PFD in Figure 21 shows how the components are connected to each other.

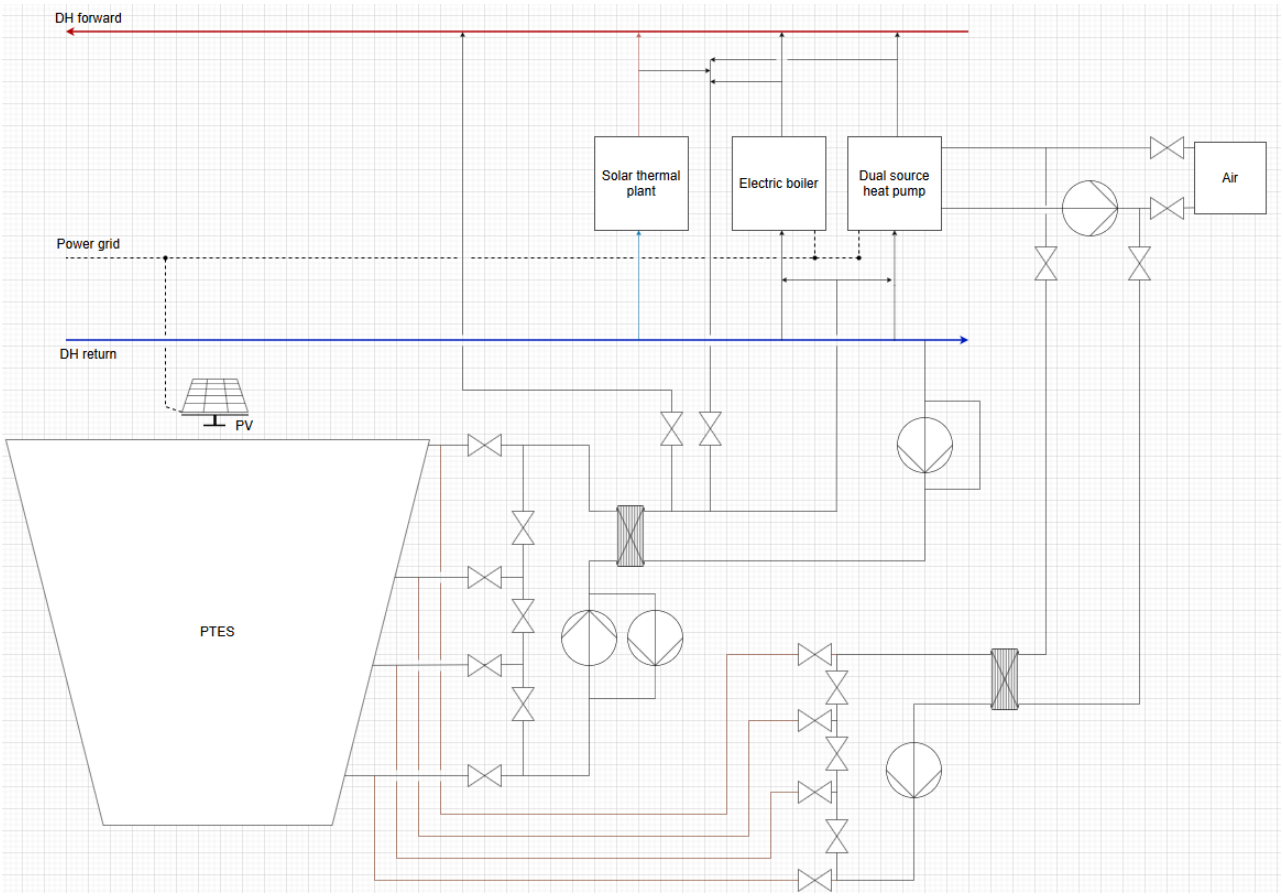


Figure 21: Process flow diagram of a sector-coupled renewable energy system.

The different components are expected to generate more heat at different times of the year. Figure 22 visualizes the expected heat production and the operating focus of the various components. Note that this is not definitive, as it depends on factors such as the weather or electricity market prices.

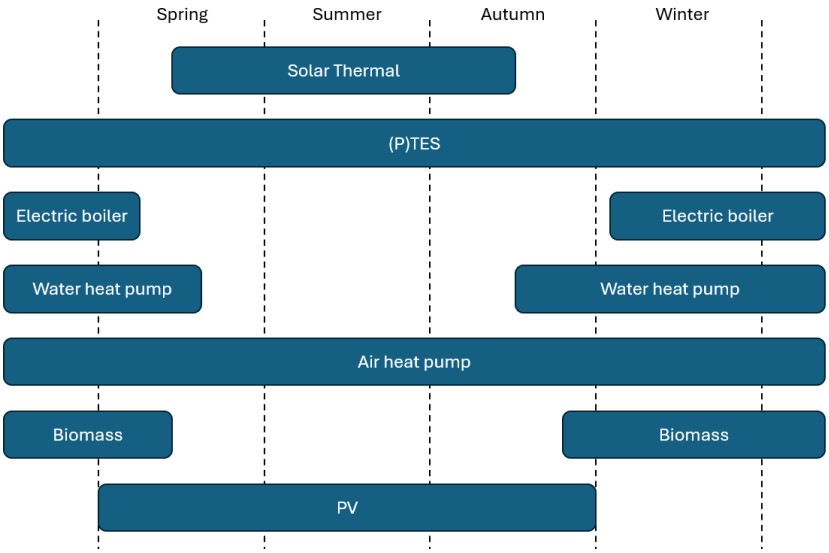


Figure 22: Operational focus and heat generation of the components of an exemplary integrated renewable energy system over the course of a typical year.

4. Analysis of provided data and information

There is no “one-size-fits-all-solution” for district heating systems. Each heating system needs to be adapted to the specific case and consider several parameters such as heat demand, heat demand profile, climate data, electricity prices, available land area, environmental constraints, legal or bureaucratic constraints or even societal aspects. Only after analysing all the boundary conditions and parameters, a heating system including all its components can be designed accordingly.

The data and information provided by the University of Tuzla and the corresponding analyses are shown as follows.

4.1. Analysis of climate data

The local climate and weather data in Tuzla is of major importance not only in regard to the heat demand, but also in connection with a potential introduction of a solar thermal plant. As no measured weather data was available, such data has been agreed to be simulated by Aalborg CSP.

For the weather analysis of the requested site the globally accredited software Meteonorm 8.1™ has been used. Meteonorm is a meteorological database containing climatological data for solar engineering applications at every location on the globe. The results are stochastically generated typical years from interpolated long-term monthly means. They represent an average year of the selected climatological time period based on the user's settings. As such the results do not represent a real historic year but a hypothetical year which statistically represents a typical reference year at the selected location. Meteonorm is primarily a method for the calculation of solar radiation on arbitrarily orientated surfaces at any desired location. The method is based on databases and algorithms coupled according to a predetermined scheme. It commences with the user specifying a particular location for which meteorological data are required and terminates with the delivery of data of the desired structure and in the required format. The visualisation of the simulation results is presented in Figure 23.

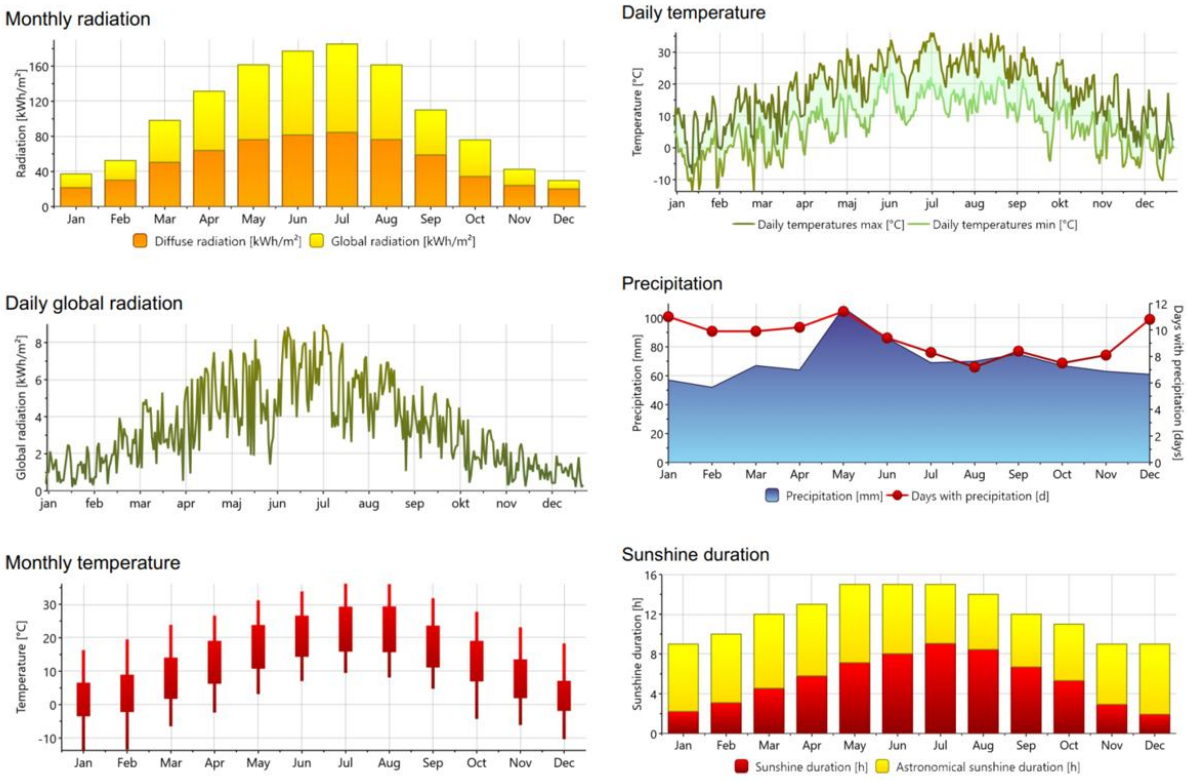


Figure 23: Depiction of simulated weather data by Meteonorm.

The interpolated weather data for a reference year for the given location of the university campus of Tuzla has been further analysed and used in the progress of this study. A monthly analysis of the ambient air temperatures, which is important for the creation of the heat demand profile and hence the heating system design as shown later, is shown below in Figure 24.

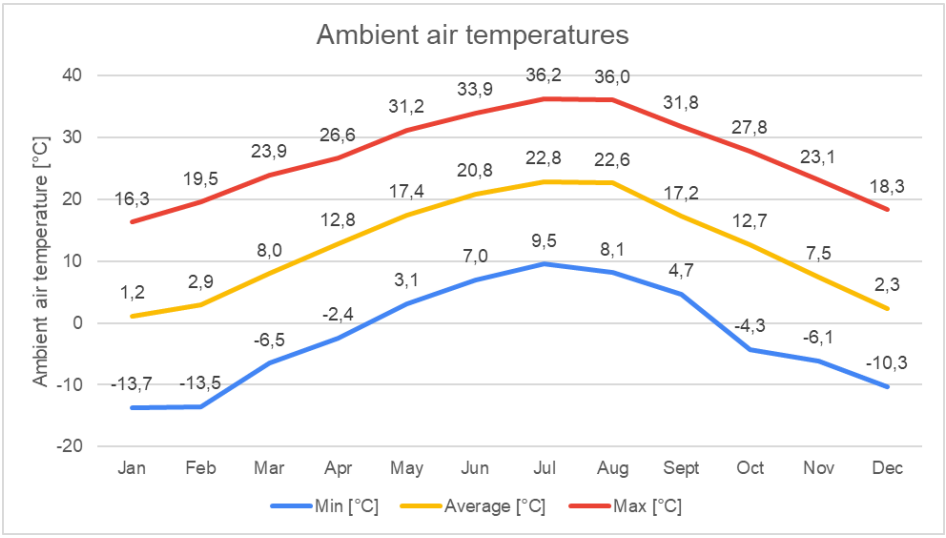


Figure 24: Monthly analysis of ambient air temperatures.

4.2. Analysis of heat demand profile

The key element for designing a heating system is the heat demand and the distribution of the heat demand over the entire year in a heat demand profile. The heat supplying units have to meet the heat demand at every given moment of the year.

In the case of the University of Tuzla, no heat demand profile has been shared nor exists. Instead, a heat demand profile had to be created based on assumptions for heat load factors and a maximum heating demand of 14 MW at -18°C outside air temperature. These assumed heat load factors are stated in the following Table 3 and depicted in Figure 25.

Table 3: Assumptions for creation of heat demand profile.

Month	Average Temp. (°C)	Heating Load Factor	Comments
Jan	−2.0 to 1.0	0.60 to 0.80	Holidays (Jan 1st & 2nd).
Feb	0.0 to 3.0	0.50 to 0.70	
Mar	4.0 to 7.5	0.35 to 0.55	Holiday (Mar 1st).
Apr	8.5 to 13.0	0.10 to 0.20	Heating season until April 15th.
May	13.5 to 17.5	0.00	Heating off.
Jun	17.5 to 21.0	0.00	Heating off.
Jul	20.0 to 23.5	0.00	Heating off.
Aug	19.5 to 23.0	0.00	Heating off.
Sept	15.0 to 19.0	0.00	Heating off.
Oct	10.0 to 14.0	0.15 to 0.25	Heating season starts Oct 1st.
Nov	5.0 to 9.5	0.35 to 0.55	Holiday (Nov 25th).
Dec	1.0 to 4.5	0.55 to 0.75	Full heating

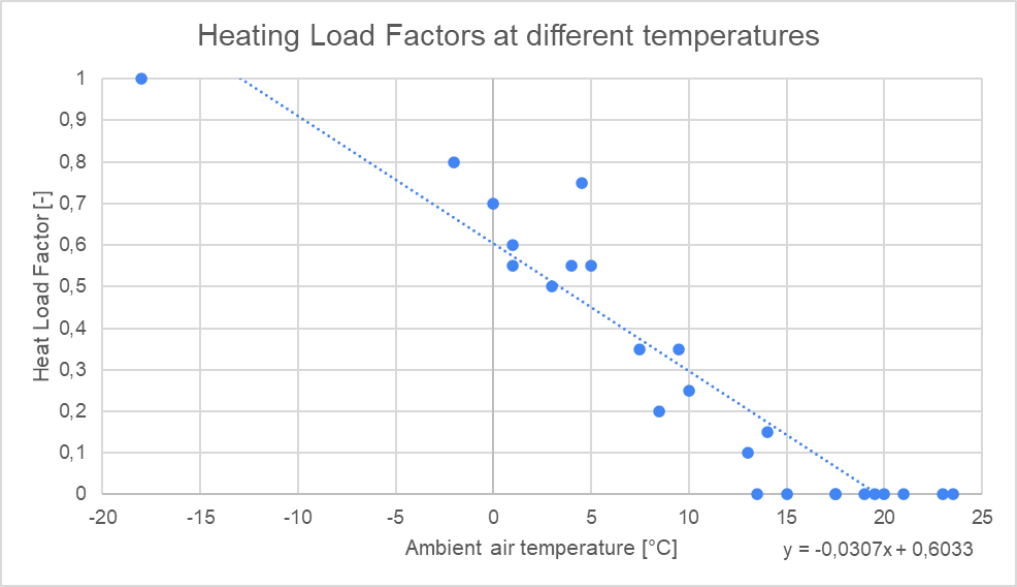


Figure 25: Heat load factors as a function of varying ambient air temperatures.

These assumed heat load factors have been used for interpolation to simulate the heat load factors at different ambient air temperatures for an entire reference year.

Based on the simulated weather data for a reference year, the resulting heating load factors and the other provided information in Table 3, a heat demand profile was simulated. This heat demand profile is depicted in Figure 26 below.

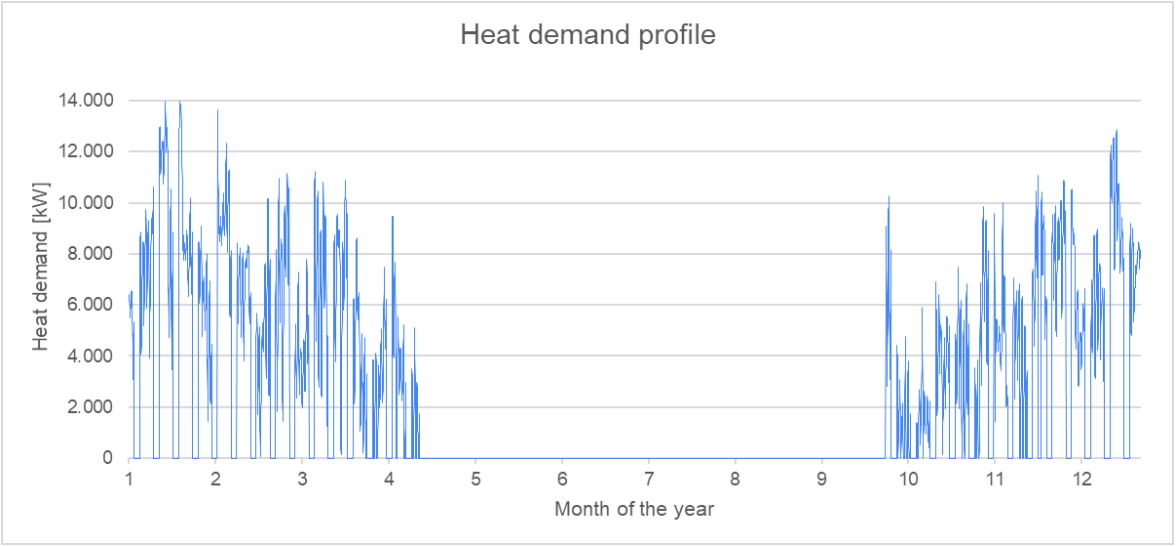


Figure 26: Simulated heat demand profile for the reference year.

