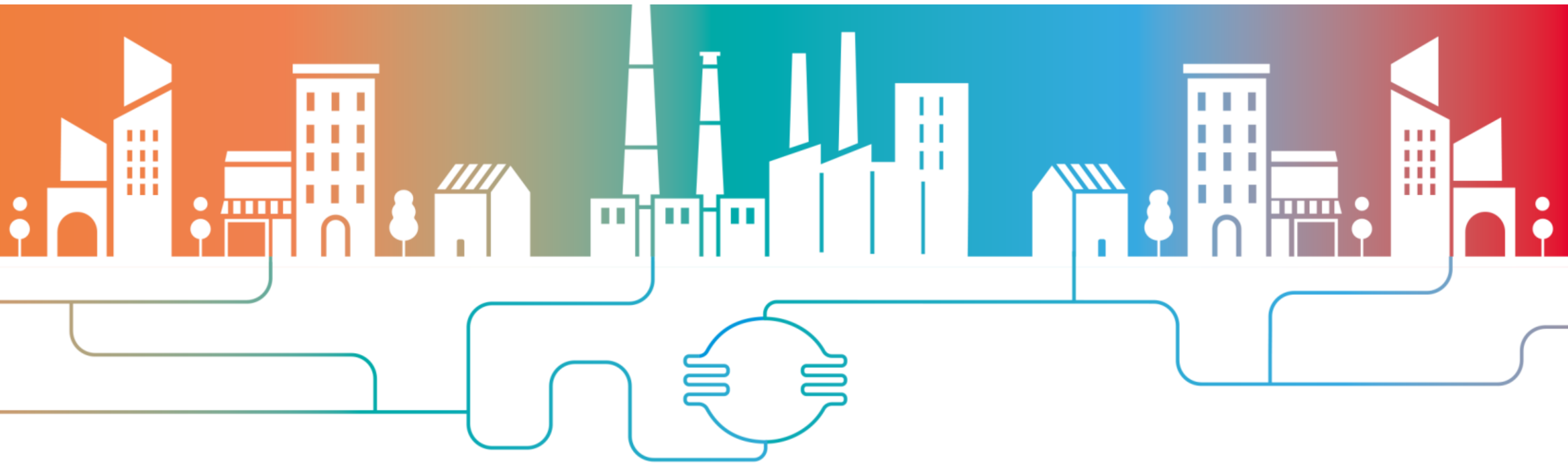
C6.2 – Report on the pre-design studies at the Early Adopters' networks



Low temperature, urban waste heat into district heating and cooling networks

as a clean source of thermal energy

LIFE4HeatRecovery

Project Title: Low temperature, urban waste heat into district heating and cooling networks as a clean source of thermal energy

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1 Summary

The feasibility study "*Report on the pre-design studies at the Early Adopters' networks*" is elaborated within Action C.6 of the LIFE4HeatRecovery project, aimed at fostering replication and transfer of the project results.

Concept and solutions developed within the LIFE4HeatRecovery project Demo Sites are used as background to develop a feasibility study on the integration of the modular and scalar Skid into the district heating network of the Early Adopters.

Alperia operates the 3rd generation district heating network of Bolzano (Italy) and is involved in the development of an overall heating and cooling solution for an urban requalification project in the city centre of Bolzano: large amounts of low temperature heat from HVAC equipment are to be dissipated mainly to grant internal environment comfort. The feasibility study shows that the financial sustainability of the measure is not reached in the peculiar context of Bolzano, but it can be achieved in a more general Italian context. Furthermore, energy vector prices that allow to reach the sustainability of the heat recovery measure are determined so to extend the applicability of the obtained results.

KWA/EVIVA in the role of project developer and operator is involved in the definition of a CO_2-neutral energy supply for a new living area in the city of Schwaigern (Germany). The realization of a cold district heating network supplied by the waste heat of a nearby supermarket and by an agrothermal field is the topic of the feasibility study. Results show that 19% of the total energy demand of the new living area can be sourced from the waste heat of the supermarket, 56% from the agrothermal field and the remaining 25% through the use of heat pumps. In the general German context, benefitting of a national funding program (Wärmenetzsysteme 4.0), it is possible to build up business cases to supply cities with sustainable energy.

The *pre-design studies at the Early Adopters' networks* highlight therefore the potential of urban waste heat recovery measures as a tool to enhance the sustainability of heat supply into existing and planned district heating networks.

2 Introduction

The beneficiaries Alperia and KWA have analysed the integration of waste heat in 2 different networks they are responsible for. Waste heat sources to be eventually integrated have been previously individuated and within sub-action C.6.2 the technical and economic feasibility of their exploitation have been assessed.

Alperia is involved in the development of an overall heating and cooling solution for a new large shopping mall under construction in the city centre of Bolzano. Large amounts of low temperature heat from HVAC equipment are to be dissipated mainly in order to grant internal environment comfort. The lack of a simple solution suitable for waste heat recovery into the existing high-temperature district heating network was the base factor that motivated Alperia in evaluating the prefabricated, modular and standardised heat recovery solution defined within the LIFE4HeatRecovery project.

KWA/EVIVA was involved in the elaboration of a tendering process for a feasibility study in the city of Schwaigern. The feasibility study will be the base for a CO_2-neutral energy supply for a new living area. KWA/EVIVA as a project developer and operator intend to take part in the following tendering process for the implementation and operation. As the elaboration of the feasibility study overlaps with the LIFE4HeatRecovery project KWA/EVIVA have seen a perfect opportunity to investigate the impact of a waste heat source within the system.

In the ensuing paragraphs the cases studied by both Early Adopters are described in detail, starting from an introduction on the context of the selected case study, proceeding with the description of the technical solution to be implemented and followed by an assessment, under a set of different boundary conditions, of the technical and financial performance of the studied initiative.

3 Early Adopter Bolzano

3.1 Description of the Case Study

The Municipality of Bolzano started in 2009 a process to reshape the use and the urban role of a pivotal area located between the train station and the historical city centre. A Masterplan (Comune di Bolzano, 2009) has been elaborated to indicate the guidelines to be followed by urban planners in the proposal of new concepts for the area.

The project for urban requalification presented by a private society (WaltherPark SpA) in 2013 has undergone several steps of public engagement and authorization, to be definitively approved by a public consultation in 2016.

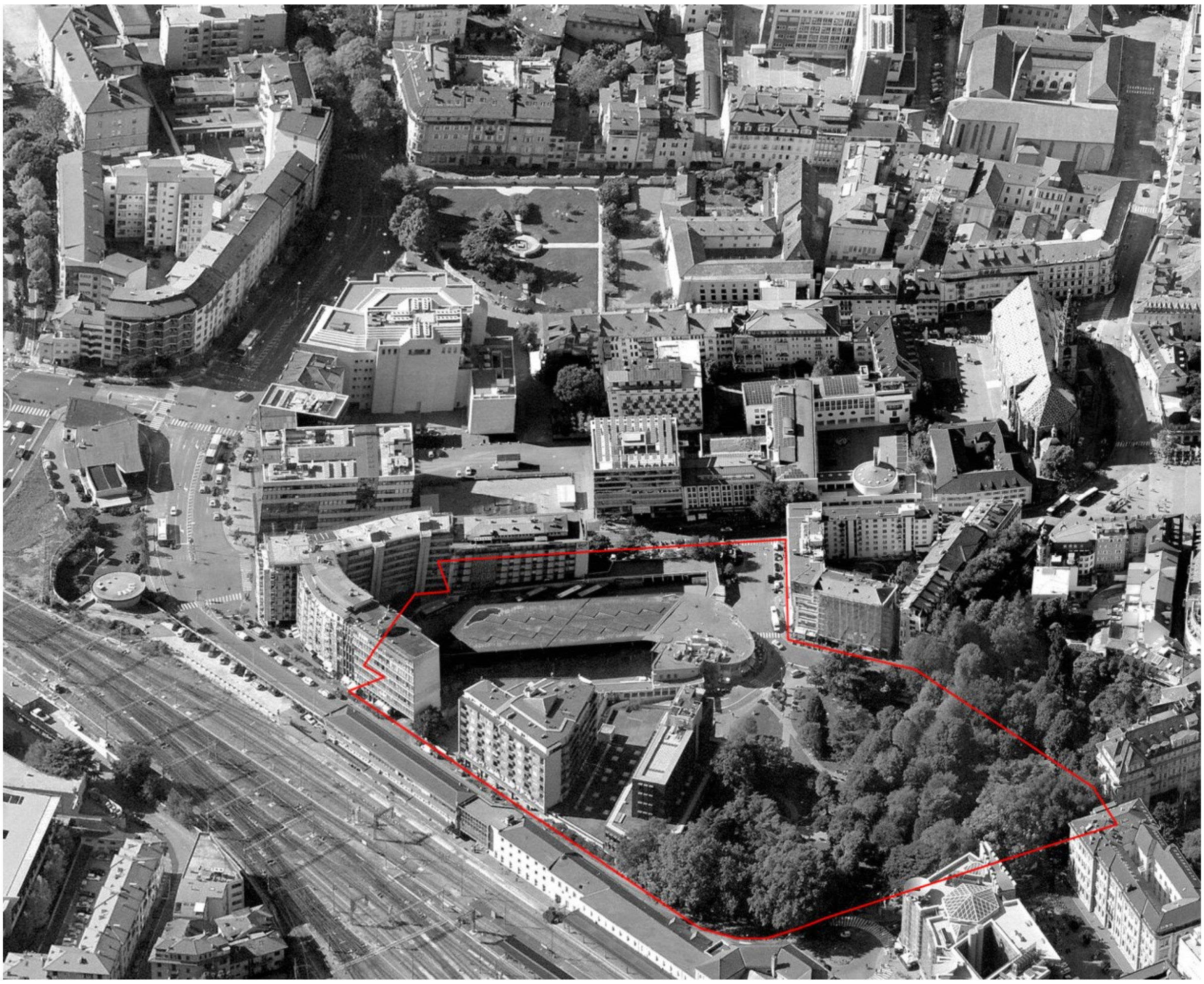


Figure 1: Aerial view of the area subject to urban requalification (within the red line)

The project approved by the public consultation (Comune di Bolzano, 2014) consists in the creation of a shopping centre, apartments, offices, parks, car parks and a hotel in the centre of Bolzano. The aim of the project is also to introduce a new and modern mobility system and concept, create variety of infrastructure as well as urban solutions, new bicycle paths, pedestrian and green areas that will replace roads, redevelop the area and establish a new destination point for Bolzano.

This project is located on a 15,000 m^2 surface area near the railway station, which for years has been a run-down and little frequented part of Bolzano; the focus of the design is to create new spaces for the public, extending and expanding Bolzano city centre. Along with the redevelopment of the district, the project also aims to the restoration and rehabilitation of the area.

The new urban area will be accessible from the pedestrian area in the centre of Bolzano or from the underground car park for those arriving by bus or by car. Moreover, 850 new parking spaces both public and private will be built. The proximity to the railway station with its local and international connections offers good and environmentally friendly travelling opportunities to future users.

Inside the main buildings, shops will be located from the first underground floor to the third floor. On the roof of the third floor there will be a rooftop garden which will be the green area and entrance to the apartments. The hotel will include about one hundred rooms and suites and will leverage on its vicinity to the city centre and high-quality services to attract guests.

The urban requalification project takes into high consideration the need for green areas to enhance living quality: hence, as part of the project the park near the railway station will be redeveloped and transformed into a "green oasis".

Figure 2: Rendering of the urban requalification project

In terms of the new mobility concept, particular attention is paid to the road system and to traffic reduction in the city centre. By creating a new underground connection (tunnel) between Via Josef-Mayr-Nusser, the new underground car park of WaltherPark, and the underground car park of Piazza Walther, the traffic in the city centre of Bolzano will be significantly reduced and the pedestrian area will be considerably expanded.

In order to grant a sustainable and efficient supply of energy for the new buildings in the urban requalification project, the choice was made to create both a district heating and district cooling network to serve the whole area. This solution has the valuable upside of requiring less surface to be dedicated to mechanical machinery inside and on top of the buildings, letting the highly valuable space free to be used by urban planners to enhance the living quality of the project.

The initial idea of creating distribution networks limited to the boundary of the requalification project has been abandoned following contacts between the project developer and Alperia Ecoplus, which operates the district heating network of the city of Bolzano. The alternative of integrating the local heat supply network into the urban district heating network highlighted operational benefits for both sides, contemporarily increasing the sustainability of the whole project. As for the cooling network, on the base of previous experiences of Signa, the adoption of water condensed chillers deploying the nearby river as heat sink, also in free-cooling mode, was chosen.

3.1.1 System layout

The original energy supply concept developed for the urban requalification project consisted therefore in the realization of a powerhouse, located near the vehicles entrance to the complex, where the following components were planned:

- connection to the existing 3rd generation district heating network operated by Alperia Ecoplus with design temperature of 95°C on the supply and 55°C on the return;
- 8 MW natural gas fired back-up boiler, to grant heat supply to the WaltherPark project and the surrounding area during peak demand and emergency;
- 300 kW_{el} natural gas fired co-generation unit, to allow the local production of electric energy needed to run the auxiliaries of the powerhouse;
- 25 MW water intake facility on the Isarco river to derivate up to 500 l/s of water to be used as heat sink (the sizing of the system accounts also for future possible DCN developments in the surrounding area);
- Medium temperature network to distribute river water (with temperatures ranging from 2°C in winter to 17°C in summer) to the powerhouse and eventual additional future consumers in the nearby area;
- Low temperature distribution network to supply consumers with the required cooling (from 6°C in summer to 12°C in winter), equipped with a free-cooling heat exchanger with the medium temperature network;
- 1.5 MW backup air condensed chiller to grant cooling network operation when the water intake facility is not available;
- 6.6 MW river water condensed chiller to supply the low temperature network with required colling, complete with peak shaving thermal storage.

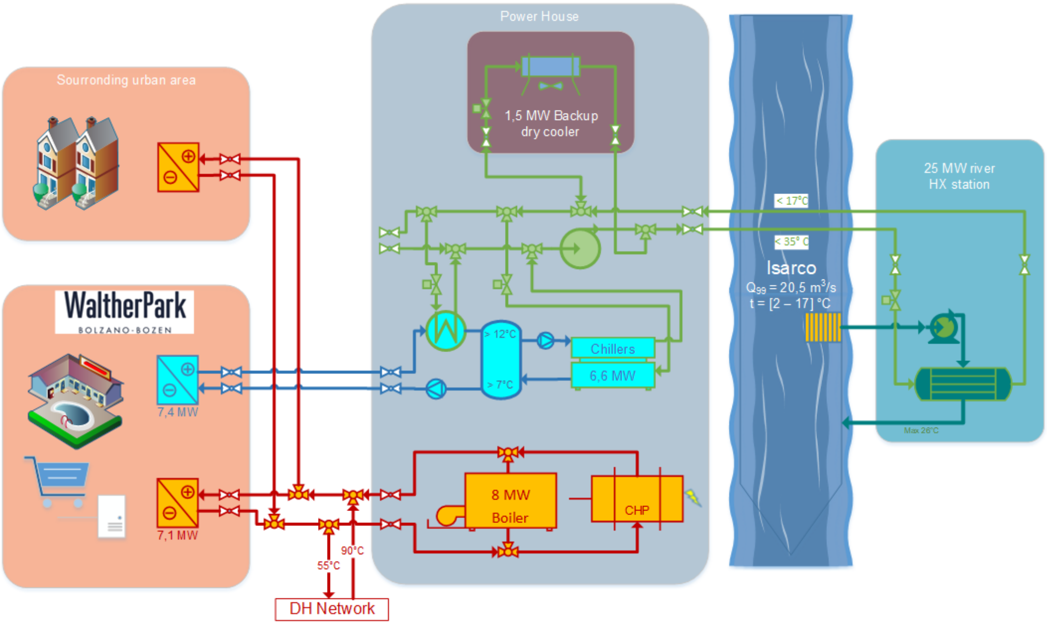
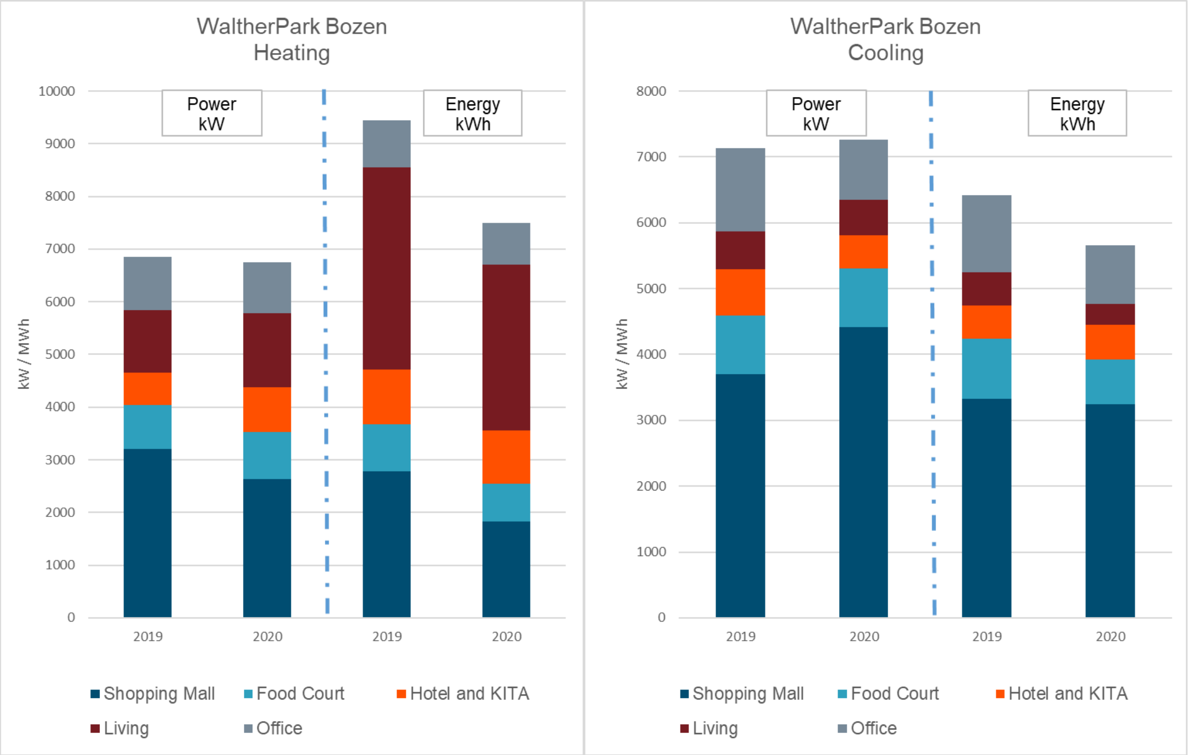


Figure 3: Conceptual scheme of the energy supply solution for the urban requalification project

3.1.2 Estimated energy consumption

Figures on the thermal energy demand of the whole complex were updated several times during the development of the present study. The first releases of the estimates granted a low degree of reliability and changes between consequent forecasts were significant. With the progress of the design process data reliability increased allowing the analysis of the case also from the perspective of waste heat recovery. The following graphs compare the figures related to maximum power and cumulated energy demand provided by the project developer in 2 consequent issues, one in 2019 and the other in 2020; data refers on both heating and cooling energy to be delivered at the WaltherPark project. It is possible to see that even though power demand values are comparable in the different forecast, the values for yearly energy demand are significantly decreased.