An analysis of the simulated heat demand profile is shown in Table 4 and Figure 27.

Table 4: Monthly analysis of the heat demand profile.

Month	Heat consumption [MWh]	Min [kW]	Average [kW]	Max [kW]	Operational hours [h]	Avg. heat demand per operational hour [kW]
Jan	4.308	0	5.791	14.000	528	8.160
Feb	3.429	0	5.103	13.641	480	7.144
Mar	2.749	0	3.694	11.237	508	5.411
Apr	882	0	1.225	9.476	233	3.787
May	0	0	0	0	0	0
Jun	0	0	0	0	0	0
Jul	0	0	0	0	0	0
Aug	0	0	0	0	0	0
Sept	0	0	0	0	0	0
Oct	1.600	0	2.151	10.292	469	3.412
Nov	2.556	0	3.550	11.065	452	5.656
Dec	4.205	0	5.652	12.868	552	7.618
Total	19.730	0	2.252	14.000	3.222	6.123

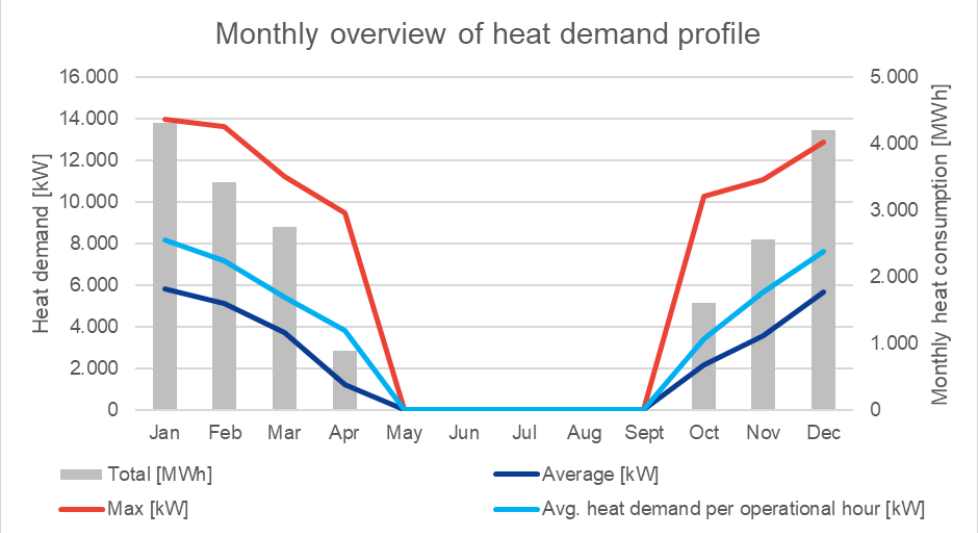


Figure 27: Monthly analysis of the heat demand profile.

It is shown that for a large part of the year, there is no heat demand. As there is no heat demand from May to September, the period with the major share of heat generation by solar thermal plants, this indicates that all the generated heat in this period needs to be stored for the heating season, which makes a large storage capacity and storage volume necessary.

The heat demand profile has been submitted to the University of Tuzla for review and has been approved for the further work in connection to this study.

4.3. Analysis of electricity prices

The level of the electricity price and the frequency of negative electricity prices or other specific electricity prices is of great importance for the operation of certain components of a sector-linked district heating system and therefore also for the dimensioning of its components. In principle, it can be assumed that the volatility of the electricity price will increase over time as the energy transition progresses and the higher share of fluctuating renewable electricity increases. This may result in more hours with peak current values, during which heat pumps or electric boilers ideally stop and the PTES covers the heat demand. At the same time more hours with negative or favourable electricity prices will occur, at which electric boilers or heat pumps can provide grid balancing services or take advantage of low/negative electricity prices and thus provide cheap or free heat, or even generate income while producing heat.

Therefore, electricity prices have been analysed. According to the information provided by Izudin Delic in October 2025, the electricity prices in Table 5 are to be assumed for the University of Tuzla.

Table 5: Assumed electricity prices for the power supply. "Winter" refers to the heating season from October to April.

Period	Days	Time	Tarif	Electricity price
[-]	[-]	[h]	[%]	[€/kWh]
Winter	Mon-Fri	0-7	50%	0,1
Winter	Mon-Fri	22-0	50%	0,1
Winter	Sat-Sun	0-0	50%	0,1
Standard electricity price all year round				0,2

These electricity prices mean, that the electricity consumption of the University of Tuzla is not priced according to the electricity spot market price of Bosnia, but to the stated costs of Table 5. A utilization of negative electricity prices of the spot market is therefore not possible. At the same time, unforeseen high electricity prices do not affect the heat production either.

4.3.1. Creation of the yearly electricity price profile

To operate the heating system in a cost-efficient way, a yearly electricity price profile, according to which the University of Tuzla has to pay for the consumed electricity, is created. This profile is simulated according to the provided information shown in Table 5, where the electricity prices for "Winter" apply to the heating season from October to April.

The simulated profile for the entire reference year is visualized in the following Figure 28, while Figure 29 shows the electricity price profile for the first week of the year (starting with Thursday) as an example.

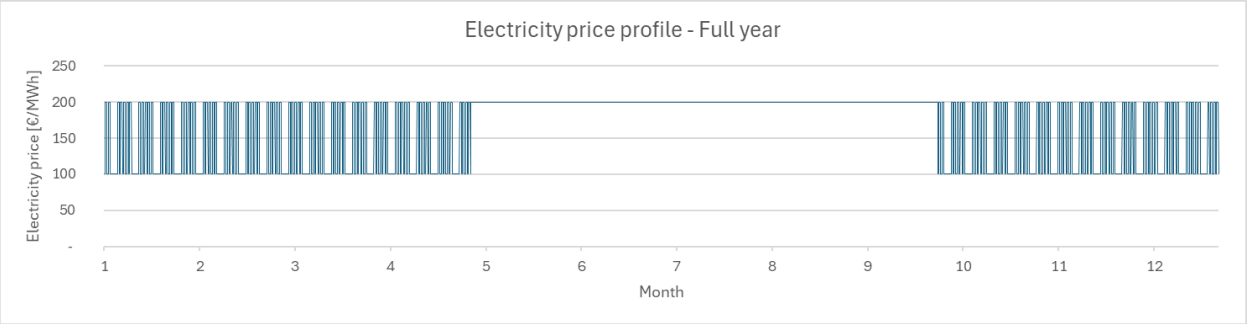


Figure 28: Electricity price profile for the full reference year in €/MWh

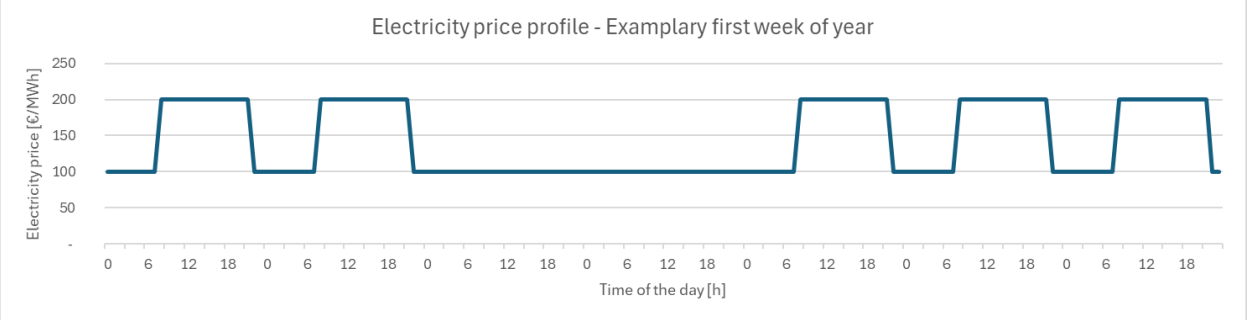


Figure 29: Exemplary depiction of the electricity price profile for the first week of the reference year in €/MWh, starting with a Thursday. There is a period with lower electricity prices during the nighttime and the weekend, as can be seen.

This profile shows that the electricity prices are on a stable high level during the summer period, when the heating system is not operational anyways. During the heating season, a period with low electricity prices occurs during the weekend, as well as during the night hours, as the weekly profile pattern shows in Figure 29. This means that during this period any electricity consuming heating plants can generate heat for half the operational costs and store it for consumption during the peak heat demand hours during the weekdays.

The electricity price profile has been submitted to the University of Tuzla for review and has been approved for the further work in connection to this study.

4.4. Analysis of available land area

Lastly, the available land area has to be analysed, as this needs to accommodate the components of the heating system and hence directly impacts is design and dimensioning.

In the case of the University of Tuzla, the available land areas and potential locations future heating plants are not clearly defined yet, as the campus will be undergoing reconstruction in the near future. Therefore, the potential land areas of approximately 2,25 ha have to be assessed in the construction plans. Specifically, the provided drawing “6-Namjena povrsina” has been analysed for available and suitable land area, to accommodate a solar thermal plant and a PTES. A screenshot of this drawing is shown below in Figure 30.



Figure 30: Drawing of the future campus area of the University of Tuzla with green areas as potential available land areas for heating installations.

The findings of this evaluation are summarized in the following:

- Limited available space: There is only 2,25 ha land area available for the solar thermal plant and the PTES. This is too small land area for an energy system which is supposed to supply a considerable share of the relatively high heat consumption of 19,7 GWh/a.
- Distribution of the land areas: The available land area is split into several small pieces, rather than one large and ideally rectangular shape. This makes it difficult to allocate an efficiently designed plant on those areas. Additionally, the challenging geometries of the available land plots are not suitable for the solar thermal plant or the PTES.
- Hilly areas: Hilly areas are generally not ideal for solar thermal plants or PTES, but still technically feasible locations. However, in the provided drawings, it is shown that the slopes are relatively steep, and height differences are relatively high, which makes expensive soil works necessary.
- Orientation of the hills towards Northeast: The slopes of the hills are facing mostly towards northeast, which means that the solar thermal collector rows (which are ideally facing towards south) are throwing shadows on each other, meaning considerably lower efficiency and heat generation. This is especially visible in the 3D view of the new university campus in Figure 31, where the view is facing towards south.

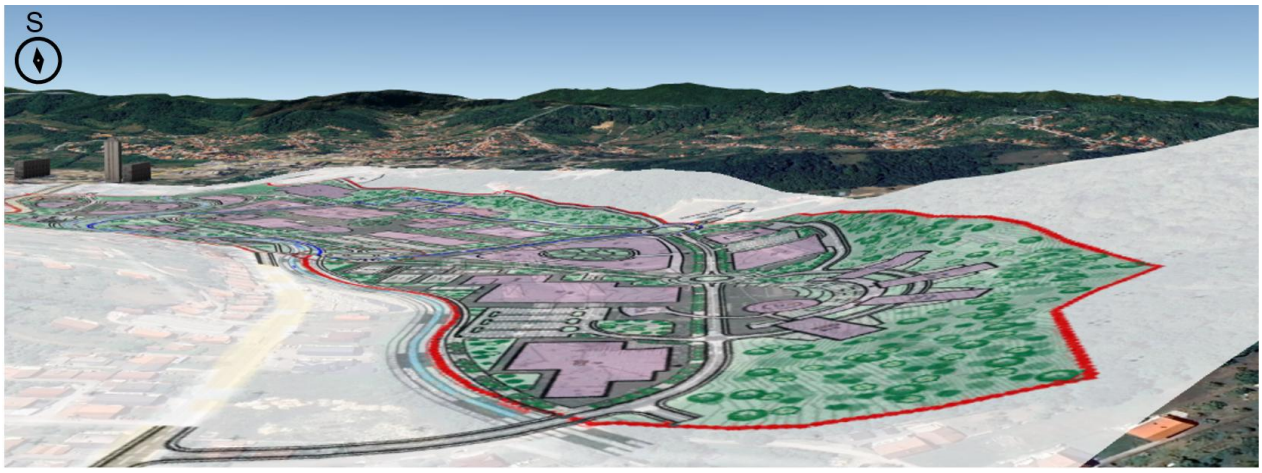


Figure 31: Overlay of the drawing of the future campus with the map in Google Earth in 3D. View towards south.

4.5. Summary

After the analyses, the originally targeted system design with a solar thermal plant, a (seasonal) heat storage system (such as a PTES) and a heat pump, has been drafted and simulated. Several challenges for the system design with these technologies have been identified:

- Limited available space: The provided info shows that there is only 2.25 ha available for the solar thermal plant and/or the (seasonal) heat storage. This is a very limited space for a system which can only supply a small fraction of the relatively high heat consumption of 19.7 GWh/a.
- Difficult geometry of the space: The geometry of the available land area is not suitable for the solar thermal plant or the PTES, as the land area is split into several small pieces, rather than one large ideally rectangular shape.
- Hilly area with slope orientation towards Northeast: Hilly areas are generally not ideal for solar thermal plants or PTES, but not necessarily a “deal breaker”. However, in the provided drawings, it is shown that the slopes are relatively steep, and height differences are relatively high, which makes expensive soil works and land levelling necessary. Additionally, the slopes of the hills are facing mostly towards northeast, which means that the solar thermal collector rows (which are facing towards south) are throwing shadows on each other, meaning considerably lower efficiency and heat generation.
- Potentially expensive solar thermal installation on roofs: Alternatively, solar thermal collectors could be installed on roofs, but this is extremely expensive in such small installations and only recommended for very large and flat roofs, which are not available in the case of Tuzla.
- No heat demand in summer: The lack of heat demand summer means that there is no heat offtake in the time of the highest heat generation. As solar thermal plants cannot be switched off, this heat needs to be stored, which means that the necessary storage capacity is increasing drastically, which consequently is increasing the investment costs and decreasing the business case for solar thermal heat.
- Increased storage demand, despite lack of space: An increased demand for seasonal heat storage is not only costly but also requires a large suitable space for the PTES, which is not available in the case of Tuzla.
- “Competition” between heat from solar thermal plant and heat pump: It must be kept in mind that every MWh of generated and stored solar heat is a MWh of heat which cannot be provided by the

heat pump, which must be ramped down. Both units are therefore in direct competition for heat production, which results in a lower utilization of the heat pump and therefore higher overall heat production costs or Levelized Costs Of Heat (LCOH).

- Higher CAPEX due to economy of scale and difficult geometry of land areas: The integration of so many different system components, which all must be adapted to the not-ideally shaped land areas and are generally of small size, lead to higher investment costs. A major reason for this is also the economy of scale, which makes larger installations relatively cheap (per produced MWh of heat), which is not the case for Tuzla due to the very limited space.

Therefore, Aalborg CSP recommended an alternative solution, which includes an air heat pump system in connection with a heat storage and potentially an electric boiler. There are several advantages for this optimized solution:

- More operational hours for the heat pump: The lack of stored solar heat, means that the heat pump needs to provide more heat. In the bottom line, more operating hours or a higher utilization of the heat pump, lead to lower overall LCOH.
- Simple system design with high degree of operational flexibility: The system design allows a flexible operation of the heat pump according to low electricity prices and storage of cheaply produced heat in the heat storage for times with higher electricity prices or higher heat demand.
- Limited demand for seasonal heat storage: The switch from seasonal and short-term storage due to the integration of solar heat, to a more short-term storage means that the storage capacity can be decreased drastically, which reduces the size, necessary land area and overall costs considerably.
- Space efficiency: The lack of solar thermal installations and large seasonal heat storage, means that the available land areas can be utilized in other ways, for example for PV installations, which could provide renewable low-price electricity for the campus or the heat pumps and electric boilers.
- Lower investment costs: Fewer system components and simpler system design lead to a lower investment cost.

Those points have been communicated by Aalborg CSP to the University of Tuzla. It has been agreed that the study will not focus on the original idea of a solar thermal plant in connection with a PTES and heat pump anymore but instead investigate the potential of utilizing an air heat pump with a steel TTES.

5. System components and plant design

This chapter describes the engineered main system components, the air heat pump, steel TTES and an electric boiler as backup unit, of the designed energy system.

5.1. Air source heat pump

The cornerstone of the energy system design is the air source heat pump. To allow a heat production at a high temperature to store as much heat as possible in the TES, as well as to limit investment costs, lower operational costs and increase performance, Aalborg CSP has opted for a heat pump based on hydrocarbon refrigerants. The chosen heat pump design consists of prefabricated standard heat pump units by the proven Danish supplier Solid Energy A/S.