Graph 1:Comparison between energy consumption forecasts provided by the project developer in 2019 and 2020

Given the spatial extension of the requalification project, it has been preferred to split the supply of energy on several substations and so to have multiple delivery points inside the buildings. This choice also takes the advantage to segregate different type of users on different substations, simplifying the fiscal management of the energy supply. In total the 7 following delivery points are planned for each energy vector:

- Hotel;
- Shopping Mall 1;
- Living Nord;
- Offices 1
- Offices 2
- Shopping Mall 2
- Living Sud

3.1.3 Estimated free-coling share

In order to understand the benefit offered by the free cooling heat exchanger described in paragraph 3.1.1 an additional elaboration of the data provided by the designers was required.

As first step temperature values of river water during the year were determined; no direct measurements were available but 2 hydrologic measuring station operated by the Autonomous Province of Bolzano (Agenzia per la Protezione Civile Bolzano, 2021) offered good quality historical data. The measurement from the stations represented in Figure 4 were used:

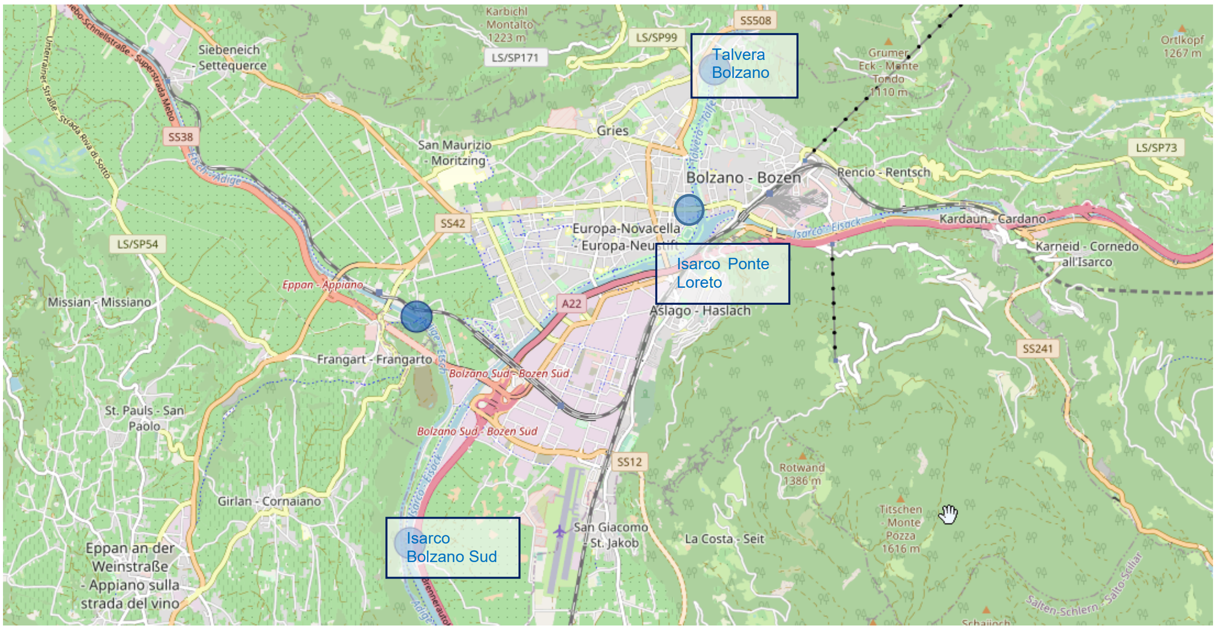
- **Isarco Bolzano Sud**, located 6 km downstream the water intake facility on the Isarco river, after the confluence of the River Talvera (400 m downstream the river intake facility);
- **Talvera Bolzano**, located 2 km upstream the confluence with the Isarco river.
- 

Figure 4: Map of the Bolzano area with identification of the hydrometric stations

Historical data of flow ($\dot{m}$; [m^3/s]) and temperature (T; [K]) are provided for each station with hourly mean values and records are continuously available from 2011 on; as for the freecoling share calculation 2020 data have been assumed in order not to cut out extreme events through an averaging process between values from different years. Since mean hourly data are recorded, the influence of transport time between different measuring stations is assumed as negligible and no correction is applied in the original dataset.

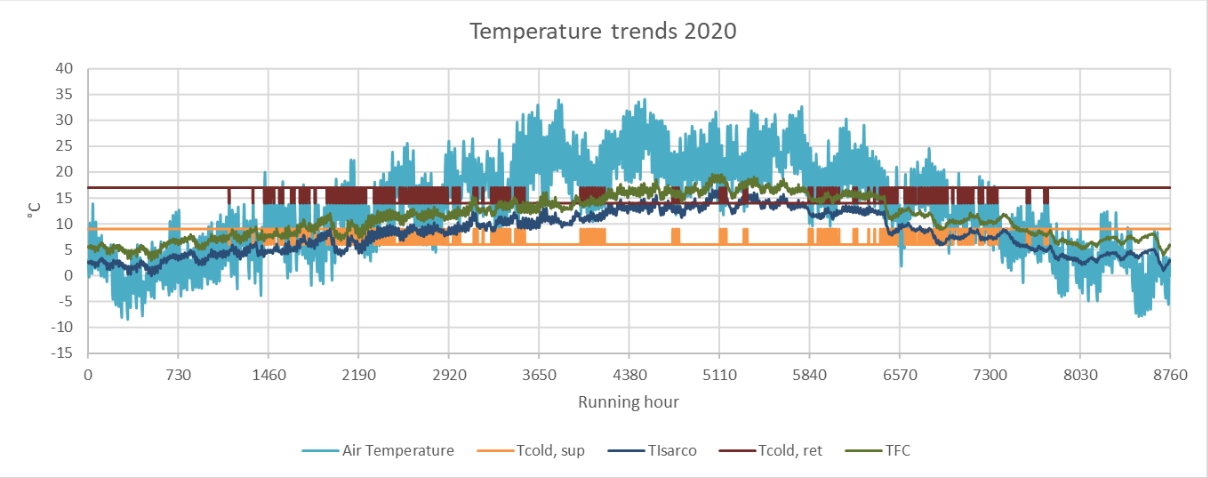
In order to compute the temperature values before the confluence of the Isarco and Talvera rivers an energy balance is performed, neglecting pressure and geodetical terms, considering the 3 different river sections:

1. Isarco Bolzano Sud
2. Talvera Bolzano
3. Isarco Ponte Loreto

$$T_3 = \frac{\dot{m}_1 * T_1 - \dot{m}_2 * T_2}{(\dot{m}_1 - \dot{m}_2)}\ [K]$$

Once the river temperature T_3 has been computed in its mean hourly value, it is possible to estimate the temperature of the district cooling network fluid in a section downstream the free-cooling heat exchanger (T_{FC}). On the base of preliminary design data of the heat exchanger, which assume:

- 2K of temperature difference between the cold inflow and the hot outflow at each heat exchanger in design conditions;
- The partial load factor at which free-cooling operation is foreseen, estimated in about 0.5;

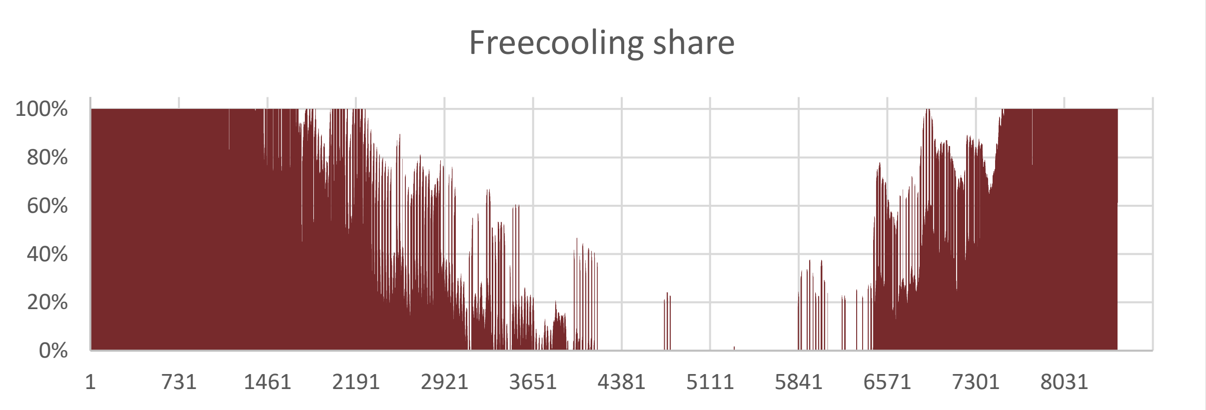


Graph 2:Simulation of temperature levels for the free-cooling equipment

A total temperature difference of 3 K for the 2 heat exchangers installed in series has been therefore assumed. Comparing the obtained value with the temperature levels of the district cooling network:

- Supply
  - 6°C when outside air temperature $T_a > 13°C$
  - 9°C when outside air temperature $T_a \leq 13°C$
- Return
  - 17°C when outside air temperature $T_a > 13°C$
  - 14°C when outside air temperature $T_a \leq 13°C$

and imposing a boundary condition aimed at limiting the total heat transfer at the nominal power of the heat exchanger, the hourly share of energy provided by the free-cooling heat exchanger (Graph 3).



Graph 3: Hourly value of the free-cooling share

The weighted average of the free-cooling share on the cooling demand (energy required by the users plus distribution grid losses), takes the mean annual value of the free-cooling share at 13.6%, corresponding to 770 MWh.

3.2 Identification of the technical solution

The lack of a simple solution suitable for waste heat recovery into the existing high-temperature district heating network was the base factor that motivated Alperia in evaluating the prefabricated, modular and standardised heat recovery solution defined within the LIFE4HeatRecovery project. Yet the system configuration was to be defined for the application and therefore 3 different configurations were selected for a first analysis aimed at identifying strengths and weaknesses of each alternative.

3.2.1 Boundary conditions and constants

In the development of the first analysis of the configurations, data referring to technical specification of equipment, energy vectors prices and values were determined on the base of typical conditions applicable to the Bolzano case study, without reference to a specific commercial product. The detailed definition of this parameters is performed for the selected configuration in the ensuing chapters.

3.2.2 Set of analysed configurations

Configuration 1

The first solution taken into consideration is to add one or more heat recovery skids into the main power, recovering heat from the medium temperature network before the heat exchange with river water takes place. The idea was originally developed during the writing of the proposal of the project and foresees the use of heat pumps capable of reaching high temperatures, up to at least 90°C, on the condenser side.

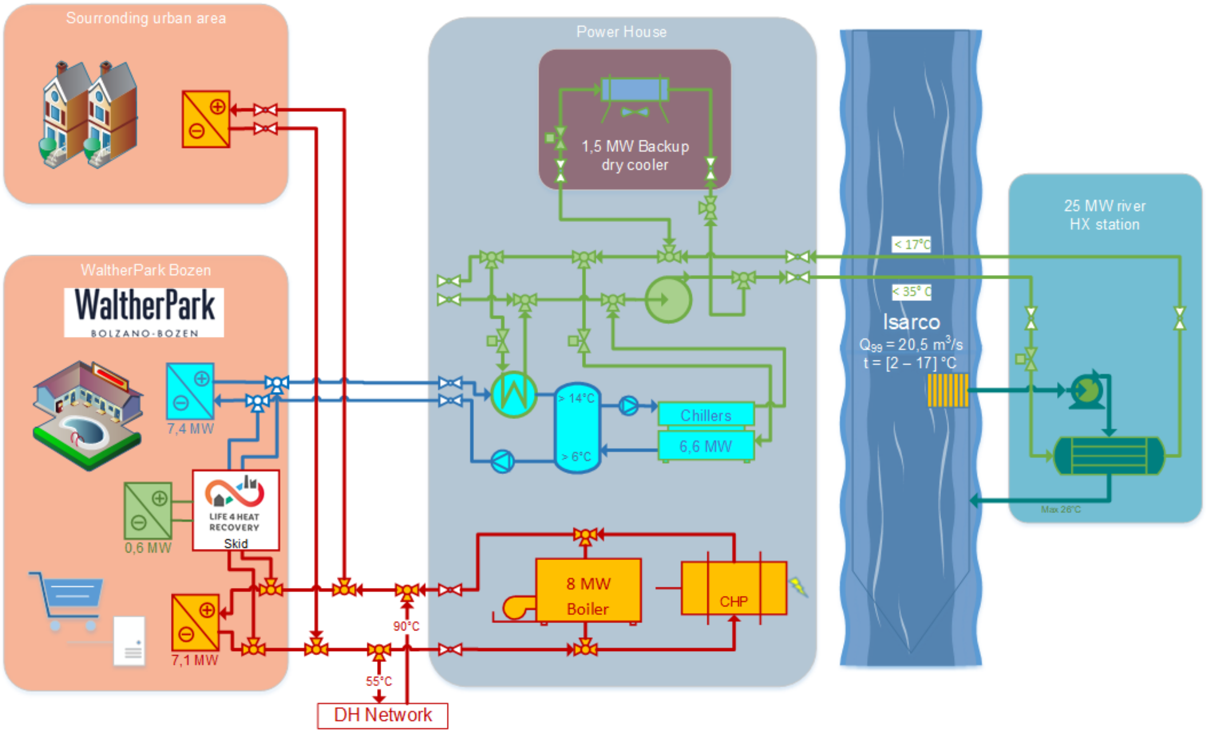


Figure 5: Conceptual scheme of the energy supply solution with waste heat recovery through Life4HeatRecovery Skids

Commercially available machines of this type are not widespread, especially for non-industrial application; they generally offer limited performances (COP 1.7 ÷ 2.5 depending on temperature levels - (Arpagaus, Bless, Uhlmann, Schiffmann, & Bertsch, 2018)) and hence find use in conditions where electricity cost is quite low and/or heat cost is quite high.

To better understand if this kind of solution is a viable alternative in the context of the Bolzano case study and to define the boundary conditions under which the solution can be successfully applied, from an economical, energetic and environmental perspectives, further study of the system operation is needed. Main strengths of the solution are:

- the possibility to harvest residual heat flows to be fed into the existing district heating network, increasing the sustainability of heat production;
- the delivery of cooling energy in a more efficient and sustainable way, without impacting on the micro-climatic conditions of the urban environment.
- On the other hand, main weakness lays in the economical operation of the system that, given the boundary conditions posed by the Italian energy market in general and the characteristics of the Bolzano energy system in particular, can be particularly challenging.

Configuration 2

In order to fully deploy the capability of the water intake facility, the idea analysed foresees its use as a heat sink for the whole District Heating network of Bolzano, with the creation of an interface between the heating and cooling network: this process allows the exploitation of the city-wide district heating network as an energy carrier between waste heat sources (which can be spread over the whole heat grid) and the heat sink while enabling all users connected to the district heating network to effortlessly withdraw residual heat before it is dissipated into the heat sink.

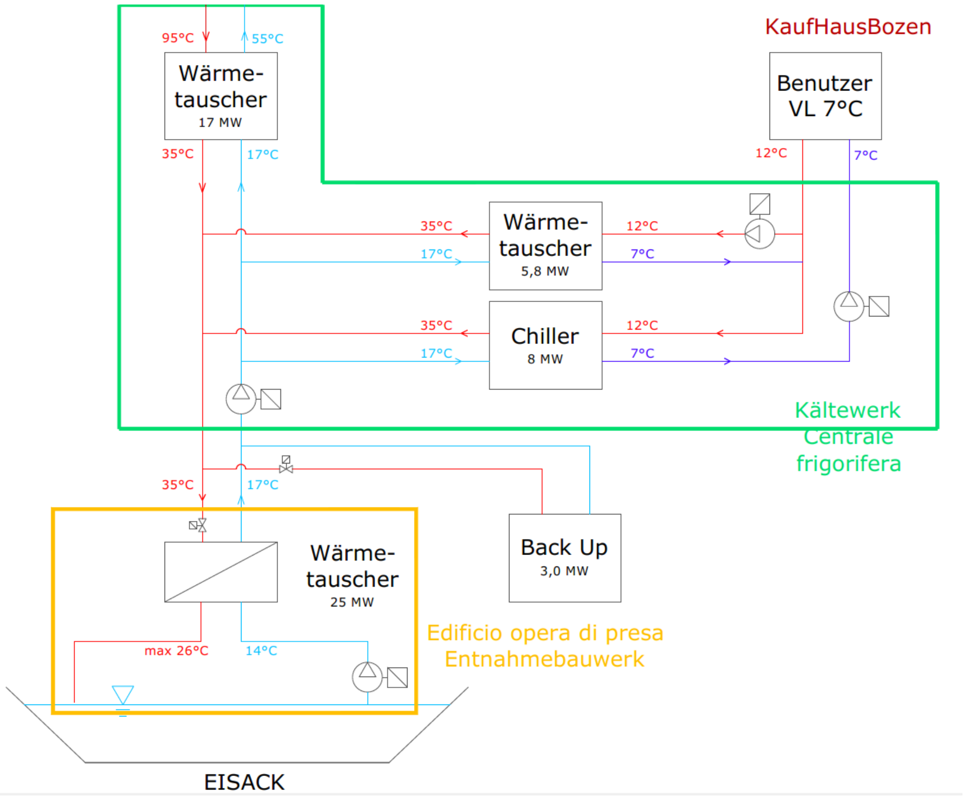


Figure 6: Layout of the heat sink system and the connection between heating and cooling network in Configuration 2; SKIDs are supposed to be spread over the extension of the district heating network and hence not represented here.

The configuration would allow on one hand the delivery of waste heat at any point in the district heating network and on the other hand the pooling of residual heat between all the users connected to the district heating network. The use of the water intake facility to dissipate excess heat would be activated only in the case of thermal drift of the district heating network: this is expected to occur during summers, where overall network heat load is foreseen to float around 3 MW while rejected heat can reach up to 18 MW.

NOTE: boundary condition applied in the analysis of this configuration differ from what assumed in the previous description; the discrepancy is due to the different time in the project development the considerations were done. Obtained results are anyhow applicable and representative of both scenarios.

First step in the evaluation process of the configuration is the assessment of the capability of the interface heat exchanger, both in terms of energy and power, the latter acting as stricter boundary condition. Main results are reported in the following tables.

Table 1: Water intake facility specifications

Water Intake Facility	
Allocated water intake	500 l/s
	1800 m^3/h
Design ΔT	12 K
Design power	25116 kW

Table 2: Estimate of the residual heat available in the requalification project

WaltherPark Waste Heat	
Design Cooling power	5866 kW
sEER (W6-W17)	7
Design Waste Heat	6703 kW

Table 3: Estimate of the deliverable cooling power

DHN residual power	
Manageable waste heat	18413 kW
sEER (W6-W85)	1,5
Deliverable cooling	12275 kW
Electrical power	6138 kW

A first economical assessment of the solution is performed through the simulation of a simplified annual cash flow, in order to identify the running costs of the solution under study. Two different values of annual full load hours are assumed to define a Realistic (800 h) and an Optimistic (1500 h) scenario. In the realistic Scenario, costs related to the water intake facility are accounted for, splitting the total cost proportionally to the use of the facility. The amount of heat recoverable into the district heating network is capped at 3 GWh/year so to consider the seasonal availability of waste heat with simultaneous demand by DHN consumers.

Table 4: Economical evaluation of annual cash flows of Configuration 2

Configuration 2: annual cash flow		
Scenario	Optimistic	Realistic
Full Load Hours	1500 h	800 h
Costs		
Electricity	-1.6 Mio€	-0.9 Mio€
River water	-	- 60 k€
Intake Facility	-	-11 k€
Revenues		
Heating energy	32 k€	32 k€
Cooling energy	1.4 Mio€	0.7 Mio€
TOTAL	-199 k€	-156 k€

Obtained results are reported in Table 4 and show that, even though the considerations are limited to operational costs of the facility, the profitability of the solution is not reached in any of the considered scenarios. The fact that the more the facility is running (Optimistic scenario) the worst are the economical results strongly highlights the non-feasibility of the solution.

Configuration 3

The last configuration considered is conceptually similar to Configuration 1: the difference lays in the place where heat recovery skids are installed. Instead of having one or more skids into the main powerhouse the installation of one skid is supposed to take place near each of the 7 delivery points (see Section 3.1.2). In this way it is possible to act only on delivery points that have load profiles compatible with the recovery measures and the infrastructural impact of the initiative can be lowered. On the other hand, energy pooling between different delivery points is no longer possible, possibly hindering the profitability of the system.

The same analysis model set up for Configuration 1 will be used to valuate in deeper detail also this solution.

3.2.3 Selected configuration

The configuration selected to be studied in deeper detail is the one described in Configuration 1: the operation of a series of modular units (Skids), each one provided with a high temperature heat pump and the hydraulic equipment to allow all the identified energy flows between the different circuits, will be simulated considering the boundary conditions applicable for the powerhouse of the WaltherPark project.

Sizing of the Skid

The sizing of the single skid will be performed taking into consideration the aim of LIFE4HeatRecovery project, where characteristics such as scalability and replicability cover a leading role in the definition of the solution to be applied.

Considering that the size of the WaltherPark case study is not a common one for the context of Bolzano, in order to identify the size of a typical system to be offered to consumers, the support of the commercial business unit of Alperia has been asked for. Available data on district heating consumers together with market research previously done on the waste heat and cooling markets, allowed Alperia to identify the ideal nominal power of a skid in the interval between 100 kW and 150 kW on the evaporator side.

Energy flows

As a first step in the definition of the layout of the system to be studied, in accordance with the work done in Action A.1, actual and future energy flows have been identified and analysed; in Figure 7 and in Figure 8 the relevant energy flows are graphically identified.

The original energy concept developed for the urban requalification project in 2014 involves two separated systems, one for cooling and the second for heating:

- the cooling solution is a traditional one, where the cooling system is fed with electricity E_{EC} to provide energy for the internal use; waste heat Q_{WH} is then dissipated into the environment.
- The heating solution present a double energy supply: the standard supply is directly offered by the district heating network through standard heat exchangers $Q_{DH.IU}$; due to the peculiarity of the consumer a natural gas fed back-up system (E_{EH}+$Q_{EH,PE}$) is installed in its premises, so to offer redundancy of the heating supply both to the consumer itself $Q_{EH,IU}$ and to the surrounding area (this flow is anyhow not considered in the study).

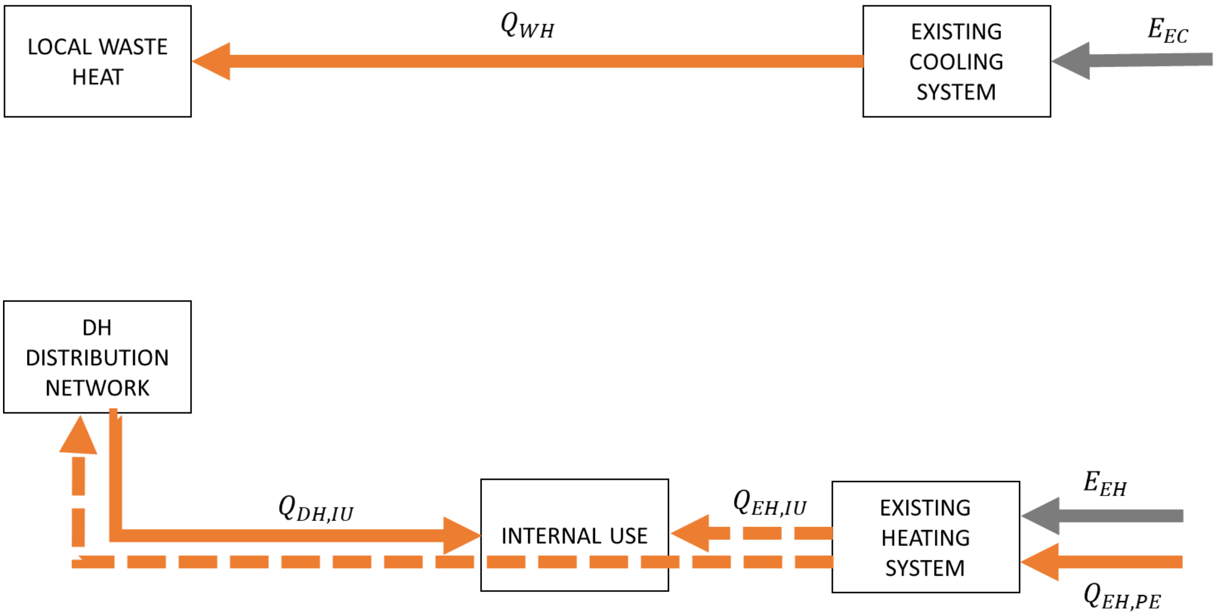


Figure 7: Energy flows identified for the actual situation of energy supply

The energy concept adopted within this feasibility study (Figure 8) enables the interconnection of the heating and cooling systems by creating an interface between the two systems: the skid. A set of hydraulic connections and actuators and a high temperature heat pump, respectively fed with electrical energy E_{AX} and E_{HP}, allow the recovery of part of the low temperature waste heat generated by the cooling system $Q_{WH,SK}$ into:

- The user's internal distribution circuit $Q_{SK,IU}$ in case there is an internal heat demand;

- The local district heating network $Q_{SK,DH}$ in case no local demand is present.

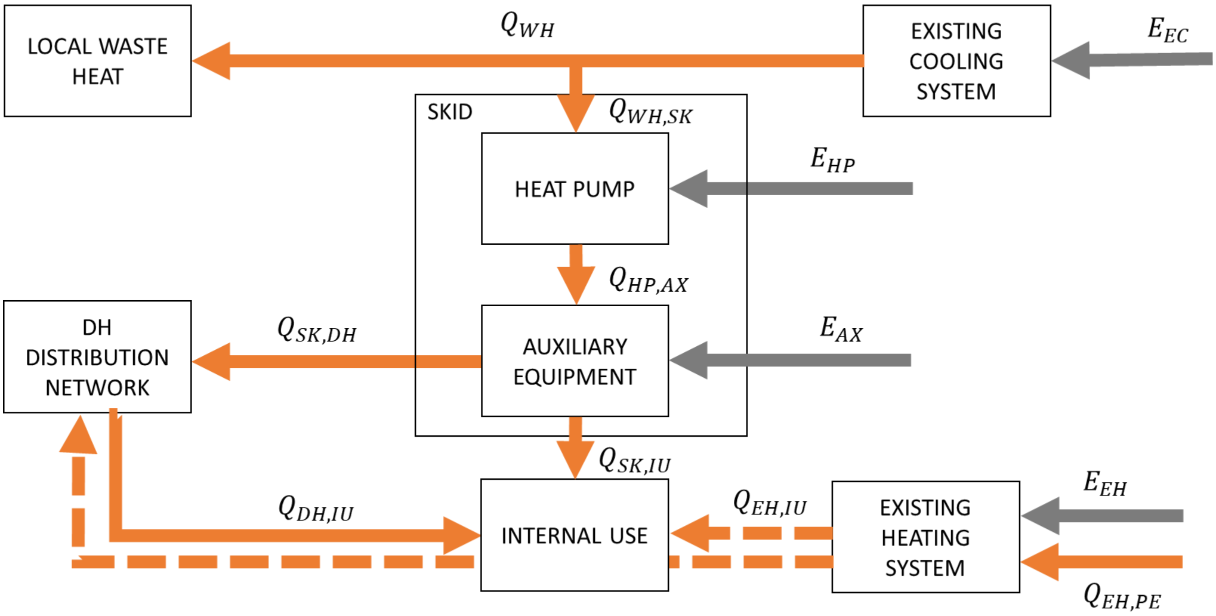


Figure 8: Energy flows for the Life4HeatRecovery feasibility configuration

Piping and Instrumentation Diagram

- Since the operating conditions in the various configurations are different and they have a significant impact on the performance of the skid, a more detailed operating scheme of the skid has been laid out with the drawing of a simplified Piping and Instrumentation Diagram (P&ID).

The system allows a number of different configurations in which energy flows are exchanged between the three main systems at play (Figure 9):

- District heating network, DHN, represented in red;
- District Cooling network, DCN, represented in blue;
- Users internal heating network, USER LOAD, represented in green.
- An additional circuit, internal to the skid and represented in yellow, is functional to the transfer of heat flows between the 3 main users circuits described above.

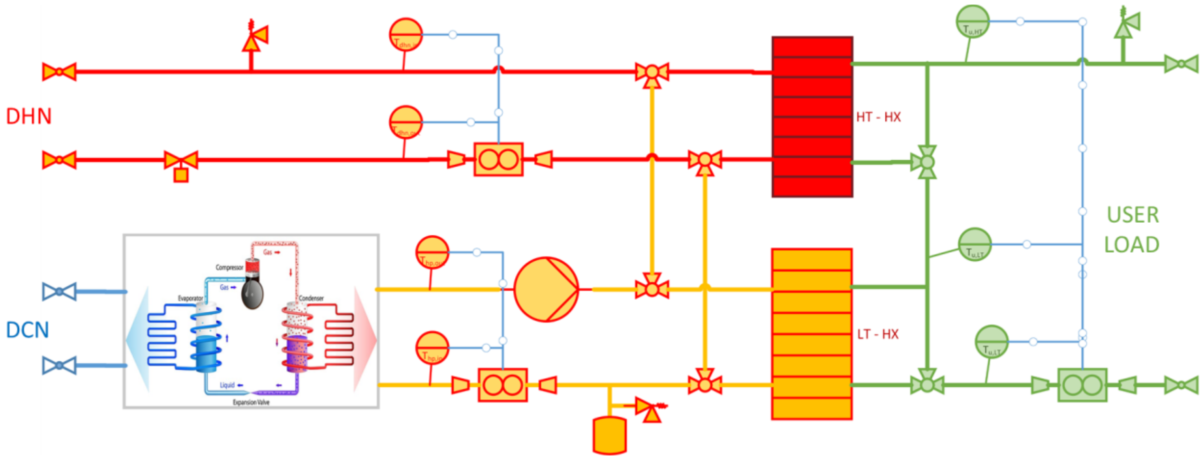


Figure 9: Feasibility Piping and Instrumentation Diagram of the Skid

- This representation allows to identify all fundamental pieces of equipment needed to properly run the skid, to identify the boundary conditions of each configuration and finally to assess the performance of the skid as a whole.

Each main circuit is fitted with shut-off valves, to hydraulically isolate the skid from the network, and diaphragm safety valves, to discharge hazardous pressure surges in the circuit. Energy meters fitted with ultrasonic flow meters and resistive temperature sensors are installed to record energy flows exchanged between the 4 circuits identified. Motorized three-way valves are installed at the junction of different circuits and are operated by a central controller to define the set-up needed for a certain *Load case* (see below).

Since the internal circuit of the skid can be operated as a closed circuit, it is fitted with a circulation pump and an expansion vessel, to accommodate the expansion volume of the circuit water. The dimensioning of the pump is anyhow to be determined taking into consideration the possibility to provide recovered heat to the district heating network when a full local exploitation is not possible. This implies that its design is highly dependent on the operating conditions of the district heating network at the installation point and hence this piece of equipment cannot be standardised and must be selected considering the installation context.

A peculiarity in the layout of the skid is the presence of a double heat exchanger (high temperature heat exchanger + low temperature heat exchanger) on the User Load circuit; this configuration is adopted to enable the operation of the heat pump at low temperature levels, working as pre-heater in the case of high temperature load demand by the user. More importantly, the configuration allows the separate metering of locally recovered heat from that originated from district network, and consequently to apply the relevant tariffs and supply requirements, resulting in a greater valorisation for the locally recovered source. The increased constructive complexity is therefore outweighed by the economical benefits of this solution.

Load Cases

First step in the evaluation of the operating conditions of the skid was the definition of the different sets of boundary conditions (*Load Cases*) at which the system is supposed to operate. Five different Load Cases have been identified.

Each Load Case has been later studied in detail to identify operating conditions, performances and limits of the skid. In the ensuing paragraphs, a representation of each load case is given along with a description of the performances of the skid.

Table 5: Definition of the operating "Load Cases"

Load case	Heat Sources	Heat Load	Required Temperature
1	DHN	L4HR User	75 °C
2	Heat Pump + DHN	L4HR User	55°C – 75 °C
3	Heat Pump	L4HR User	55°C
4	Heat Pump	DHN	85°C
5	Heat Pump	DHN + L4HR User	85°C

In Load Case 1 the user demand is entirely provided with energy from the district heating network; the low temperature heat exchanger is by-passed on the user side, and the heat pump is not in operation (both represented in grey). This configuration is equivalent to a standard connection of a consumer to the district heating network, where the temperature required by the user can be as high as 75 °C.

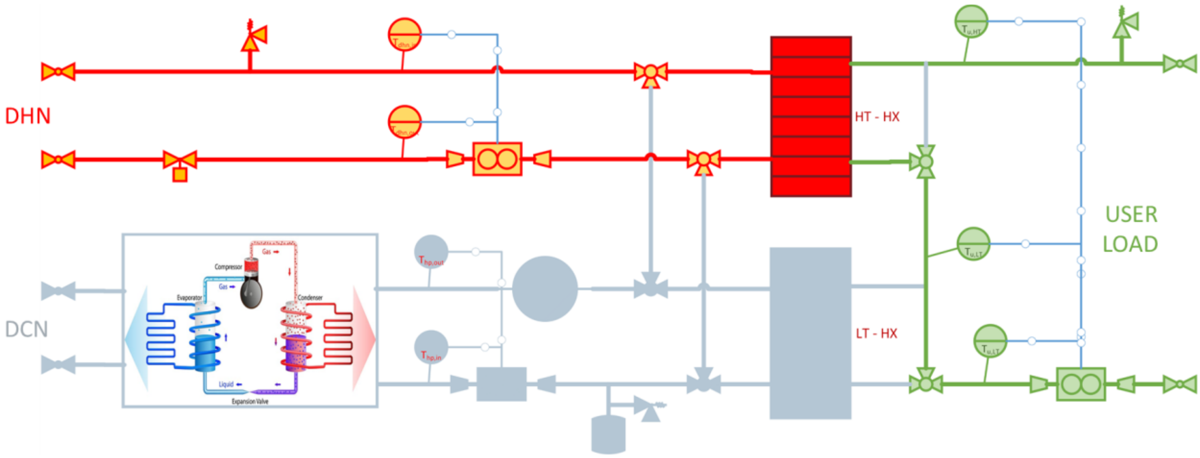


Figure 10: Load case 1

In Load Case 2 both the skid's heat pump and the district heating network are used to provide heat to the user: this happens when locally recovered heat is not enough to satisfy the user demand or when the heat pump operates as a preheater on the low temperature heat exchanger and the district heating network provides the boost in terms of temperature or power. Supplied heat can be delivered in the temperature range between 55°C and 75 °C. By-passes on the user side of low temperature and high temperature heat exchangers are deactivated as well as the connection between the internal circuit of the skid and the district heating network.

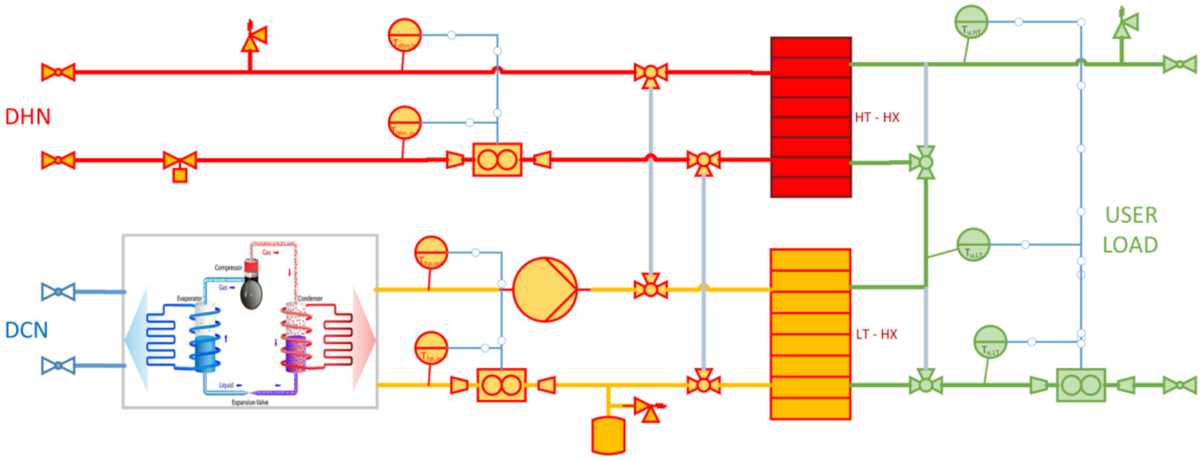


Figure 11: Load Case 2

Load case 3 represents the condition that occur when locally recovered heat is directly fed to satisfy the users' needs; since supply requirements for the district heating network (i.e., supply temperature ≥ 75°C) do not apply here and in order to enhance the efficiency of the system, heat production in this configuration is limited at a temperature of 55°C.

The circuit referring to the district heating network is deactivated as well as the connection with the skids internal circuit and the high temperature heat exchanger.