Figure 32: Standardized heat pump units by Solid Energy A/S.

This heat pump system consists of 4 heat pump units, each equipped with 4 compressors.

The heat pump units use, depending on their role in the overarching system and temperature levels they are operating at, the refrigerants propane and isobutane. These refrigerants are classified as so-called natural refrigerants and do not harm the environment as synthetic refrigerants, while still performing efficiently and reliably.

A more detailed engineering of the plant including Process Flow Diagrams (PFD), Piping and Instrumentation Diagram (PID), and further engineering can be conducted in a detailed feasibility study.

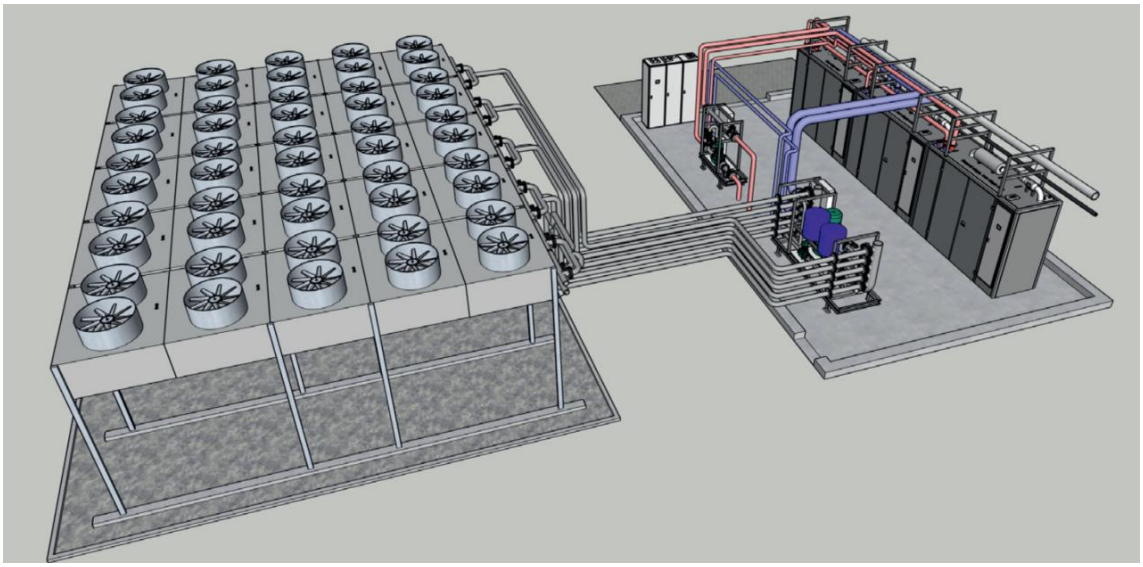


Figure 33: Preliminary visualization of air heat pump system with air coolers and heat pump units.

5.1.1. Performance parameters of heat pump

The performance parameters of the heat pump are shown in Figure 34. The heating capacity as well as the COP show good values even at low outside air temperatures. The size of the heat pup can be stated as 10 MW heating capacity at 2°C. This air heat pump can operate at temperatures down to -18°C, by utilizing an integrated defrosting mechanism on the air coolers.

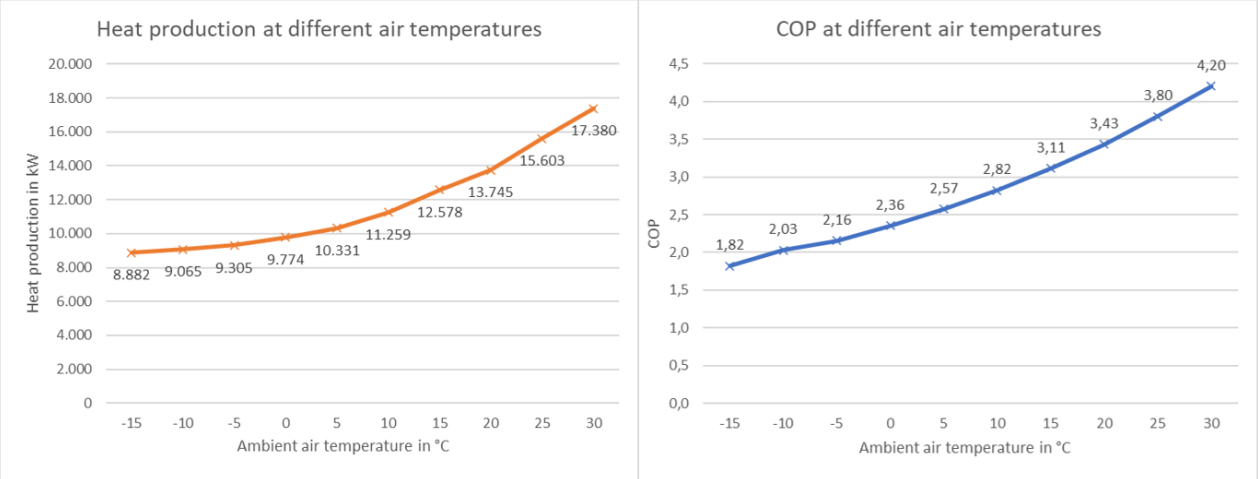


Figure 34: Performance parameters of the air heat pump for different air temperatures.

These performance parameters are used for the simulation of the heat production and performance of the heat pump in the reference year, according to the outside air temperatures. An overview of the simulated average monthly air temperatures in Tuzla and the corresponding COP values is shown in the following Figure 35.

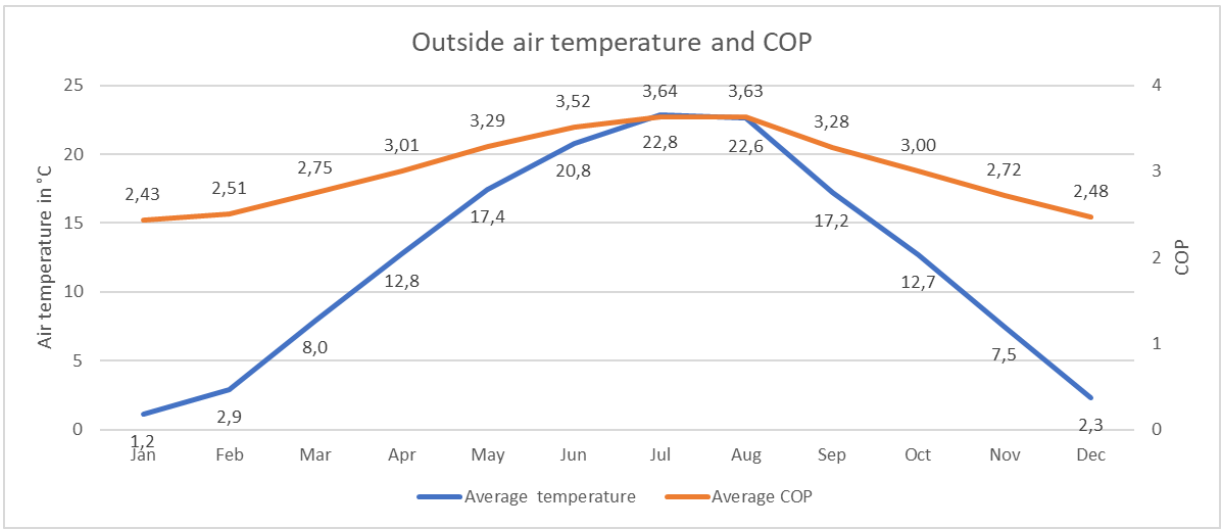


Figure 35: Average monthly air temperatures in Tuzla and corresponding average COP of the engineered heat pump.

The technical parameters and performance parameters of the engineered heat pump system are shown in the following Table 6 for different ambient air temperature or Load Points (LP). Please keep in mind that those parameters are preliminary and will change in a second more detailed engineering phase.

Table 6: Preliminary performance parameters of the engineered heat pump system for different ambient air temperatures or load points.

Parameter	Unit	LP1	LP2	LP3	LP4	LP5	LP6	LP7	LP8	LP9	LP10
Air temperature	[°C]	-15	-10	-5	0	5	10	15	20	25	30
Air humidity	[%]	80	80	80	80	80	80	80	80	80	80
Flow temperature	[°C]	95	95	95	95	95	95	95	95	95	95
Return temperature	[°C]	40	40	40	40	40	40	40	40	40	40
Heating capacity	[kW]	8.882	9.065	9.305	9.774	10.331	11.259	12.578	13.745	15.603	17.380
Cooling capacity	[kW]	4.497	5.068	5.414	5.900	6.517	7.412	8.657	9.852	11.619	13.384
Power demand	[kW]	4.870	4.464	4.312	4.150	4.013	3.989	4.042	4.004	4.101	4.134
Power for ventilators	[kW]	109,2	109,2	109,2	109,2	109,2	109,2	109,2	109,2	109,2	109,2
COP	[-]	1,82	2,03	2,16	2,36	2,57	2,82	3,11	3,43	3,80	4,20
Flow heating circuit	[m³/h]	139	156	145	153	161	176	196	215	244	271

The high flow temperatures on the heating side of 95°C have been used to store heat at the highest possible temperature in the TTES, leading to an increase in storage capacity. These load points from Table 6 have been used in the simulation works of this study, later described in chapter 6.

5.1.2. Technical parameters and technical information of heat pump

Further preliminary technical parameters and information of the heat pump system is summarised in the following Table 7.

Table 7: Preliminary technical parameters of heat pump system.

Parameter	Value / Information
Heat pump type	Air heat pump
Heating capacity (at 2°C)	10 MW
No. of stages	2
No. of heat pump units	4
No. of compressors	16
Refrigerants	Propane and isobutane
Type of refrigerants	Natural refrigerants (free of HFO)
GWP of refrigerants	3,3
Type of evaporation	Direct evaporation of refrigerant inside air coolers
No. of air coolers	26
Type of air coolers	Flatbed configuration
Minimum operational temperature	-18°C
Defrosting mechanism	Continuous hot-gas-defrosting from compressor, during continuous plant operation

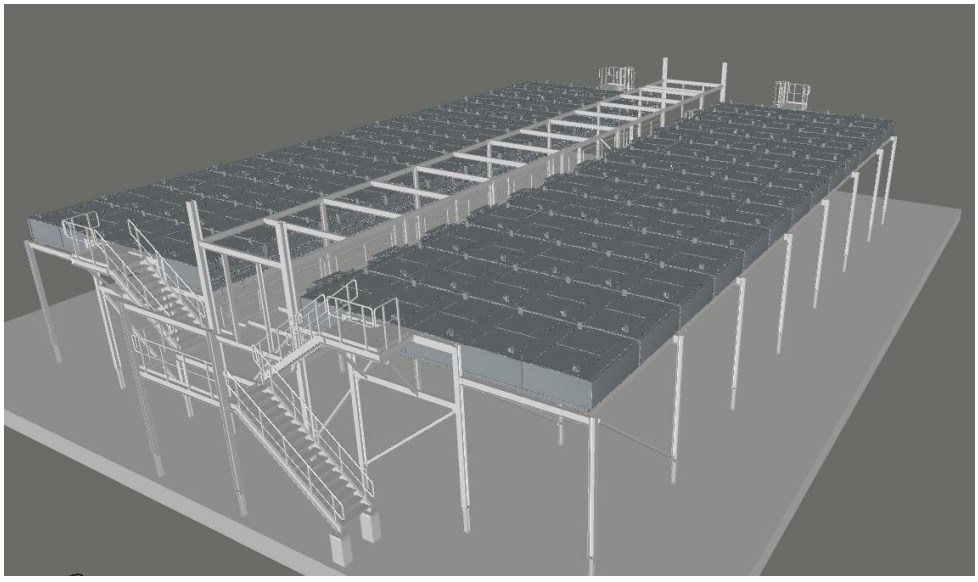


Figure 36: Preliminary 3D view of the 26 air coolers.

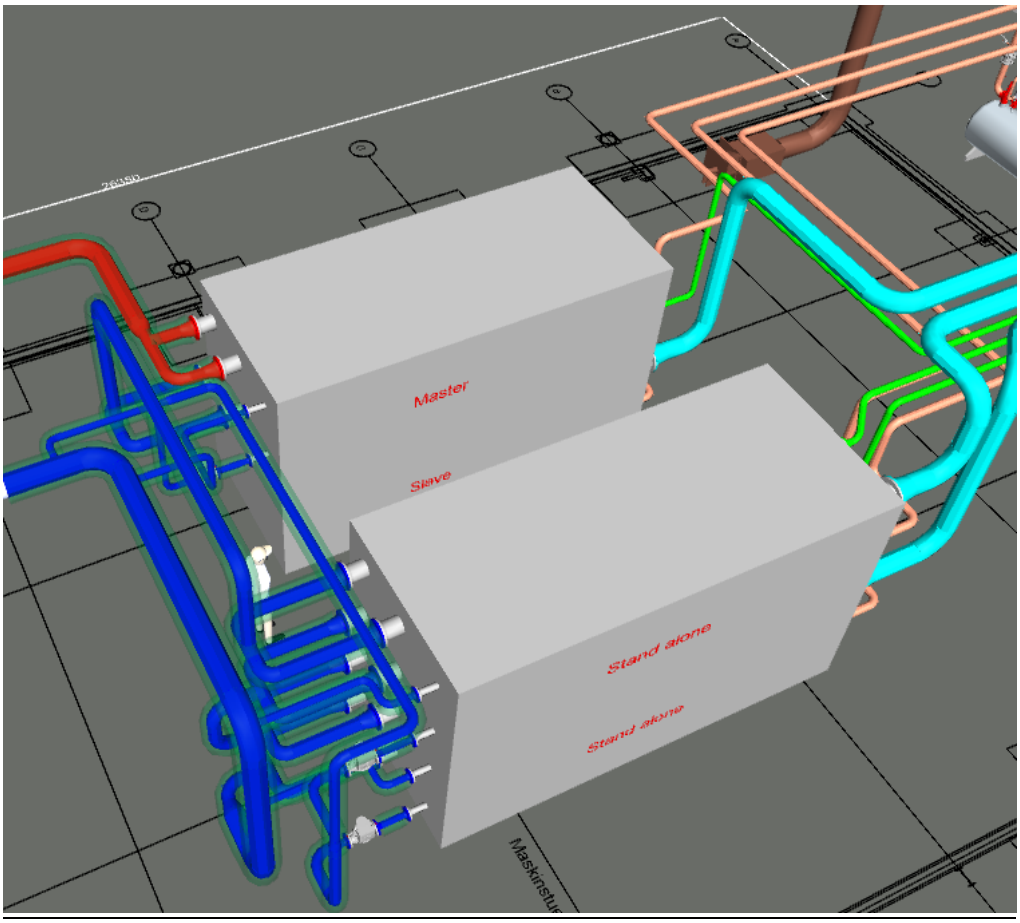


Figure 37: Preliminary 3D view of the heat pump system, consisting of 4 heat pump units.

As the 3D drawing in Figure 37 indicates, the heat pump system consists of 4 heat pump units. These are categorized as 2 “stand alone units”, 1 “master unit” and 1 “slave unit”. As the PFD in Figure 40 shows later, the standalone units and the slave unit are utilizing the air coolers on the cooling side in parallel. The standalone units are preheating the district heating return in series, as two single step heat pump units. Finally, the slave unit and master unit are acting as a two-stage heat pump, where the slave unit is “feeding” the master unit, which then reaches the desired heating temperatures. This approach allows to reach high forward temperatures, which can then be stored in the TTES.

5.2. Thermal energy storage tank

A steel TTES has been determined as a suitable storage type for the project of the University of Tuzla. The engineering has resulted in a preliminary storage size of 5.000 m³. Such an unpressurized storage tank can store temperatures up to 99°C, to avoid a boiling of the storage water.

In this preliminary design, the TES is approximately 16 m wide and 25 m high. A specific ratio between the height and diameter has to be kept, to ensure good temperature stratification within the tank. In this preliminary design the TTES will be equipped with 4 diffusors as inlets and outlets, to operate with different temperature levels within the TES.

An exemplary 3D sketch of a similarly sized TES is shown in Figure 38.