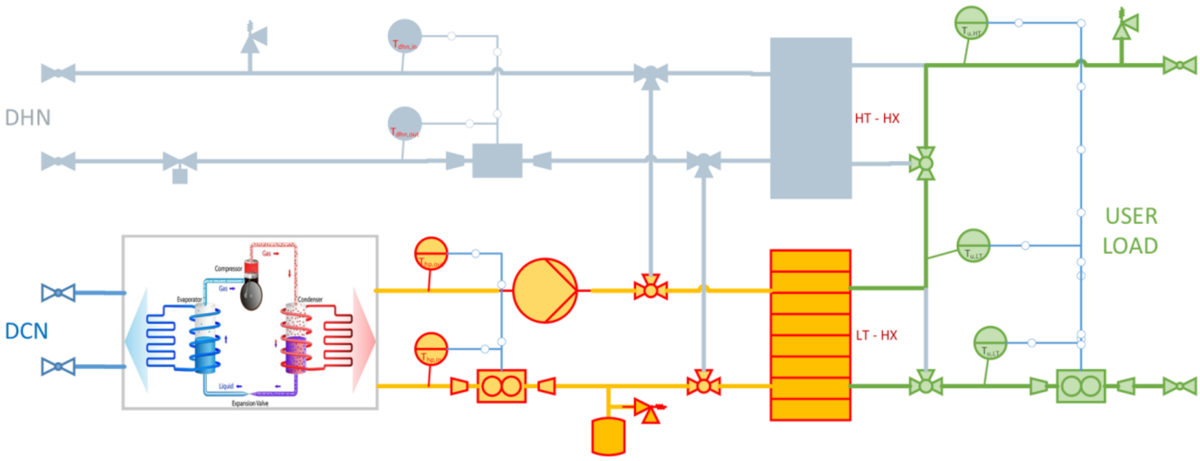


Figure 12: Load case 3

The fourth load case represents the operation of the skid when no user load is present; all the pieces of the equipment referred to the user are shut off, locally recovered heat is fed into the district heating network by means of the pump installed on the skid internal circuit through the connection by-pass. The dimensioning of the pump must be performed considering this operating point, which is highly influenced by the operating conditions of the district heating network; therefore, in the development of the skid, which has to be scalable and replicable by definition of the Life4HeatRecovery project, an important degree of freedom has to be allowed in this point.

Given the operating conditions of the network and in order to feed into the network a fluid with similar characteristics to the one that is circulating, a supply temperature of 85°C is assumed for this load case.

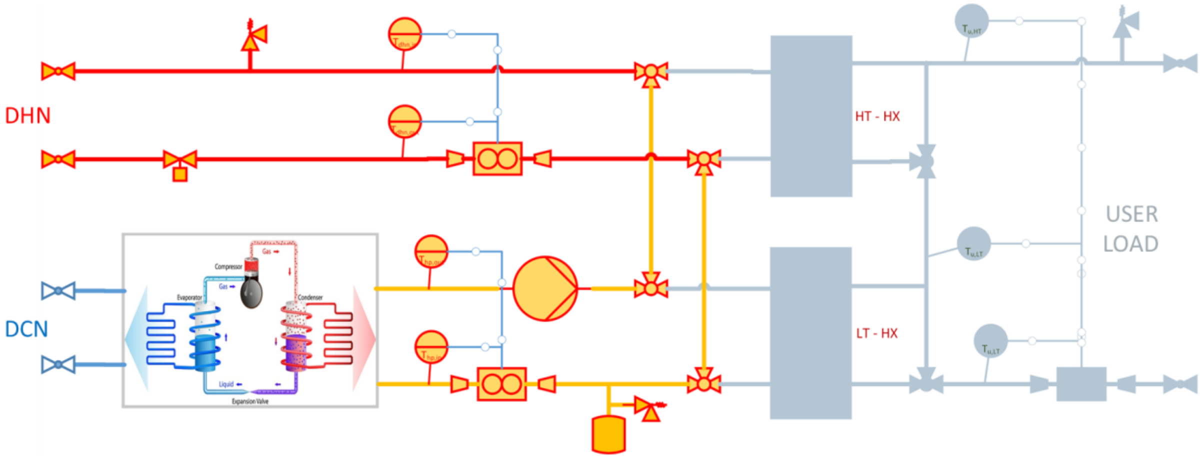


Figure 13: Load case 4

Load case 5 is similar to load case 4 in terms of boundary conditions applied for the energy recovery. From the point of view of the energy flows, this configuration is selected when locally recovered heat is higher than the user heat demand: therefore, heat has to be produced with the more stringent characteristics required for it to be injected into the district heating network, while part of it is still delivered directly to the consumer. Heat production takes place at 85°C and no integration of the high temperature heat exchanger is needed.

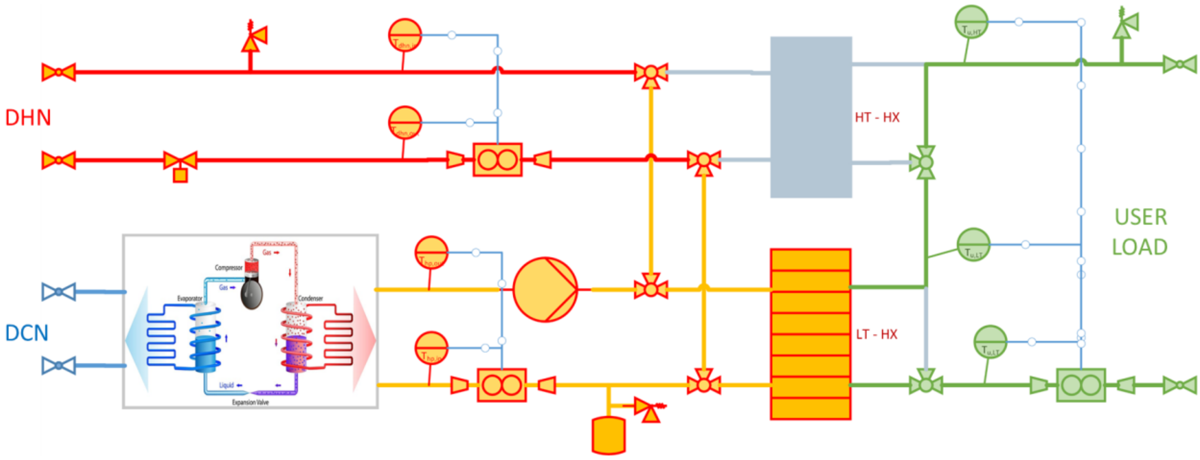


Figure 14: Load case 5

Cooling network temperature

An additional factor influencing the operation and the performance of the Skid is the temperature at which refrigerated liquid has to be fed into the district cooling network. As described in paragraph 3.1.3, data made available from the designers of the WaltherPark project indicate that 2 operating temperature levels are foreseen for the network: the actual one is selected as a function of outside air temperature.

Each operating temperature level is given a label (H or L) that is used as suffix to the naming of each Load Case to better specify the working conditions of the heat pump.

Table 6: District cooling network operating temperature

District Cooling Network Operating Temperature		
Outside Air Temperature	< 14°C	≥ 14°C
Supply Temperature	9°C	6°C
Return Temperature	17°C	14°C
Suffix for Load Cases	H	L

Heat pump performance

In order to determine the performance of the heat pump in each one of the identified load cases and with different cooling supply temperatures, several commercially available machines data sheets have been compared.

The selection of the heat pump refrigerant has been done in accordance with the considerations made by Warmtebedrijf Rotterdam in the first steps of development of the Rotterdam Demo Case. This operation is possible since the operating temperature of the systems are comparable as well as the main boundary conditions for the heat recovery. As refrigerating fluid is therefore chosen *R1234ze*. Detailed considerations about the lower flammability of the fluid are not covered into this feasibility study and must be taken care of in the future development of the design project.

Analysed data sheets of different manufacturers did not differ too much in the nominal data declared; in most cases anyhow, not all information was available to extract the machine performance in off-design conditions, and hence to evaluate the behaviour of the machine during real operation.

A single manufacturer (Oilong Group Oy, 2021) was able to provide a dimensioning software for the heat pumps fitted with the performance matrices required to determine operation parameters in the whole operating range. This tool has been therefore selected for the purpose of this feasibility study. In Table 7 a summary of the operating condition with relative performances and boundaries is reported; reported performance values consider auxiliaries consumption and off design operation.

In detail, for each of the 2 district cooling network temperature levels and considering the 3 different heat production temperatures seen before, values for maximum heating and cooling power as well as for the coefficient of performance for heating (COP) and of energy efficiency ratio for cooling (EER) are reported.

Table 7: Performance matrix of the selected heat pump

Heat Pump Performance Matrix						
Cooling Temperature	Heating Temperature	Cooling Power	Heating Power	Electric Power	COP	EER
[°C]	[°C]	[kW]	[kW]	[kW]	[-]	[-]
6°C	55	149	207	59	3.16	2.27
	75	113	178	66	2.43	1.54
	85	104	171	68	2.26	1.38
9°C	55	170	231	62	3.35	2.47
	75	130	200	70	2.57	1.67
	85	122	195	73	2.40	1.50

Cost estimates

A budget estimate of the investment cost required for the realisation of the described Skid has been performed on the base of prices obtained through direct quotation of bigger equipment and referring to existing frame contracts for the supply of district heating related equipment that Alperia acquired through open tenders with different suppliers. Total realisation cost for the skid is estimated in 91500 €, as detailed in Table 8.

Table 8: Budged estimate for the investment cost needed for a single Skid

Skid Realisation Cost Budget		
1.1	Frame and supports	2000 €
1.2	Piping and accessories	2500 €
1.3	Heat exchangers	3500 €
1.4	Pumps, metering equipment	5000 €
1.5	Electrical system	1500 €
2.0	Heat Pump	65000 €
3.0	Automation and Control	12000 €
TOTAL		91500 €

3.3 Performance evaluation

The process of performance evaluation is key to select the most favorable setup for the heat recovery measure studied in this project. The evaluation is performed on the base of the energy consumption curves of the WaltherPark project both in energetic and environmental terms, as well as from the economic point of view.

A simulation model has been built to compute the hourly performance of the skid on the base of the boundary conditions applied and the performance matrix defined above. Results are then aggregated to obtain energetic, environmental and economical balances used to assess the viability of each configuration and each scenario.

3.3.1 Technical performance evaluation

- As first step, a technical evaluation is performed in order to identify, between the possible system layouts, the one that allows maximizing the share of recovered heat. For each scenario, a set of free variables is taken into consideration, such as:
- The number of skids to be installed;
- The position of the skids, being them installed in the central power house, at each delivery point inside the buildings or on a selection of them;
- The minimum partial load factor required for the sturt-up of an additional skid.

3.3.2 Environmental performance evaluation

The environmental performance evaluation is performed on the base of the annual energy balances of each scenario applying at each form of energy consumed the relevant conversion factor; it is therefore obtained the amount of carbon dioxide emitted in the delivery of the service required by the consumer.

A scenario that considers standard solutions for the supply of energy to the final consumer is also considered, in order to have a reference to use in the evaluation of the environmental performance of the heat recovery solution.

Conversion factors assumed are those that apply for the energy delivered by Alperia to its consumers within the District Heating Network of Bolzano and are certified by an external independent entity.

Table 9: Conversion factors adopted in the definition of the environmental performance

Energy Vector	Conversion Factor	Unit	Notes
Electricity	0.327	$kgCO_2/kWh_{el}$	
DHN heat	0.029	$kgCO_2/kWh_{th,user}$	
Cold, standard	0.093	$kgCO_2/kWh_{th,user}$	A value of sEER=3.5 is assumed for a standard air condensed unit

3.3.3 Economic performance evaluation

Different layouts are considered in order to define the optimum solution for a series of installation Scenarios:

- The WaltherPark case study, where actual boundary conditions of the project are assumed;
- A generic Italian installation case, where general Italian market condition are considered;
- A generic Italian installation case, as above, combined with a CHP;
- Two hypothetic cases where minimum thresholds for electrical energy and heat prices are determined in order to grant the bankability of the project.

For each Scenario, characterised by its annual energy balance, a financial model of the plant operation has been computed so to evaluate the economic performance of each initiative. The following constants and variables were considered in the model:

- the duration of the financial initiative is supposed to last 30 years;
- Unlevered simulation that does not consider financing costs, introducing instead a value for WACC equal to 5.9%;
- Inflation rate is assumed at 1.30%, in accordance with the long-term estimates of the Banca d'Italia;
- Capex depreciation is assumed to current Italian standard for this kind of equipment at 6.66%, corresponding to an estimated lifecycle of 15 years;
- Ordinary maintenance costs for external and internal personnel;
- Rental cost for the space needed to install the skids;
- Co-generated power available at favourable prices and reduced taxation;
- Avoided investment on alternative thermal power production units (a traditional gas boiler cost is assumed in this case).

3.4 Results

Results obtained by the simulation models in terms of energy, environmental impact and finance are reported in the ensuing sections.

Details on energy balances are provided, both in terms of absolute values and share, for each Load Case; an aggregation per heat production temperature of the same dataset is also reported in the following tables.

Environmental balances are originated by annual energy balances and provide, for each energy vector, the computed amount of emitted carbon dioxide, according to conversion factors of Table 9.

Financial balances are based on single year energy balances figures to compute the running costs of each configuration; energy prices are represented as Levelized Cost of Energy to the district energy network operator; the financial model then simulates the evolution of the scenario, considering the variables listed in paragraph 3.3.3. Results are represented by values of the Internal Rate of Return and of the Net Present Value of the investment, computed both at 15 years and 30 years' time span.

3.4.1 System layout

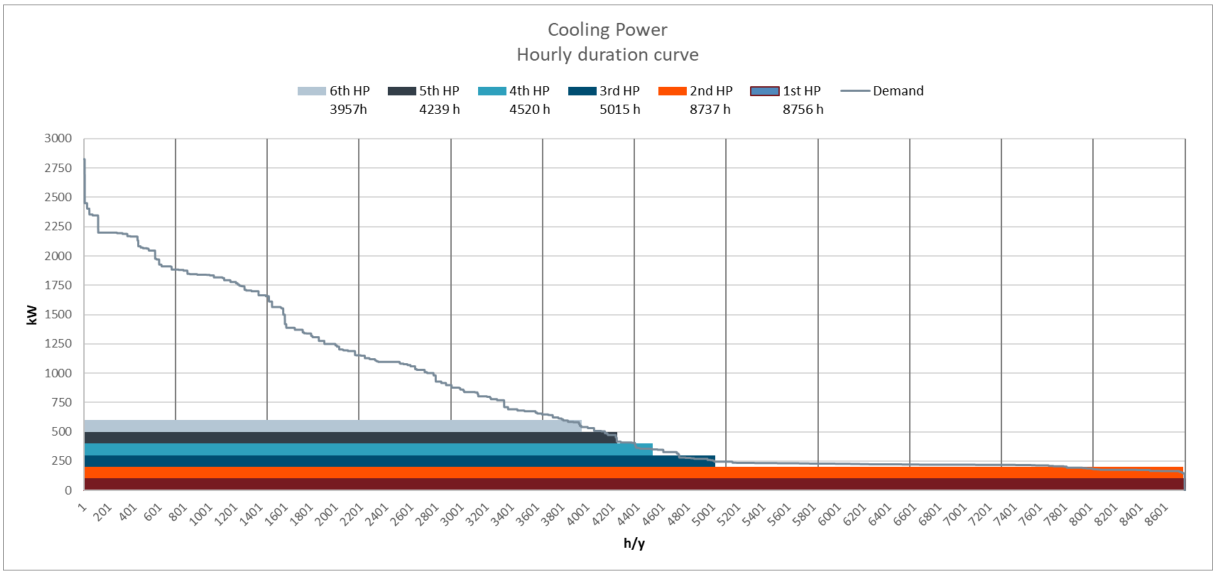
Results show that the installation of skids at delivery points level, even considering only the ones that have a consumption profile that is more suitable to energy recovery, is not a good solution.

Table 10:Energy balances for centralised vs distributed skid layout

Delivery Point	Recovered Heat [MWh]	Autoconsumption [MWh]	Share of autoconsumption
Retail / Mall	973.0	226.9	23%
Gastronomie	344.4	0.0	0%
Hotel	451.9	172.6	38%
Wohnen	340.7	340.7	100%
Büro	834.5	340.6	41%
Total	2944.6	1080.8	37%
Centralised	2983.7	1704.1	57%

In the centralised solution (here assumed with 5 skids in order to have comparable investment costs) the possibility to pool energy consumption, both for cold and heat, between different kind of users results beneficial in terms of energy recovered and more importantly on the share of energy recovered and directly consumed by the user.

Established that a centralised solution would be preferred, the number of skids to be installed is to be determined. A first assessment at the early stages of the project, based on a draft of the hourly duration curve of the cooling demand and assuming a minimum of about 4000 hours of operation, pointed to the installation of 6 skids (Graph 4).



Graph 4: First estimate of the number of skids to be installed

A more detailed simulation with the energetic model, that considers a more accurate estimate of the contemporaneity of heating and cooling demand during the year, indicates that the number of skids that allow to maximise both the energy recovered from the waste heat source and the simultaneous use by heat users is equal to 2.

Table 11:Energy balances for different centralised skid layouts

Skids installed	Recovered Heat [MWh]	Autoconsumption [MWh]	Share of autoconsumption
1	1555.6	1555.6	100%
2	1704.1	1704.1	100%
3	2244.3	1704.1	76%
4	2623.1	1704.1	65%
5	2983.7	1704.1	57%
6	3325.9	1704.1	51%

As for the minimum partial load factor to be adopted in the simulations, results show negligible influence of the parameter on the results, therefore a value of 30% (as from the datasheet) has been assumed.

The choice for the solution to be further studied in the feasibility study is referred to a system layout that foresees the installation of **2 skids** in a **centralised configuration** inside the powerhouse.

3.4.2 Actual Bolzano Scenario

The Scenario assumes the boundary conditions expected to apply for the study case of Bolzano, with all its peculiarities: the main anomaly of this scenario is the low price of heat, that is provided through the existing district heating network.

Table 12: Energy balance of the Actual Scenario, detailed per load case and production temperature

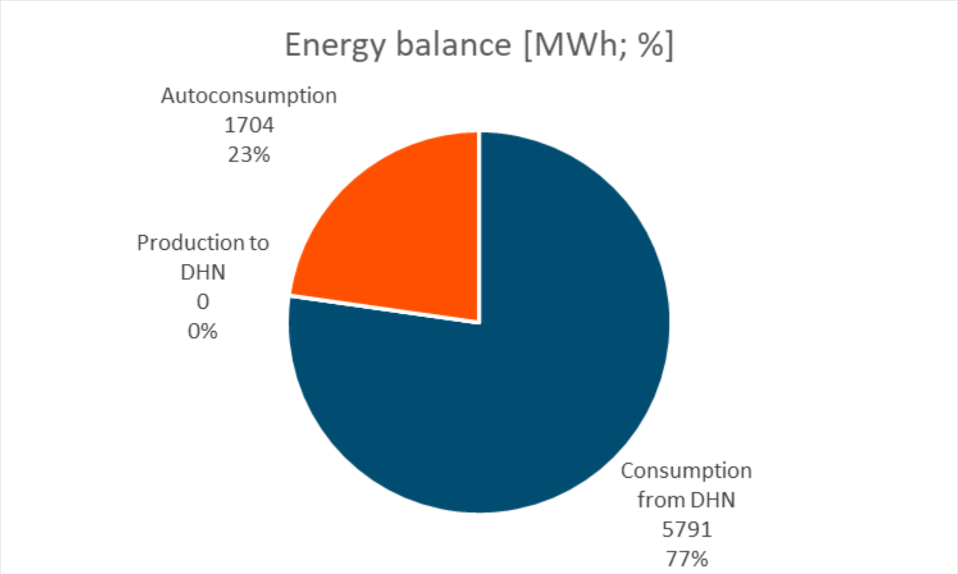
Load Case	Recovered heat	Consumption from DHN	Production to DHN	Auto consumption	Hours
	[MWh]				
1H	0.0	0.0	0.0	0.0	0
1L	0.0	0.0	0.0	0.0	0
2H	774.2	5601.8	0.0	774.2	4658
2L	314.1	188.9	0.0	314.1	1844
3H	0.0	0.0	0.0	0.0	0
3L	615.9	0.0	0.0	615.9	2258
4H	0.0	0.0	0.0	0.0	0
4L	0.0	0.0	0.0	0.0	0
5H	0.0	0.0	0.0	0.0	0
5L	0.0	0.0	0.0	0.0	0
55°C	1704.1	5790.7	0.0	1704.1	8760.0
85°C	0.0	0.0	0.0	0.0	0.0

Total	1704.1	5790.7	0.0	1704.1	8760.0

Table 13: Energy shares of the Actual Scenario, detailed per load case and production temperature

Load Case	Recovered heat	Consumption from DHN	Production to DHN	Auto consumption	Hours
	%				
1H	0%	0%	0%	0%	0%
1L	0%	0%	0%	0%	0%
2H	45%	97%	0%	45%	53%
2L	18%	3%	0%	18%	21%
3H	0%	0%	0%	0%	0%
3L	36%	0%	0%	36%	26%
4H	0%	0%	0%	0%	0%
4L	0%	0%	0%	0%	0%
5H	0%	0%	0%	0%	0%
5L	0%	0%	0%	0%	0%
55°C	100%	100%	0%	100%	100%
85°C	0%	0%	0%	0%	0%
Total	100%	100%	0%	100%	100%

In the Actual Scenario about 77% of the total heat energy dispatched by the powerhouse of the WaltherPark project is provided via the district heating network and 23% is sourced through the Skid by means of local heat recovery; recovery of heat from the local waste heat source to the district heating network does not take place.



Graph 5: Actual scenario energy balance

Comparing the Actual Scenario with a standard solution of energy supply, where no heat recovery measures are implemented and cooling is completely provided by a standard air condensed chiller, in economic and environmental terms the following results are obtained. The difference is computed considering current scenario minus reference on annual figures for:

- Electricity, needed to run the SKID and auxiliaries;
- District Heating Network heat, delivered through the DHN;
- Cooling, obtained respectively through the District Cooling Network or with an air condensed chiller.

Table 14: Annual running cost for the Actual and Reference Scenarios

Scenario	Electricity cost	DHN Heat cost	Cooling cost	Total cost	Difference
	[€]				
Actual	-86,091 €	-183,465 €	-240,172 €	-509,728 €	-13,293 €
reference	- €	-215,583 €	-307,438 €	-523,020 €	

Table 15: Environmental balance for the Actual and Reference Scenarios

Scenario	Electricity CO_2	DHN CO_2	Cooling CO_2	Total CO_2	Difference
	[ton CO_2]				
Actual	171.8	172.9	413.3	758.1	5.1
reference	0	223.8	529.1	752.9	

In term of running costs an advantage of the Actual Scenario is highlighted; energy costs are reduced by 2.5% compared to the reference scenario. Considering instead carbon dioxide emissions, since electricity consumption is assumed to be sourced from the distribution grid, national energy mix factors are applied. Total emission result to be 0.6 % lower in the reference scenario, due to the unfavourable conversion factors for electricity.

In order to reach the same impact for the two scenarios in terms of CO_2 emission, electricity production has to be generated with a lower carbon intensity that the Italian Energy Mix: the goal can be achieved by sourcing part of the electricity through photovoltaic panels. Given the characteristics of the site of the powerhouse, a PV system of 14 kW_p would be able to guarantee equal impact of the two scenarios.

Anyhow in financial terms, the performance of an investment is not such to justify the realisation of the project. The simulation is performed considering the following variables, yearly updated to inflation:

- initial investment for 2 SKIDs of about 201,000 €;
- second investment after 15 years to replace heat pumps in the skid of 170,000 €;
- mean annual O&M cost of about 11,000 €;
- Annual cost for electricity (105,000 €) to feed the heat pumps and auxiliaries;
- revenues from heat sold to the DHN (34,000 €) and cooling sold to the DCN (69,000 €)

Results show that all considered indicators (IRR and NPV at 15 and 30 years) present negative values.

Table 16: Financial indicators for the Actual Scenario

Scenario	IRR_{30}	NPV_{30}	IRR_{15}	NPV_{15}
Actual	-5.8%	-100,141.10 €	-6.1%	-75,941.30 €

As a conclusion, the implementation of the heat recovery measure for the Bolzano Case Study, even if technically feasible and environmentally neutral, is **currently not financially sustainable due to the exceptionally low cost of heat guaranteed by the waste-to-heat (W2H) plant feeding the DH network**; no further designing phases are therefore foreseen for this application. On the other hand, one should observe that: (1) such a peculiar situation, where the existence of an extremely cheap heat source makes so difficult for other sources to compete, is not common, so that **the generic Italian case is much more promising** (see below); (2) in the future, with a further expansion of the Bolzano network (currently covering only about 25 % of the city), the W2H plant will not be enough to satisfy the heat demand, and the competition will not be between low-temperature waste heat (WH) and W2H, but between low-temperature WH and other additional sources. This will open up new opportunities for low-temperature WH even in the Bolzano case.

In order to extend the applicability of the present feasibility study, additional scenarios are examined in order to identify possible other boundary conditions that allow the realisation of the heat recovery measure taken into consideration.

3.4.3 Actual Bolzano Scenario with DHN exchange

The first additional scenario considered aims at analyzing the possibility to recover heat from the local source to the district heating network, as foreseen by the general layout of the Skid. As seen in paragraph 3.4.2 this configuration does not result to be profitable and is excluded from the Actual Bolzano Scenario.

In order to allow the recovery of local heat into the DHN, a third SKID has to be included in the system layout; in this way it is possible to increase the heat recovery capability above the user demand. Excess energy will therefore be fed into the district heating network, requiring to produce heat at 85°C. Resulting energy and environmental balances are reported in the following tables.

Table 17: Energy balance of the Actual Scenario with DHN exchange, detailed per load case and production temperature

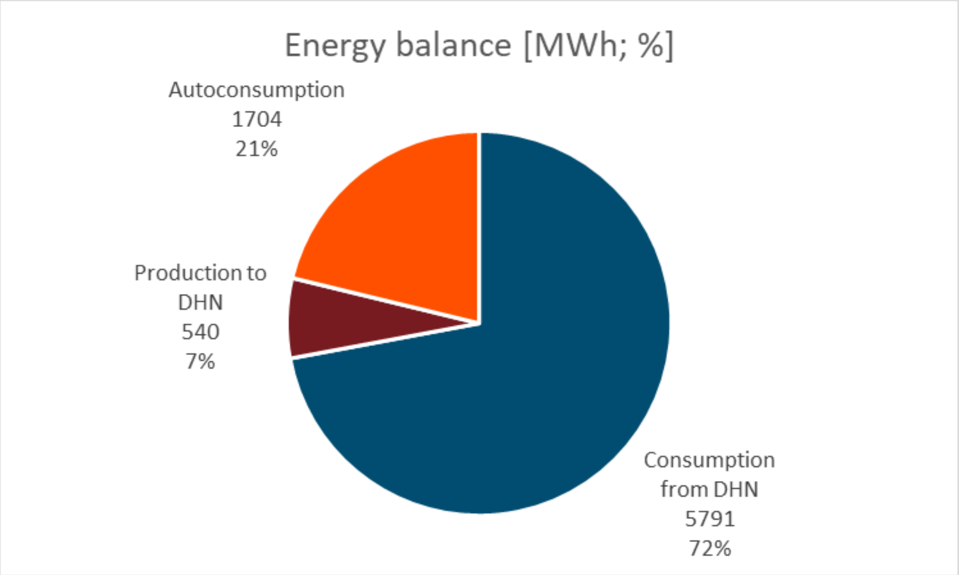
Load Case	Recovered heat	Consumption from DHN	Production to DHN	Auto consumption	Hours
	[MWh]				
1H	0.0	0.0	0.0	0.0	0
1L	0.0	0.0	0.0	0.0	0
2H	774.2	5601.8	0.0	774.2	4658
2L	314.1	188.9	0.0	314.1	1844
3H	0.0	0.0	0.0	0.0	0
3L	0.0	0.0	0.0	0.0	0
4H	0.0	0.0	0.0	0.0	0
4L	0.0	0.0	0.0	0.0	0
5H	0.0	0.0	0.0	0.0	0

5L	1156.0	0.0	540.1	615.9	2258
55°C	1088.2	5790.7	0.0	1088.2	6502.0
85°C	1156.0	0.0	540.1	615.9	2258.0
Total	2244.2	5790.7	540.1	1704.1	8760.0

Table 18: Energy shares of the Actual Scenario with DHN exchange, detailed per load case and production temperature

Load Case	Recovered heat	Consumption from DHN	Production to DHN	Auto consumption	Hours
	%				
1H	0%	0%	0%	0%	0%
1L	0%	0%	0%	0%	0%
2H	34%	97%	0%	45%	53%
2L	14%	3%	0%	18%	21%
3H	0%	0%	0%	0%	0%
3L	0%	0%	0%	0%	0%
4H	0%	0%	0%	0%	0%
4L	0%	0%	0%	0%	0%
5H	0%	0%	0%	0%	0%
5L	52%	0%	100%	36%	26%
55°C	48%	100%	0%	64%	74%
85°C	52%	0%	100%	36%	26%
Total	100%	100%	100%	100%	100%

In the Actual Scenario with DHN exchange about 72% of the total heat energy dispatched by the powerhouse of the WaltherPark project is provided via the district heating network and 21% is sourced through the Skid by means of local heat recovery; recovery of heat from the local waste heat source to the district heating network accounts for about 7% of the total energy needs.



Graph 6: Actual scenario with DHN exchange energy balance

The significant amount of operating hours in which heat is produced at 85°C, means that the average performance of heat pumps is lower compared to the previous scenario; as a consequence both economic and environmental indicators perform worse than the reference and the Actual scenarios.

Table 19: Annual running cost for the Actual Scenario with DHN exchange and Reference Scenario

Scenario	Electricity cost	DHN Heat cost	Cooling cost	Total cost	Difference
	[€]				
Actual with DHN exchange	-129,675 €	-178,064 €	-226,070 €	-533,808 €	10.788 €
reference	- €	-215,583 €	-307,438 €	-523,020 €	

Table 20: Environmental balance for the Actual Scenario with DHN exchange and Reference Scenario

Scenario	Electricity CO_2	DHN CO_2	Cooling CO_2	Total CO_2	Difference
	[ton CO_2]				
Actual with DHN exchange	275.0	172.9	389.1	837.0	84.1
reference	0	223.8	529.1	752.9	

Both in running cost and environmental terms an advantage of the Actual Scenario is confirmed; energy costs increase in the scenario with 3 skids by 2.1% while carbon dioxide emissions are 11.1 % higher. In order to reach the same impact for the two scenarios in terms of CO_2 emission, electricity production has to be generated with a lower carbon intensity that the Italian Energy Mix: the goal can be achieved by sourcing part of the electricity through photovoltaic panels. Given the characteristics of the site of the powerhouse, a PV system of 225 kW_p would be able to guarantee equal impact of the two scenarios.

Updating the financial analysis of the scenario, it emerges an even worse performance of the investment. The simulation is performed considering the following variables, yearly updated to inflation:

- initial investment for 3 SKIDs of about 311,000 €;
- second investment after 15 years to replace heat pumps in the skid of 255,000 €;
- mean annual O&M cost of about 13,000 €;
- Annual cost for electricity (130,000 €) to feed the heat pumps and auxiliaries;
- revenues from heat sold to the DHN (37,000 €) and cooling sold to the DCN (81,000 €)

Table 21: Financial indicators for the Actual Scenario with DHN exchange

Scenario	IRR_{30}	NPV_{30}	IRR_{15}	NPV_{15}
Actual	n.a.	-526,517.39 €	n.a.	-360,128.26 €

Due to the high supply temperature (ranging around 80°C) at the DH network in Bolzano, results show that all considered indicators (IRR and NPV at 15 and 30 years) present negative values or cannot be computed due to the lack of positive cash flow. Since all indicators for the present scenario, both from the environmental and financial point of view, do not show any advantage in the adoption of a third Skid, the configuration will not be subject of further analysis in the present study.

3.4.4 General Italian Scenario

The Scenario assumes, for the configuration studied in the Actual scenario, the boundary conditions that are generally found in the Italian context, mainly in relation to heat and electricity costs. Those values are determined on the base of an extended study developed by GSE (Gestore Servizi Energetici, 2016) on the potential of a district heating system in Italy (electricity at 190 €/MWh and heat at 35 €/MWh).

Given the financial nature of the change in boundary conditions, energetic balances as well as maintenance costs are not affected and present the same values seen in the Actual Scenario. Environmental balances are to be updated to consider the carbon footprint of heat generation for the considered scenario instead of the value certified for the Bolzano system.

Comparing the General Scenario with a standard solution of energy supply, where no heat recovery measures are implemented and cooling is provided by a standard air condensed chiller, in economic terms the following results are obtained (difference is obtained considering current scenario minus reference):

Table 22: Running cost for the General and Reference Scenarios

Scenario	Electricity cost	DHN Heat cost	DCN Cold cost	Total cost	Difference
	[€]				
General	-99,822 €	-202,674 €	-240,172 €	-542,668 €	-27,088 €
reference	- €	-262,318 €	-307,438 €	-569,756 €	

The change in boundary conditions takes a beneficial advantage when the Skid is installed in a site where general Italian boundary conditions apply. This is underlined by the financial indicators of the initiative which show and interesting increase in their absolute values.

Table 23: Financial indicators for the General Scenario

Scenario	IRR_{30}	NPV_{30}	IRR_{15}	NPV_{15}
General	3.6%	79,188 €	2.8%	41,675 €

From the environmental point of view the beneficial effect of the heat recovery measure is highlighted by the reduction of the total CO_2 emission of more than 300 tons per year.

Table 24: Environmental balance for the Actual Scenario with DHN exchange and Reference Scenario

Scenario	Electricity CO_2	DHN CO_2	Cooling CO_2	Total CO_2	Difference
	[ton CO_2]				
Actual with DHN exchange	275.0	1512.5	389.1	2176.7	310.1
reference	0	1957.7	529.1	2486.8	

As a conclusion, the realisation of the heat recovery measure for a general application case in Italy takes evident environmental benefits and seems economically viable, even though the indexes obtained are not compatible with investment approval procedures within the Alperia Group.

3.4.5 General Italian Scenario with CHP

The Scenario assumes the same boundary conditions as in paragraph 3.4.4 with the difference that all electrical power consumed is supposed to be generated locally by a CHP; this allows to assume favourable prices and reduced taxation, taking the electricity price at 110 €/MWh.

As seen before, given the financial nature of the change in boundary conditions, energetic balances are not affected and present the same values seen in the Actual Scenario. Obtained results for running costs and financial indexes are reported in the following tables. Environmental balances are to be updated to consider the carbon footprint of heat and electricity generation for the considered scenario instead of the value certified for the Bolzano system or the National Grid. From the environmental point of view the beneficial effect of the heat recovery measure is highlighted by the reduction of the total CO_2 emission of almost than 400 tons per year.

Table 25: Environmental balance for the Actual Scenario with DHN exchange and Reference Scenario

Scenario	Electricity CO_2	DHN CO_2	Cooling CO_2	Total CO_2	Difference
	[ton CO_2]				
Actual with DHN exchange	196.7	1512.5	389.1	2098.4	388.4
reference	0	1957.7	529.1	2486.8	

As a conclusion, the realisation of the heat recovery measure for a general application case in Italy where a cogenerative unit is installed to provide cheap electricity is environmentally beneficial and economically viable, with financial indexes compatible with investment approval procedures within the Alperia Group.

Table 26: Running cost for the General+CHP and Reference Scenarios

Scenario	Electricity cost	DHN Heat cost	DCN Cold cost	Total cost	Difference
	[€]				
General+CHP	-57,792 €	-202,674 €	-139,047 €	-399,513 €	-40,796 €
reference	- €	-262,318 €	-177,990 €	-440,308 €	

Table 27: Financial indicators for the General+CHP Scenario

Scenario	IRR_{30}	NPV_{30}	IRR_{15}	NPV_{15}
General+CHP	10.2%	257,378 €	9.6%	158,543 €

3.4.6 Boundary electricity price Scenario

The Scenario assumes the same boundary conditions as in paragraph 3.4.4 with the difference that electricity prices are kept as a free variable. An optimisation routine is then applied so to define the electricity price threshold below which the financial viability of the project is verified in compliance with investment approval procedures within the Alperia Group. This means that the Internal Rate of Investment for a 15-year duration is equal or above 6%.

The resulting **electricity threshold cost**, below which it is possible to meet the financial requirement for an investment to be approved within the Alperia Group, is equal to **154 €/MWh** (assuming heat cost at 35 €/MWh). Energy prices are intended as Levelized Cost of Energy to the system operator.

As seen before, given the financial nature of the change in boundary conditions, energetic and environmental balances are not affected and present the same values seen in the Actual Scenario. Obtained results for running costs and financial indexes are reported in the following tables.

Table 28: Running cost for the Boundary electricity price and Reference Scenarios

Scenario	Electricity cost	DHN Heat cost	DCN Cold cost	Total cost	Difference
	[€]				
Boundary electricity	-80,908 €	-202,674 €	-194,665 €	-478,248 €	-33,225 €
reference	- €	-262,318 €	-249,186 €	-511,505 €	

Table 29: Financial indicators for the Boundary electricity price Scenario

Scenario	IRR_{30}	NPV_{30}	IRR_{15}	NPV_{15}
Boundary electricity	6.7%	159,374 €	6.0%	94,266 €

3.4.7 Boundary heat price Scenario

The Scenario assumes the same boundary conditions as in paragraph 3.4.4 with the difference that heat prices are kept as a free variable. An optimisation routine is then applied so to define the price of heat withdrawn from or supplied to the district heating network above which the financial viability of the project is verified in compliance with investment approval procedures within the Alperia Group. This means that the Internal Rate of Investment for a 15 year duration is equal or above 6%.

The resulting **heat threshold cost**, above which it is possible to meet the financial requirement for an investment to be approved within the Alperia Group, is equal to **38,6 €/MWh** (assuming electricity cost at 190 €/MWh). Energy prices have to be intended as Levelized Cost of Energy to the district energy system operator, where all cost items are to be included (i.e., carbon tax).

As seen before, given the financial nature of the change in boundary conditions, energetic and environmental balances are not affected and present the same values seen in the Actual Scenario. Obtained results for running costs and financial indexes are reported in the following tables.

Table 30: Running cost for the Boundary heat price and Reference Scenarios

Scenario	Electricity cost	DHN Heat cost	DCN Cold cost	Total cost	Difference
	[€]				
Boundary Heat	-99,822 €	-223,521 €	-240,172 €	-563,515 €	-33,223 €
reference	- €	-289,300 €	-307,438 €	-596,737 €	

Table 31: Financial indicators for the Boundary heat price Scenario

Scenario	IRR_{30}	NPV_{30}	IRR_{15}	NPV_{15}
Boundary Heat	6.7%	158,936 €	6.0%	93,978 €

3.4.8 General Italian Scenario with carbon tax

In order to consider the impact of the introduction of compensation measures to account for externalities with regard to carbon emissions, the General Italian Scenario has been modelled considering the application of a leavy on carbon emission equal to 70 €/ton_{CO2}. This affects significantly the economic figures obtained previously as shown in the following tables.