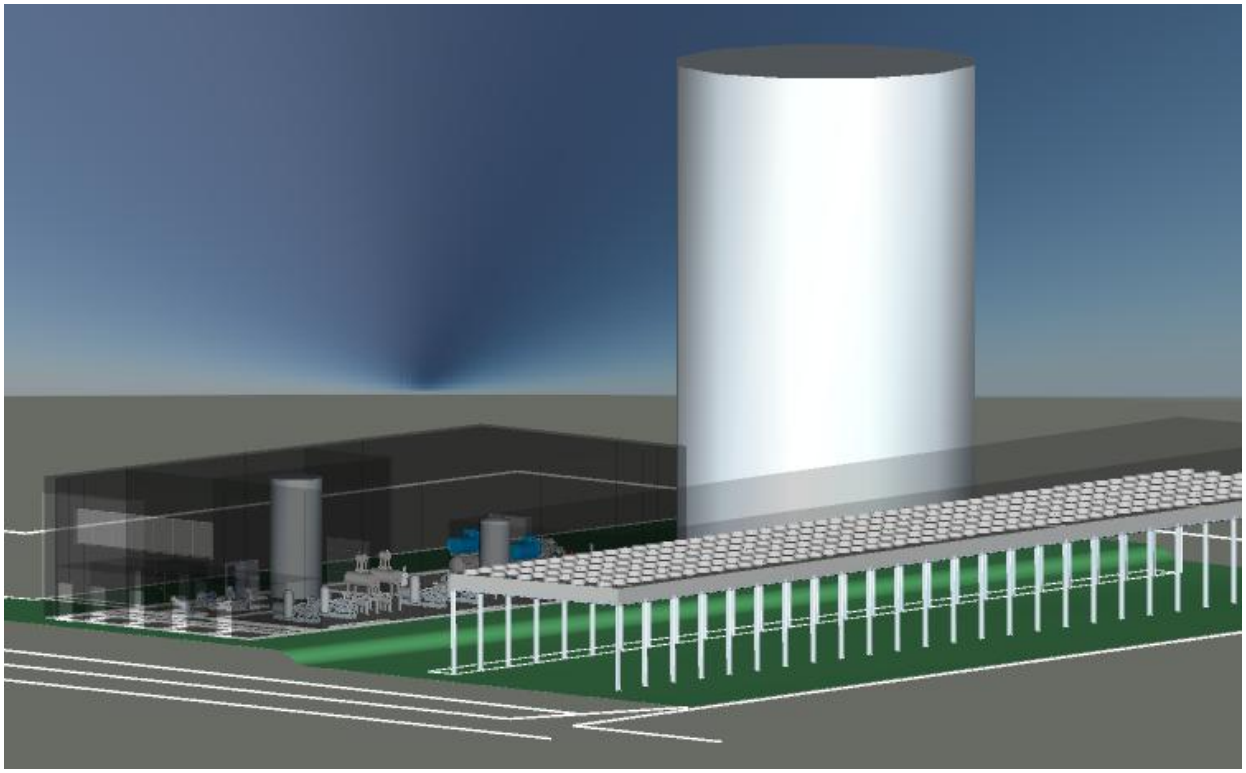


Figure 38: Exemplary 3D sketch of a 5.000 m³ TES next to aircoolers and technical building of a heat pump system.

The preliminary technical design of the TTES shows the following parameters, which will most likely change at a later detailed-engineering stage.

Table 8: Preliminary technical parameters of the TTES.

Parameter	Unit	Value
Height	m	25
Diameter	m	16
Volume	m³	5000
Design code	-	EN14015
Design temperature	°C	0 to +99
Operating temperature	°C	+35 to +99
Design pressure	mbar	+30 to -5 (low pressure tank)

Maximum bulk density	kg/ m³	1000
Wind load	m/sec peak	45
Corrosion allowance	mm	0
Steel material	-	Mild steel – S355 J2 + N /S235 JR in accordance with EN10025-2;2004
Diffusors	-	4 x DN300
Insulation	mm	300 to 400 made of HPS200 ultra steel trapezoidal sheets
Tank foundation		Standard ring foundation with sand bed covered with 30 mm smooth-applied powder asphalt

A nitrogen system is needed to pressurise the tank and to prevent corrosion of the top part of the steel tank. It is important to pressurise the tank to avoid the water to start boiling at the top, and to prevent air from degassing from the water. It also helps to keep the water flow from the tank steady, since the pressure is always kept constant. The corrosion aspect comes to play due to nitrogen being an inert gas, meaning it cannot react with the metals of the tank, while filling up the free space, which then pushes all potential air out of the tank, minimizing the corrosion risk.

5.3. Electric boiler

The sizing of the electric boiler depends on the purpose of such. If the electric boiler is meant to serve as a redundancy in case of failure of the heat pump and delivery the entire heat demand alone, it needs to be sized according to the maximum heat demand. If the electric boiler is meant to serve as a peak load supply, it needs to be sized according to desired share of supply during peak load hours in connection with the base load supply. If the electric boiler is meant to add flexibility to the heat production and energy grid, as well as taking advantage of low / negative electricity prices, the boiler needs to be sized according to the desired or available power connection.

In the case of University of Tuzla, it has been agreed that an electric boiler must serve as a backup unit in case of a malfunction of the heat pump, while in the future, when the electricity generation is increasingly based on renewable energy and therefore intermittent, the boiler can flexibly use excess electricity and low / negative electricity prices. Therefore, the electric boiler is sized at a minimum of 18 MW. Large scale electric boilers are typically available in 5 MW capacity ranges. Therefore, and to account for an approx. 10% safety margin added to the 18 MW heat demand, an electric boiler capacity of 20 MW has been chosen, split into 4 identical 5 MW boilers.

Preliminary technical parameters are shown in the following Table 9. Please keep in mind that these parameters are preliminary and will change in a later detailed-engineering step.

Table 9: Preliminary technical parameters of the electric boiler system.

Parameter	Unit	Value
Total heating capacity	MW	20
Number of boilers	-	4
Heating capacity per boiler	MW	5
Diameter per boiler cylinder	m	1,6
Voltage	kV	10,5
Frequency	Hz	50
Operational pressure	bar	10
Maximum operational temperature	°C	184
Standby power consumption	kW	0
Minimum load per boiler	MW	0,3
Empty weight per boiler	t	4,5
Max. filled weight per boiler	t	12,8

The electric boiler is characterized by low investment costs, while the operational costs are relatively high. This makes an electric boiler a suitable choice for a backup unit, especially for redundancy purposes. As the electric boiler is operating with an efficiency of almost 100%, corresponding to a COP of 1, it is operating much less efficient than the air sourced heat pump. Therefore, the operation of the electric boiler is limited to a minimum, if electricity prices are not negative.

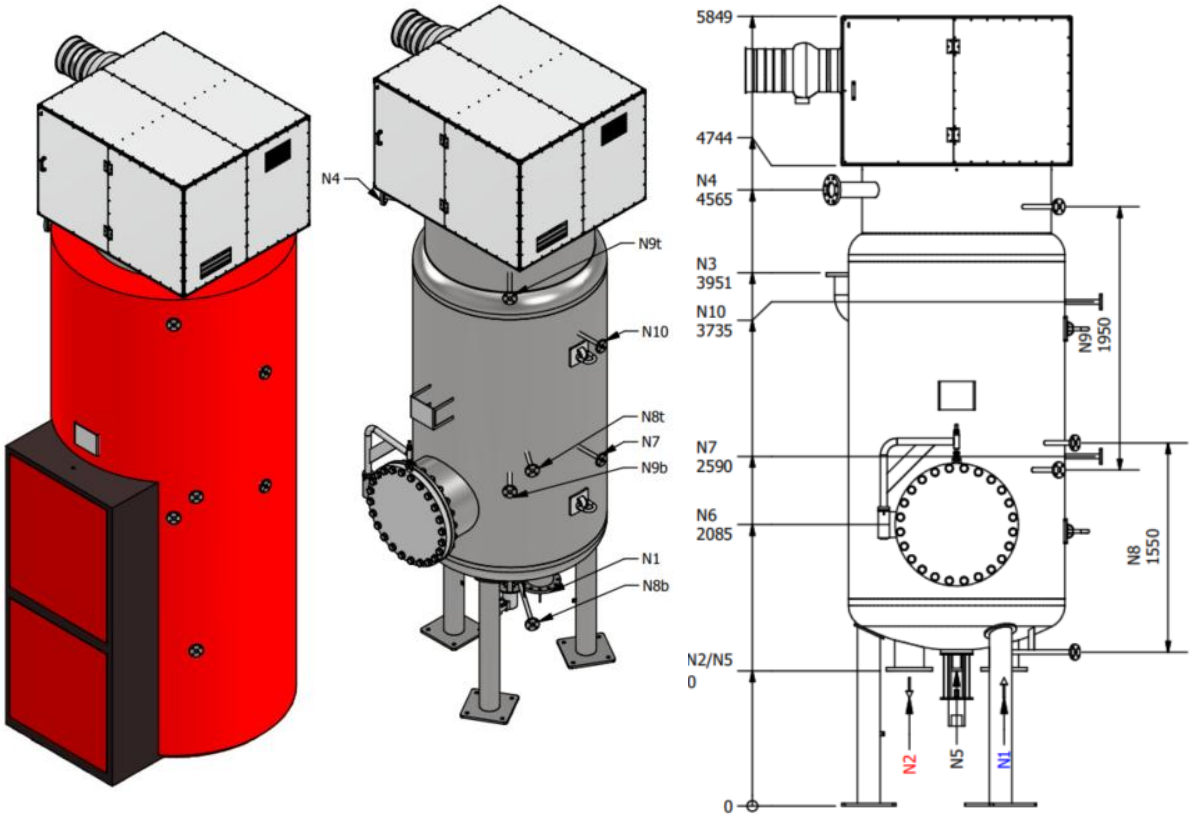


Figure 39: Depiction and dimensions of a single 5 MW electric boiler.

The integration of the electric boiler in the overall heating system is shown in the Process Flow Diagram (PFD) in the following section 5.4 and the Piping and Instrumentation Diagram (PID) in section 5.5.

5.4. Process Flow Diagram (PFD)

To gain an easy understanding of the heating system and to show the system integration of the single components of the energy system, the following PFD has been created. It is based on the PID shown later in section 5.5 and is a simplified version of such.

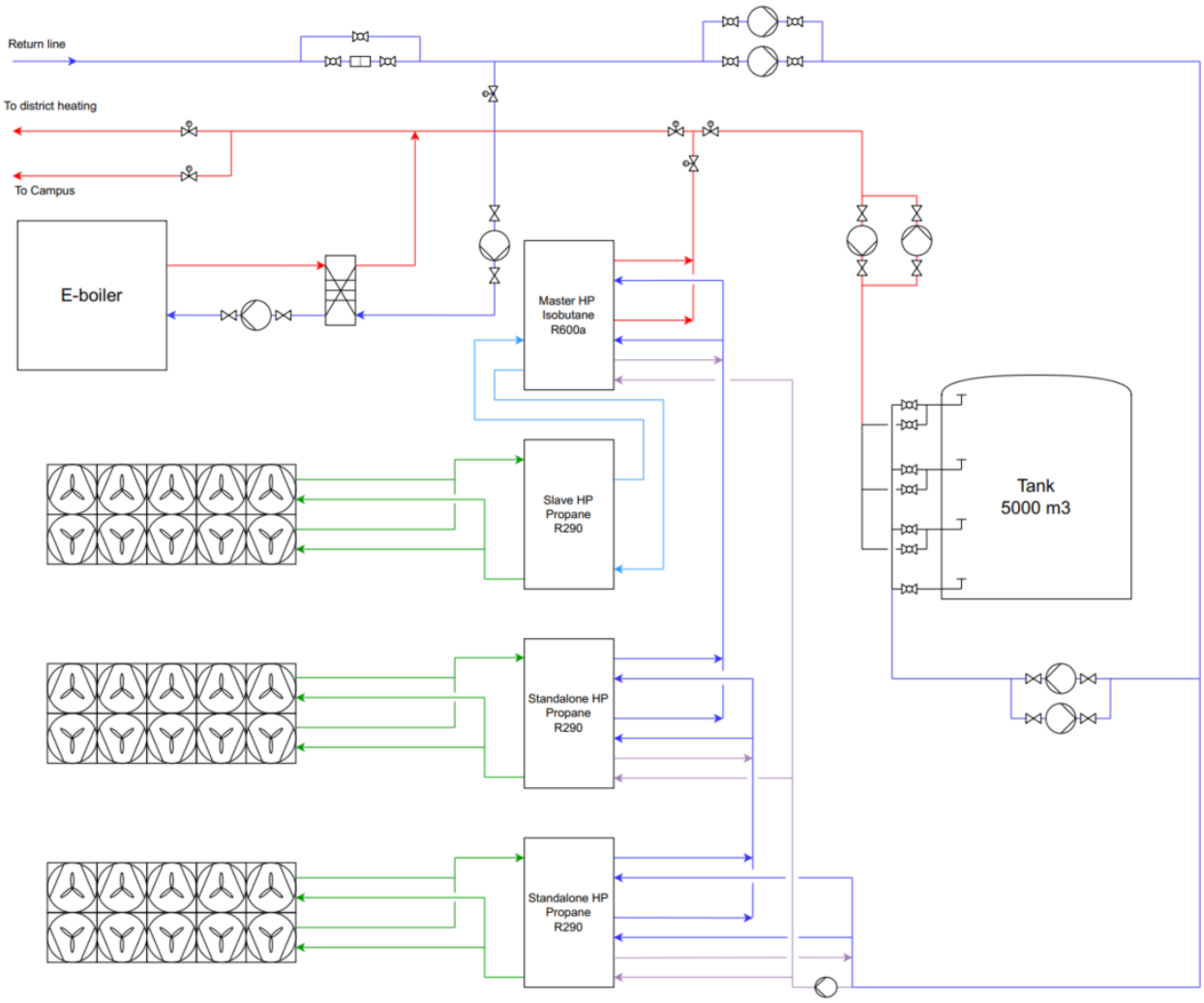


Figure 40: PFD of the heating system, consisting of an electric boiler (top left), the 5.000 m³ TTES (right side) and the air heat pump system (centre) with the air coolers (left side).

As mentioned in section 5.1.2 before, the PFD visualizes the setup of the heat pump system with its 4 different heat pump units. As can be seen, the standalone units use the refrigerant propane to preheat the district heating side in series. Then the slave heat pump unit is providing the master unit – which is the only heat pump unit with the refrigerant isobutane – with heat, which then reaches the desired forward temperature.

The PFD and the presented illustrations of the operational modes are attached to this report in appendix *"40157-D781-00002-A Tuzla PFD"*

5.4.1. Operational modes of the heating plant

The PFD from Figure 40 is used to demonstrate different potential operational modes of the heating system. Each operational mode is shown by highlighting the flows within the system (in bold print) and the operational instruments and system components (in green).

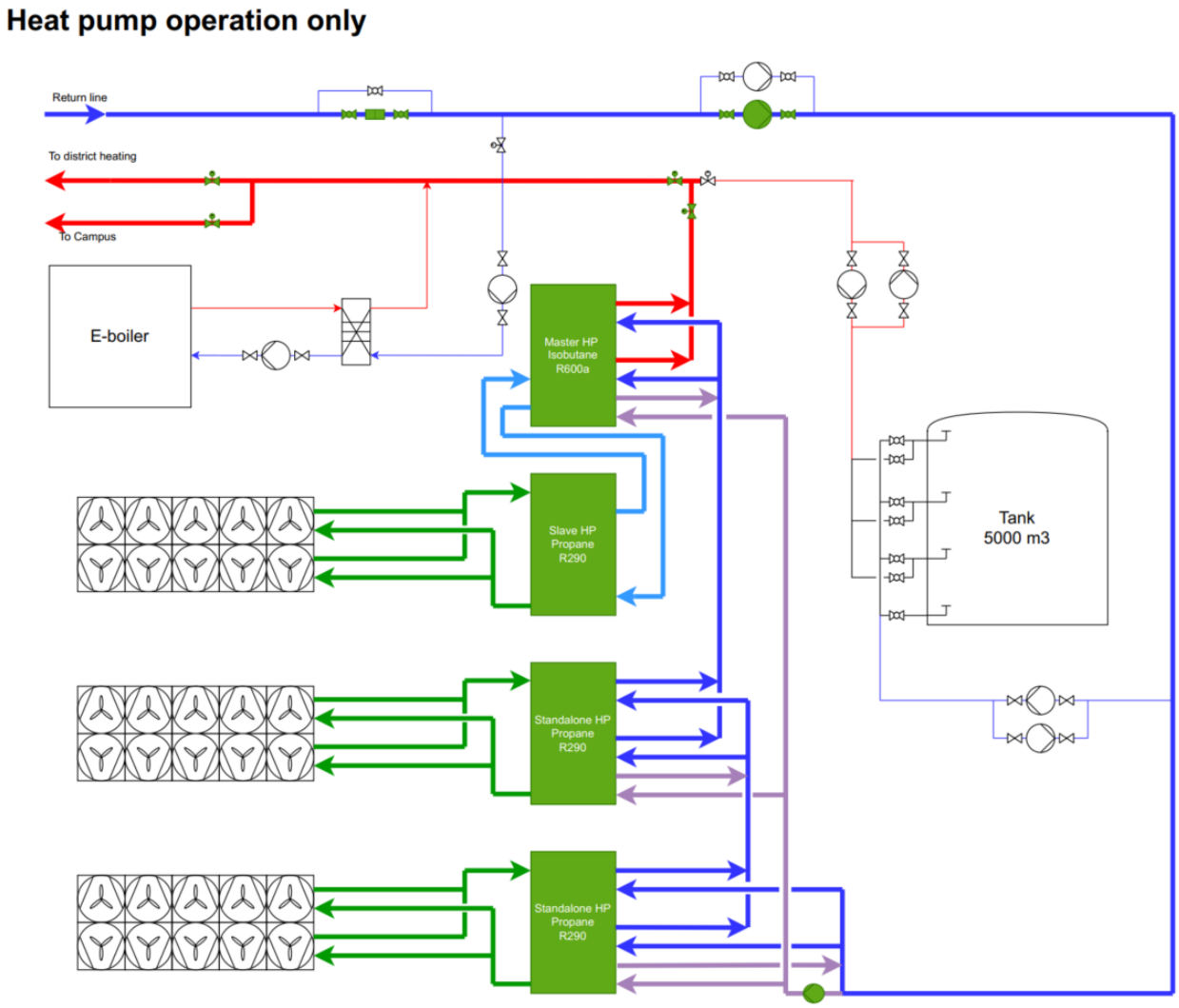


Figure 41: Operational mode "Heat pump operation only", where only the heat pump operates without any utilisation of the TTES.

As a simple starting point, the operation of the heat pump without any utilisation of the TTES is shown. Such an operation might be the case when the TTES is fully charged, making any additional heat storage impossible, while the heat demand can be fully covered with the heat pump. This case might be rather common during warmer periods of the year such as late spring or early fall. The valves and pumps lead the return of the district heating grid to the heat pump system, which is heating up the district heating water to the desired forward temperature level of the heating grid.

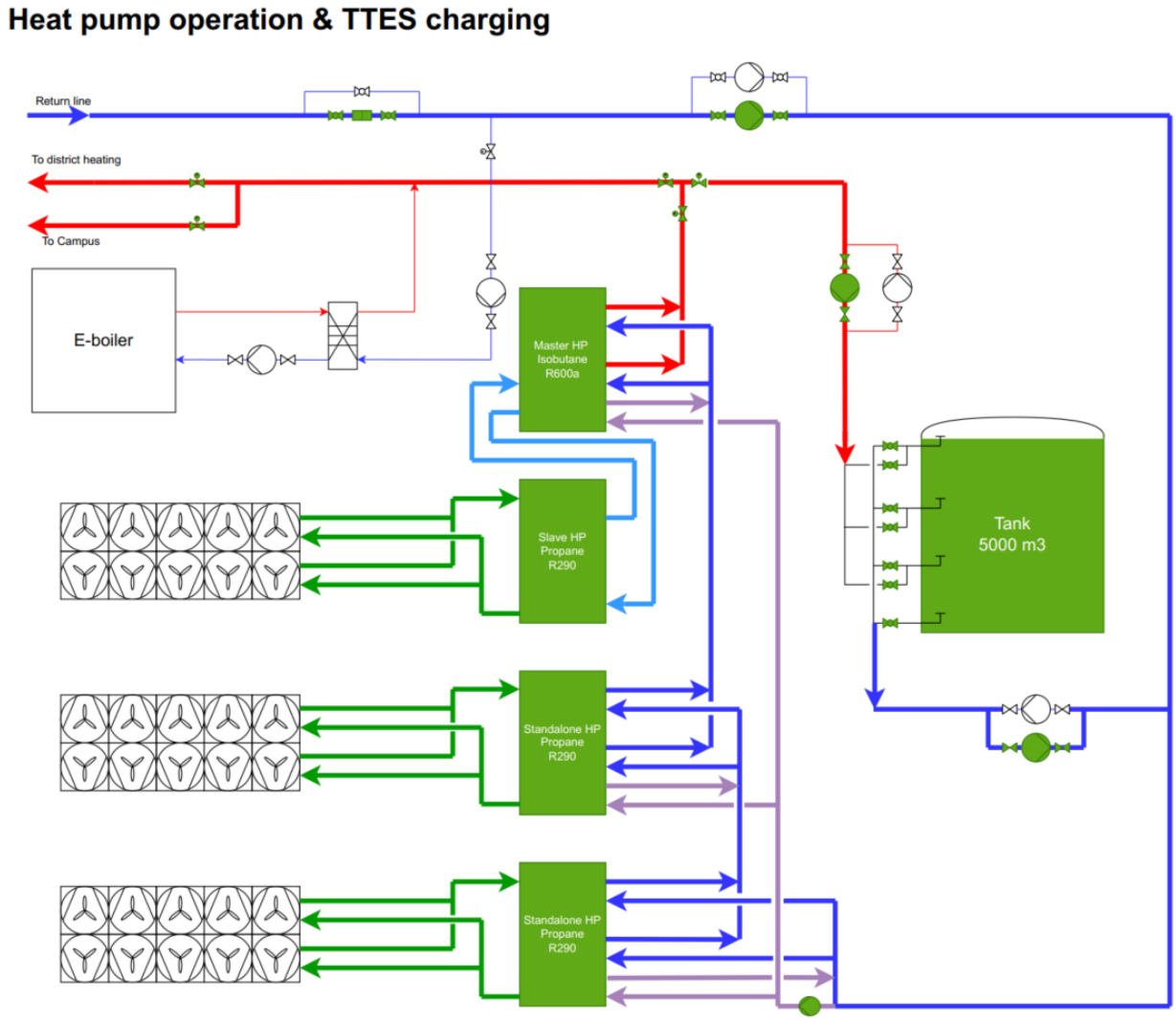


Figure 42: Operational mode "Heat pump operation and TTES charging", where the heat pump delivers heat to the heating grid, while simultaneously charging the TTES with excess heat.

For a large share of the year, when electricity prices are low, the heat demand is not too high and operational conditions for the heat pump are good, the heat pump can generate more heat than needed at the moment. In such a case, the produced excess heat is charged into the TTES and stored there for later usage, while low temperature water is discharged from the TTES.

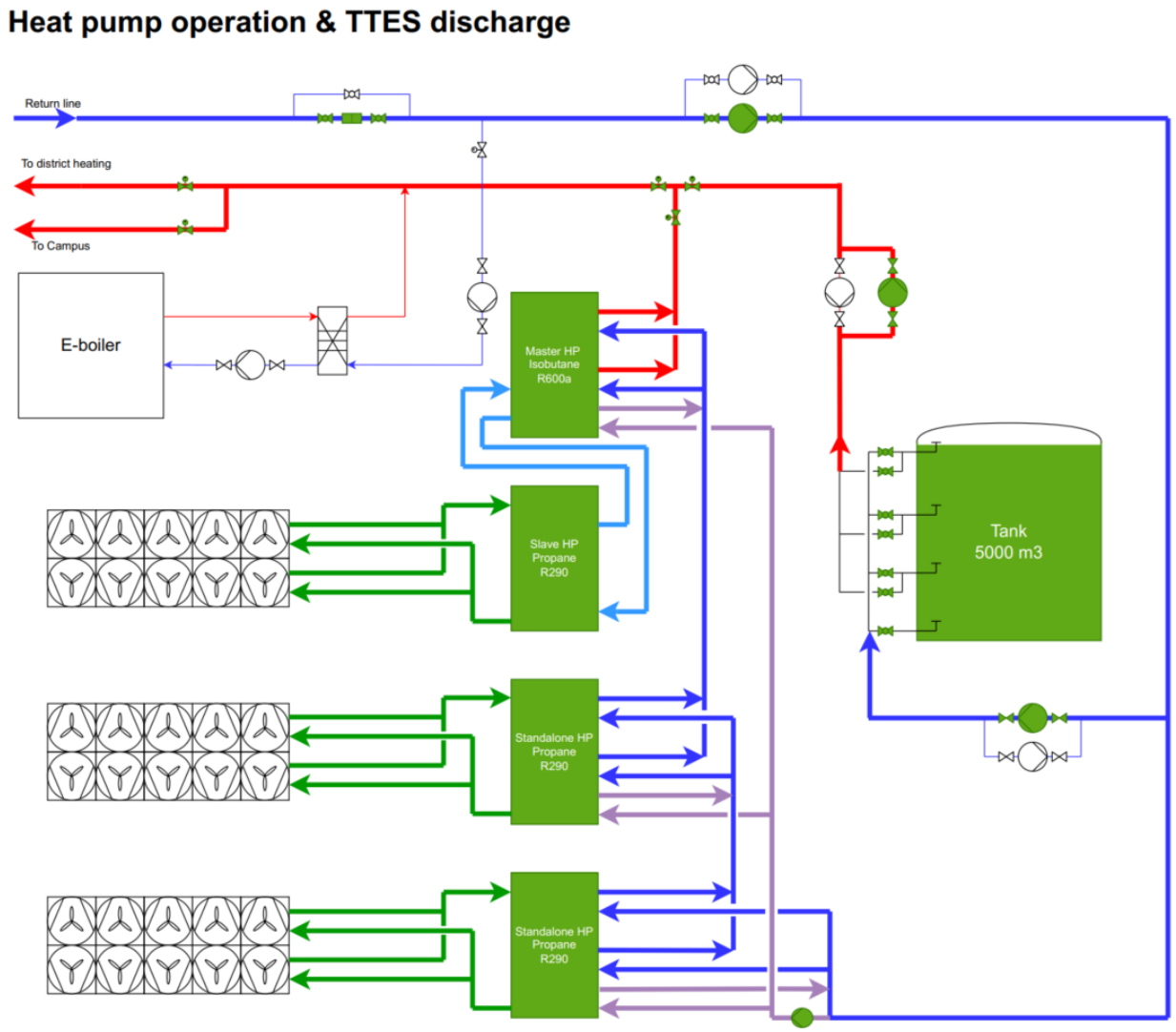


Figure 43: Operational mode "Heat pump operation and TTES discharge", where the heat pump delivers heat to the heating grid, while simultaneously discharging stored heat from the TTES.

If operational conditions for the heat pump are not good due to low temperatures or the heat demand is higher than the heating capacity of the heat pump, the TTES is used to supply a share of the heating demand. The heat pump and the TTES can operate and supply heat to the grid simultaneously.

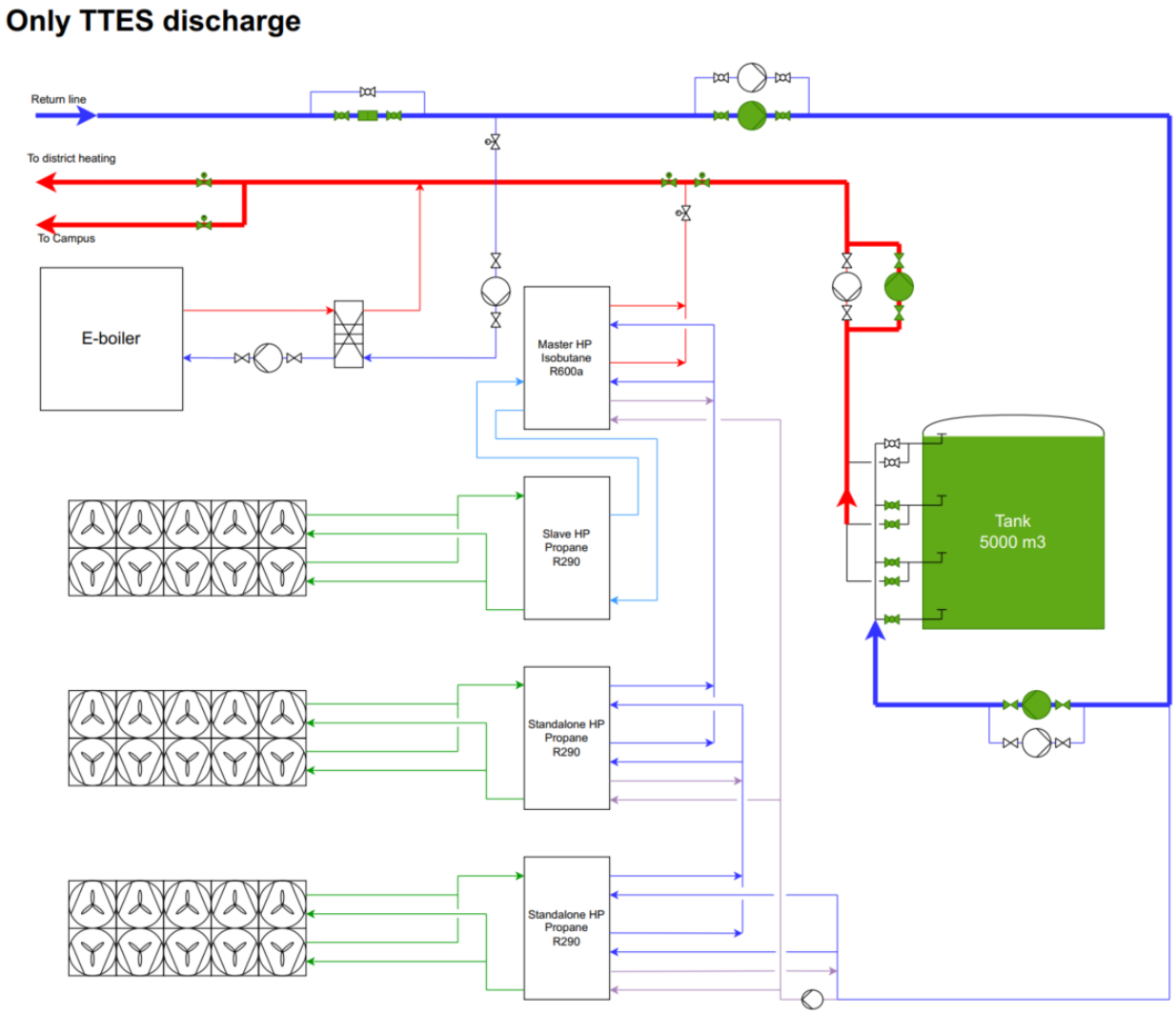


Figure 44: Operational mode "Only TTES discharge", where the heat pump is shut down, while the TTES delivers stored heat to the grid.

According to the provided data and information, for a large part of the heating season, the heat pump might be shut down during the day due to high electricity costs. In this case the TTES will cover the heat demand in those periods as a short-term storage. The cold return water from the heating grid will be stored in the TTES, while the stored hot water is discharged from the TTES and fed into the heating grid.

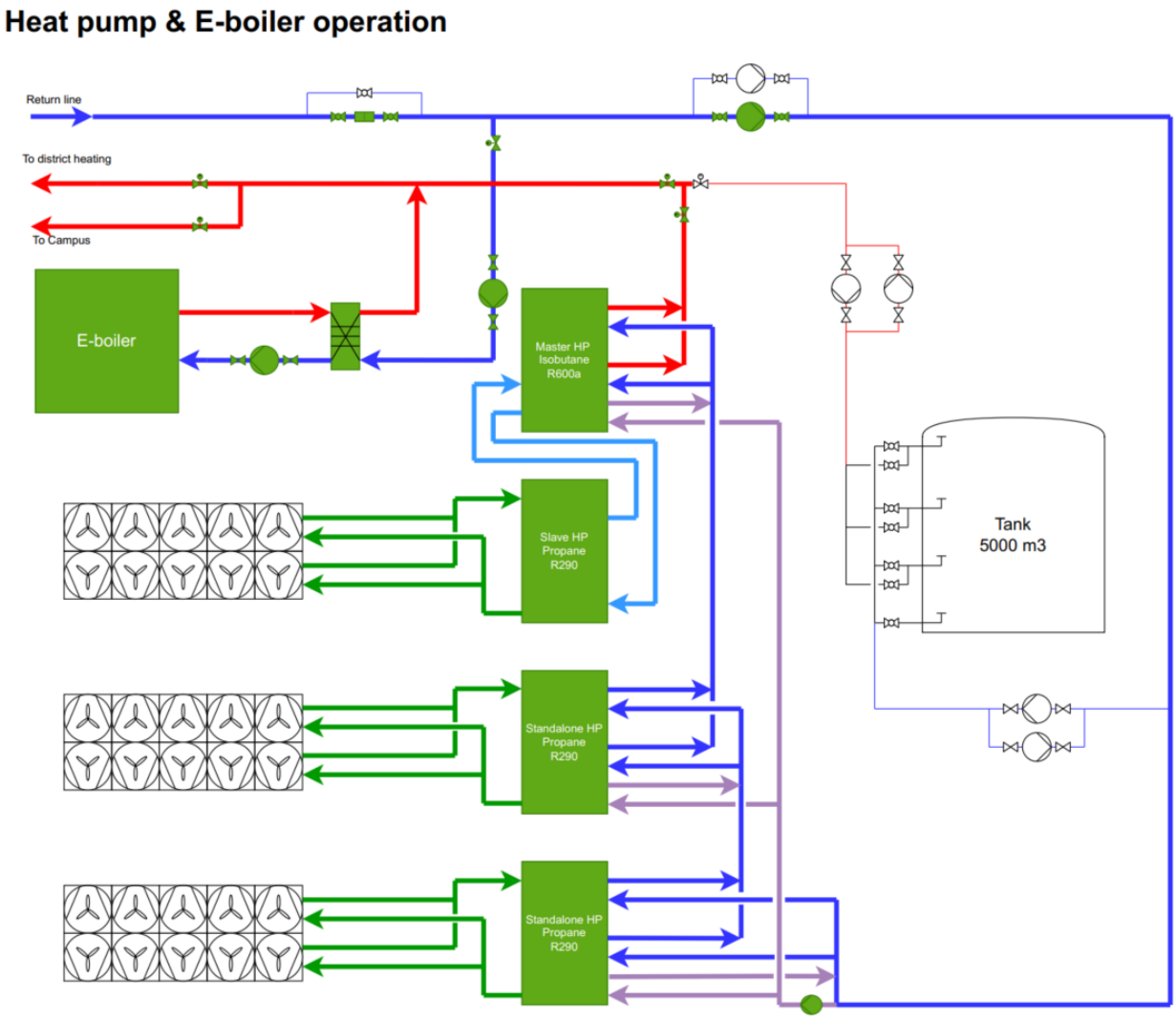


Figure 45: Operational mode "Heat pump and electric boiler operation", where the heat pump and the electric boiler operate simultaneously.