Table 32: Running cost for the General and Reference Scenarios with cabon tax

Scenario	Electricity cost	DHN Heat cost	DCN Cold cost	Total cost	Difference
	[€]				
General + Carbon tax	-106.691 €	-295.847 €	-256.699 €	-659.237 €	-52.267 €
reference	- €	-382.910 €	-328.593 €	-711.503 €	

The monetisation of externalities simulated in this scenario highlights the beneficial impact of heat recovery measures on the environment; financial indicators below underline the attractiveness of this kind of investment.

Table 33: Financial indicators for the General Scenario with carbon tax

Scenario	IRR$_{30}$	NPV$_{30}$	IRR$_{15}$	NPV$_{15}$
General + Carbon tax	15.2%	406,495 €	14.8%	256,344 €

3.4.9 General Italian Scenario with CHP and carbon tax

In analogy to what done for the General Italian Scenario, in order to consider the impact of the introduction of compensation measures to account for externalities with regard to carbon emissions, the General Italian Scenario with CHP has been modelled considering the application of a leavy on carbon emission equal to 70 €/ton$_{\mathrm{CO2}}$. This affects the economic figures obtained previously as shown in the following tables, even though the impact of the carbon tax is lower that in the General Italian Scenario.

Table 34: Running cost for the General and Reference Scenarios with CHP and carbon tax

Scenario	Electricity cost	DHN Heat cost	DCN Cold cost	Total cost	Difference
	[€]				
General + CHP + Carbon tax	-64.661 €	-295.847 €	-155.574 €	-516.082 €	-69.975 €
reference	- €	-382.910 €	-199.146 €	-582.056 €	

The monetisation of externalities highlights the beneficial impact of heat recovery measures on the environment; financial indicators below underline the attractiveness of this kind of investment.

Table 35: Financial indicators for the General Scenario with CHP and carbon tax

Scenario	IRR$_{30}$	NPV$_{30}$	IRR$_{15}$	NPV$_{15}$
General + CHP + Carbon tax	20.8%	584,685 €	20.5%	373,212 €

4 Early Adopter Schwaigern

4.1 Description of the Case Study

In order to decrease all types of emissions in the cities, innovative systems need to be concepted. In the best-case scenario, the new technologies will be integrated into the existing systems. This allows to optimise bigger systems without the need of dismantle and replace the functioning old ones. This can be realized by looking at waste heat as a source of energy. Another important factor in such big and long-term projects is the flexibility to switch between changing heat sources and locations. One possible solution to reach this target is a portable skid for waste heat recovery extraction.

In the City of Schwaigern a new residential area with 254 single-family-houses with a total heat demand of 2098 MWh/a is planned. In order to maintain a low emission profile, the source is chosen among reasonable environmentally friendly solutions considering the geographical circumstances. The best option in this case, results to be an agrothermal plant. The source of waste heat is a close-by supermarket in the commercial area of the city. By extracting the waste heat of the cooling system and coupling it with a cold district heating (CDH) network the investment costs for the agrothermal heat source can be reduced significantly. The agrothermal heat source can be used as buffer storage as well. The combination of this solution and the waste heat can cover 75% of the residential area's heat request. The remaining 25% will be covered by the electricity used by the decentralized heat pumps connected to the cold network, which carry the total CO_2-emission of the system of 210 t/a (where the emission factor for electricity was assumed to be 0.400 t/MWh).

The extraction of waste heat from the supermarket will be done within a movable container, which connects different systems like the entire hydraulic system, sensor technology and the control technology. They are all meant to be fixed to the robust steel frame of the construction. So, if the supermarket changes location, the container can be moved to another waste heat source and integrated again into this or another system.

At the end of the case study a technological, economic and environmental assessment is performed, in order to analyse and evaluate the feasibility of the entire system. Additionally, the possible funding program, that could financially support the project, is presented.

4.2 Identification of the technical solution

4.2.1 Set of analysed configurations

In almost every city several supermarkets can be found. Mostly they are located in city centres, adjacent to industrial areas or near to residential areas. Grocery retails are very energy-intensive and most of the energy is needed for the refrigeration technology. In fact, the installed refrigerating system by itself demands almost half of the total electricity consumption of a supermarket. As cooling systems are needed in every supermarket to guarantee the durability of groceries, they represent an important factor for both economic efficiency of the supermarket company and for the primary energy consumption.

Both old and new supermarket buildings are nowadays going into a process of optimization of the overall energy performance. Also, these types of buildings are planned to cover their heating need through the operation of the own cooling/refrigeration system. As refrigerant for these heat recovery systems (HRS) carbon dioxide (R744) is widely established, thanks to its good thermophysical characteristics, low global warming potential (GWP) (=1) and no ecol. ozone depletion potential (ODP) and it represents the state of the art. Therefore, systems using CO_2 are simple, space-saving, cost- and energetic-efficient.

In the following picture is a simplified representation of a CO_2-cooling plant with integrated HRS to be seen. In the shown concept a two-staged compression has been used. Thereby the cooling-system is subdivided into three pressure-sections: low pressure (LP), middle pressure (MP) and high pressure (HP). The Task of such an installation is to continuously provide cooling energy at two different temperatures: one for normal refrigeration cooling (RC) and one for freezing cooling (FC). Such CO_2-cooling plants are nowadays realized as so-called booster-systems. Because of the thermodynamic characteristic of the coolant, the critical temperature is at 31°C and 74 bar. Therefore, there is a difference between two operational modes: subcritical (heat supply under critical temp.) and transcritical (heat supply over critical temp.) mode.

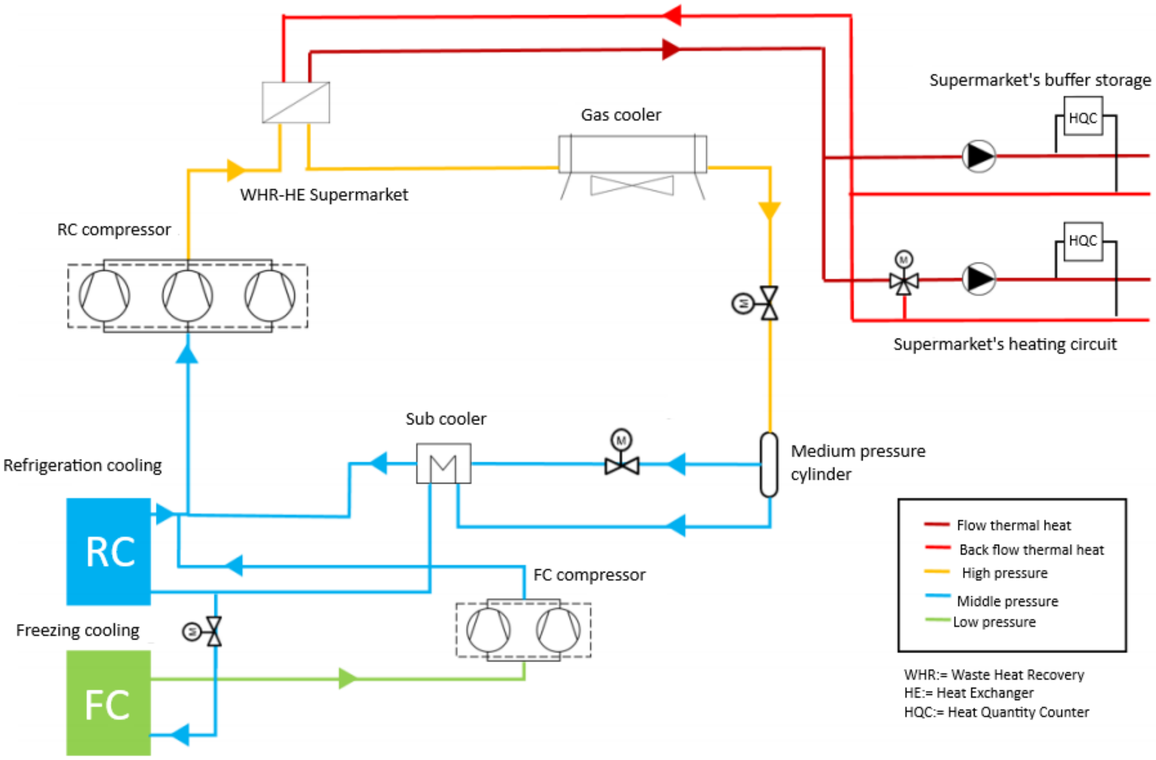


Figure 15: Simplified system diagram of a CO2-cold district heating with integrated heat recovery system

4.2.2 Selected configuration

Supply area Mühlpfad/Herrengrund

The new residential area "Mühlpfad/Herrengrund" is located in the south of Schwaigern (near Heilbronn). The district is northerly limited from the "Weilerweg" and easterly from the "Nippiger Straße". Its total area amounts to about 410 ha, of which 300 ha are not built yet. The considered areal of the project includes 254 single-family houses (SFH). The commercial area of Schwaigern is located in the east of the new living area and includes middle-sized companies and a big supermarket.

Figure 16: New residential area "Mühlpfad/Herrengrund" with the supply area marked in blue and the bordering commercial area marked in red

General requirements

The core of the heat supply of the project is the CDH with flow temperatures beneath 20°C. The main energy source will be the agrothermal field. But another important factor of the concept is the integration of the waste heat coming from the supermarket nearby.

Through decoupling of the supermarket's waste heat into a CDH, the waste heat can be used as one of the sources to supply decentralized monovalent heat pumps of the residential area. The electricity demand of these heat pumps will be covered through the local power network.

Heat demand of the residential area

For the realization of this concept, the total heat demand of the 254 houses has to be determined. In order to do that the following factors have also to be determined:

1. Thermal heat (TH) and warm potable water (WPW) demand of one building
2. Electricity demand of the heat pump (HP)
3. Balancing of the network heat demand
4. Total heat demand of the residential area simultaneity factor

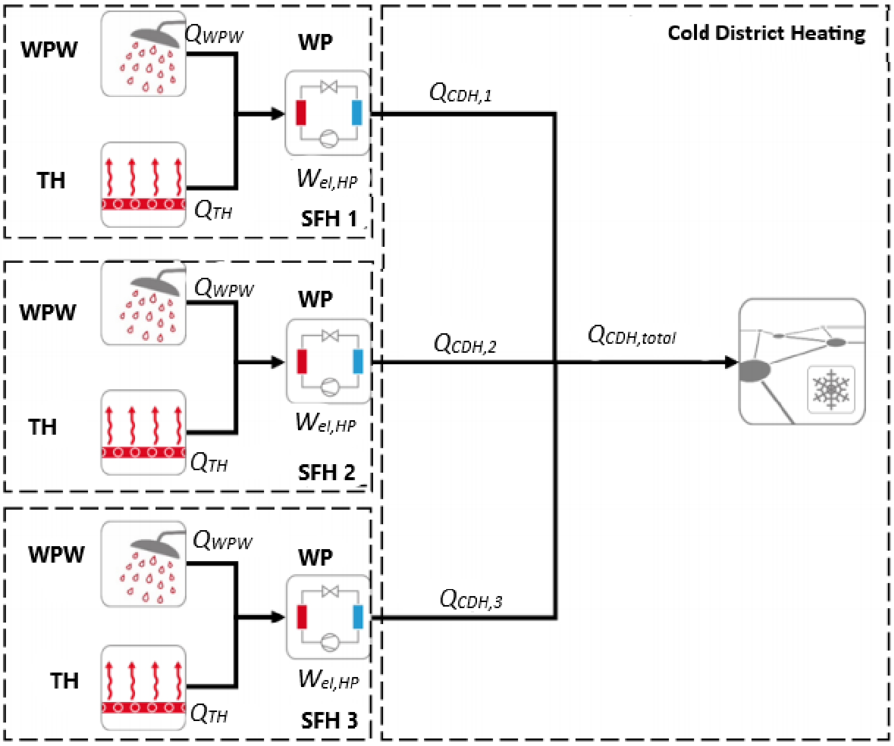


Figure 17: Schematic representation of the CDH heat demand dimensioning

As a base of the calculation, we defined the building type, its TH and WPW demand and the number of people living in the building is needed.

Table 36: Average specifications of one single family house

Building type	Single family house (SFH)	
Gross building surface (GBS)	178	m^2
Specific TH demand	30.4	$kWh/m^2_{GBS}*a$
Specific WPW demand	16	$kWh/m^2_{GBS}*a$
Number of persons	3.5	Persons

This information results in the following total demands:

Table 37: Specifications of all 254 buildings

Number of SFH	TH demand	WPW demand	Total heat demand
[Units]	[MWh/a]	[MWh/a]	[MWh/a]
1	5.41	2.85	8.26
254	1374	724	2098

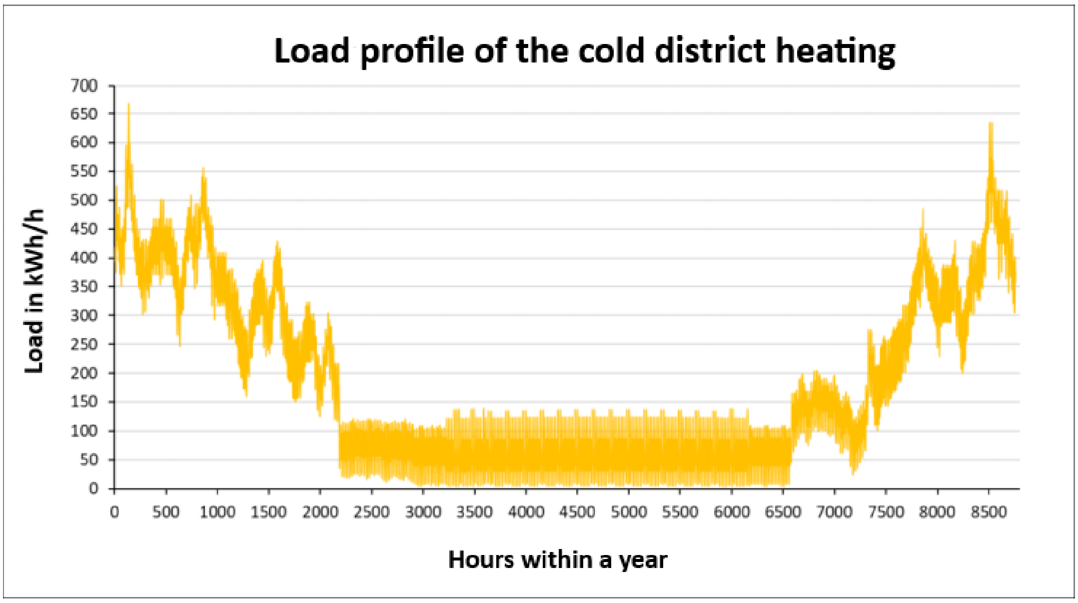
The heating capacity of an SFH in Schwaigern is estimated to be 5.1 kW. Considering operating conditions and the presence of a buffer, the dimensioning of the decentralized HP results in a nominal capacity of 6.8 kW.

Network heat demand

In order to determine the CDH heat demand, the HP heat demand must be identified. If a constant flow temperature for TH of 35°C and for WPW of 55°C is needed, it results in an electricity demand of 2.07 MWh/a for each SFH. Dividing heat and electricity demand, results an annual performance factor of 4.0.

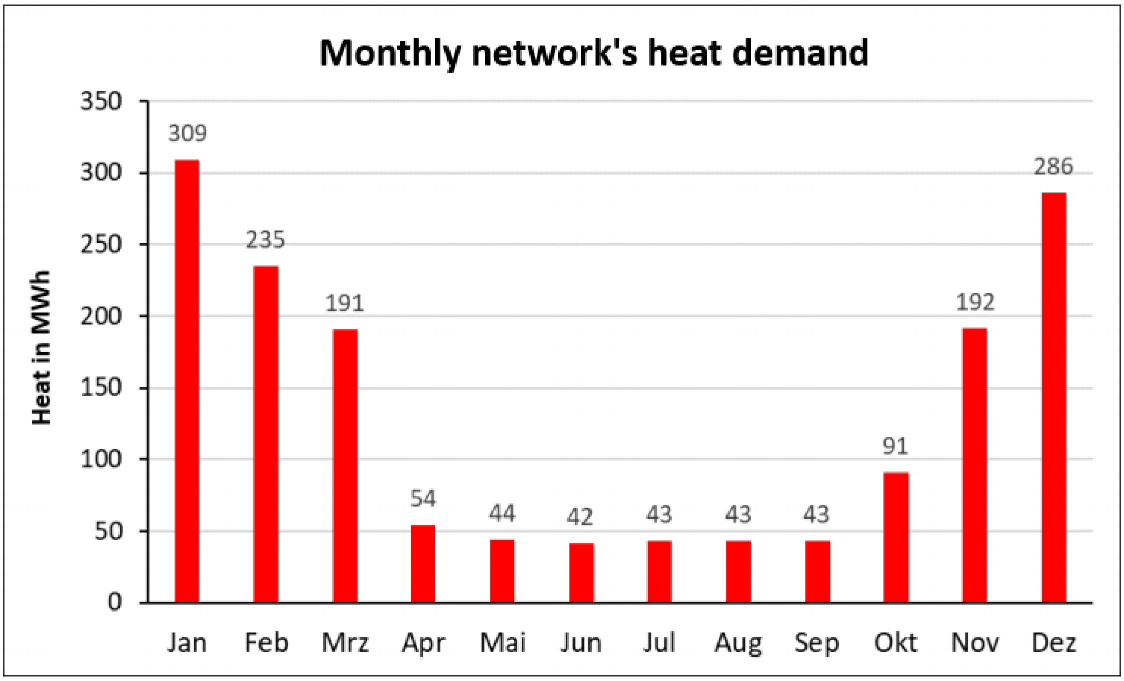
An important factor to dimension a heat network is the simultaneity factor, which causes a temporal deferral of the peak loads and a reduction of the network total power request compared to the sum of the single consumer's nominal capacity. In this case, the simultaneity factor is set at 0.64 (calculation based on an internal tool of EGS) and the network total heat demand amounts to 1573 MWh/a (total heat demand minus electricity demand) and a maximum capacity of 667 kW (calculation based on an hourly calculation of EGS; the order of magnitude corresponds to application of the simultaneity factor, as 5.1 kW x (1-1/COP) x 254 x 0.64 = 622 kW).

In the following diagram the CDH load profile, which must be covered by the heat source, is to be seen. Here it is evident, that the load decreases during summer (max. load about 140 kW) while it gets to its peak in the winter months (max. load over 650 kW).



Graph 7: Dimensioned load profile of the CDH

In the next diagram the monthly CDH heat demand is shown. Again, the highest heat request coincides with the colder months (max. heat demand of 309 MWh in January). During the warmer months instead, an average heat demand of about 43 MWh can be noticed.