If the storage content of the TTES falls to zero during long-lasting cold periods, this operational mode is used. As the heat pump struggles to cover the high heat demand due to lower heating capacity at very low air temperatures, the electric boiler will switch on to support the heat pump and cover the needed backup heat supply.

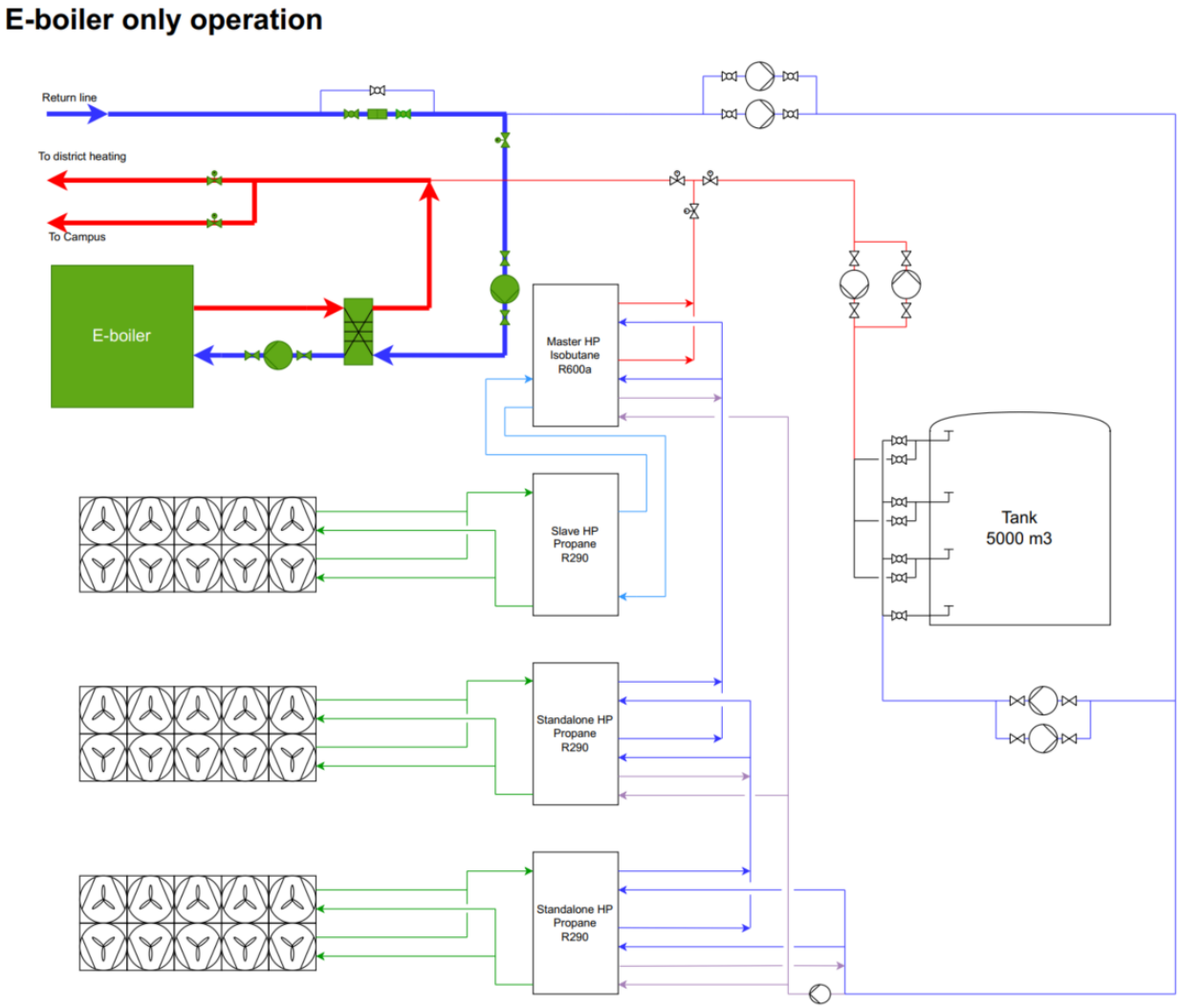


Figure 46: Operational mode "Electric boiler only operation", where only the electric boiler operates.

In case of a long-lasting downtime of the heat pump system, or a short-lasting downtime of the heat pump in combination with insufficient stored heat, this operational mode will come into effect. The electric boiler operates according to the heat demand, covering such completely. This operational mode could also be utilized if the University of Tuzla would like to offer grid stabilisation services to the grid operator and take-off excess renewable electricity during peak hours.

5.5. Piping and Instrumentation Diagram (PID)

For a more detailed understanding of the energy system, a preliminary PID has been drafted and is shown in Figure 47. This preliminary version will be updated and adapted at each of the further project development stages. The PID is attached to the study report as appendix *"40157-D781-00001-A Tuzla PID"*.

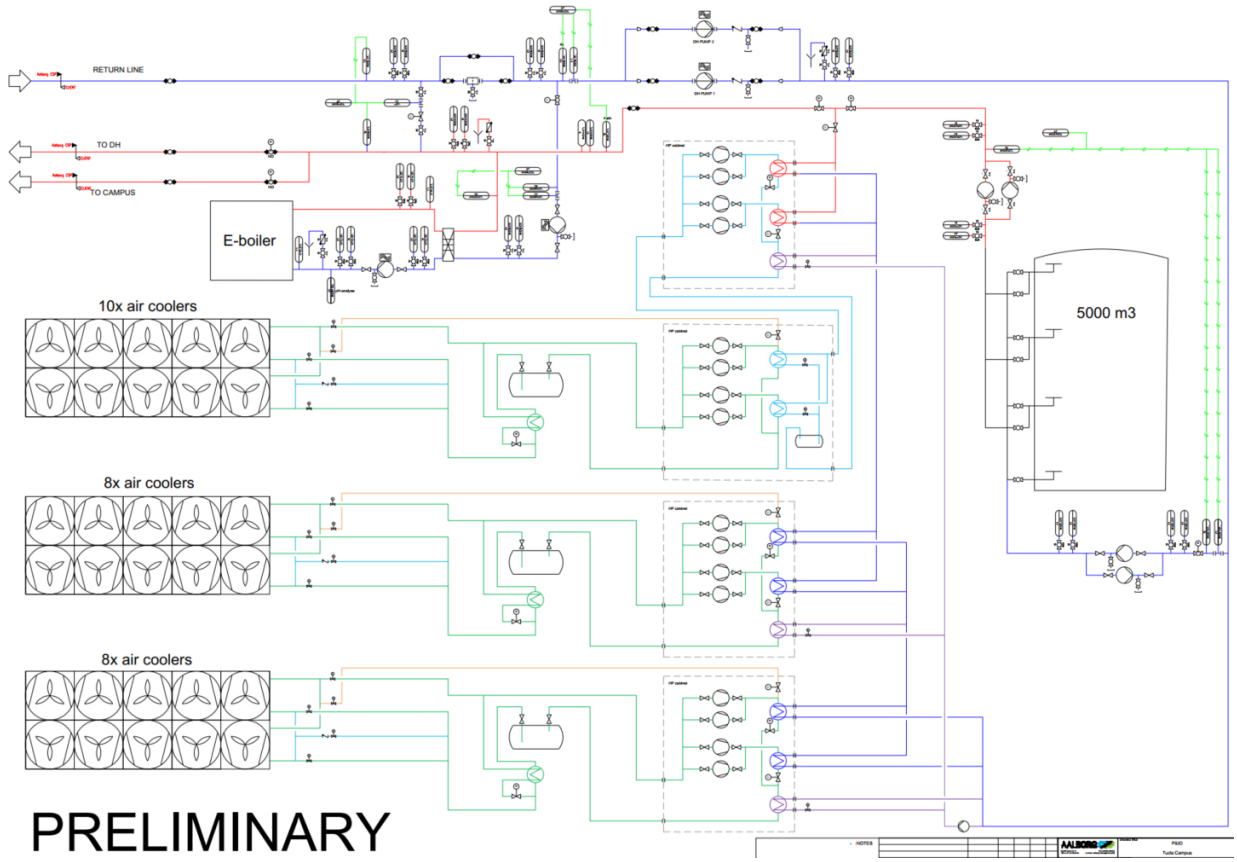


Figure 47: Preliminary PID of the heating system, with the scope of Aalborg CSP consisting of an electric boiler (top left), the 5.000 m³ TTES (right side) and the air heat pump system (centre) with the air coolers (left side).

5.6. Required land area

The air coolers of the heat pump measure approximately 32 meters by 23 meters in this preliminary assessment. These air coolers must be located freely standing on 3- to 4-meter-high legs, allowing efficient air circulation. At this early stage, a land area of approx. 32 meters by 23 meters (736 m²) is necessary for the installation of these coolers.

The heat pump with all its auxiliary equipment (transformers, control units, pumps, piping etc.) are to be installed inside a simple technical building. The required building size is approximately 470 m² (with 26,5 meters by 17,75 meters). The required technical building size is split into a heat pump machine room of approx. 345 m² and an auxiliary room of approx. 125 m², which accommodates components such as transformers, electrical panels/switchboards, control room and toilet facilities etc. A preliminary design is shown in Figure 48.

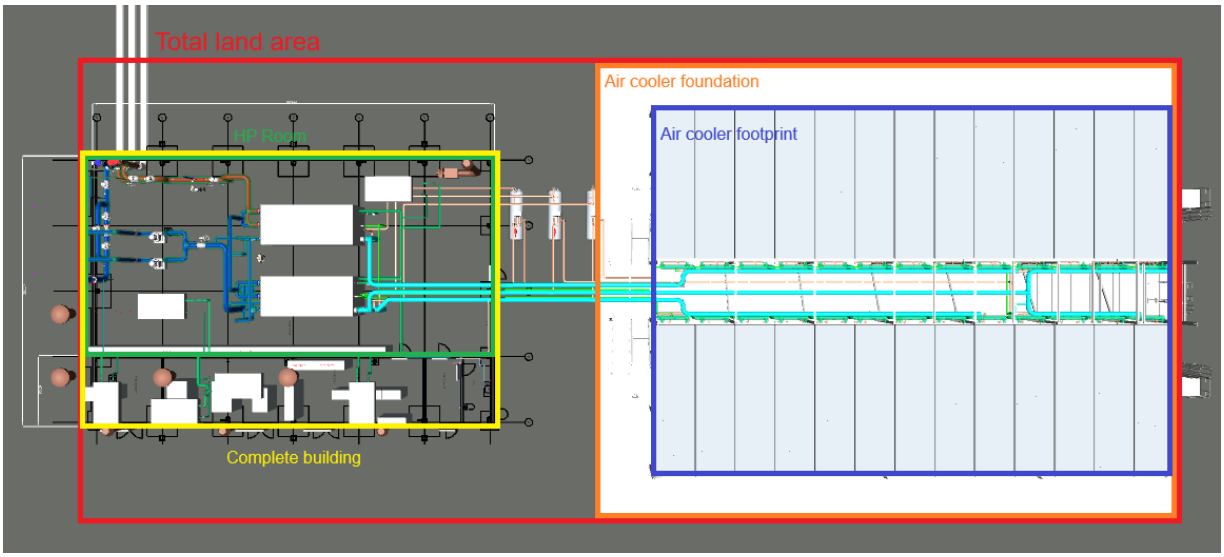


Figure 48: Top view of the preliminary design of the heat pump system, used to assess the land footprint.

The preliminary dimensioning of the TES resulted in a 25 meter high and 16 meter wide steel tank. Including foundations, pumps, etc. a land footprint of approx. 200 m² is estimated. Keep in mind that some area around the TTES needs to be available for possible maintenance and operation.

The electric boiler is to be installed in a technical room, ideally close to the other units of the heating system. The required space for the machine room with the electric boilers is rather small, with an initial estimate of 168 m²

The overall land footprint of the entire heating system can therefore be assumed to be 1.963 m², as shown in the overview of the land footprint in Table 10: Estimated required land footprint of preliminarily designed system components.

Table 10: Estimated required land footprint of preliminarily designed system components.

Component	Land footprint [m²]
Technical building (heat pump and technical equipment)	470
Air coolers (incl. foundation)	1.125
TTES (incl. foundation)	200
Electrical boiler building	168
Total	1.963

Potential sites of the heating plants have been assessed, and two potential locations have been identified, as shown in Figure 49. These potential locations are shown in detail in Figure 50. It has to be kept in mind, that depending on the specific conditions and requirements of the future plant location, the system design must be adapted.



Figure 49: Two potential locations for the heating system, marked in red. Either in the upper center of the map (west side of the campus) or the lower left side (north side of the campus).

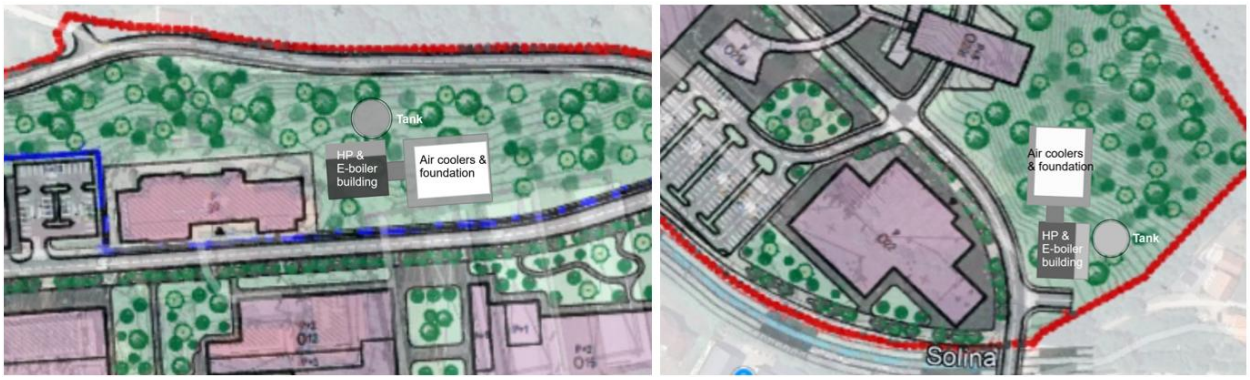


Figure 50: Detailed view of both potential heating plant locations, according to the preliminary design.

6. Simulation of the energy system

A simulation of the heating system was carried out to engineer and validate the design. The approach and methodology are based on Aalborg CSP's many years of experience in the planning and implementation of district heating systems.

6.1. Assumptions and simplifications

Several assumptions and simplifications were made for the simulations. These are generally as follows:

- Heat demand profile simulated according to a simulated temperature reference year and estimated heat load factors, agreed upon by University of Tuzla.
- Balance of heat demand and heat production on an hourly basis.
- Electricity prices, according to which the operation of the energy system is based, are based on assumptions made by the University of Tuzla.
- The electricity target price for the economic operation of the heat pump was fixed for the whole year. As soon as the respective electricity target price is undercut, the heat pump switches to full load operation.
    - Electricity target price for operation of the air-to-water heat pump: 150 EUR/MWh
- The number of annual potential operating hours is determined based on the electricity prices.
- The temperature was not balanced or tracked for the entire system, but assumed as follows:
    - District heating flow temperature: 60°C.
    - District heating return temperature: 40°C.
    - Maximum heat storage temperature and supply temperature by the heat pump: 95°C
- Heat loss in the district heating pipes was not taken into account and is therefore assumed to be included in the targeted heat demand of 19,7 GWh/a.
- A TTES size of 5.000 m³ has been simulated and deemed suitable.
    - A heat loss in the TTES has not been included in the simulations.

These constraints pose the operational philosophy with which the operation of the energy system is simulated.

6.2. Simulation results

The simulations show that the heat pump can supply almost all of the heat demand of the university campus, even during the winter months when the demand is high and the heating capacity and efficiency are low due to cold air temperatures.

A monthly overview of the heat supply shows that the heat pump can cover the majority of the demand directly even in the winter months. Another major share is covered by the pre-produced and stored heat via the TES. Yet backup heat supply is necessary for this period to cover all the heat demand, as can be seen in Figure 51. This is mainly due to the fixed operational philosophy, as explained later in 6.2.2.

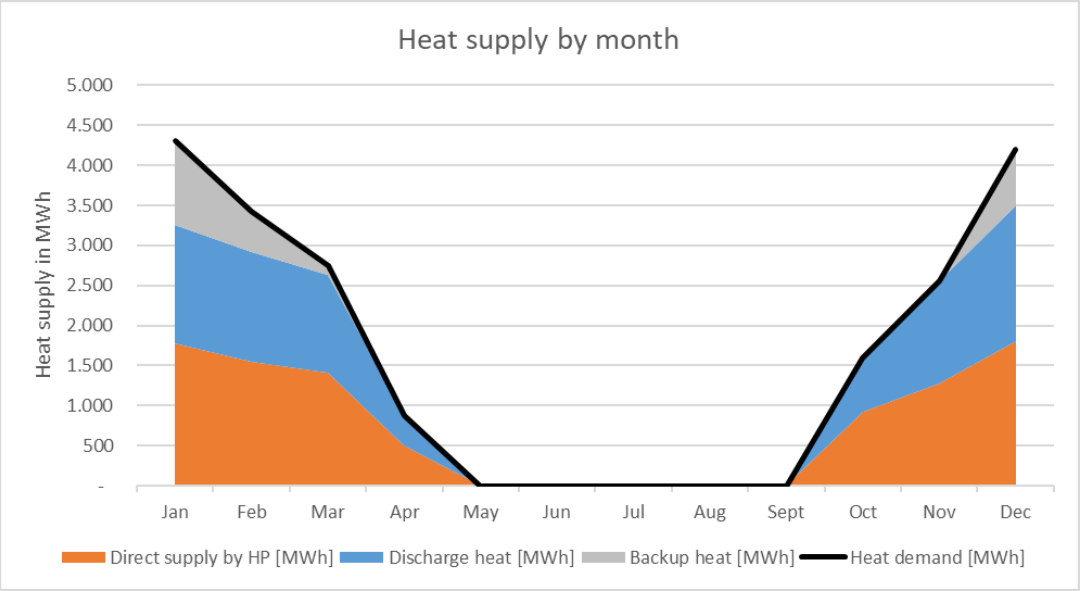


Figure 51: Heat supply by energy system unit per month in MWh.

Overall, the heat pump system can supply approx. 47% of the heat demand directly, while another 41% can be covered by the stored heat in the 5.000 m³ TES, which is also produced by the heat pump and then stored. The final 12% are to be covered by the backup heating system, shown in Figure 52.

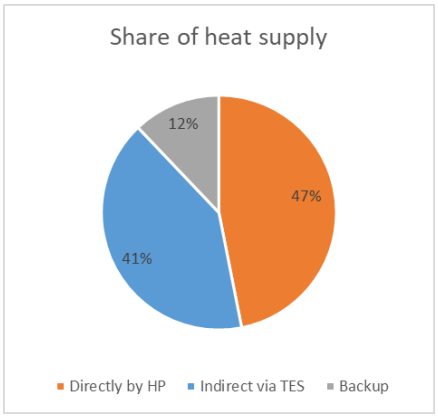


Figure 52: Share of the heat demand coverage by unit.

Investigating the heat supply more detailed in hourly resolution shows, that the backup boiler is typically operational when the heat pump is not producing any heat during periods of high electricity prices and a simultaneously empty TES storage content. The storage content is usually reaching a minimum towards the end of a week during the cold season, as the TES is typically filled to maximum capacity during the weekend when the heat pump system is operating 24 hours per day to utilize low electricity prices. This weekly charging and discharging patterns are clearly visible in Figure 53, where the charging and discharging profile of the TES is shown, as well as Figure 54 where the storage content of the TES is shown.

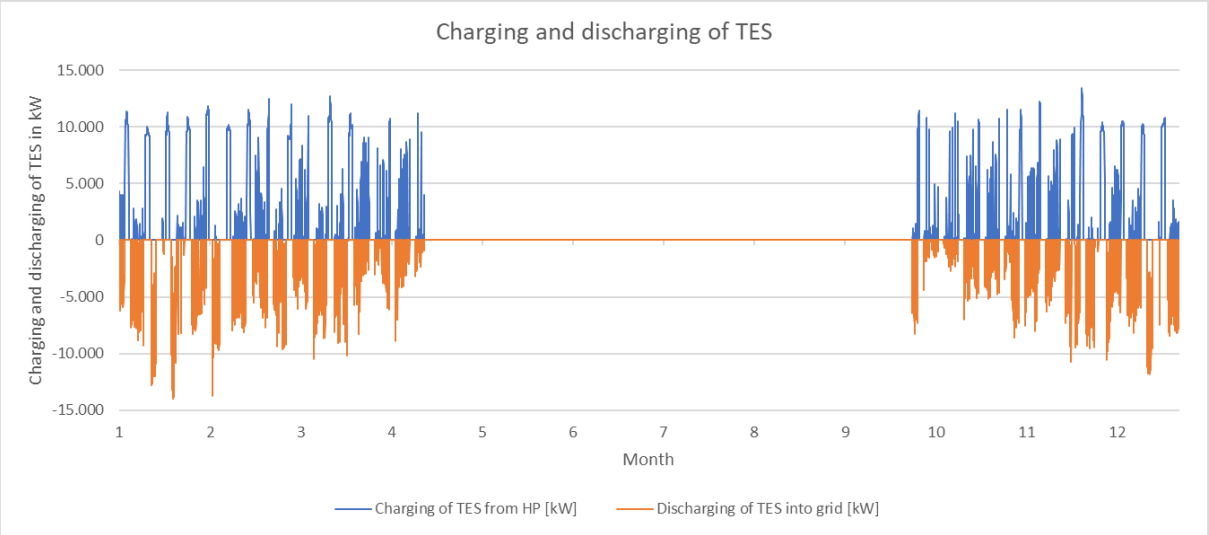


Figure 53: Charging and discharging profile of the TES in kW. Weekly charging and discharging patterns are clearly visible.

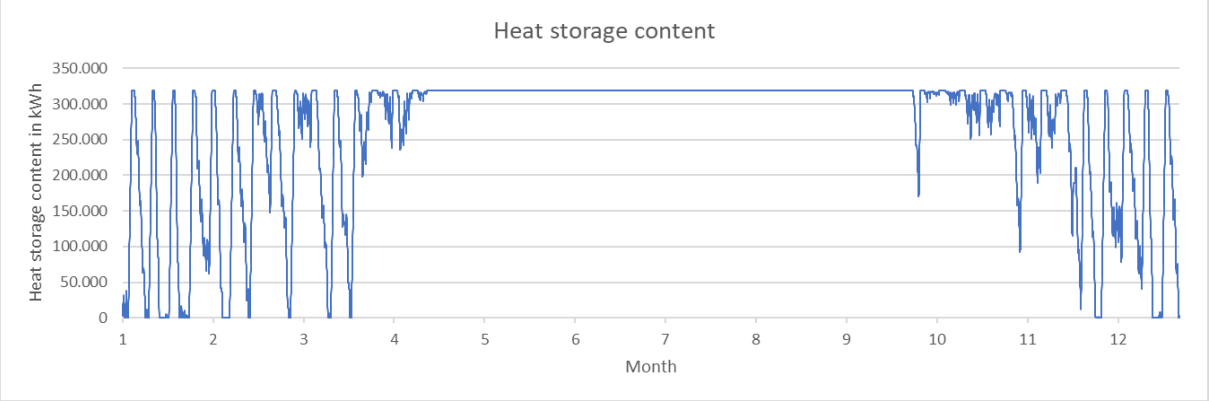


Figure 54: Storage content levels of the TES in kWh. Weekly and daily storage patterns are clearly visible.

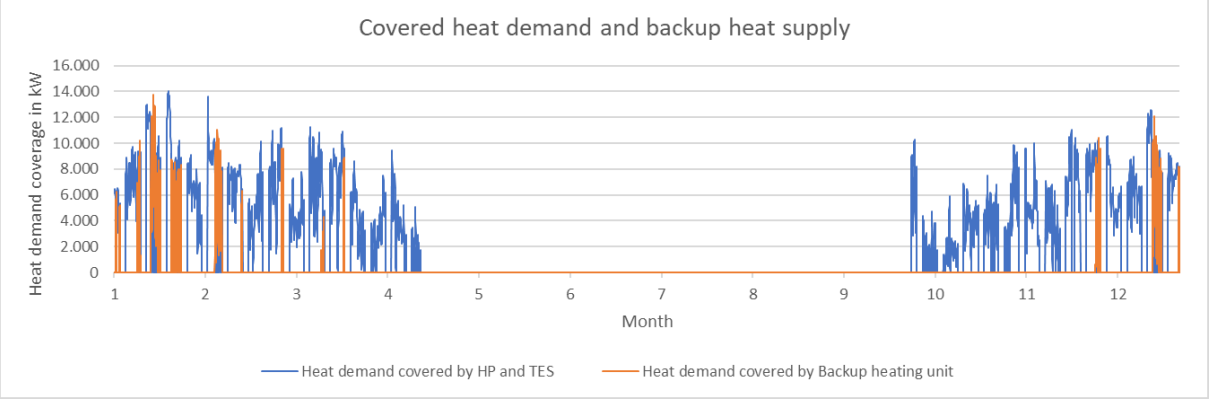


Figure 55: Heat supply covered by the heat pump and TES, compared to the heat supply by the backup unit. Weekly operation patterns for the backup unit are clearly visible.

The periods where the TES is empty means that backup heating capacity is typically necessary, as the overlap between Figure 54 and Figure 55 shows.

On the other hand, not only the electricity price but also the lack of heat demand or available heat storage capacity determines the shut-down of the heat pump. As Figure 56 indicates there is a daily and weekly pattern for the heat pump operation due to electricity prices, but also a weekly pattern due to limited storage capacity and heat offtake during the weekend.

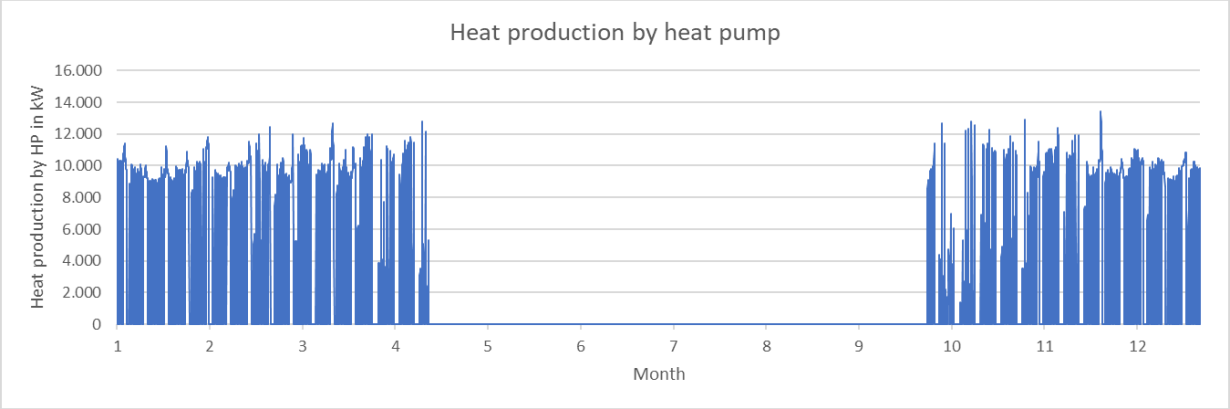


Figure 56: Heat production profile by the heat pump. Weekly operation patterns are clearly visible.

The simulated yearly electricity demand of the heat pump system amounts to approx. 7.050 MWh/year, while the backup electricity boiler consumes approx. 2.387 MWh/year, resulting in a total electricity consumption of 9.436 MWh/year.

6.2.1. Impact of TES size on heat demand coverage

The sizing of a suitable TES volume has a significant impact on the energy system. A larger TES allows more heat to be stored, which means more operational hours and heat production by the heat pump, as well as a larger share of the heat demand covered. On the other hand, a larger TES also means higher investment costs and space requirements.

Different TES sizes have been simulated to understand the impact of the sizing on the energy system performance, as well as to help finding a suitable size. The results of this investigation can be seen in Figure 57, where the share of covered heat demand and necessary backup heat supply is shown for different TES sizes.

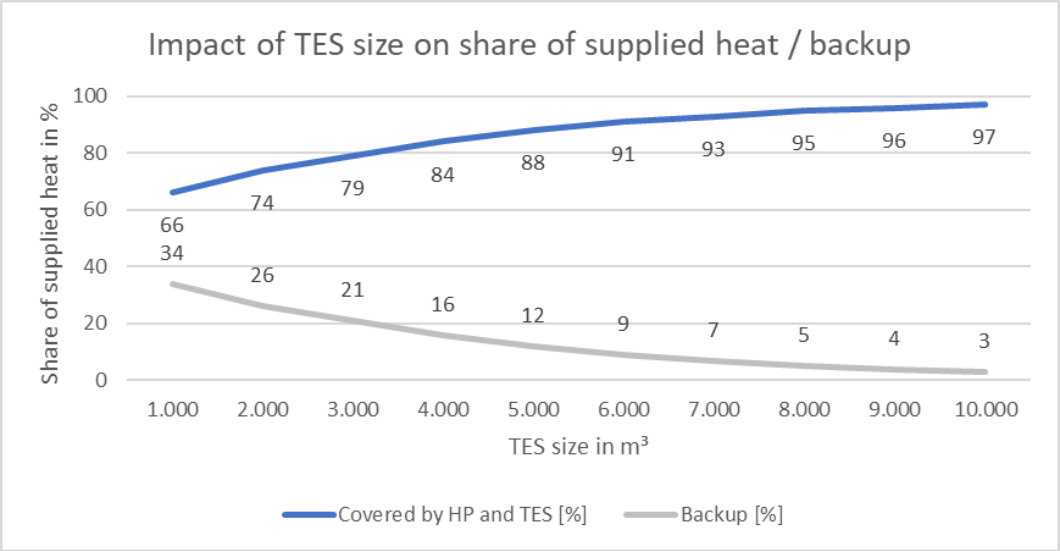


Figure 57: Share of supplied heat for different TES volumes.

It can be concluded that a 5.000 m³ large TES provides sufficient storage capacity, with almost 90% heat demand coverage by the heat pump and TES.

6.2.2. General remarks about operational philosophy and backup heat supply

It has to be emphasized that this energy system simulation is aiming towards a simplified heat pump operation according to the electricity price profile. This means that the heat pump only operates during relatively cheap operation hours and does not consider the storage content of the TES, or forecasts for future heat demands and weather.

In a real-life operation, the system operator or control system would consider weather forecasts and predict the upcoming heat demand for the following days. If the air temperature would be forecasted to decrease and the heat demand to subsequently increase, the control system could operate the heat pump despite the higher electricity costs and hence produce and store enough heat to cover the heat demand over the next day(s). Or the system would simply switch on the heat pump (despite higher electricity prices) as soon as the storage content is too low to cover the heat demand over the following hours until the electricity price is decreasing again. This is shown in the comparison in the following Figure 58, where in the upper diagram the operational philosophy described in section 6.1 is used, and the lower diagram is showing a smarter system operation where the heat pump is activated despite higher electricity prices when the TES content is low – to avoid an operation of the backup unit.



Figure 58: Comparison of a fixed operational philosophy with a flexible operational philosophy including a forecast of operation. In the flexible approach, the control system detects a low TES content during a period with high heat demand, which leads to an activation of the heat pump despite higher electricity prices to avoid backup heat supply.

As the heat pump is sized in a way that even on cold days the majority of the heat demand can be covered and the TES is large enough to cover approximately 2 winter days of heat demand, the system would be sized large enough to cover the heat demand without the use of backup units. This is confirmed by the simulations: If the switch-off price for the heat pump operation is removed, the heat pump and TES can cover 100% of the heat demand, with no need for backup heat supply. This scenario is shown in the following Figure 59, Figure 60 and Figure 61.

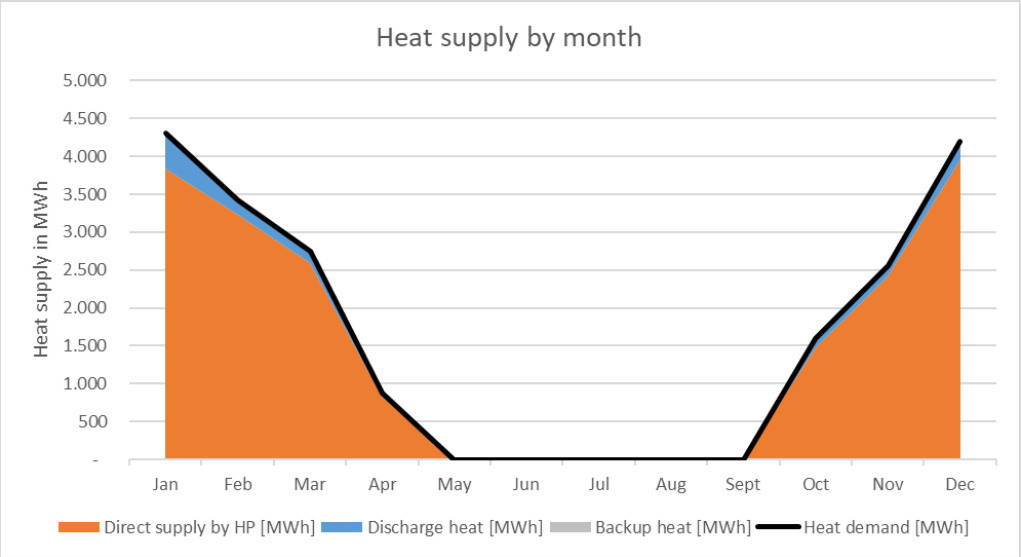


Figure 59: Heat supply by unit per month if heat pump operation is not curtailed by switch-off electricity price.