Graph 8: Monthly heat demand of the CDH

4.2.3 Waste heat profile analysis

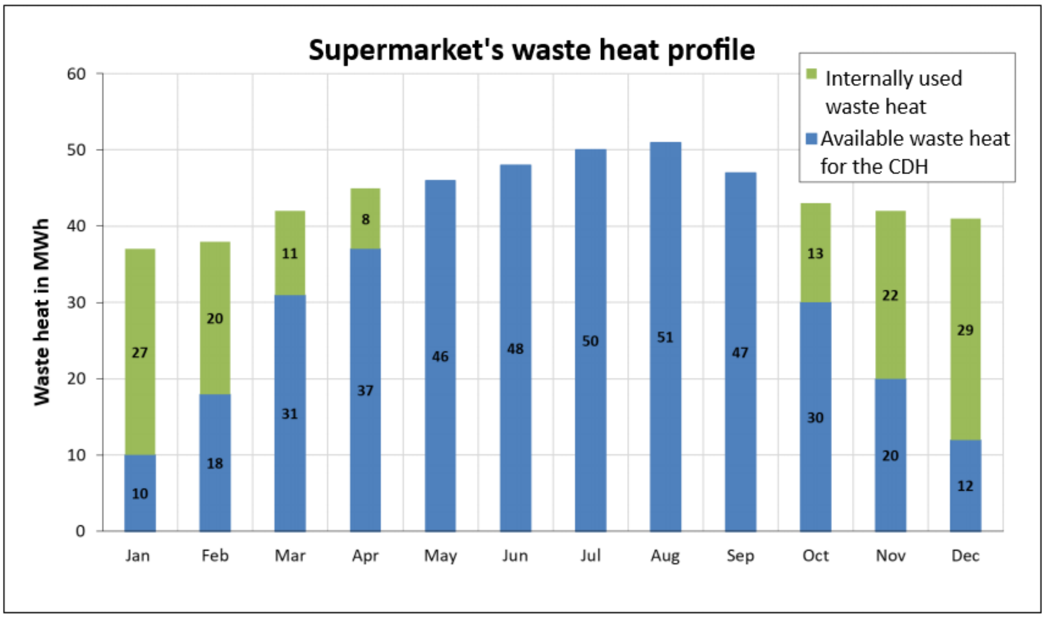
In order to evaluate the applicability of this model, the supermarket's waste heat potential must be determined. The used data for this analysis corresponds to a middle-sized supermarket with a gross area of 1.800 m^2, which coincides with Schwaigern's commercial area. From the same data emerges a waste heat potential of 530 MWh/a, of which 25% is used for internal heating purposes. The remaining 75% can be used for external heating. In the following table, a summary of the data is to be seen.

Table 38: Summary of the plant's general data

Plant type	CO_2-booster-cooling plant	
Coolant	Carbon dioxide	
Waste heat	Total: 530 MWh/a	
	Internal usage	Extern usage
	130 MWh/a	400 MWh/a
Max. waste heat capacity	110 kW	

Being waste heat dependent on the ambient temperature, follows a higher heat availability during the summer months which can be seen in the next figure.

During the winter months, a high internal heat demand can be noticed, which leads to a lower supply of heat for the CDH (lowest amount of heat in January and December with 10 and 12 MWh). At the same time a constant increase of waste heat potential in the warm periods was evaluated. In fact, during the months from May till September, 100% of the waste heat can be used by the CDH.

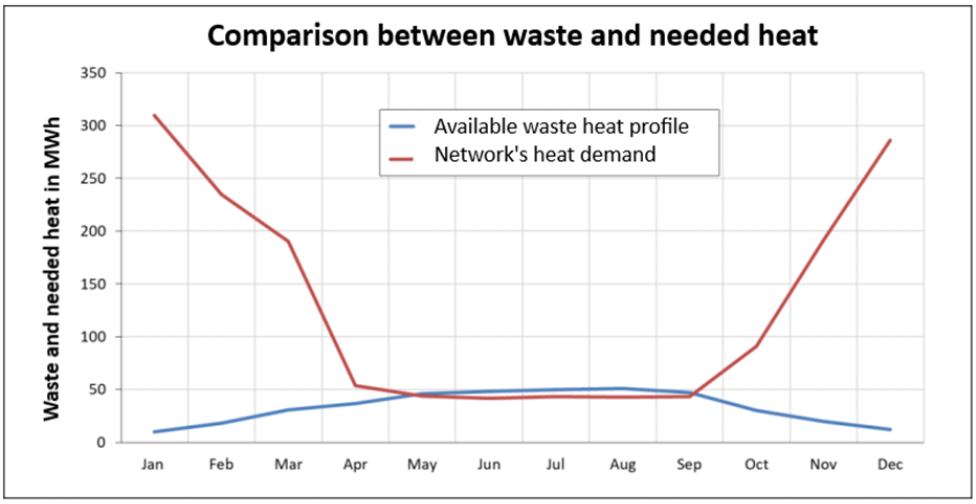


Graph 9: Monthly waste heat quantity of the supermarket over an entire year

Evaluation of the applicability

The usable waste heat coming from the supermarket reaches about a quarter (400 MWh/a) of the determined heat demand of the residential area (1.573 MWh/a). The maximum amount which can be reached if the whole supermarket's waste heat is used, could cover a maximum of one third of the demand. Due to those numbers the size of the agrothermal field can be determined.

To optimize the systems specifications the profile of the available waste heat must be compared to the CDH's heat demand. This can be seen in the following chart.

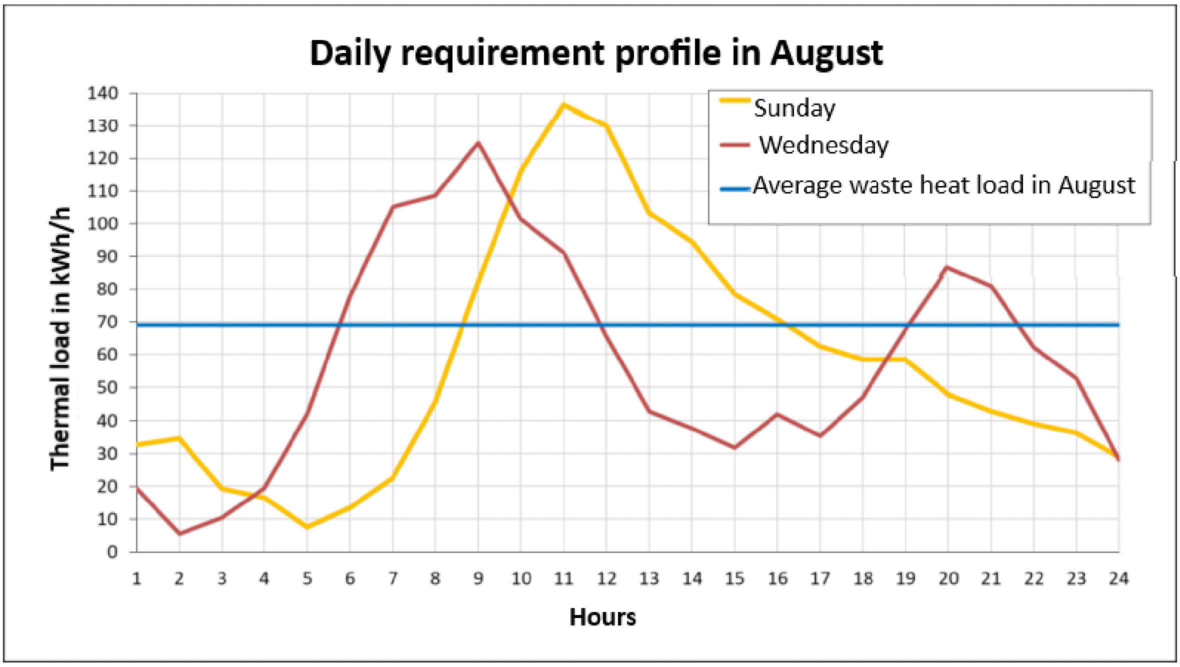


Graph 10: Comparison between waste and needed heat

Here again, it is easy to notice, that during summer the available heat is way bigger than in winter (blue line) and that the heat demand during winter is much bigger than the obtainable waste heat (red line). During the periods from January till April and from October till December the supermarket's operator benefits from the waste heat extraction. As all the waste heat will be brought into the CDH, the cooler temperature can be re-cooled in the return flow by both the integrated heating circuit and the CDH. Consequently, the down-streamed gas coolant usage decreases or is even cancelled. This increases the efficiency of the cooling plant while saving power costs and CO_2-emissions.

Furthermore, from the chart it can be deduced, that from May till September the waste heat supply is high enough to cover the demand of the whole residential area. What cannot be concluded is if the waste heat supply is sufficient in every week, day or hour of these months. Now looking at the next chart, where the demand on a Wednesday and on a Sunday in August are compared, it can be deduced that every day has a different curve. The maximum demand occurs on Wednesday at 8 am (155 kW) and on Sunday at 11 am. While on Sundays the load decreases to 29 kW, it increases again on Wednesdays in the evening from 5 till 8 pm, to a peak of 86 kW. If we relativized the 51 MWh of highest supply of waste heat in August to the 744 hours of the months, the average heat performance is 69 kW per hour.

Another consideration, that has to be done, is that the cooling plant of the supermarket goes into partial-loading operation during closing hours, which means that during nights and early in the morning the waste heat supply is lower.



Graph 11: Daily requirement profile in August

So, the waste heat source won't be a base load source and it is also not flexible to control the system. But it is an add-on to recycle cheap energy and lower the cost of the main heat source. Additionally, the supermarket benefits from the decoupling of the heat source and the heat sink through a heat reservoir/accumulator or involving a geothermal probe or a ground collector. For the supermarket, this kind of solution is a major advantage. On one hand because of the yearly relief of the excessive waste heat and because of the performance increase of the cooling plant, which decreases or even avoids the operation of gas cooler.

4.2.4 Combination of the waste heat source with the agrothermal field and the network

To cover the complete heat demand of the residential area another heat source additionally to the waste heat is needed. The available sustainable possibilities are a geothermal heat exchanger, ground water, waste heat from wastewater and agrothermal energy. Because of the local boundary conditions, in this project an agrothermal solution has been chosen. This type of source allows average temperatures between 10°C and 12°C and the system can represent a heat buffer storage for the CDH system as well. For this project there are 667 kW maximal load needed. Therefore, the agrothermal plant will extend on an area of 30,000 m^2, south of the residential area. In the figure below the typical structure of the planned agrothermal system can be seen.

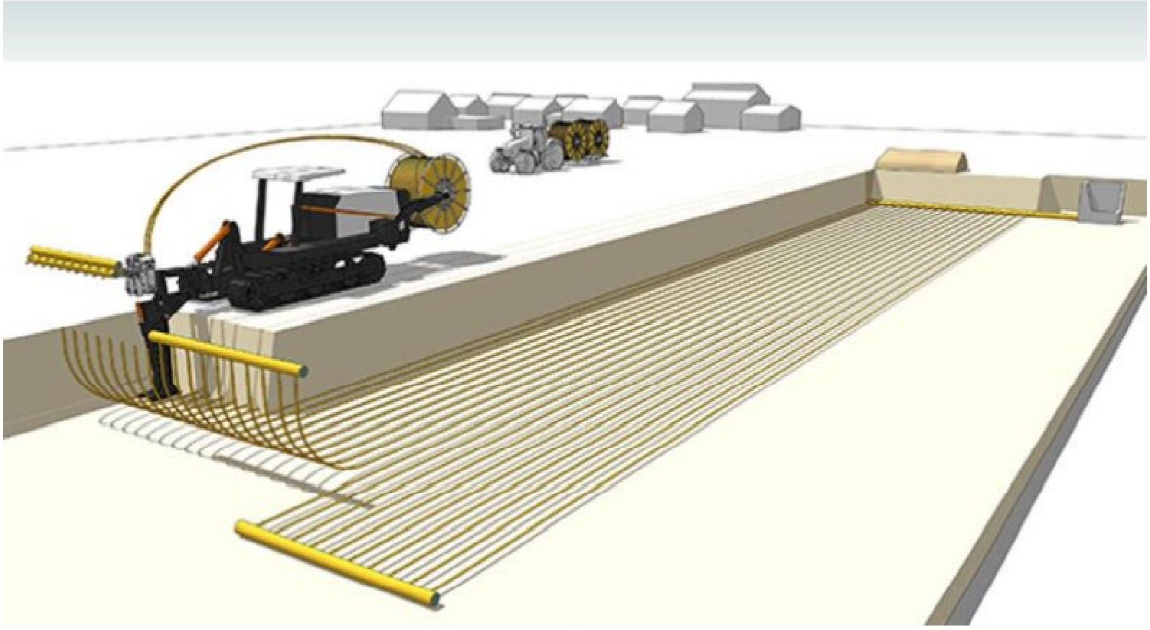


Figure 18: Graphic representation of the relocation of agrothermal collectors

Decoupling and integrating waste heat

In order to be able to reuse the supermarkets waste heat, it must be made technically available. The technical solution for the decoupling and integration of the waste heat into a CDH is based on the present project data. In the system diagram below the presence of a heat exchanger (HE) in the CO_2-cooling plant is to be seen. This element allows the integration into the CDH system. For its technical realization a plate heat exchanger is integrated in the re-cooling conduction of the cooling process between the supermarket´s heat recovery and the gas cooler. The heat exchanger will then be connected to the re-cooling system through a pipeline, that connects the HE to the supermarket’s technical centre.

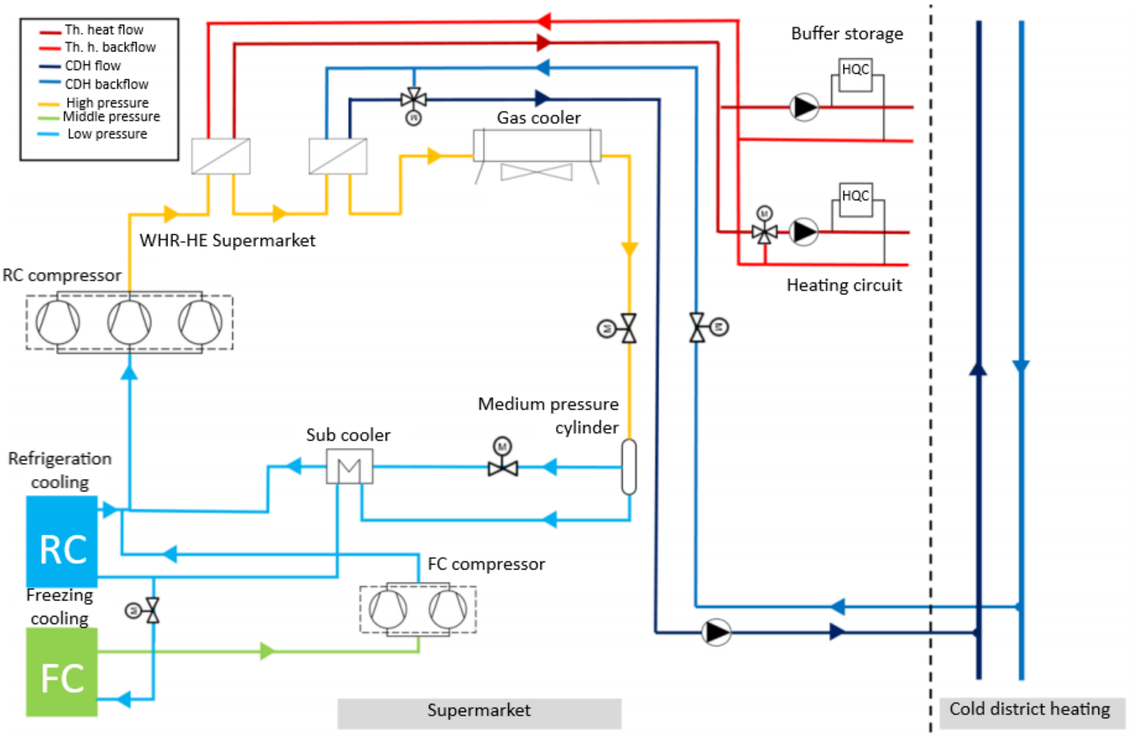


Figure 19: System diagram of a CO_2-cooling plant with integrated heat exchanger for the decoupling into the CDH

In the following diagram the hydraulic system of the heat exchanger can be seen. For this particular system, it is important to design a special control technology. This has to be able to additionally activate the gas cooler, when the CDH is incapable of cooling the coolant 5K over the ambient temperature. It guarantees a secured operation of the cooling plant on the supermarket's side at any time. For the implementation of this project flow simulations as an additional planning support are recommended.

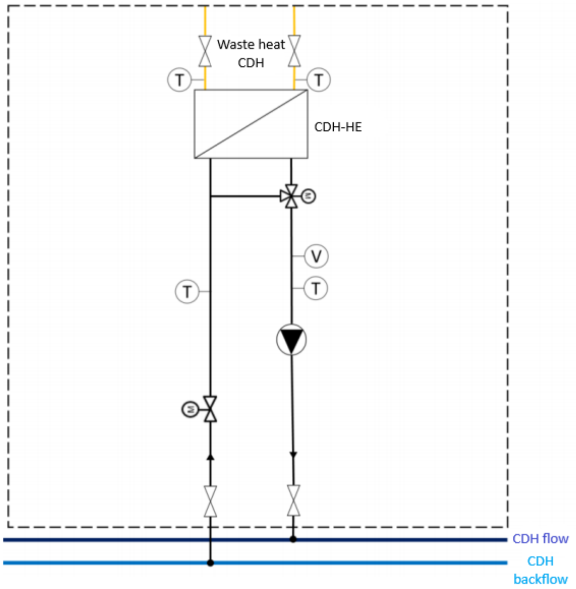


Figure 20: Hydraulic scheme of the heat exchanger station

To achieve a higher flexibility of the system and to give the possibility to relocate the heat recovery system, a container solution has been designed. The container will have a length of 3 m and a height and width of 2.20 m. It will be positioned on an open area next to the supermarket. The container encloses the entire hydraulic system and sensor technology and the control technology, that allows to withdraw waste heat from the supermarket (or any other waste heat source) and feed it into the DHN. The equipment technologies will be installed onto a stable steel frame in the container.

Cold district heating network

In the following map the course of the total network, whose length amounts to 6.47 km, can be seen. The route of the CDH is marked in blue. The network is designed as a radiation-net, although some individual meshes can be found in the northern zone. The connection line to the waste heat source is marked in red, while the agrothermal buffer storage is marked in yellow and can be found in the southern area of the map.

Figure 21: Representation of the developed CDH network for the supply area

To transport the agrothermal and supermarket's heat into the heat pumps of the respective buildings of the residential area, a distribution network has to be designed. The routing will be done by following the local conditions and the draft plan of the city Schwaigern.

Primarily the network will be realized as a 2-pipe system and owns therefore a feed line and a return flow line. The pipeline will be located in the underground and will be placed into the unpaved terrain. The built-in pipes are made of polyethylene, more specifically of FE-RC 100 SDR 17. The heat transfer medium in the pipeline will be a water glycol mixture. Additionally, the CDH will be designed as an undirected network, which means that there won't be a central heat pump putting the heat transfer medium in circulation. In the undirected network the heat transfer medium flows by decentralized circulation pumps, which are located in each residence building. The operation of these pumps is controlled from each heat pump, depending on the individual heat demand of each consumer. In this case, the decentralized circulation pump is considered to be an integrated component of the compact heat pumps.

In order to make a better approximation of the economic efficiency of the complete system, a more accurate dimensioning of the pipeline network is needed. This can be done considering the following technical data of the systems:

Table 39: System's technical data for detailed dimensioning of the pipeline network

Network temperature difference	4 K
Flow temperature	15 °C
Return flow temperature	11 °C
Pipe system	PE-RC 100 SDR 17
Heat exchange medium	Water glycol mixture
Maximal pressure gradient in the pipeline network	100 Pa/m

Assuming a COP value of 4.0, the nominal capacity of the heat pump amounts to 6.8 kW. Therefore, the evaporation capacity is 5.1 kW. It results in a connection line of DN 40 for the connection of the buildings. For the total network some additional regards about temporal scatters and individual peaks have to be considered. Because of that, the pipeline dimensioning for the main route results to DN250. Finally, with the data of the following table, for the heat transport connection line from the supermarket a dimensioning to DN100 is calculated. The costs for both underground routing and material can be suggested to roundabout 330 €/m.

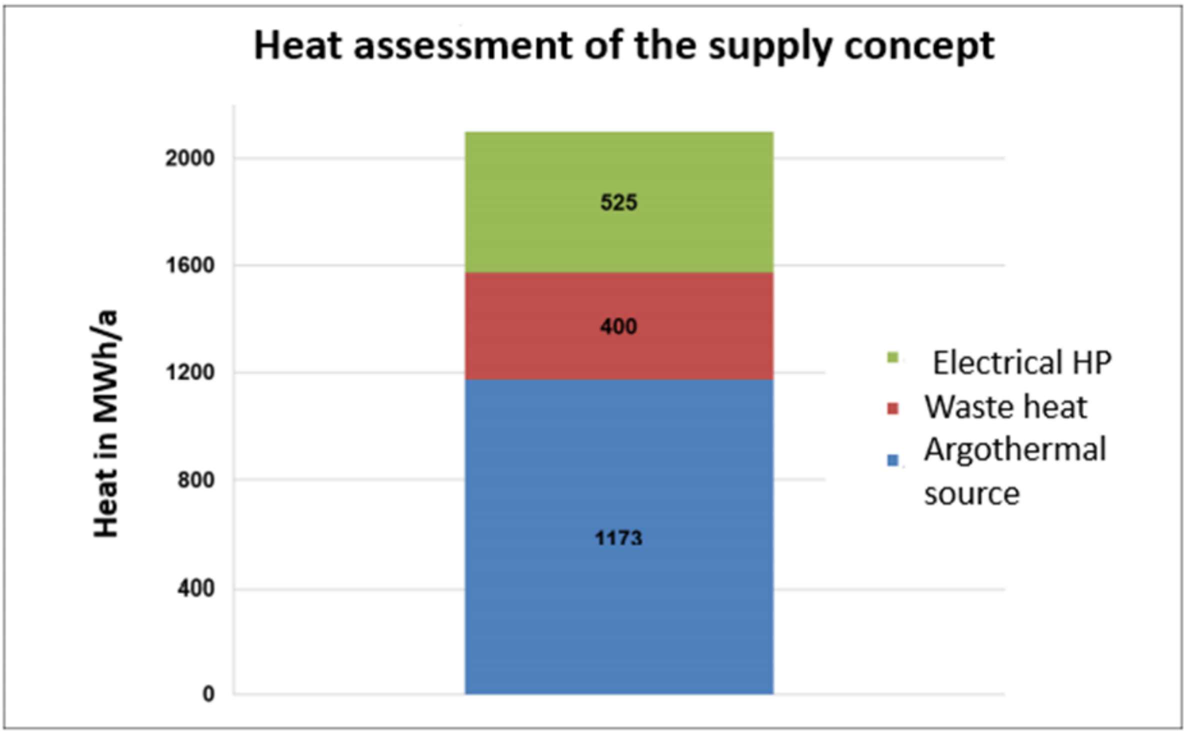
Table 40: Complementary technical data of the system

Heat exchanger capacity	110 kW
Network temperature difference	4 K
Specific heat capacity of heat transfer the medium	1.3 kWh/m^3*K
Volume flow rate	24.34 m^3/h
Mass flow rate	7.02 kg/s
Maximal allowed pressure drop	100 Pa/m

4.3 Performance evaluation

4.3.1 Technical performance evaluation

Summing up all previous considerations it can be said, 56 % of the 2.098 MWh/a needed for the residential area (1.173 MWh/a) are covered by agrothermal energy, 25% (525 MWh/a) are covered by heat pumps, while the remaining 19 % (400 MWh/a) are covered by waste heat.



Graph 12: Heat assessment of the CDH

4.3.2 Environmental performance evaluation

In order to evaluate the ecological impact of this heat supply concept, the system will be compared to a gas-fired condensing boiler and both will be evaluated based on their emission of CO_2-equivalent.

To calculate the emission of the heat pumps a CO_2-equivalent of 0.4 t_{eq}/MWh is assumed (electricity emission factor). As the electricity demand of the HP is set with 525 MWh/a, the CO_2-emissions for the heat pumps result in 210 t/a. For the calculation of the gas-fired system's CO_2-emission a CO_2-equivalent of 0,24 t_{eq}/MWh is assumed (gas emission factor). To cover the total heat demand of 2.098 MWh/a, the CO_2-emissions for gas would be a total of 504 t/a. So, the installation of the CDH systems reduces the CO_2-emissions of the area about 60% compared to an area supplied by gas.

4.3.3 Economic performance evaluation

Now, to be able to determine the economic viability of the system, some factors such as costs and revenues have to be defined. For the calculation of the system's total cost these cost groups are needed: capital costs, operational costs and consumption costs

Furthermore, these assumptions have been done:

- Considered period of time: 25 years
- Inflation rate: 1%
- Interest rate: 2.5%
- Funding is considered to be available at beginning of the investment

Funding

In order to increase attractiveness for those kinds of projects, there are many state funding instruments. In Germany there is the program called "Wärmenetzsysteme 4.0" ("heat grid systems 4.0"). This is a very specific funding program from the German "Bundesamt für Wirtschaft und Ausführungskontrolle BAFA" to incentivize the construction of highly innovative heat grid systems for a sustainable supply of residential areas. The program is divided in four modules, thereof the first two are the most important ones:

- Module I: Funding of the feasibility study
- Module II: Funding and realization of a heat grid system 4.0
- Module III: Supplementary funding of information measures to reach the requested closure rate and economic efficiency
- Module IV: Supplementary funding for regional research cooperations and cost reductions, on-site research support and communication recognition

Through the first Module, by covering a feasibility study, a funding up to 600.000 € can be reached. The funding rate depends on the size of the enterprise and varies between 50% and 60% of the accrued costs.

Through Module II the funding can be extended to additional 15 Million Euro. The funding rate of the second module is composed of two different components:

- 30 - 40 % funding of the investment costs for general support
- Up to 10 % for sustainability in addition to the general support funding by using renewable energy and waste heat

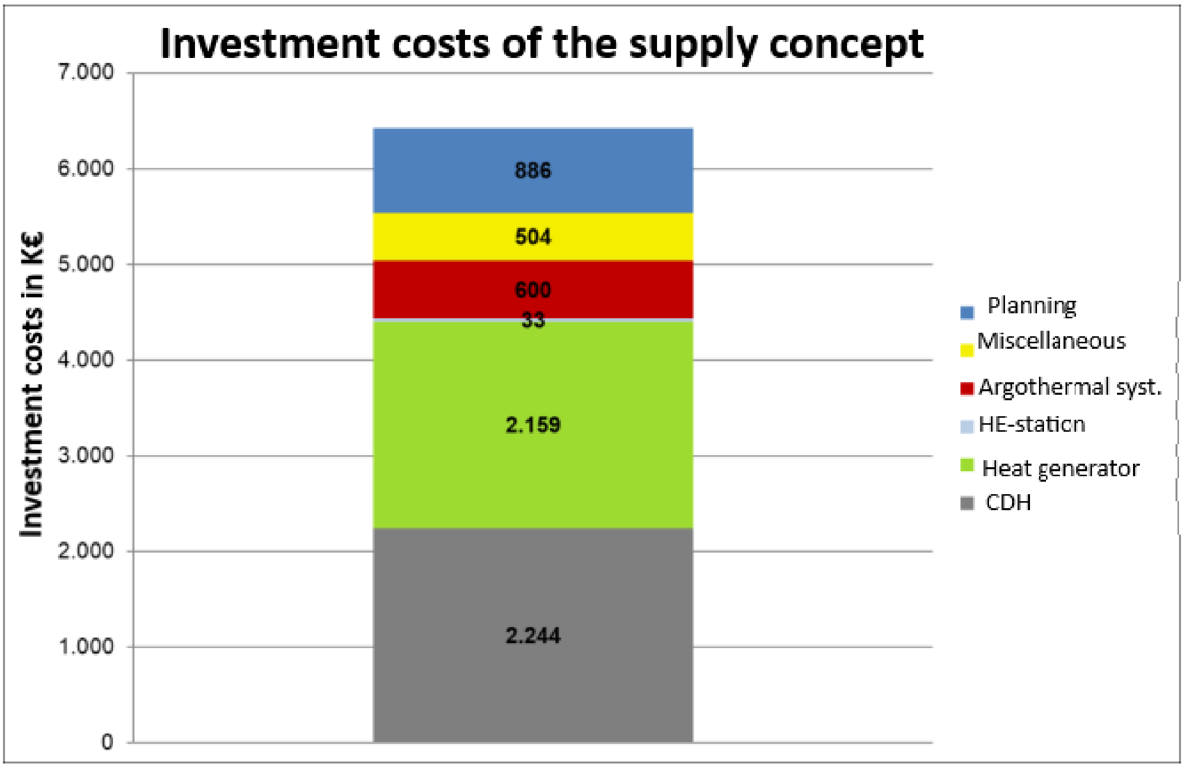
Investment costs

For this Project the investment costs are attributable to the CDH network, to the heat generator, to the heat transfer station and to the agrothermal system. In addition to that, one-time-costs for planning and miscellaneous are defined at 16% and 10% of the total investment costs. Those are determined as follows:

- CDH: for this system, the costs are determined by the dimensioning of the pipe-network and they amount to 328 € per meter of route inclusive of material and underground construction/engineering costs, for a total of 2.24 Million Euro.
- Heat generator: the costs for heat pumps have been taken from internally available price lists and can be approximated at 2.16 Million Euro

- Agrothermal system: Here the costs are attributable to the collector relocation, to the material and to the installation. Through comparison of this system with another pilot project (Wüstenrot), the costs will be up to 20 €/m^2, for a total of 600,000 €
- Heat transfer station: The costs for this system are defined through addition of the container, heat exchanger, pipe-network material, valves, pumps, installation and commissioning costs from empirical values. The total costs of this system amount therefore to 33,000 €

Hence, the total investment costs amount to 6.43 Million Euro, of which CDH and heat generator solely constitute 70%.



Graph 13: Investment costs of the entire supply concept

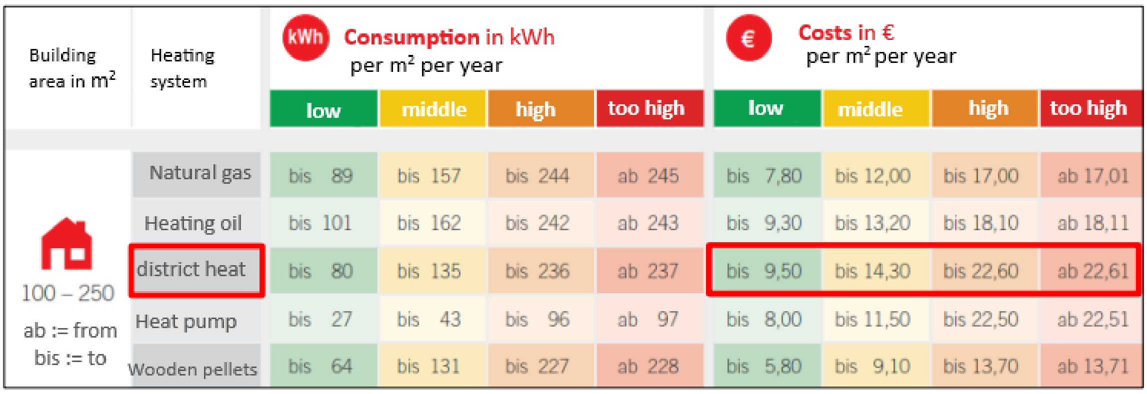
Yearly costs

Considering a linear depreciation over 25-years (378.000 €/a), regular maintenance (171.000 €/a), energy costs (138.000 €/a) and 40% of general support funding from "WN4.0" spread over 25 years (-140.000 €/a), the yearly total costs amount 547.000 €.

Comparing those costs to the yearly heat demand the heat production costs (HPC) can be calculated. In this case, for the 2098 MWh/a, the HPC amounts to 261 €/MWh.

To check the economic performance of the system, we compared the accruing costs with the German heating tables of 2020. The yearly costs for the CDH system result in 16 €/m^2. Compared to the costs of normal district heat with a minimum of 9.50 €/m^2 it can be said that the price for CDH systems belongs to the "elevated range", but still in the regular price range of the last years. Also compared to other heat sources it is still in the regular price range.

Table 41: Germany's heating costs table in 2020



Building area in m²	Heating system	Consumption in kWh per m² per year				Costs in € per m² per year			
		low	middle	high	too high	low	middle	high	too high
100 – 250 ab := from bis := to	Natural gas	bis 89	bis 157	bis 244	ab 245	bis 7,80	bis 12,00	bis 17,00	ab 17,01
	Heating oil	bis 101	bis 162	bis 242	ab 243	bis 9,30	bis 13,20	bis 18,10	ab 18,11
	district heat	bis 80	bis 135	bis 236	ab 237	bis 9,50	bis 14,30	bis 22,60	ab 22,61
	Heat pump	bis 27	bis 43	bis 96	ab 97	bis 8,00	bis 11,50	bis 22,50	ab 22,51
	Wooden pellets	bis 64	bis 131	bis 227	ab 228	bis 5,80	bis 9,10	bis 13,70	ab 13,71

However, the heat price of 26.1 c€/kWh is similar to the current electricity price and way above the usual market range for CO_2-neutral contracting solutions (10 – 15 c€/kWh). The difference between both conclusions results from the fact that the case study assumed 254 SFH with plenty of living room. As the price per kWh is more important to convince the municipality and the customers, we cannot recommend the system as it stands.

On the other hand, it is clearly to be seen, that the high energy price results in the usage of the agrothermal field as a main heat source. As the investment cost of the agrothermal is 18 times higher than the investment costs of the waste heat source, the outcome is only 3 times higher. It shows that in this case the inclusion of a waste heat source is highly recommendable as it lowers the investment costs by 25 %. Disregarding this specific cold district heating system and considering only the point of view of low-temperature waste heat recovery, these estimates hence show the strong potential of the considered skid solution.

5 Conclusion

5.1 Early Adopter Bolzano

The application of heat recovery measures at the WaltherPark project in Bolzano has been analysed in this feasibility study. Waste heat generated from heat pumps supplying a local district cooling network is supposed to be transferred locally to the same consumers when there is a heat demand, or to be delivered to the 3rd generation district heating network supplying the residents of Bolzano.

The development of a standardised and scalable solution is a pivotal strategy to reduce risks related to heat recovery measures: it allows adapting the solution to the availability of waste heat or to the users' demand, leaving the possibility to relocate the equipment if not needed or profitable.

The application of the Skid in the context of Bolzano does not result to be a viable investment, mainly due to the fact that recovered heat competes with cheap energy sources such as the one made available by the main waste-to-heat plant.

The analysis of additional scenarios, developed to extend the scope of the present feasibility study, shows however that **measures of heat recovery realised through the use of modular skids**:

- in a general Italian context are environmentally beneficial, economically sustainable but not financially attractive based on standard IRR and NPV values;
- **in a general Italian context where electricity is locally generated by a CHP are both sustainable and financially attractive**;
- the threshold electricity price below which financial sustainability is reached is 169 €/MWh (with a heat price set to 35 €/MWh);
- the threshold heat price above which financial sustainability is reached is 37.1 €/MWh (with a electricity price set to 190 €/MWh).
- if a carbon tax (of 70 €/tonCO_2 emitted, as of actual carbon emission costs in fall 2021) is considered a solid business is made available;

In conclusion, the feasibility study shows that the application of the described heat recovery measures for the Bolzano Case Study is not sustainable, but a good potential for the measure to be adopted in other application cases is highlighted, in spite of the considered high network supply temperature.

5.2 Early Adopter Schwaigern

The presented system shows a state-of-the-art network with a high efficiency standard and low CO_2-emissions. This is one example to show the feasibility of the usage of waste heat for residential heating. Moreover, this system is no individual case. It presents an opportunity which can be used and adapted to many different conditions and specifications. The idea of portable skids is neither limited to cold district heating nor to residential areas or supermarkets as waste heat sources. Many more usable waste heat sources can be found and by using all of the industrial waste heat in Germany up to 37 million tons of CO_2 can be saved yearly.

By decoupling the waste heat of the supermarket in our project and connecting a cold district heating of the residential area, an amount of 19% of the heat demand can be covered. During the warmer periods of the year, there's still a surplus of heat coming from the supermarket although the waste heat is used by the supermarket to cover its internal needs and to supply the residential area. In order to decouple the waste heat and to allow its utilisation during the colder months, an agrothermal storage, which allows to cover additional 56% of the heat demand, is connected to the system. The residual heat demand is covered by the electricity consumed by decentralized heat pumps.

By including the supermarket with a portable system, the investment of this container is just partly dependent on one heat source. If the existing heat source runs dry, the skid can be moved to another waste heat source nearby or even be used at a different similar project. This reduces the financial risks for the operator and gives him a highly flexible and affordable heat source opportunity.

Differently from the Bolzano case, the Schwaigern case considers a cold district heating network where the main source is given by an agrothermal field. Under the current economic conditions, this configuration does not appear economically viable for this specific case. This is of no surprise considering the absence of cooling needs in the buildings (cooling would be one important point for the convenience of cold networks) and the low heat density of the area (individual buildings with high energetic performance). However, **the inclusion of low-temperature waste heat** (here recovered from a supermarket) **improves the business case** and proves to be much more economically convenient than the agrothermal source. Hence, the skid solution proposed by the LIFE4HeatRecovery project shows a strong applicability in this context.

5.3 Pre-design studies at the Early Adopters’ networks

The analyses carried out for the Early Adopters’ network in Bolzano and Schwaigern both show a potential positive benefit of the introduction of modular heat recovery measures into the local distribution networks both in terms of energy balances and of environmental impact.

The application studied for the Schwaigern site shows the convenience of low-temperature waste heat recovery in the context of low-temperature networks. On the contrary in Bolzano, the higher energetic effort required to increase the waste heat temperature to levels compatible with a 3rd generation district heating network hinders the financial sustainability of the project. This is however strongly dependent on the large availability of cheap heat from a waste-to-energy plant. Considering instead a general installation case in Italy, it is possible to determine the viability of the studied heat recovery measure; the introduction of a carbon tax in the heating sector, would result in solid business cases potentially implemented.

The work done in the LIFE4HeatRecovery project highlights therefore the potential of urban waste heat recovery measures as a tool to enhance the sustainability of heat supply into existing and planned district heating networks at different operating temperatures. The adoption of modular and scalable solutions results in this case to be a key feature needed to reduce the risk of changes in heat demand or waste heat availability and to enhance the attractivity of this kind of investment.

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