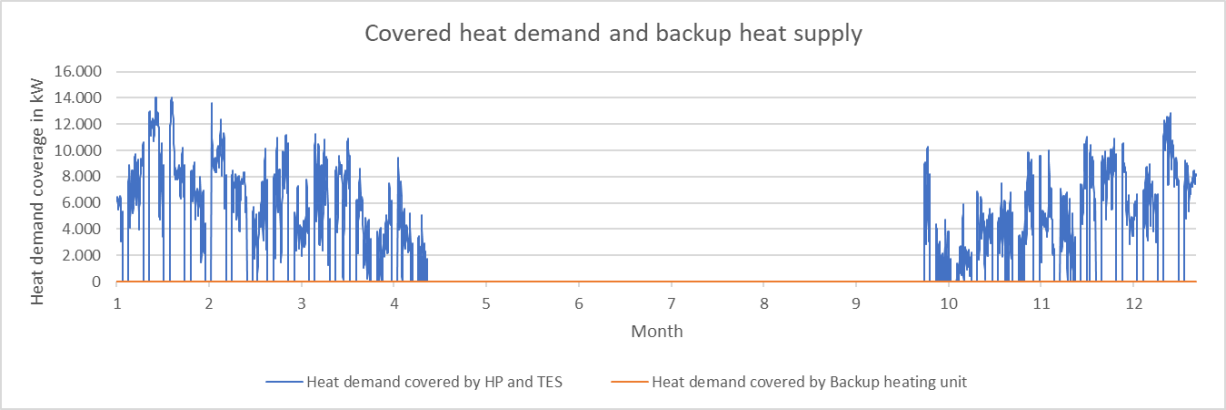


Figure 60: Covered heat demand by heat pump and TES, as well as backup unit, if heat pump operation is not curtailed by switch-off electricity price.

The heat storage content of the TES in Figure 61 even shows, that the storage content in this case is for most of the year almost full. Only during long lasting periods with cold weather and corresponding lower heat output and higher heat demand, the storage content is falling to a low level. This can be seen for instance during mid-January in Figure 61.

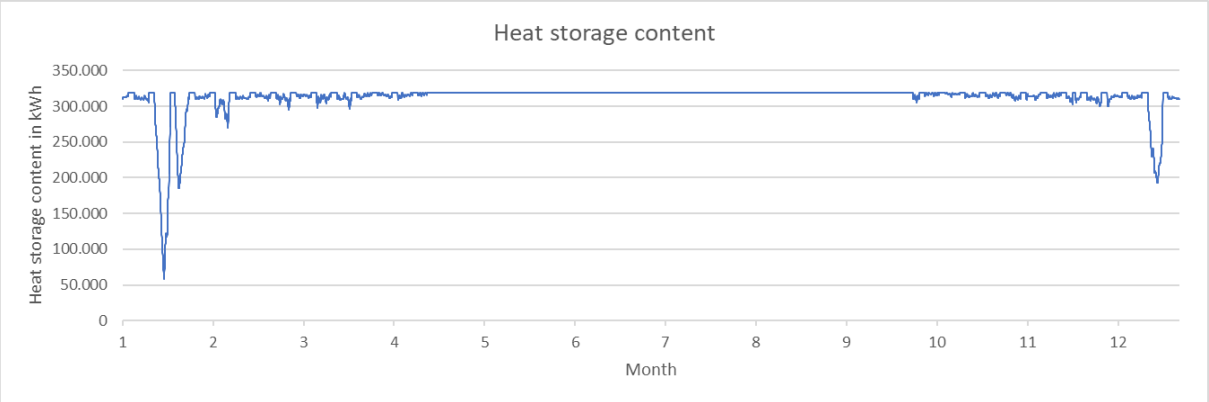


Figure 61: Heat storage content if heat pump operation is not curtailed by switch-off electricity price.

The simulated yearly electricity demand of the heat pump system in this scenario amounts to approx. 8.032 MWh/year, with no additional electricity consumption by the boiler. The total electricity demand would therefore be 1.404 MWh/year lower than in the previously simulated scenario with a fixed operational philosophy, thanks to the better efficiency of the heat pump compared to the electric boiler.

7. Economics of the energy system

The economical calculations of the sector-linked district heating system are based on Aalborg CSP's many years of experience in the construction and integration of energy systems, as well as on current sub-supplier offers. This ensures that the price reflects reality. However, the prices are based on Danish market rates, while the costs for a local installation in Bosnia have not been investigated.

An overview of the investments can be found in Table 11.

Table 11: Overview of estimated investments.

System component	Investment costs [million EUR]
Air heat pump system	8.718.000
Steel tank TES	1.855.000
Electric boiler	1.944.000
Other technical equipment and works*	1.729.000
Total	**14.246.000**

*Other technical equipment contains items like soil works and land preparation, simple technical building installation, main electrical supply, electrical installation, control and programming etc.

8. Considerations for a future proof energy system

The proposed heating system is offering a sector coupled approach, where the heat pump system and electric boiler are combining the electricity sector with the heating sector and the TTES is offering much needed system operation flexibility, making this energy system future proof. As the heating system is supposed to be operational for several decades, its design cannot only take the status quo into account, but it needs to be adapted to future conditions and challenges.

Slowly but steadily electricity generation worldwide is transitioning from dispatchable fossil fuelled energy towards fluctuating renewable energy. This further increases the demand for flexibility, which can be offered by combining the heating and electricity sector, as is done with this system design. Similar system designs are already successfully operating in countries with high renewable electricity share and strong developed district heating markets such as Denmark.

When excess electricity is generated by solar PV systems and wind turbines, the electricity price is lowered, and grid operators seek to find consumers who can offtake large amounts of electricity to stabilize the grid. In such moments, district heating operators can offer dispatchable grid balancing services by switching on electric boilers or heat pumps, lowering the strain on the electric grid and simultaneously producing heat for low costs, for free or even while generating revenue from it.

On the other hand, when renewable electricity production is low and electricity prices are high, suitable storage capacities are needed to bridge the gap or period between cost-efficient heat production periods. This means that produced excess heat during times with low heat production costs has to be stored, to be utilized at a later time when heat production costs would be higher, in order to avoid these high costs. The added flexibility by the storage does not only result in lower heating costs but also increases the share of renewable energy by making backup heat supply – which is often fossil fuel based – unnecessary.

Even though the Bosnian grid does not necessarily experience the challenges arising with a mainly renewable electricity mix nowadays, it will definitely do so in the future with the ongoing renewable transition and electrification. More flexibility and smart energy system integration will be key topics for any energy system operator in the coming years and decades. Keeping in mind that this energy system of the University of Tuzla is not supposed to be operational today but over the next decades, the energy system must not be optimised according to todays or yesterday's demands and challenges, but it must be designed according to the future of the energy systems.

8.1. Integration of renewable electricity from PV

The integration of electricity from photovoltaic (PV) modules was originally not within the scope of this study. At a later point it has been agreed to include an assessment about the integration of PV systems in order to provide the heating system with renewable electricity as well as sell excess electricity to the grid. Any electricity produced by the University of Tuzla can be used to power the heat pumps, making electricity purchases from the grid unnecessary and can therefore promote a heat supply which is more independent from fluctuating electricity spot market prices.

It has to be kept in mind that the peak production hours of PV systems usually do not collide with the peak heat demand times. Therefore, the integration of the TTES could help to increase the flexibility and usage of self-produced electricity from PV panels on the university campus.

Analysing the maps and drawings of the future university campus, the available land areas and roof areas have been assessed. Additionally, the potential installation of PV carports on the main parking lots has

been taken into account. Assumptions for the usability of the areas have been used, as detailed information is not available at this early stage in project development.

As shown in Table 12, for each of the three potential locations of PV installations, available land area (discounting for the land footprint of the heat pump system including air coolers and TTES), the roof areas and the parking lots, a specific utilisation factor has been used. This utilization factor is taken into account to assess how much of the gross area can actually be utilized for PV installations, as for example not all of the roof area can be utilized due to roof windows, ventilation outlets, other HVAC or technical installations, or parts of the land area are not utilizable due to shadowing from buildings or the steep slopes as mentioned earlier in section 4.4. Then the amount of m² PV modules installed per m² available or utilizable land area has been assumed for each type of location, resulting in the installed PV area. These assumptions, calculations and results are shown in the following Table 12.

Table 12: Estimated area sized for PV installation and resulting PV system size.

Area	Approx. size of area	Assumed utilization factor	Utilized area for PV	Assumed PV area per m² utilized area	PV area
Land area	20.537 m²	20%	4.107 m²	40%	1.643 m²
Roof area	71.273 m²	25%	17.818 m²	50%	8.909 m²
Parking area	9.912 m²	30%	2.974 m²	90%	2.676 m²
Total	101.722 m²	-	24.899 m²	-	13.228 m²

Then the electricity output of this PV area has been estimated. A PV module capacity[a] of 0,2 kWp/m² and a yearly specific electricity power output[b] of approx. 1249,5 kWh/kWp (see Figure 62) of renewable electricity has been assumed. As a result of this estimation approx. 3.306 MWh of electricity could be generated by PV on the campus of the University of Tuzla. This would cover around 35% to 41% of the yearly electricity demand simulated in sections 6.2 and 6.2.2.

An overview of the estimated potentially installed PV capacity and yearly generated electricity are shown in the following Table 13.

[a] Assumption of 5 m²/kWp based on: https://www.jojusolar.co.uk/faqs-solar-power/#:~:text=For%20standard%20modules%20of%2016,take%20up%205m2%20of%20roofspace.

[b] According to the Global Solar Atlas for the location of Tuzla: https://globalsolaratlas.info/map?c=44.567725,18.473511,11&s=44.53911,18.675193&m=site

Table 13: Estimated installed PV capacity and resulting yearly electricity production.

Area	Estimated installed PV capacity	Estimated yearly electricity from PV
Land area	329 kW_p	411 MWh
Roof area	1.782 kW_p	2.226 MWh
Parking area	535 kW_p	669 MWh
Total	2.646 kW_p	3.306 MWh

As all of those estimations are heavily based on assumptions, simplifications and preliminary information, any input or improvements of these estimations by the University of Tuzla could make the results more reliable.

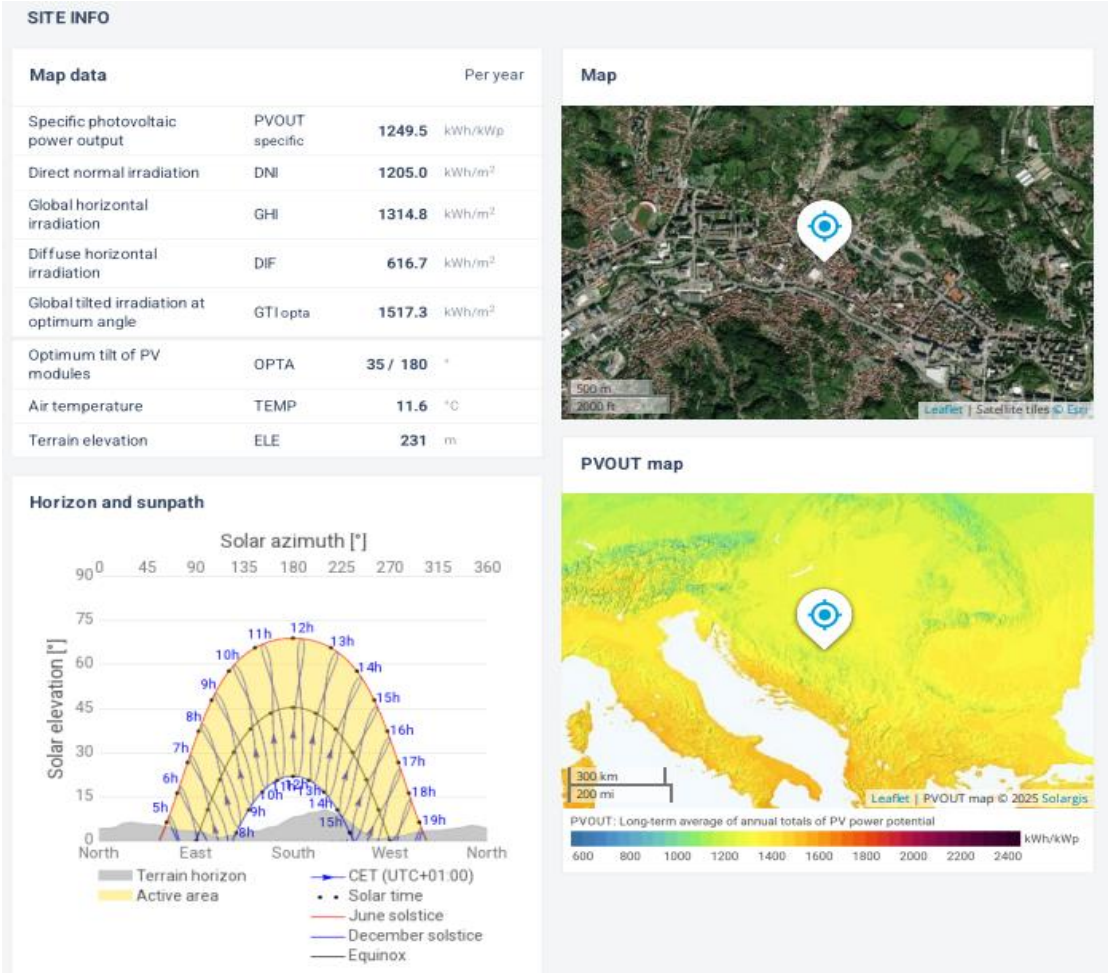


Figure 62: Screenshot taken from the Global Solar Atlas Report for the location of Tuzla: https://globalsolaratlas.info/map?c=44.567725,18.473511,11&s=44.53911,18.675193&m=site

8.2. Selling excess heat to the public district heating grid

As stated in section 6.2.2, the engineered heat pump system in combination with the TTES is large enough to supply the university campus all year round with heat, depending on the operational philosophy. As seen before in Figure 54 and Figure 61, the storage content is often reaching maximum capacity, meaning that the heat pump has to switch off despite low electricity prices and good operational conditions as there is no heat offtake or storage capacity available. Instead of curtailing the heat pump system, it could be beneficial for the University of Tuzla to produce and sell heat to the external public district heating grid. By doing so, the university could generate revenue from sold heat, add flexibility to the energy system, increase the share of self-consumed PV electricity, while helping to decarbonize the local district heating supply in the city of Tuzla.

This possibility has been considered in the engineering done by Aalborg CSP, as can be seen in the PFD in Figure 40 and the PID in Figure 47, where the district heating forward is directed towards the university campus as well as the public district heating grid.

9. Conclusion

This present proposal with an air heat pump and a steel tank TES is a suitable solution to ensure renewable and reliable heat supply at a competitive price for the University of Tuzla. In this concept study, different technologies were evaluated according to their suitability for this project.

The results show that the initial system design with solar thermal plant, PTES, dual-source heat pump and electric boiler are not suitable options for the university campus, due to a variety and combination of reasons. An alternative simplified system design with an air heat pump, a steel tank TES and a backup electric boiler would make technical and economic sense and shows great potential to ensure a sustainable and efficient renewable district heating supply for the University of Tuzla. The design of this energy system resulted in a 10 MW heat pump system at 2°C in combination with a 5.000 m³ TES to cover the assumed heat demand of approx. 10 GWh/year. Depending on the operational strategy and the final heat demand profile, this system could supply up to 100% of the heat demand at all times. An additional 20 MW electric backup boiler would offer redundancy and ensure security of supply in case of an malfunctions of the heat pump, as well as allow to integrate fluctuating renewable electricity (such as from PV) in a flexible and cost-effective way.

The proposed heat pump system is utilizing the environmentally friendly and real-life proven natural refrigerants propane and isobutane, allowing efficient heat production even during cold winter times when the heat demand is high.

Due to the early initial stage of project development, many calculations and simulations are based on assumptions or approximate data, which sometimes entails greater uncertainties and could have implications for a later more detailed design. Therefore, it is advisable to clarify the following data in a further study in a second step, which is likely to be possible in a later stage of the overarching project development:

- Annual heat consumption
- Heat demand profile
- Temperature levels
- Electricity prices and self-use of electricity

Aalborg CSP is happy to support the further project development and proposes a meeting with University of Tuzla, the Aarhus Centre Bosnia and Herzegovina, and other relevant actors, where the results and further steps can be discussed.